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PHONETIC EVIDENCE FOR THE PHONOLOGICAL STATUS OF THE TENSE-LAX DISTINCTION IN GERMAN[1]

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ABSTRACT

Recently (Hoole, Mooshammer & Tillmann, 1994), we compared with Electromagnetic Articulography the kinematic properties of German tense and lax vowels over changes in speech rate: They appeared not to differ in the internal organisation of the elementary CV and VC movements, but the lax vowels showed tighter serial coupling of CV to VC movement. These results were suggestive given the strong phonological tradition (on a phonetically elusive substrate) of accounting for the differences between these vowels at the level of word prosody (especially in the link between vowel and following consonant).

Nevertheless, important questions had remained open: Firstly, analysis of the velocity profiles of the CV and VC movements had been based on a parameter (ratio of peak to average velocity) that may not capture all relevant differences. Secondly, it was unclear whether tense-lax differences are equally clear-cut for all vowel subcategories (e.g high, low, rounded, unrounded) and also for different consonantal contexts.

The more refined and extensive analyses carried out in the present contribution essentially confirmed the well-foundedness of the earlier preliminary conclusions.

1. INTRODUCTION

Preliminary results comparing articulator movement for German tense and lax vowels (Hoole et. al., 1994) over differences in speech rate led to the following hypothesis about kinematic characteristics of the tense-lax contrast: Tense and lax vowels do not differ in the internal organisation of the elementary CV and VC movements, but do differ in their serial organisation, i.e in the tightness of the coupling of the CV to the VC movement (tighter for lax vowels).

After presenting the experimental procedure in Section 2, we then summarize in Section 3 some of the phonological background, pointing out why this is a very promising result considering a long tradition in German phonology viewing these two vowel categories as distinguished at the level of word prosody.

This hypothesis is now examined in the light of more extensive analyses and data.

[1]This work was presented as a poster (Abstract-No: 3aSC27) at the 132nd ASA meeting / 3rd ASA/ASJ joint meeting, Honolulu, December, 1996. A more extensive version is in preparation.

2. MATERIALS, TALKERS AND SEGMENTATION PROCEDURE

* Seven speakers of Standard German
* Two speech rates in two recording sessions: Normal and fast
* Target word (logatom in carrier phrase): /gəC_1VC_2ə/
  with $C_1 = C_2$ = /p, t, k/ and
  V = /iː,ɪ;yː,ʏ;eː,ɛ;ɛː;øː,œ;ɑː,a;oː,ɔ;uː,ʊ/
  (45 Items)
* Carrier phrase: "Ich habe *target word* gesagt"
* Five repetitions of every item
* Monitoring of tongue, lower lip and jaw movements with EMMA (AG100, Carstens Medizinelektronik). See Fig. 1.

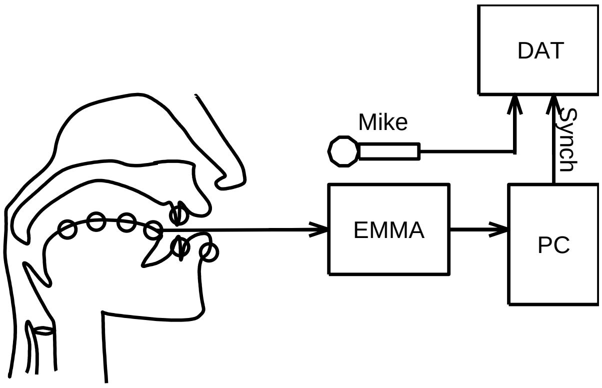

Fig. 1: *Experimental setup showing approximate sensor locations (omitting reference sensor on bridge of nose).*

* Articulatory analysis based on:
  lower-lip sensor for /p/-context
  tongue-tip sensor for /t/-context
  tongue-dorsum sensor for /k/-context
* The complete CVC movement enclosing the target vowel was divided into CV, Nucleus and VC phases using a velocity threshold criterion[2].The velocity threshold defined the onset and the offset of the CV and VC movements; the nucleus was operationally defined as the interval between CV offset and VC onset. This procedure is shown in Fig. 2 for two representative utterances. The movement segmentation was based on the tangential velocity signal. However, for illustrative purposes Fig. 2 also shows velocity and acceleration of the vertical movement component. Analysis was based firstly on a set of kinematically-defined durational parameters (also illustrated schematically in Fig. 2) and secondly on assessment of the shape of velocity and acceleration profiles.

