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(this PDF version has minor changes in formatting, and correction of one important typo in paragraph preceeding Table 2 at top of p.99)

TONGUE-JAW COORDINATION IN GERMAN VOWEL PRODUCTION

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ABSTRACT

Linguo-mandibular coordination in the production of front vowels by seven speakers of German was analyzed with respect to the three phonological oppositions of Height, Tenseness and Rounding. The effect of consonantal context was also examined. The three oppositions differed characteristically in the relative amount of jaw involvement in tongue-height differences: greatest for Height, least for Rounding. Tenseness was located in between; moreover it showed the greatest influence of consonantal context. While speakers differed, for example, in the precise amount of jaw involvement in the tense-lax opposition, nonetheless all speakers showed the same overall pattern over the three oppositions. Thus articulatory organisation in the realization of such oppositions may be more stable than has sometimes been assumed.

La coordination langue-mâchoire dans la production de voyelles antérieures par sept locuteurs allemands a été analysée dans son rapport avec les trois oppositions phonologiques de Hauteur, de Tension, et d'Arrondissement. L'effet du contexte consonantique a été également examiné. Les trois oppositions présentaient des différences caractéristiques en ce qui concerne l'importance relative du rôle joué par la mâchoire dans les variations de hauteur de la langue: plus grande pour la dimension de Hauteur, moins grande pour celle d'Arrondissement, intermédiaire pour celle de Tension, qui a en outre donné à observer les effets de contexte consonantique les plus grands. Bien que des différences inter-individuelles aient été observées, portant par exemple sur le degré précis de la contribution de la mâchoire dans l'opposition tendu-lâche, tous les locuteurs ont presenté le meme patron d'ensemble toutes oppositions confondues. Ainsi, l'organisation articulatoire dans la realisation de ces oppositions est peut-etre plus stable qu'on a pu quelquefois le supposer.

INTRODUCTION

The coordination of tongue and jaw has been a key topic in speech motor control in general and in vowel articulation in particular. Consider two important phonological oppositions for vowels: "Height", e.g / **i** / vs. / **e** / and "Tenseness", e.g / **i** / vs. / **ɪ** /. Based on an extensive review of the radiographic literature Wood (1975a, b) proposed a simple scheme for tongue and jaw involvement in these oppositions: "Height" pairs are distinguished by jaw-height but have a similar tongue position relative to the jaw; "Tenseness" pairs share a similar jaw height but are distinguished by tongue-height relative to the jaw - lax vowels have a lower tongue position, and concomitantly greater pharyngeal constriction.

On the other hand, further influential investigations, e.g Ladefoged, DeClerk, Lindau & Papçun (1972) and Johnson, Ladefoged & Lindau (1993) have highlighted the apparent inconsistency in the articulatory strategies employed by speakers to realize these oppositions (i.e considerable intra- and interspeaker variation). For these authors a potentially far-reaching conclusion of such results is that speech motor goals should be defined in auditory terms.

The present investigation uses an articulatory analysis of German vowel production to reassess the empirical well-foundedness of these differing accounts of vowel production, extending the work just discussed in several respects:

Firstly, we consider the influence of consonantal context on tongue-jaw coordination in vowels. This has received little attention in the literature (but see Lindau & Ladefoged, 1990), which is surprising when one considers that lax vowels are more susceptible to coarticulatory effects and that this fact may well influence patterns of tongue-jaw coordination in realizing the tense-lax opposition. Secondly, we exploit the fact that German offers, in addition to Height and Tenseness, a third opposition that is relevant to tongue-jaw coordination, namely the contrast of front unrounded and rounded vowels, since the latter typically have a lower tongue position than the former. Thirdly, the speech material was available at two speech rates, which was expected to aid the identification of robust patterns in the data. Fourthly, German was considered to provide a useful contrast to English since it does not have the diphthongization characteristic of many long English vowels.

METHOD

Tongue and jaw positions were monitored by means of electromagnetic articulography for a corpus containing all the monophthongal vowels of German (see Hoole, 1996, for details of recording procedures). In the present study we restrict attention to the front vowels since this allows the most direct comparison of the three oppositions Height, Tenseness and Rounding. The 8 vowels studied can be grouped into 4 pairs with respect to each of the oppositions as follows:

Height: / **iː eː** /, / **ɪ ɛ** /, / **yː øː** /, / **ʏ œ** /

Tenseness: / **iː ɪ** /, / **yː ʏ** /, / **eː ɛ** /, / **øː œ** /

Rounding: / **iː yː** /, / **ɪ ʏ** /, / **eː øː** /, / **ɛ œ** /

Of the four tongue sensors used we will base analysis here only on the vertical position of the one closest to the main constriction location for these palatal vowels (the second sensor from the front). Each vowel was embedded in 3 symmetric CVC sequences with C=/p, t, k/. 7 speakers spoke 5 repetitions of each of these CV combinations in a carrier phrase at two speech rates.

RESULTS

1. The phonological oppositions

The main sets of analyses to be presented here were based on the computation of differences in tongue and jaw height for each of the vowel pairs given above. This was carried out separately for each speaker, speech rate and context after first averaging the 5 repetitions in each condition. The value for the second member of each pair (this being always the one expected to have the lower tongue position) was subtracted from the first member. The basic trends in the data are summarized in Table 1 with respect to the three groups of oppositions.

Table 1
Average jaw-height and tongue-height differences, in mm.

