FACTORS OF VARIATION IN THE PRODUCTION OF THE GERMAN DORSAL FRICATIVE

B. Pompino-Marschall and Ch. Mooshammer
Zentrum für Allgemeine Sprachwissenschaft, Typologie und Universalienforschung,
Geisteswissenschaftliche Zentren Berlin e.V.
Jägerstr. 10/11, D-10117 Berlin, Germany.
Tel.: +49 30 20 192 419, FAX: +49 30 20 192 402, E-mail: bobby@fas.ag-berlin.mpg.de

ABSTRACT

The articulatory variability of the Standard German (voiceless) dorsal fricative /x/ - surfacing as [ç], [x] or [χ] depending on the position within the syllable and the vowel context (cf. [2, 3]) - is analysed by using electropalatographic and electromagnetic articulographic as well as averaged spectral data. The results are compared to those for the coronal fricatives and the velar plosive in German.

1. INTRODUCTION

As has been shown (cf. [1]) phonemic variation in place of articulation should be distinguished from coarticulatory/assimilative allophonic variation (e.g. fronting of velar stops).

In Standard German there is a complementary distribution of the allophones of the (voiceless) dorsal fricative /x/: [ç] occurs after front vowels and consonants as well as morpheme initially whereas [x] (and [χ]) occur after high (and nonhigh) back vowels.

In the following study we want to compare this variation in place of articulation from palatal to velar (and even uvular) (1) with the coarticulatory effect of vowels on following coronal fricatives as well as (2) with the fronting of the velar stop depeending on the identity of the following vowel.

2. METHOD

2.1. Material and procedure

The recorded material consisted of German words embedded in the carrier phrase *Ich habe __ er wähnt* ('I've mentioned __'). These words varied systematically with respect to (lax) vowel ([ɪ, ɛ, ʊ, ɔ, a]) and target consonant ([s, ʃ, ç/x/χ, k]); where [s] and [ʃ] where only produced directly following the vowel (e.g. *fis* [fɪs] ('F sharp'), *fesch* [fɛʃ] ('smart')); [ç/x/χ] (e.g. *mich* [mɪç] ('me'), *Bucht* [bʊxt] ('bay'), *Koch* [kɔχ] ('cook')) also after a preceding coronal [l, n] (e.g. *Milch* [mɪlç] ('milk'), *manch* [manç] ('many a')) or a preceding rhotic coda consonant (e.g. *Storch* [ʃtɔʀç] ('stork')). For every vowel series one of the word items was chosen to start with [k] (e.g. *Kuß* [kʊs] ('kiss')).
In a pilot study this material was recorded with five repetitions in randomized order by means of the Reading EPG.3 system both palatographically and acoustically by two native German speakers, BPM (male) and TMO (female). The same material was recorded with the male subject (BPM) of the pilot study and two further male native German subjects (JDR, PJA) with simultaneous recordings of tongue movements by a Carstens AG100 articulograph with 5 sensor coils mounted midsagittally on the tongue surface 1 cm from the tip (tongue blade - TB), at the point opposite to the border between hard and soft palate (tongue dorsum - TD) and halfways in between (predorsally - PD). Reference coils were placed at the upper incisors and at the bridge of the nose.

2.2. Data analysis

The EPG data was analyzed with respect to the position of the centre of gravity of the area of linguopalatal contact at the point of maximal constriction at the temporal centre of the obstruent articulation calculated with reference to row number (1-8, counting from front; cf. CGR in the tables) as well as to distance from the inner edge of the upper incisors (cf. fig. 1; CGD). The second EPG parameter was the weight of these centres of gravity (expressed in numbers of electrodes contacted; WR/WD), the third maximal contacts within a single row of EPG-electrodes (MC).

The EMMA data of the consonantal articulations were analyzed with respect to their extreme positions of the PD coil at the articulatory obstruent centre (defined as the minimum in the tangential velocity function of this coil; cf. MAXX/MAXY in table II). This coil was chosen since the articulation of the dorsal fricative was the main focus of this study. This choice will clearly somewhat distort the results for the coronal fricatives as well as for the velar stops since their extreme articulatory positions better should be registered with reference to the TB or TD coil respectively.