3. THE PHONOLOGICAL CONCEPT OF CLOSE AND LOOSE CONTACT ('SILBENSCHNITT') IN STANDARD GERMAN

The phonological status of the tense-lax distinction (or even the mere fact of its existence) in German has been subject of intense debate, concentrating on the relative importance and status of durational and qualitative differences.[3]

Recently, a fresh angle was brought into the discussion with renewed interest in the concept of close and loose contact ('Silbenschnitt'; Vennemann, 1991) for an explanation and systematic simplification of the complicated German vowel system (see Becker, 1995, for an overview).

This concept dates as far back as Sievers (1901) and exploits the fact that lax vowels occur only in closed syllables. It assumes that both the qualititative and quantitative differences are directly caused by different kinds of contact between the vowel and the following consonant (close for lax, loose for tense vowels), determined in turn by the syllable structure. Yet, hitherto, attempts to show a phonetic foundation for this conception had been inconclusive (e.g Fischer-Jørgensen & Jørgensen, 1969).

[2] After considerable experimentation the threshold was set at 20% of the difference between the minimum velocity and the maximum velocity

[3] There is one exception: almost all researchers agree that for the /a/-/ɑː/ opposition the two vowel categories are distinguished only by duration.

/teːt/ (tense) /tɛt/ (lax)

