TEMPORAL MODELLING OF GESTURES IN ARTICULATORY ASSIMILATION

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ABSTRACT

Gestural trajectories for consonants in coronal + velar clusters were derived using EPG contact data from speakers of English and Russian. Evidence from rapid speech indicates a variety of articulatory strategies available to speakers of the two languages, with notably a high-level discrete assimilation process found only in the some utterances by the English speakers. The remaining data involve partial loss of the coronal gesture, and are therefore not susceptible to description within conventional phonological formalisms. The weakening of coronal gestures in certain contexts appears only as an arbitrary stipulation within the theory of Articulatory Phonology. It is argued that the theory requires further elaboration to allow the behaviour of the coronals to be modelled adequately.

1. CORONALS IN CC CLUSTERS

A number of studies have drawn attention to the tendency of alveolar and dental stops and nasals to assimilate to the place of articulation of a following non-coronal obstruent. The process is attested as source of phonological change in many languages, and gives rise, for example, to the presence only of homorganic intramorphemic NC clusters in English. The process has typically been formulated within the apparatus afforded by phonological theory in terms resembling those in figure 1, either, as in (a), in the linear formalism of early Generative treatments or as in (b), employing an autosegmental treatment of those features specifying place of articulation.

In this paper, however, I shall present evidence and arguments from rapid speech indicating that the formulations of fig. 1 are insufficiently revealing both of the phonetic facts obtaining in both English and Russian, and of the knowledge to which a native speaker of either language must have access in order correctly to produce sequences such as those under discussion.

2. ALVEOLARS IN ENGLISH

I have reported [1] an investigation into CC clusters in rapid speech in English, where C_1 is an alveolar stop or nasal and C_2 a velar stop, with an intervening mor-

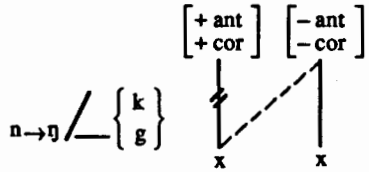

Figure 1: conventional phonological representations for alveolar and dental assimilation

pheme or word boundary. Qualitative examination of electropalatographic (EPG) contact data for several speakers reveals a large number of utterances in which the coronal gesture is significantly reduced in magnitude, such that complete closure is not attained during the consonant. Speakers appear to differ in their choice of articulatory strategy here: the three options seemingly available are: (i) to execute a full coronal gesture, giving rise to full alveolar closure; (ii) to execute a weakened coronal gesture, with no complete closure; and (iii) to execute only the following velar gesture. While tokens of type (iii) are those which may be modelled in conventional phonological descriptions as an assimilation, as in fig. 1, it is those of type (ii), exemplified in fig. 2, which, insofar as the forms they manifest are under the speaker's deliberate control rather than as the natural consequences of the inertial properties of the speech apparatus, must pose problems for conventional phonological rules and representations. This is because in these cases the coronal gesture involves a degree of lingual displacement, and perhaps also a duration, inconsistent with the discrete categories of binary feature-value and of timing-slot provided by theory.

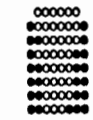

Figure 2: EPG contact pattern for a weakened alveolar gesture

3. QUANTITATIVE INVESTIGATIONS OF ARTICULATORY GESTURES

Further insight into patterns of articulatory activity may be gained by a consideration in terms of the trajectories of individual articulatory subsystems, recently restored to the phonetician's armoury through the development of the concept of the *gesture* in the paradigm of Articulatory Phonology developed by Browman and Goldstein [3]. In the work reported in the present paper gestural trajectories were approximated from time-varying summations of EPG contact

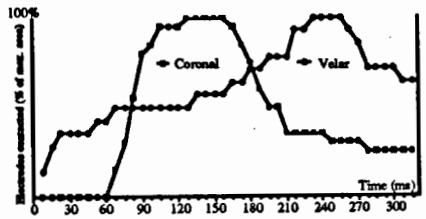

Figure 3: Gestural Trajectories for [n g] in 'hand grenade' (slow utterance)

data, and a number of measures devised by which temporal aspects of the various articulatory strategies might be compared. Figures 3 and 4 show gestural trajectories for the nasal + plus stop sequence [n g] in the phrase *hand grenade*. From the data values were obtained for (a) the duration of the alveolar and velar closures (DAC, DVC); (b) the overall duration of the coronal and dorsal gestures (DCG, DDG); (c) the degree of lingual displacement, corresponding to the height of the peaks for the two gestures (CMAX, DMAX); and (d) the interval between the onsets of the two closures, or, in the case where no alveolar closure was formed, between the peak in the coronal gesture and the onset of velar closure (INT)[1].