Besides the measurement of consonantal duration, the fricative productions were acoustically analysed with respect to their average spectrum during the steady state phase with the help of the Signalyze software for Apple MacIntosh (300Hz broadband without preamplification).

Statistical analysis was done for each subject individually with the help of the ANOVA procedure of the StatView software for Apple MacIntosh. Single ANOVAs were calculated for the EPG and EMMA parameters: (1) compar-

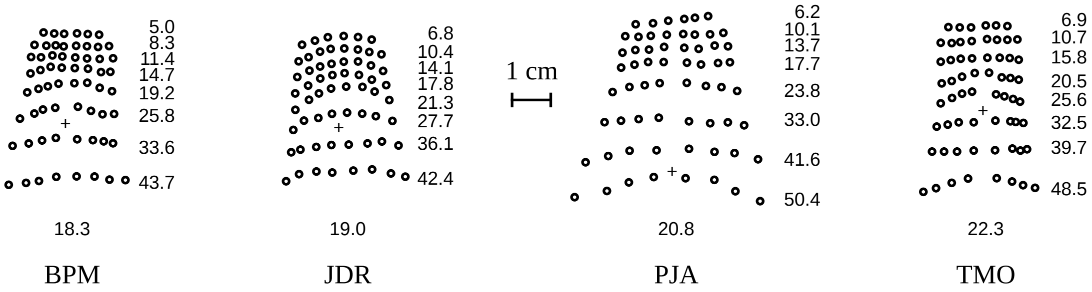

Fig. 1: Electrode placement in the bite plane for the four subjects (the mean distance of the electrode rows (1-8) from the inner edge of the upper incisors (in mm) is given at the right side of the individual plots; the highest point of the palate marked by a cross, its distance (in mm) from bite plane is given beneath individual plots).

ing the different influences of vowel context on the articulation of directly following fricatives (/s/ vs /ʃ/ vs /x/), (2) the influence of different preceding coda consonants on the articulation of / x/ (none vs coronal vs rhotic), (3) the vowel effects on the following dorsal fricative vs velar plosive, and (4) the differences in vowel effects for syllable initial vs syllable final velar stops.

3. RESULTS

For all subjects the EPG parameter centre of gravity of the contact area (when calculated with respect to electrode rows as well as calculated with respect to distance) yielded a higly significant effect of the fricative (/s, ʃ, x/), the vowel (/ɪ, ɛ, ʊ, ɔ, a/), and a higly significant interaction (all $p < .001$). Single analyses and a posteriori Scheffe tests again for all subjects showed highly significant ($p < .001$) vowel effects for the dorsal fricative, clearly distinguishing between front (/ɪ, ɛ/ with a more fronted place of constriction) and back vowels (/ʊ, ɔ, a/). Other effects (e.g. some vowel effects for /ʃ/ for BPM and TMO or / a/ having a further distinct effect on the dorsal fricative for JDR) remained quite marginally and greatly varied between subjects. Table I clearly shows the distinct locations for the constriction for the different fricatives (from front to back: [s, ʃ, ç, x/χ]; the standard deviations not given there for CGD are all in the order of 1 mm, for WD all about .5 contacts).

In the statistical analyses the parameter WD/WR results in the same distinctions between the different fricative categories.

Comparing the dorsal fricatives (directly vowel adjacent or preceded by another coda consonant) the parameter CGD/CGR for all subjects again unequivocally showed higly significant effects for the vowel and consonant factor and a highly significant interaction (all $p < .001$). For all subjects, the dorsal fricative after consonants is produced more fronted, i.e. as [ç] and interindividually shows no consistent vowel effects.

