AN ARTICULATORY INVESTIGATION OF FRONT ROUNDED AND UNROUNDED VOWELS

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ABSTRACT

Using electromagnetic and palatographic techniques stable differences in lingual articulation for the pair of German front rounded/unrounded vowels /i/ and /y/ were found. This result was related to S. Wood's hypothesis that the articulatory adjustments for such pairs help to maintain each vowel in regions of acoustic stability and enhance their distinctiveness. A second aim was to test the hypothesis that German's complex set of front vowels leads to less variability in the articulation of /i/ compared with the other point vowels /u/ and /a/. This expectation was also confirmed.

1. INTRODUCTION

Many languages, including German, contrast front rounded and unrounded vowels. Yet there is evidence that the distinction may also involve differences in tongue configuration [3]. Of particular interest is Wood's [6] study in which in a large number of languages he typically finds that /y/ has a lower tongue-body position than /i/. He argues that the labial, lingual and also laryngeal manoeuvres for such pairs represent a balanced set of adjustments that maintain each vowel in regions of acoustic stability and enhance their distinctivenss. Wood's evidence is based largely on radiographic data with, of necessity, a restricted range of utterances. In this study we focus on just one aspect of the i/y contrast, namely the potential lingual differences, but examine it in a wide variety of consonantal contexts in order to determine how robust the distinction is. This would then make it possible to assess the relative importance of the lingual adjustments within the bundle of features contributing to the rounded-unrounded distinction. Ultimately, in combination with studies of the other aspects of the distinction, this work should give a better understanding of the extent to which articulation actually takes into account considerations of acoustic stability derived on the basis of acoustic theory.

The second aim of this study is dependent on the first one: if stable differences were found this would mean that German may make up to an 8-way distinction in tongue position for front vowels. It then becomes pertinent to ask whether this complexity results in reduced contextual variability for front vowels compared with back vowels.

Electromagnetic articulography (EMA) and electropalatography (EPG) were used to collect the relevant data on lingual configuration. Both techniques readily allow recording and analysis of a large number of utterances.

In order to be able to use EMA and EPG as complementary sources of information, which seemed highly desirable, the main part of this investigation was restricted to high vowels since EPG provides only negligible information on low vowels.

2. PROCEDURE

The material analyzed here forms part of a larger investigation of coarticulatory processes in VCV syllables using EMA and EPG. To date two subjects have been analyzed using EMA and two using EPG with one subject in common; they will thus be referred to as subjects COM (= "common"), EMA2 and EPG2.

2.1 EMA recordings

A commercially available system for electromagnetic movement transduction (Carstens Medizinelektronik) was used to monitor movement of tongue and jaw [4], [5], [2]. To this end 3 receiver coils were mounted on the midline of the tongue at locations ranging from 1 to 5 cm from the tongue tip, together with one on the lower incisors (jaw) and upper incisors (reference). The x/y coordinates at these five positions were recorded by a dedicated PC at a sample rate of 193.5 Hz for COM and 250 Hz for EMA2. Audio and synchronization information were recorded on DAT tape and all signals were then transferred to a laboratory computer for further processing.

For the purposes of this experiment the data were placed in a coordinate system whose origin is at the average jaw position for the high front vowels examined here, and with the principal component of jaw movement oriented vertically.

2.2 EPG recordings

The EPG recordings were made on the Reading University multichannel data acquisition system, the EPG sample rate being 200 Hz. The EPG and accompanying audio signal were also transferred to the lab computer for further analysis together with the EMA data.

2.3 Material

A large corpus of VCV nonsense items was recorded. The corpus for the EMA recordings consisted of words of the form /bV1CV2/, the consonants being /p, b, m, f, v, t, d, n, l, s, sh, k, g, h/ and the vowels /i, y, u, a/. All combinations of /i, u, a/ were used but /y/ was only combined with /a/, giving 154 forms in all. The corpus for the EPG recordings was basically the same but without the consonants /m, f, v, g, h/ and also without the initial /b/. The EMA corpus was spoken with a carrier phrase "sage — bitte" whereas the EPG recordings were not.

For both techniques 5 repetitions of each item were aimed for, which was slightly overachieved for EPG and slightly underachieved for EMA due to coils becoming detached prematurely.

