PATTERNS OF LINGUAL VARIABILITY IN GERMAN VOWEL PRODUCTION

Philip Hoole[1] and Barbara Kühnert[1,2]
[1]Institut für Phonetik, Munich University, Germany
[2]Department of Linguistics, Cambridge University, England

ABSTRACT

This study aimed to assess the relative importance of biomechanical and linguistic constraints on articulatory precision by analyzing contextual and token-to-token variability in tongue postioning for vowels. Contextual variability proved greater for lax vowels. Back vowels showed substantially increasing variability towards more front tongue locations. Regarding token-to-token variability, lax vowels were more variable for front vowels, but less so for back ones. Again, back vowel variability increased towards the front. The main distinction in variability was thus between palatal vowels (whole tongue constrained) and non-palatal vowels (anterior tongue unconstrained).

INTRODUCTION

This study analyzes patterns of tongue configuration variability in the articulation of German vowels. The guiding assumptions are, firstly, that a physiologically realistic theory of vowel production must account for magnitude of both contextual (e.g coarticulation) and token-to-token (henceforth "T-T") variability, and secondly, that it is essential to view the vowels as a system. Consider here some major hypothetical influences on magnitude of variability. Firstly, finite-element modelling of the tongue (see [1] for discussion) suggests that for high vowels bracing of tongue against hard palate helps attain a stable tract configuration. Secondly, tense vowels may be more tightly controlled than lax vowels - in any case, better understanding of the precise physiological substrate of this distinction is an important issue in German [2]. Thirdly, crowded regions of a vowel system may be less variable than less crowded ones. If, however, the complete system is not examined the weight to be accorded these potential influences is difficult to assess. In fact, there are few articulatory studies investigating multiple repetitions of complete vowel systems. One exception is a glossometer study by Bohn et al. [3] of token-to-token variability in German. Surprisingly, the tendency was for high vowels and tense vowels to show more variability. The present study reviewed these results using a different technique (EMA) and extends them by examining contextual in addition to T-T variability.

METHOD

Six German speakers spoke 5 repetitions of a nonsense-word corpus of the form /gəCVCə/ with C1=C2=/p, t, k/ and with V consisting of 7 pairs of tense-lax vowels (/i: ɪ, y: ʏ, e: ɛ, ø: œ, ɑ: a, o: ɔ, u: ʊ/) embedded in a carrier phrase. The corpus was recorded at both normal and fast speech rates. Electromagnetic articulography (AG100, Carstens Medizinelektronik) was used to monitor movement of tongue (4 sensors mounted approx. 1 to 6 cm from the tongue tip), lower lip and jaw. Sensors on upper incisors and bridge of nose were used to compensate for head movement. Articulatory configurations were determined at the mid-point of the target vowels using a minimum-velocity criterion. Measures of contextual and T-T variability were derived in the following way: At each sensor position (on the tongue) a principal components analysis of the two-dimensional coordinates was performed: the variability measure was defined as the area in mm^2 of the 2-sigma ellipse oriented with its main axis along the first principal component of variation (cf. [1]). For contextual variability the ellipse area was simply calculated over all tokens of each vowel in turn. For token-to-token variability, the area was calculated separately for p-, t- and k-context, and then averaged over the three consonants.

RESULTS

The two different speech rates produced very similar variability patterns so we will present here only those obtained at the normal rate.

Contextual Variability

The 3 panels of Fig. 1 display the results first for each vowel averaged over sensor positions (top), and then for each sensor position individually with the vowels grouped into a front group (middle) and a back group (bottom). We will consider the vowels under three headings:

(i)The front high vowels /i:, ɪ, y:, ʏ, e:, ɛ/ (Fig.1, top and middle)

For these 3 pairs the tense member shows less variability than the lax at all sensor positions, and indeed the lowest variability of any vowels.

(ii) The pair /ø:, œ/ (Fig.1, top)

This is an anomalous pair (left out of the front group in the middle panel) as it has unusually high variability for the tense member compared to the other front vowels. This in turn means that no very clear answer emerges as to whether front rounded vowels show more lingual variability than the unrounded counterparts. (While these two vowel categories differ reliably in tongue position, it might have been hypothesized that tongue position in the rounded vowels is a subsidiary feature and thus liable to vary more).

(iii) The low and back vowels /ɑ:, a, o:, ɔ, u:, ʊ/ (Fig.1, top and bottom)

These vowels all show lowest variability at the rearmost sensor location. The variability at this position is somewhat higher than the minimum variability found for the front coils, but for the low back vowels the least variable sensor is probably rather further away from the actual vocal tract constriction than is the case for the front vowels. Thus while this group of vowels is clearly overall more variable than the front vowels (Fig.1, top), it would be hazardous to claim that the tongue is less tightly controlled at the site of maximum constriction.

The most striking feature of the results for this third group of vowels is the steady and extensive increase in variability from back to front sensor location, with the tense-lax distinction in variability becoming less clear-cut in the process.

Nonetheless, the higher variability for the lax vowels as a whole can be assumed to be a natural consequence of their shorter duration and the concomitant greater overlap with the adjacent consonantal articulations.