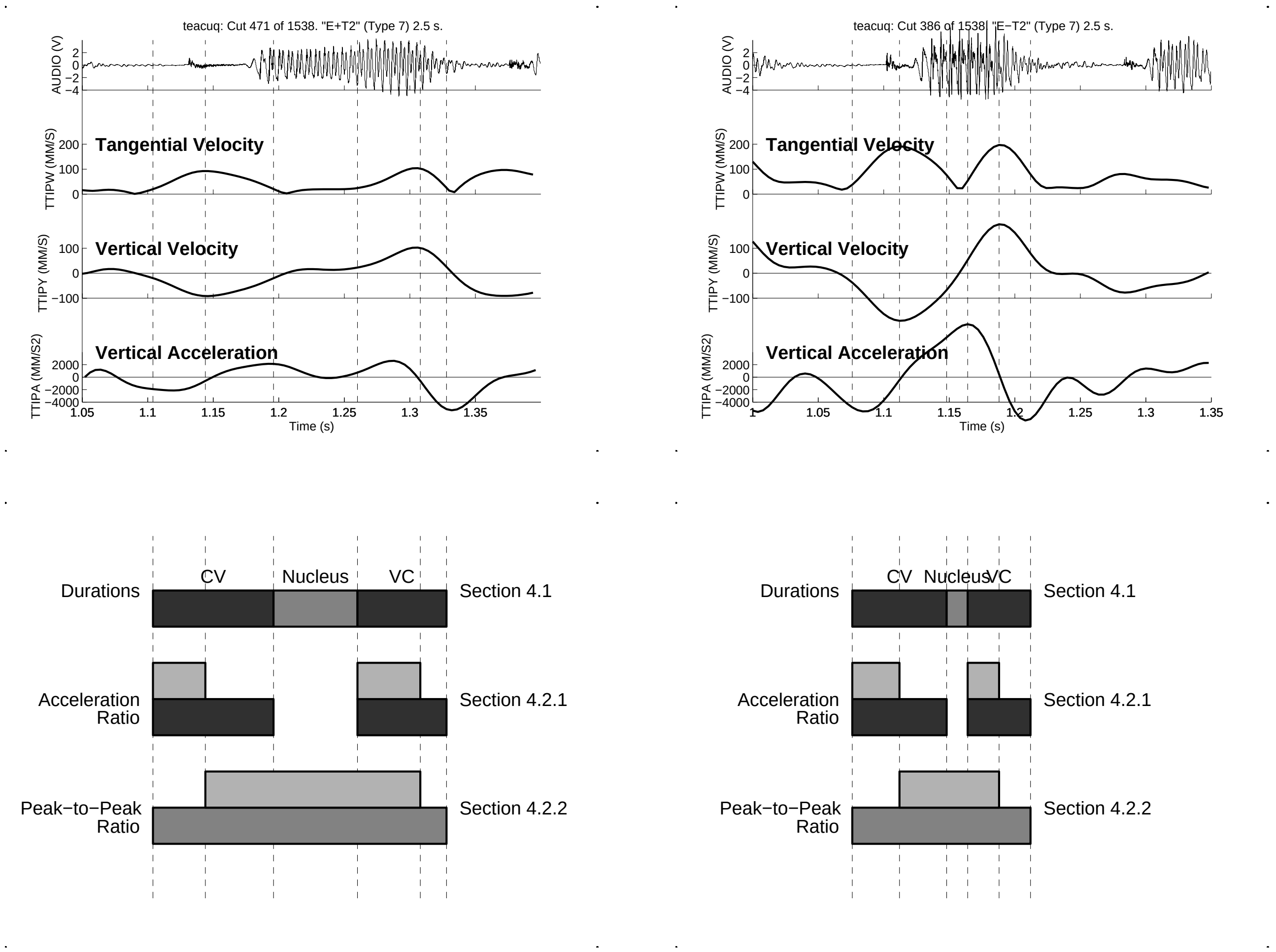

Fig. 2: *Examples of tongue-blade velocity signals for tense vowel /e:/ in /t_t/ context (left) and corresponding lax vowel /ɛ/ (right). Below each set of velocity signals is a time-aligned schematic illustration of the kinematically-defined durational parameters used for analysis of the CV and VC movements. The dashed vertical lines correspond (from left to right) to CV onset, CV maximum velocity, CV offset, VC onset, VC maximum velocity, and VC offset.*

4. KINEMATIC ANALYSES

4.1 Patterns of temporal compression over speech rate

4.1.1 Method

Durational change over speech rate was examined for the CV, Nucleus and VC segments.

4.1.2 Results

Mean absolute durations are shown in Fig. 3.

Mean proportional durations are shown in Fig. 4.

For both tense and lax vowels CV, nucleus and VC durations not surprisingly all shorten as tempo changes from normal to fast. However, the nucleus of the tense vowel contracts far more then any other segment. Especially the comparison to the behavior of the lax nucleus is revealing. In terms of proportional durations the temporal structure of CVC sequences with lax vowel hardly changes over speech rate, whereas sequences with tense vowel do show a marked change. This differential behaviour of the nucleus suggests tighter coupling of CV and VC phases for lax vowels and looser coupling for tense vowels.

The compression pattern stays essentially the same for different consonant contexts (/p, t, k/), and vowel subcategories (rounded/unrounded, front/back, high/low). There is no indication that the low-vowel pair is an odd-man out (cf. footnote in section 3).

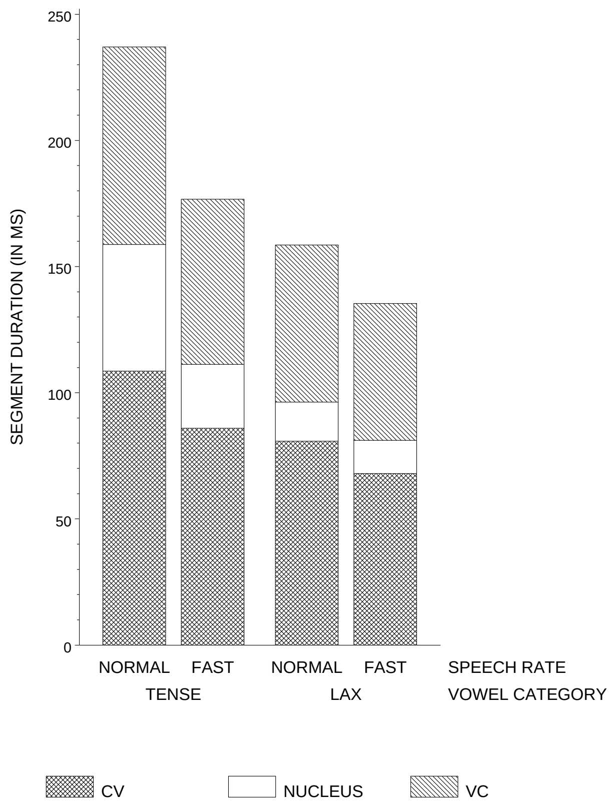

Fig. 3: *Absolute durations of the three kinematically-defined segments for each of the four main utterance categories*