3. ANALYSIS AND RESULTS

A waveform editor was used to locate the beginning and end of each vowel in the audio signals. All articulatory analyses were carried out at the mid-point of the vowels so defined.

Since the EPG results are rather more clear-cut they will be discussed first.

3.1 EPG

The electrodes on the artificial palate can be regarded schematically as being arranged in 8 rows and 8 columns. A measure of the location of the articulation on the front-back dimension can be derived by summing the number of contacts in each row and then determining the centre of gravity ("CG") of this vector of 8 values. One additional parameter proved sufficient to capture the difference between /i/ and /y/, namely the grand total ("TOTAL") of the number of contacts. For similar values of CG different values of TOTAL will indicate differences in tongue height. The results are accordingly presented in Fig. 1 with CG on the x-axis and TOTAL on the y-axis. This figure shows all V1 tokens of /i/ and /y/ with V2=/a/, the data for each vowel being enclosed by a 2-sigma ellipse. The i/y distinction is obviously very clear-cut for both subjects. COM distinguishes the vowels solely on the basis of TOTAL indicating a lower tongue position for /y/, whereas EPG2 also distingushes in terms of CG. In fact, the shift of CG to a more rearward value is probably also the reason for less overall contact (an increasing number of anterior rows becoming devoid of contact), so that in contrast to COM the primary mechanism in the i/y distinction can be assumed to be tongue retraction for /y/.

3.2 EMA

The EMA results for the two subjects are shown in Fig. 2, each plot showing both subjects at one tongue measurement position. In parallel with Fig. 1 larger values on the x-axis indicate more posterior tongue position.

Although the distinction between /i/ and /y/ is less sharp than in the palatographic data clear tendencies remain. COM shows overall a lower tongue position for /y/, thus reinforcing the interpretation placed on his palatographic data, while speaker EMA2 has a more retracted position for this vowel, thus patterning like the second EPG speaker. The distance between the centres of the /i/ and /y/ ellipses, averaged over the three coils, amounts to 1.75 mm for COM and 1.85 mm for EMA2. Although the main purpose of this study was to determine whether the i/y contrast is stable over many contexts we nonetheless examined to what extent the contrast is enhanced in a more restricted context. The tongue position was accordingly re-evaluated in labial consonantal contexts (p, b, m, f, v). The average distance between /i/ and /y/ increased to 2.3 mm for COM and 2.2 mm for EMA2. Of greater significance was a reduction in the size of the 2-sigma ellipses (averaged over the 3 coils and 2 vowels) from 15.1 to 7.7 mm2 for COM and 14.5 to 11.8 mm2 for EMA2, the net result being virtually no overlap between the /i/ and /y/ ellipses.

The question arises as to whether the differences in tongue position are a passive effect of differences in jaw position. Both speakers had for /y/ a slightly higher (by 0.4 mm for COM and by 0.7 mm for EMA2) and more retracted (by 0.9 mm for COM and 0.6 mm for EMA2) jaw position. Thus the low tongue position in COM cannot be explained by jaw influence, but the more retracted tongue position for EMA2 might be partly explained in this way.

Comparison of the EMA and EPG results gives some indication of the robustness of the i/y distinction. As seen above, the separation is sharper in the EPG data. One possible reason is that the EPG recordings were spoken without a carrier phrase, thus encouraging a more deliberate style of speech. This was certainly the case for COM whose EPG vowels were almost 100 ms longer than the EMA vowels. On the other hand the vowels of EMA2 proved somewhat longer than those of EPG2 so speaker-specific traits may also play a role as well as influences of the carrier phrase not reflected in vowel length.

3.3 Overall vowel variability

Accepting that there are consistent differences in tongue position in /i/ and /y/ and thus potentially a large number of lingual distinctions to be made among German front vowels we aimed to determine whether this is reflected in different ranges of contextually inducible variability for different vowels.

As a first approach to this question we simply measured in the EMA data the areas of the 2-sigma ellipses for each of the point vowels /i, u, a/ in the corpus over all consonantal and vocalic contexts. A highly consistent picture emerged. Both subjects showed a variability order of i < u < a at back and mid coils and i < a < u at the front coil. The results averaged over all coils are given in Table 1, clearly showing the lesser degree of variability for /i/.