	Jaw	Tongue
Height	2.34	3.22
Tenseness		
/p/	2.19	5.34
/t/	0.72	3.85
/k/	1.63	2.92
Rounding	-0.30	2.40

Tongue height differences are greatest for Tenseness, followed by Height and Rounding. For jaw height the order is Height, Tenseness, Rounding. Table 1 breaks the Tenseness opposition down further by consonant context. This was necessary since statistical testing of each vowel pair in a two-way ANOVA with consonant as the second factor (each vowel in the pair forming the two levels of the Vowel factor) showed frequent Vowel by Consonant interactions when tense-lax pairs were examined, but only rare interactions for Rounding and Height pairs. In other words, the manifestation of the tense-lax opposition tends to depend on consonantal context: tongue-height differences decline from context /p/ via /t/ to /k/, while jaw differences decline from /p/ via /k/ to /t/. The less pronounced tongue-height difference in /k/ context is readily understandable in terms of the greater coarticulatory effect of tongue-dorsum raising for /k/ on the lax vowel. The less pronounced jaw height difference in /t/-context presumably reflects the constraining effect of alveolar closure on freedom of jaw movement.

Table 2
Mean values of tongue-jaw slope for main categories of vowel opposition, broken down by consonant context

Height. Averaged over 2 vowel pairs, 7 speakers and 2 speech rates

	/p/	/t/	/k/
Tense	0.66	0.58	0.72
Lax	1.01	1.12	0.85

Tenseness. Averaged over 4 vowel pairs and 7 speakers

	/p/	/t/	/k/
Tempo			
Norm.	0.44	0.18	0.91
Fast	0.48	0.26	0.78

Rounding. Averaged over 2 vowel pairs, 7 speakers and 2 speech rates

	/p/	/t/	/k/
Tense	0.04	-0.10	-0.22
Lax	0.03	-0.32	-0.23

At the next stage of the analysis the relative participation of the jaw in oppositions involving tongue-height was captured in a single numeric parameter by dividing the difference in jaw height for each vowel pair by the corresponding difference in tongue height: "tongue-jaw slope". The results of this procedure are tabulated in Table 2.

Although space prevents us from discussing the effects of all the independent variables in the experiment with regard to this parameter, the important point to notice is that the values can be regarded as following a continuum, decreasing from Height via Tenseness to Rounding. This common descriptive framework helps in particular to bring out the relationship between Tenseness, with its clear consonant-related effects, and the other two oppositions: In /t/ context Tenseness is at the Rounding end of the continuum (small jaw differences), but at the Height end for the /k/ context (jaw differences similar in magnitude to the tongue differences).

2. Speaker-specific effects

Clear evidence of speaker-specific behaviour was found: for example, some speakers showed statistically significant jaw height differences for almost all tense-lax vowel pairs, while others showed hardly any such differences. Thus, similarly to Johnson et al., two-way ANOVAs of individual vowel pairs with Speaker as the second factor showed frequent Vowel by Speaker interactions. On the other hand, one of the most striking examples in Johnson et al's data of idiosyncratic tongue-jaw patterns, namely significantly higher jaw position in the lax member of a pair (/ **e**ⁱ / vs. / **ɛ** /) simply does not occur in our material. Note in this American English example that the vowels are also distinguished by presence or absence of diphthongization. Here one must ask whether it is realistic to expect consistent patterns of tongue-jaw coordination to emerge from analysis of one time frame per vowel (however carefully selected) given that the dynamic diphthongal movement is available as a powerful articulatory means for signalling the required distinction. When we examine the behaviour of our German speakers in terms of the tongue-jaw slope defined above, we find, despite the undoubted variability, that it may nonetheless be possible to define a level of articulatory organization at which consistent interspeaker behaviour occurs. Table 3 breaks down the values of the slope parameter by speaker and phonological opposition.

Table 3
Tongue-jaw slope for each opposition broken down by subject. Averaged over 4 vowel pairs, 3 consonant contexts and 2 speech rates.

	Height	Tenseness	Rounding
HT	0.90	0.59	0.23
TA	0.65	0.26	-0.27
CK	0.72	0.33	0.07
BK	0.71	0.28	-0.67
MH	0.43	0.31	0.32
PF	1.52	1.37	-0.33
FS	0.85	0.40	-0.30

Speakers clearly differ in terms of the range of the continuum that they exploit (and probably also in their overall location on the continuum, though this latter point is currently difficult to assess since we have not yet attempted to factor out the influence of inevitable speaker differences in the relative position of the tongue sensor relative to the jaw sensor and to the temporo-mandibular joint). Importantly, however, the 3 oppositions Height, Tenseness and Rounding occupy the same *relative* position on the continuum for all speakers (with one minor exception for speaker MH).

CONCLUSIONS

The results can be seen as fleshing out Wood's original scheme for tongue-jaw coordination in vowel production, firstly with respect to the third phonological opposition of rounding, and secondly with respect to consonantal context. His scheme is broadly supported by our data as long as it is not interpreted in the hard and fast sense that, for example, statistically significant differences in jaw height for the tense-lax opposition should never occur (and this was probably not Wood's intention).

With regard to speaker-specific differences, we believe that the conclusion of Johnson et al. that the goal of speech movements should be defined in auditory terms could well turn out to be correct in the long run. However, it is probably not yet possible to take the results of either their study or ours as providing unequivocal evidence in favour of this conclusion.

In short, on the basis of the extensive corpus and of the proposed descriptive framework we believe that it has been possible here to arrive at a more balanced picture of this long-standing problem of speech motor control.

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