In comparison with the slow utterance, for the fast utterance (fig. 4) CMAX is reduced to 70% of its maximum possible

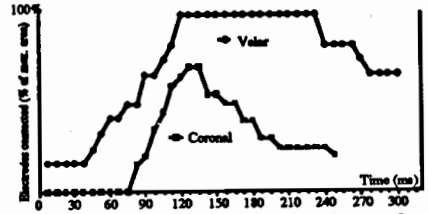

Figure 4: Gestural Trajectories for [n g] in 'hand grenade' (fast utterance)

value, DCG is reduced by 10%, and DAC is zero: that is, the coronal gesture is diminished in magnitude to such an extent that no closure is formed, and also somewhat in duration. DMAX remains constant at 100%, DVC increases by 78% and DDG increases by 43%: the velar stop is fully articulated, and now significantly longer. INT is now –11 ms: the velar closure is formed before the coronal gesture reaches its peak. Note also that the dorsal gesture is initiated before the coronal gesture. The data suggest therefore a partial implementation of the restructuring implied by the autosegmental treatment of fig. 1b: the place of articulation originally associated only with the velar stop has 'spread' to occupy two conso-

[1]Note that for the speakers investigated the final [d] in *hand* was usually elided in fast speech; and that the present investigation is confined to lingual gestures and hence has nothing to say about the timing of velic lowering and raising. The nasalisation associated with [n] is retained even when the coronal gesture is lost altogether, giving rise to a velar nasal [ŋ].

nantal timing slots, and the original underlying alveolar place-autosegment is partially delinked.

4. DENTALS IN RUSSIAN

A consideration of the behaviour of speakers of Russian in similar contexts reveals some significant differences. The sound system of Russian differs from that of English in two significant respects: in general the requirement that NC clusters should be homorganic within the morpheme does not apply; and there is no surface contrast between dental and velar nasals. A large body of data from two speakers of Russian was subject to the same qualitative and quantitative investigation as the data from English. To begin again with qualitative observations, two points are immediately evident:

(i) in the case of CC clusters where C_1 is a stop, *no* reduction can be observed in the magnitude of the coronal gesture as speaking rate increases (CMAX remains constant at 100%);
(ii) the range of contexts in which complete assimilation (i.e. a velar nasal) is encountered is very narrow, and apparently not sensitive to speech-rate. The cases involved are words such as /sanktsia/ and /funktsia/, in which the nasal and the following stop *must* be syllabified together (since the sequence /kts/ is impermissible as a syllable-onset).[2] These forms showed [ŋ] even in slow, careful speech.

In the remainder of cases (where the n and the following stop are heterosyllabic) the forms recorded typically reveal a fully articulated dental nasal in slow speech, and in fast speech a reduction in the magnitude of the coronal gesture, generally leading to the absence of a complete dental closure.

Applying the same quantitative measures as for English to the Russian data reveals further cross-linguistic differences. In the fast-speech examples from the Russian speakers in the experiment, the reduction in magnitude of the coronal gesture is not accompanied by a corresponding lengthening in the duration of the dorsal gesture (CMAX decreases but DDG remains constant, or even undergoes a slight reduction typical at increased rates of speech), and while INT decreases, the velar closure is nonetheless formed *after* the peak in the coronal gesture. Thus while the phonological formulation of fig. 1b was seen to be roughly appropriate to the articulatory patterns found in English, with weakened alveolars and lengthened velars suggesting a partial implementation of the phonological processes of autosegmental delinking and spreading, no such interpretation appears suitable for the patterns found in Russian-speakers.

It is appropriate instead, I would argue, to view the weakening of the Russian dentals as the manifestation of a process more 'phonetic' than 'phonological': that is, more representative of the natural constraints acting on the articulatory apparatus than of the principles of phonological organisation which may be discerned in the English data. This view accords with Ohala's view [4] that if a phonological pattern (a "sound change" in a diachronic perspective) has a phonetic motivation, it is reasonable to expect to find evidence of the relevant phonetic process in speech production. Thus diachronic evidence of the instability of coronals in CC clusters leads us to expect a phonetic process of the sort encountered in the Russian data.