Token-to-Token Variability

Analogously to Fig.1, the results are summarized in the 3 panels of Fig.2. A similar grouping of the vowels also proves convenient. Regarding first the tense-lax distinction, the high front vowels show a pattern of slightly but consistently higher variability for the lax vowels (Fig.2, top and middle); the /ø:,œ/ pair (Fig.2, top) shows marginally more variability for the tense vowel; the low and back group (Fig.2, top and bottom) shows consistently more variability for the tense vowels, thus contrasting notably with the contextual variability results in Fig.1, especially at the more front sensor locations. The results thus provide neither a simple confirmation nor disconfirmation of the results in [3]. It is not immediately clear why the tense-lax distinction should be

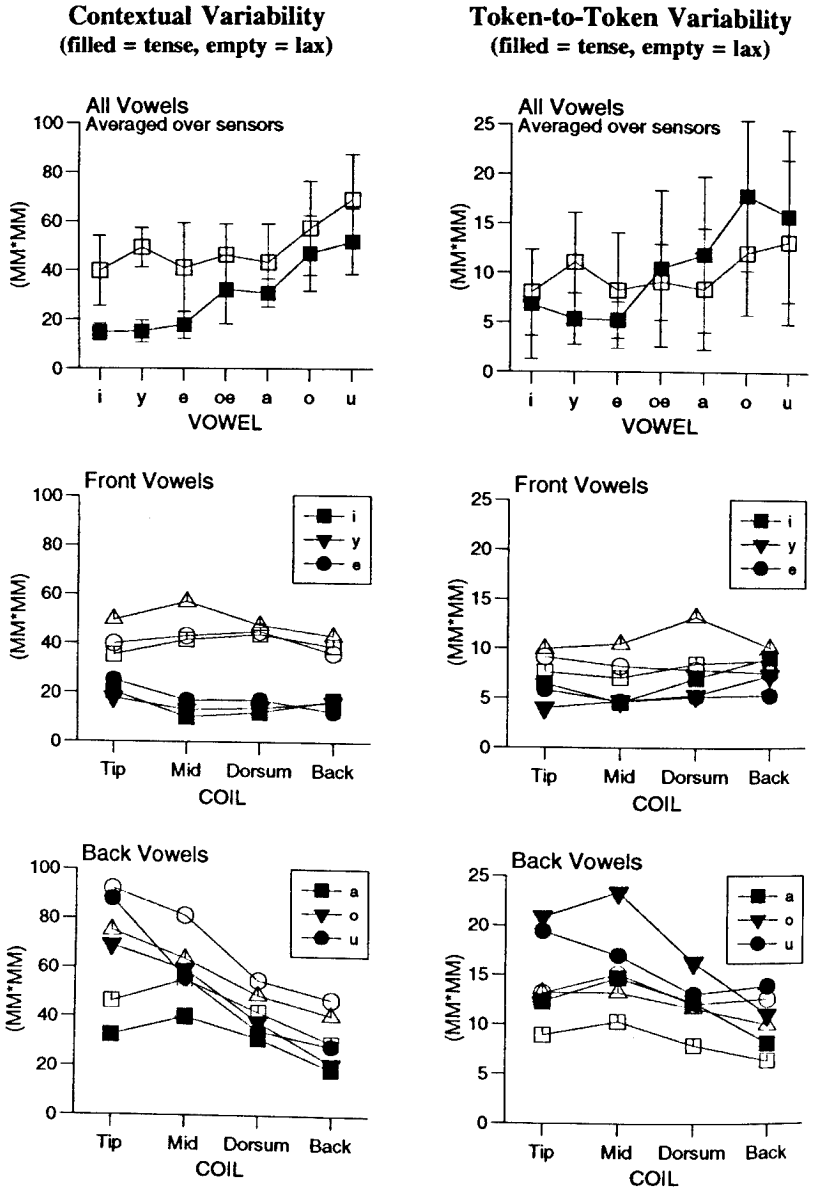

Fig.1 Contextual variability averaged over speakers and sensors (top, n=24) and over speakers (n=6) for the front and back vowel group (middle, bottom).

Fig.2 Results for token-to-token variability. Details as in Fig.1.

coupled with different T-T variability patterns for the front and the back vowels. One possible factor is the distance travelled by the tongue in the CVC movements. In t-context, for example, the tense variants of the low and back vowels have further to travel, while the reverse is the case for the high front vowels. However, the precise extent to which T-T variability may be explainable by articulator displacement remains to be explored in detail.

In considering whether high front vowels may be able to profit from the proximity to the hard palate to achieve a relatively invariant configuration, the first point is that we clearly cannot confirm Bohn et al.'s contrary finding of *more* variability on the high vowels, at least not for the front vowels (cf. Fig.2, top). On the other hand, the simple alternative conclusion of increasing variability with decreasing tongue height is also not completely warranted. If we inspect the values in Fig.2 (top) after ordering tense and lax vowels separately into two rows with respect to tongue height (i.e /iː, yː, eː, øː, ɑː/ and /ɪ, ʏ, ɛ, œ, a/) then no dependency of variability on tongue height is found for the lax vowels. For the tense vowels we do indeed find a difference between the 3 highest and the 2 lowest, but no obvious gradual increase from high to low. In fact, the question of high vs. low vowels may be wrongly posed. It may be more profitable to point to the one major parallel between contextual and T-T variability, and to reformulate the question in terms of a distinction between a palatal group and a velar-pharyngeal group.

CONCLUSIONS

As just mentioned, analysis of the patterns of contextual and T-T variability suggested the existence of two main vowel groups. This distinction is undoubtedly partly a biomechanical one: palatal constrictions constrain the whole of the tongue, whereas constrictions further back leave the mobile anterior tongue much freedom to vary. However, additional factors could underly the variability in back vowels: firstly, the acoustic consequences of variability remote from the main constriction may be rather slight, particularly when coupled, secondly, with the relatively uncrowded back vowel region in German. Assessment of these factors awaits the completion of the acoustic counterpart to this investigation.

The second conclusion is that the slightly untidy results found for the comparison of tense vs. lax vowels and rounded vs. unrounded vowels underline the importance of investigating sound systems as nearly as possible in their entirety, as otherwise the danger of spuriously clear-cut results may be considerable.

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