Besides the expected further backward articulation of [k] in comparison to the dorsal fricative after a rhotic conso-

Table I: The centres of gravity of the linguopalatal contact area (position in mm distance from upper incisors: CGD; weight in electrodes contacted: WD) for the different fricative categories and the single subjects (BPM1, BPM2, JDR, PJA, TMO).

consonant	CGD	WD
/s/	17.208 17.698 17.996 24.321 20.847	2.545 2.287 2.138 3.882 2.259
/ʃ/	22.440 21.012 23.524 31.872 28.232	2.301 1.955 3.218 4.259 2.572
front V /x/	26.326 28.278 24.036 34.268 29.109	3.894 4.869 4.918 5.602 4.475
back V /x/	43.700 43.700 40.888 45.118 48.207	0.000 0.000 1.996 2.996 1.800

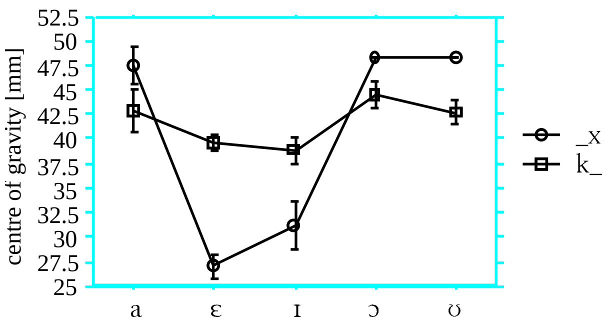

Fig. 2: Interaction plot for vowel effect on the position of the centre of gravity for the syllable final (vowel adjacent) dorsal fricative and the syllable initial velar plosive (TMO; error bars representing 1 sd).

Table II: EPG and EMMA parameters of the dorsal fricative production (means and standard deviations in parenthesis) for the subjects BPM2, JDR and PJA (see text for details).