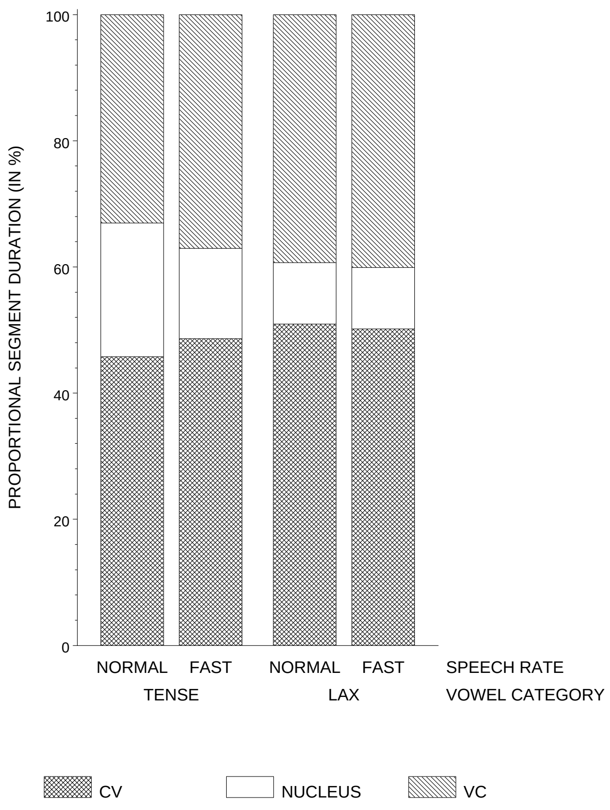

Fig. 4: *Proportional durations of the three kinematically-defined segments for each of the four main utterance categories.*

4.2 Timing relations in CV and VC Movements

4.2.1 Measure 1: Ratio of the duration of the acceleration phase to movement duration

This parameter was calculated separately for each CV and VC movement.The acceleration phase was defined as the interval from time of movement onset to time of peak velocity. This duration was divided by total movement duration (i.e onset to offset as defined by the velocity threshold criterion). See panels labelled "*acceleration ratio*" in Fig. 2 for illustration (cf. also Adams, Weismer & Kent, 1993).

Table 1 gives mean values (in percent, with 50% corresponding to equal duration of acceleration and deceleration phases), standard deviation and, lastly, correlation to segment duration of this parameter (shown separately for CV and VC movements).

The difference between lax and tense vowel is always highly significant ($p < 0.001$). Moreover, this is not a simple side-effect of differences in movement duration between tense and lax vowels: The rightmost column in the table shows that the correlations between the acceleration ratio and CV or VC duration are close to zero even though the values are here pooled over speech rate.

The deviation of the peak velocity point from the center of the segment (i.e deviation of the acceleration ratio from a value of 50%) shows a mirror-image over the CV and VC segments (for both vowel categories): Lax vowels have relatively long acceleration phases and relatively short deceleration phases for CV movements, but relatively short acceleration phases and relatively long deceleration phases for VC. For tense vowels this pattern is reversed. The tense-lax pair shown in Fig. 2 exemplifies this point quite well. Refer not only to the acceleration ratio panels themselves but also to the corresponding portions of the tangential velocity signals.

However, further analysis showed that these deviations from symmetrical acceleration and deceleration phases are largely due to higher minimum velocities at the centre of the lax vowels (also just about visible in the tangential velocity traces in Fig. 2), and do not reflect fundamentally different shapes of the velocity profiles.

This finding again suggests tighter CV-VC coupling for lax vowels.

Table 1: Ratio of the duration of the acceleration phase to duration of the complete single movement (opening or closing) [in %]

		mean	s.d.	correlation to segment duration
CV	Tense	**47.63**	11.10	-0.13
	Lax	**56.35**	9.72	0.02
VC	Tense	**53.56**	8.68	0.21
	Lax	**44.85**	6.65	-0.08

4.2.2 Measure 2: Ratio of the interval between velocity peaks to total movement duration

As illustrated in the bottom panels of Fig. 2, this parameter is derived by taking the duration of the interval from time of peak velocity in the CV movement to time of peak velocity in the VC movement and dividing it by total CV-VC movement time, i.e CV-onset to VC-offset (cf. also Harrington, Fletcher & Roberts, 1995)

Table 2 again shows mean values (in %), standard deviation and correlation to total CV-VC duration of this parameter.

Harrington et al. (1995) showed for jaw movements that increasing truncation of an articulatory gesture produces decreasing values for this parameter.

The values for lax vowels are clearly lower than those for tense ($p < 0.001$). This still holds if one compares tense fast and lax normal (which have fairly similar durations; cf. Fig. 3). This can be seen as an indication of truncation for lax vowels.