4. OUTLOOK

The aim of this paper was to provide a foundation on which to generate hypotheses for future work. Little would be gained from a more comprehensive investigation of the front rounded vs. unrounded vowels if the lingual differences proved highly unstable. But this was not the case. One important point that emerges from this investigation is that speakers appear to differ somewhat in the articulatory adjustments they use to distinguish the rounded/unrounded pairs. In particular, the tendency towards retraction in two of the three speakers was slightly unexpected as this pattern was not found by Wood, and in fact he suggests on the basis of his modelling studies that it is a pattern that is not conducive to maximum acoustic distinctiveness between /i/ and /y/. Acoustic analysis that is in preparation, and lip-movement recordings that are planned, should help throw more light on this issue.

It also remains to be demonstrated that an 8-way distinction in front vowel tongue position actually occurs in German. Based on the results found here for the effect of vowel length on the distinction one specific expectation is that these potential oppositions will be effectively neutralized in the short, lax rounded/unrounded pairs.

Finally, support was also found for the suggestion that the crowded front vowel space will constrain the amount of contextual variation for these vowels. However, there may well be a bias towards low variability in /i/ in this experiment. Firstly, none of the coils were really placed very far dorsally. Secondly, it has been suggested [1] that high vowels tend to benefit from the proximity of the hard palate to reduce the range of variability. These issues could be easily resolved in future work with a more comprehensive sample of the German vowel system.

Acknowledgment

Thanks to Claudia Mässiggang for help with data analysis and to Bill Hardcastle, Fiona Gibbon and Katerina Nicolaidis of Reading University for managing the EPG recordings. Work supported by ESPRIT/BRA 3279 ACCOR.

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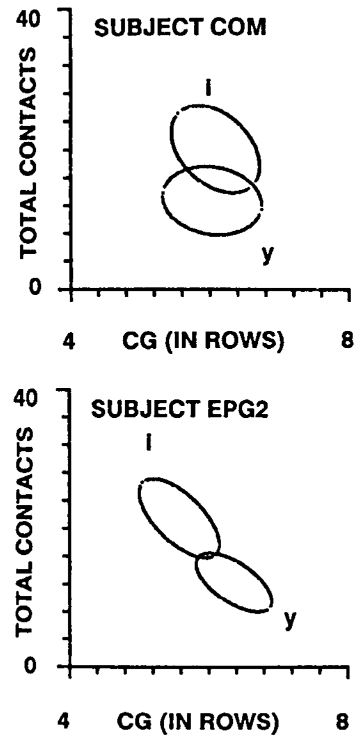

Fig. 1: Results for the two EPG subjects. Higher values of CG indicate more posterior tongue position. COM: N = 70; EPG2: N = 48.

Table 1

	/i/	/u/	/a/	
COM	14	31	34	N = 167
EMA2	14	32	33	N = 210

2-sigma area of variability in mm2, averaged over the 3 tongue coils.

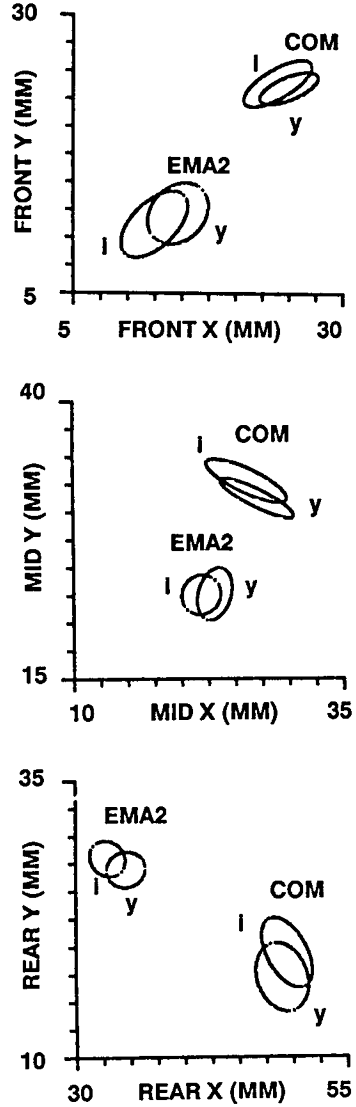

Fig. 2: Results for the two EMA subjects, displayed separately for each tongue measurement position. Higher values on the x-axis indicate more posterior tongue position. COM: N = 56 (Front and Mid coils), N = 42 (rear coil); EMA2: N = 70.