C	V	CGR	WR	CGD	WD	MC	MAXX	MAXY
_x	ɪ	6.071 (0.135) 4.740 (0.099) 5.938 (0.109)	4.703 (0.332) 4.661 (0.177) 5.559 (0.501)	28.048 (1.008) 23.249 0.476) 33.368 (0.893)	4.828 (0.308) 4.946 (0.184) 5.730 (0.457)	6.000 (0.000) 5.400 (0.548) 7.000 (0.000)	-0.952 (0.722) -0.238 (0.454) -3.030 (1.589)	-0.136 (0.811) -0.159 (0.461) -0.362 (1.805)
	ɛ	6.144 (0.188) 5.083 (0.080) 6.177 (0.358)	4.775 (0.750) 4.628 (0.237) 5.271 (0.163)	28.507 (1.217) 24.823 (0.389) 35.168 (2.457)	4.909 (0.768) 4.889 (0.250) 5.474 (0.134)	5.600 (0.894) 5.200 (0.447) 7.000 (0.000)	-0.65 (1.653) 0.259 (1.119) -1.535 (1.685)	0.602 (1.134) 0.444 (0.382) -0.784 (1.761)
	ʊ	8.000 (0.000) 7.853 (0.202) 7.300 (o.340)	0.000 (0.000) 2.320 (0.477) 3.287 (0.193)	43.700 (0.000) 41.476 (1.274) 44.259 (2.974)	0.000 (0.000) 2.332 (0.482) 3.357 (0.198)	0.000 (0.000) 2.600 (0.894) 4.200 (0.447)	17.708 (2.251) 3.214 (1.276) 13.239 (1.450)	-16.312 (1.840) -2.896 (0.634) 4.437 (0.934)
	ɔ	8.000 (0.000) 7.933 (0.149) 7.530 (0.201)	0.000 (0.000) 1.907 (0.209) 2.954 (0.268)	43.700 (0.000) 41.980 (0.939) 46.280 (1.745)	0.000 (0.000) 1.916 (0.208) 2.994 (0.253)	0.000 (0.000) 2.000 (0.000) 4.000 (0.000)	16.551 (1.546) 10.824 (0.922) 8.673 (0.778)	-16.757 (1.719) -12.283 (0.842) -14.640 (0.790)
	a	8.000 (0.000) 7.523 (0.327) 7.356 (0.219)	0.000 (0.000) 1.726 (0.277) 2.574 (0.242)	43.700 (0.000) 39.208 (2.278) 44.814 (1.797)	0.000 (0.000) 1.740 (0.272) 2.638 (0.230)	0.000 (0.000) 2.000 (0.000) 3.800 (0.447)	13.489 (1.877) 7.612 (0.642) 5.583 (0.913)	-13.177 (1.461) -9.386 (0.493) -15.363 (0.666)
Cx	ɪ	5.837 (0.477) 4.841 (0.140) 6.565 (0.164)	4.207 (0.408) 4.756 (0.194) 4.915 (0.267)	26.670 (2.903) 23.699 (0.747) 38.060 (1.385)	4.258 (0.400) 5.036 (0.196) 5.138 (0.241)	5.400 (0.894) 5.200 (0.447) 7.000 (0.000)	0.149 (0.609) 0.104 (0.888) 1.925 (1.223)	-0.840 (0.897) 0.591 (0.461) 1.779 (1.390)
	ɛ	5.984 (0.152) 4.838 (0.094) 6.511 (0.168)	4.539 (0.759) 4.700 (0.249) 4.977 (0.226)	27.446 (0.960) 23.712 (0.423) 37.558 (1.346)	4.632 (0.799) 4.984 (0.264) 5.188 (0.217)	5.400 (0.894) 5.200 (0.447) 6.800 (0.447)	-1.148 (0.758) 0.422 (0.651) 0.914 (0.691)	-0.732 (0.904) 0.478 (0.565) 1.101 (0.572)