Furthermore, while there is not much change from lax normal to lax fast, tense normal to tense fast does change (which is also reflected in the higher correlation of the peak-to-peak ratio with total duration for the tense vowels, especially for data pooled over both speech rates). But this should not necessarily be seen as movement truncation in tense vowels at the faster rate - it comes mainly from shortening the nucleus (which corresponds to a quasi hold-phase for tense vowels with long durations), not from VC truncating CV.

Table 2: Ratio of the interval between velocity peaks to total movement duration (in %)

		mean	s.d.	correlation to total duration
Normal	Tense	**63.70**	7.52	0.32
	Lax	**49.59**	6.61	-0.05
Fast	Tense	**58.32**	8.23	0.29
	Lax	**49.44**	6.78	0.16
Together	Tense	**60.99**	8.33	0.43
	Lax	**49.51**	6.69	0.05

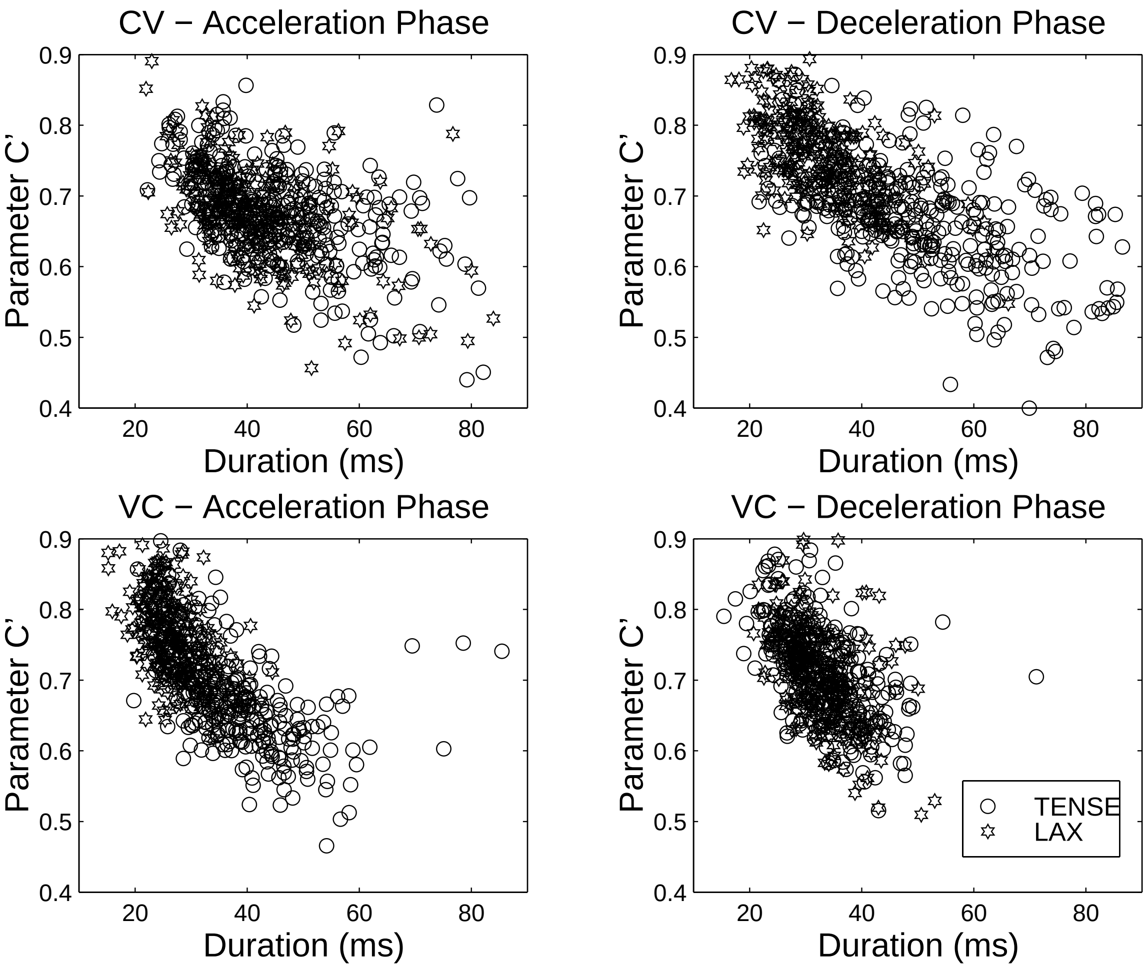

***Fig. 5:** Parameter **c'** as a function of CV (top panels) or VC (bottom panels) phase durations. Left panels: Acceleration phase. Right panels: Deceleration phase. Each data point represents the median over the 5 repetitions recorded for each combination of subject, speech-rate, vowel and consonant. Data points are labelled with circles for tense vowels and stars for lax vowels.*

4.3 Velocity profile shape

Here we turn to the first of two sets of analyses not based on purely durational considerations.