It would be incautious, however, to attribute the variety of weakened coronal gestures to the operation of a freely-applying natural phonetic effect: there is evidence that the phonetic form of utterances such as these is determined at least in part under the cognitive control of the speaker at least in so far as that the process is seen to apply in some contexts and not others. The fact that the dental stops in Russian are robustly resistant to weakening suggests at least that a particular phonetic effect may be blocked as part of the native speaker's low-level phonetic knowledge.

5. LEVELS OF PHONOLOGICAL KNOWLEDGE

We are therefore led to a picture of the organisation of the various types of knowledge of pronunciation, in which the variety of forms encountered in the data in this study are governed by principles operating on several levels:

- High-level phonological rules (cf. lexical rules)
  Expressible in conventional phonological formalisms
  e.g. distribution of Russian [ŋ]; intramorphemic NC clusters in English
- Low-level phonological rules (cf. postlexical rules)
  Partial applications not expressible
  e.g. English alveolar C_1 in CC clusters across morpheme boundaries
- Phonetic effects
  Phonetically motivated articulatory processes; may be phonologically blocked (*e.g. Russian [t,d]*) or may apply freely (*e.g. Russian [n]*)

Two important consequences emerge: that some aspects of the speaker's knowledge of how their language is pronounced involve forms which conventional phonological theories are not equipped to represent; and that language-specific knowledge of pronunciation extends to the operation or blocking of natural low-level processes.

6. CORONALS IN ARTICULATORY PHONOLOGY

The paradigm of Articulatory Phonology [3] appears well-equipped to accommodate the variety of low-level phonetic detail which, as I have argued, falls within the subject-matter of a comprehensive theory of phonology. Gestural scores correspond to high-level phonological representations, and the operation of the task-dynamic model yields a spatio-temporal representation in terms of gestural trajectories in which the non-discrete application of phonetic and phonological processes may be formalised. In addition, the application of general principles governing relationships of phase between gestures accounts for much of the data we have observed, in which the velar gesture is responsible for the 'masking' of the coronal gesture.

What is still lacking in current formulations of the theory is a convincing account for the facts of coronal-gesture weakening. That gestures weaken in casual speech is stipulated somewhat axiomatically, and in no sense can be said to emerge from the mathematical properties of the model. Moreover, there appears be no way, in a model which treats all gestures as formally identical objects, in which it can be shown that *coronal* gestures specifically are subject to elision in CC clusters. At the heart of the matter is the modelling of gestures as the critically-damped *attraction* of the active articulator towards its target. Thus for an articulator to fall short of its target during the execution of a gesture seemingly requires the target itself to be reprogrammed. Within existing versions of the theory it would seem to be necessary to abandon the assumption of critical damping (such that an articulator always reaches its target) in order to accommodate gestural weakenings, and other undershoot phenomena. A more drastic revision of the model would be to abandon the modelling of gestures in terms of attraction, in favour of a 'ballistic' model: in which the articulator is pushed rather than pulled towards its target. But this would be to abandon entirely the mathematical content of the existing theory. The issue of gestural weakening clearly remains a problem for the development of the theory: it seems clear that evidence of the kind presented in this paper will be of relevance in seeking a solution.

[2] The principles governing this small class of exceptional forms are discussed further in [2].

REFERENCES

[1] BARRY, M.C. (1985), A palatographic study of connected speech processes. *Cambridge Papers in Phonetics and Experimental Linguistics*, 4:1-16. (Cambridge University Linguistics Department).

[2] BARRY, M.C. (in prep.), *A cross-linguistic study of connected speech processes.* PhD dissertation, University of Cambridge.

[3] BROWMAN, C.P. & GOLDSTEIN, L. (1990), Tiers in articulatory phonology, with some implications for casual speech. *Papers in Laboratory Phonology I*, J. Kingston & M.E. Beckman, eds. (Cambridge: CUP). pp 341–381.

[4] OHALA, J.J. (forthcoming), Comments on Nolan's 'The descriptive role of segments: evidence from assimilation'. *Papers in Laboratory Phonology II* D.R. Ladd & G.J. Docherty, eds. (Cambridge: CUP).