	ʊ	5.831 (0.081) 4.806 (0.162) 6.314 (0.185)	4.200 (0.556) 4.456 (0.181) 4.899 (0.136)	26.417 (0.531) 23.613 (0.777) 36.115 (1.299)	4.229 (0.540) 4.736 (0.205) 5.114 (0.125)	5.000 (0.707) 5.200 (0.447) 6.800 (0.447)	0.691 (1.094) 1.772 (0.756) 0.499 (0.444)	1.175 (0.540) 0.283 (0.290) 0.489 (0.590)
	ɔ	5.815 (0.126) 4.852 (0.243) 6.437 (0.146)	4.018 (0.488) 4.417 (0.225) 4.628 (0.376)	26.374 (0.853) 23.764 (1.199) 36.958 (1.178)	4.053 (0.503) 4.680 (0.247) 4.800 (0.333)	5.000 (0.707) 5.200 (0.447) 6.000 (0.000)	0.602 (1.534) 1.347 (0.586) 1.675 (1.894)	-0.579 (0.530) 0.432 (0.436) 1.194 (0.694)
	a	5.679 (0.139) 4.787 (0.173) 6.220 (0.235)	4.625 (0.544) 4.861 (0.083) 5.214 (0.377)	25.584 (0.838) 23.364 (0.756) 35.409 (1.623)	4.639 (0.557) 5.133 (0.092) 5.420 (0.355)	5.800 (0.447) 5.200 (0.447) 7.000 (0.000)	0.797 (0.997) 0.209 (0.471) 2.054 (0.609)	0.665 (0.850) 0.774 (0.291) 1.783 (1.083)
Rx	ɪ	5.955 (0.173) 5.112 (0.113) 6.569 (0.174)	4.224 (0.420) 4.567 (0.208) 5.020 (0.469)	27.412 (1.146) 25.073 (0.463) 38.072 (1.412)	4.324 (0.453) 4.847 (0.245) 5.253 (0.428)	5.400 (0.548) 5.400 (0.548) 7.000 (0.000)	0.803 (0.859) 0.133 (0.821) 1.105 (1.194)	0.976 0.801) -0.431 (0.545) -1.416 (0.751)
	ɛ	5.747 (0.150) 4.777 (0.130) 6.516 (0.332)	4.667 (0.347) 5.017 (0.256) 4.971 (0.341)	26.022 (0.963) 23.392 (0.638) 37.635 (2.687)	4.700 (0.392) 5.314 (0.276) 5.169 (0.331)	5.600 (0.548) 5.600 (0.894) 6.600 (0.548)	1.529 (0.750) -0.883 (1.055) 0.666 (1.250)	1.396 (0.403) -0.094 (0.539) 1.353 (1.742)
	ʊ	5.986 (0.190) 5.195 (0.213) 6.457 (0.322)	4.653 (0.665) 5.057 (0.666) 5.137 (0.394)	27.505 (1.200) 25.373 (1.072) 37.203 (2.417)	4.737 (0.678) 5.385 (0.689) 5.349 (0.364)	5.600 (0.894) 5.800 (0.837) 7.000 (0.000)	1.750 (0.857) -1.517 (0.751) 0.646 (0.207)	0.842 (0.894) 0.243 (0.292) 1.536 (1.303)
	ɔ	5.915 (0.180) 5.142 (0.281) 6.348 (0.064)	4.555 (0.505) 4.694 (0.295) 4.921 (0.322)	27.075 (1.056) 25.147 (1.456) 36.368 (0.566)	4.626 (0.523) 4.966 (0.311) 5.162 (0.308)	5.600 (0.548) 5.400 (0.548) 7.000 (0.000)	1.448 (1.171) -0.401 (0.808) 0.851 (0.956)	1.074 (1.030) 0.795 (0.410) 2.399 (1.148)
	a	5.762 (0.173) 4.965 (0.100) 6.574 (0.180)	4.927 (0.432) 5.178 (0.454) 5.006 (0.383)	26.052 (1.134) 24.255 (0.383) 38.084 (1.473)	4.954 (0.460) 5.474 (0.512) 5.239 (0.372)	5.800 (0.447) 6.000 (1.000) 7.000 (0.000)	0.762 (1.326) -2.084 (0.533) 1.016 (0.533)	1.805 (0.495) -0.131 (0.347) 0.709 (0.851)