4.3.1 Method

Velocity profile shape has often been characterized by the ratio of peak to average velocity (sometimes referred to in the literature as "Parameter **c**"; see Ostry, Cooke & Munhall, 1985, for background). In our earlier paper (Hoole et al., 1994), we concluded on the basis of this parameter that tense and lax vowels did not exhibit fundamental differences with regard to the kinematic characteristics of the CV and VC movements. However, because this parameter is computed for a complete movement (from onset to offset) it may be blind to some potential differences in velocity profile, particularly regarding asymmetries between acceleration and deceleration phase.

Accordingly, we devised a variant, referred to here as **c'**, (Kroos, 1996) based on geometrical considerations that can be computed separately for the acceleration and deceleration phase of each velocity profile (and normalizes for differences in minimum velocity; cf. 4.2.1).

4.3.2 Results

The results are captured in the four panels of Fig. 5, i.e one panel for each combination of CV vs. VC with acceleration vs. deceleration.

Systematic differences between lax and tense vowels can only be found in the deceleration phase of the CV-segment (top right panel) and in the acceleration phase of the VC-segment (bottom left panel). But the values show a dependency upon duration (also observed for the original parameter **c**: Ostry et al., 1987; Hoole et al., 1994; also Hertrich & Ackermann, 1997) which is enough to explain the distinction sufficiently.

Thus our original conclusion, that tense and lax vowels do not differ in terms of the kinematic properties of the elementary CV and VC movements when concomitant differences in duration are taken into account, appears to stand up to this more detailed scrutiny.

4.4 Analysis of the acceleration profile

The second set of non-durational analyses considered acceleration patterns for the relevant articulators.

4.4.1 Method

Only a very coarse measure for the acceleration profile will be presented here, namely the number of relative maxima in the acceleration signal associated with the vowel center, defined as the interval between the time instants of maximum velocity for the CV and VC movements (refer back to Fig. 2). In terms of acceleration this interval involves deceleration of the opening movement and acceleration of the closing movement, corresponding in both cases to positive values of the acceleration signal.

4.4.2 Results

Fig. 6 shows the results as block chart.

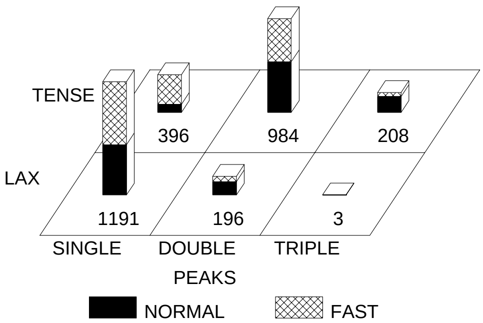

Fig. 8 *Frequency block chart of items with one, two or three acceleration peaks associated with the vowel center.*

Lax vowels usually have only one peak: Deceleration of the opening movement and acceleration of the closing movement merge into a single peak. Tense vowels, in contrast, tend to have two or three. This can be seen as a further indication that for lax vowels the timing of the initiation of a VC movement is much more tightly constrained with respect to an ongoing CV movement than it is for tense vowels.

5. CONCLUSIONS

The original hypothesis was supported:

The observable kinematic differences between tense and lax vowels can be explained by tighter CV-VC coupling for lax vowels. On the other hand, the analysis of velocity profile shape indicated that these two classes of vowels do not differ fundamentally with regard to the intrinsic kinematic properties of the CV and VC movement elements themselves.

However, firmer confirmation requires a wider range of speech rate manipulation. Firstly, tense vowels should show a greater range of stretching and compression over speech rate because the relative freedom in coupling the VC to the CV movement effectively provides them with an additional mechanism for duration change not available to lax vowels; secondly, at particularly slow speech rates lax vowels should show either very uncommon articulatory and acoustic patterns or a prolongation of the following consonant.

In conclusion, the reported results give a plausible view of phonetic correlates of "Silbenschnitt". But a comparison should be made with languages traditionally regarded as having pure quantity differences.

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