nant ($p < .001$ for all subjects) for three subjects (BPM, JDR, PJA) the statistical analyses showed a significant 'vowel' effect for [k]. This effect, i.e. a significantly more backward articulation in the context of [ɪ] and [ɔ] can be explained by a closer look at these items: only in these words the [k] is followed by a syllable final [t], i.e. the effect is rather to be understood as a 'dissimilative' influence of the following consonant. We interpret this effect as a phonetic one being due to stretching of the tongue in anticipation of the alveolar closing gesture.

The comparison of syllable initial vs coda [k] showed significantly more fronted articulations of the coda stop for all subjects ($p < .001$) and a higly significant vowel effect for syllable initial [k] (JDR, PJA, TMO; $p < .001$). But this vowel effect is rather continuous in contrast to the sharp distinction between front and back vowels in case of the dorsal fricative. It is furthermore altogether missing for subject BPM. This effect is therefore interpreted as an optional and gradual effect of consonant-vowel coarticulation. In figure 2 these differences in the vowel effects are demonstrated for subject TMO.

The EMMA data fully supports the conclusions drawn from the analyses of the EPG data. For comparison in table II the means and standard deviations for all measured parameters are given for the dorsal fricative articulations. Since due to different helmet positions and

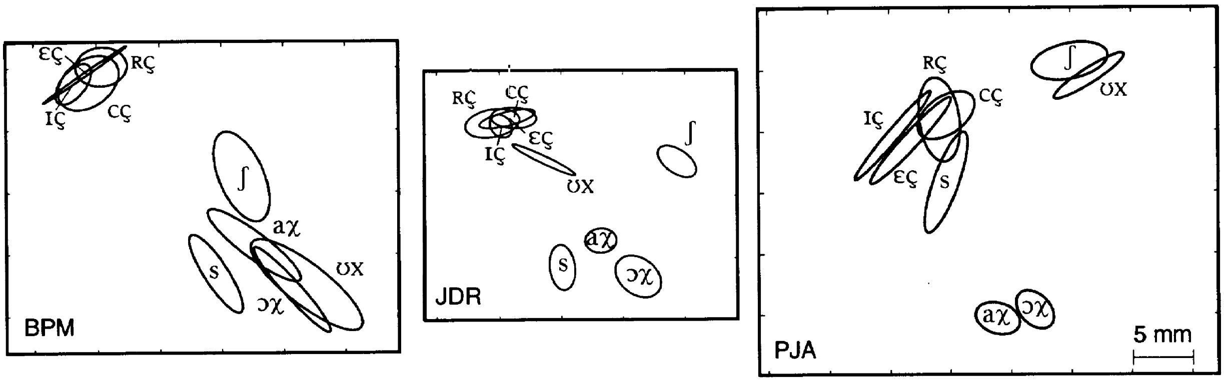

Fig. 3: Variation in the position of the PD coil at the moment of minimal tangential velocity during fricative production (left hand side of plots: front; ellipses representing 2-sigma ranges of variation).

preprocessing the absolute values of the EMMA data are not directly comparable. Therefore the data here is given as distance from mean articulatory position in the context of [ɪ]. The figures clearly demonstrate the articulatory differences in the directly vowel adjacent fricative productions according to the front/back vowel context (cf. the differently highlighted parts of the table).

Figure 3 summarizes the EMMA results as plots of the 2-sigma range of variation in the position of the PD coil at the centre of fricative articulation for the three subjects. Besides the clear articulatory difference between the coronal fricatives and the overlap between the dorsal fricatives after consonants and following front vowels one can see a difference in articulator position for the different dorsal fricatives after back vowels (at least for JDR and PJA). This latter effect, not visible in the EPG data and altogether absent for BPM, again could be interpreted as an optional gradual phonetic process.

The here found articulatory differences shall be compared to differences in the fricative spectra (cf. [4]) in the next step of this study.

4. CONCLUSION

Quite different forces seem to influence the place of articulation in dorsal obstruents. Forces of a rather phonological/phonotactical nature, influences of syllabic position, coarticulatory phonetic influences, as well as fluent speech processes have to be distinguished:

• a progressive assimilatory force on postvocalic dorsal fricatives yielding [ç] after front vowels, [x] after high back vowels, and [χ] otherwise; surfacing [ç] being due to a mandatory phonological process of an all-or-nothing nature, the variation in the back allophone due to optional and gradual coarticulatory phonetic processes,

• a phonotactically conditioned surfacing of [ç] after consonants, optionally combined with a dissimilatory force of preceding back vowels,

• a regressive assimilatory force on prevocalic velar stops yielding more fronted articulations before front vowels; this again being due to optional and gradual coarticulatory processes,

• a regressive dissimilatory force on the coda [k] yielding more backward articulations when followed by a coronal stop, again a phonetic process.

Another factor that leads to a fronting of [ç] is the often observed [ɪ] deletion in fluent/spontaneous speech which is e.g. quite common in the function word *ich* [ɪç] (‘I’). This effect will be studied in connection with the acoustic part of this study.

[work supported by German Research Council (DFG) Grant Po 334/1-1]

5. REFERENCES

[1] P. Keating and A. Lahiri, “Fronted velars, palatalized velars, and palatals”, *Phonetica*, Vol. 50, pp. 73-101, 1993.

[2] K. Kohler, “German”, *Journal of the International Phonetic Association*, Vol. 20, pp. 48-50, 1990.

[3] K. Kohler, “Comment on German”, *Journal of the International Phonetic Association,* Vol. 21, pp. 44-46, 1990.

[4] C.H. Shadle, “Articulatory-acoustic relationship in fricative consonants. In: W.J. Hardcastle and A. Marchal (eds.), *Speech Production and Speech Modelling*, Kluver Academic Publishers, Dordrecht, pp. 187-209, 1990.