EFFECTS OF STRESS AND TENSENESS ON THE PRODUCTION OF CVC SYLLABLES IN GERMAN

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ABSTRACT

In Standard German tense and lax vowels are affected by stress in different ways: Tense vowels are lengthened whereas the duration of lax vowels stays relatively constant. Both the variation of stress and tenseness can be attributed to a truncation of the opening gesture. The first aim of this study is to compare acoustical and kinematic parameters of these effects. Analyses of the durations revealed the same degree of truncation for tense unstressed and lax stressed vowels.

The second aim concerns vowel targets. It is still a subject of debate whether the tenseness contrast holds only in stressed syllables or is neutralized in unstressed syllables. Therefore we analyzed quality differences by means of formant frequencies and Canonical Discriminant Analysis of positional data of tongue, jaw and lower lip. With the exception of the low vowel /a/ no overlap between unstressed tense and lax vowels could be observed.

1. INTRODUCTION

1.1. Tenseness in Standard German

The vowel inventory of Standard German consists of seven pairs of tense and lax vowels /i-ɪ,y-ʏ,e-ɛ,ø-œ,aː-a,u-ʊ,o-ɔ/[1]. Lax vowels are produced with more centralized tongue positions and formant frequencies. In stressed syllables only tense vowels are lengthened whereas in unstressed position the quantity contrast is neutralized.

Whether or not the qualitative opposition is also neutralized in unstressed position is still a matter of debate. In casual speech unstressed tense vowels are often pronounced as the lax counterparts (pretonic laxening), e.g. /tɔˈtaːl/ instead of /toˈtaːl/ ("total"). Therefore some phonologists suggest that unstressed tense vowels are hyperarticulated and that the tenseness contrast only exists in stressed position [14, 2]. Up to now only acoustical parameters have been analyzed [7]. The results indicate that with the exception of the low vowel /a/ the contrast is maintained. One of the goals of this study is to examine articulatory and acoustic differences between tense and lax unstressed vowels.

Newly inspired by Vennemann [13] there has been a long controversy whether tenseness and vowel length should be treated as segmental features or as concomitants of the so called ‘syllable cut’. Lax vowels cannot be lengthened and are produced in a more centralized position because the vowel is cut off by the following consonant (‘close contact’ [6, 12]), whereas the tense vowel is not cut off (‘loose contact’) before the sonority peak is reached. In Vennemann’s view this prosodic feature is maintained in unstressed position.

The concept of syllable cut is primarily based on the perceptual impression and only recently has articulatory evidence been found for a closer coupling between opening and closing gestures for lax vowels [9].

1.2. Kinematic Correlates of Stress and Tenseness

As was found by Harrington, Fletcher and Roberts [4] for jaw movements, stress is produced by a difference in intergestural timing, i.e. for unstressed vowels in CVC syllables the opening gesture is truncated by the closing gesture. This mechanism leads to a reduction of the ratio of the interval between velocity peaks to total movement duration (peak-to-peak ratio) and a greater skewness of both velocity profiles (acceleration ratio) (see [1]). Furthermore the number of acceleration peaks between velocity peaks changes from two to one. There is no substantial change in peak velocities, but a small reduction of movement amplitudes.

Similar production mechanisms were observed for lax vowels compared to tense vowels by Kroos, Hoole, Kühnert and Tillmann [9]. In their study the complete CVC movement was divided into CV, nucleus and VC using a 20% velocity threshold criterion (see Fig. 1). Going from normal to fast speech the nucleus duration of tense vowels was compressed far more than any other segment. For lax vowels the change in speech rate was hardly noticeable. The authors interpret these results as a difference in intravocalic coupling of the opening and closing gestures. Further support for a tighter coupling of lax vowels was given by a peak-to-peak ratio of less than 50%, longer acceleration phases of the opening gesture and shorter acceleration phases of the closing gesture.

Thus, both accent and tenseness (but not variation in speech rate) are characterized by a change of intergestural timing. The present study aims at a comparison of the nature and extent of these mechanisms.

2. METHOD

Four native speakers of German (2 males, JD and PJ, and 2 females, SF and CM) were recorded by means of EMMA. The speech material consisted of words containing /tVt/ syllables with tense and lax nuclei (V=/i-ɪ,y-ʏ,e-ɛ,ø-œ,aː-a,u-ʊ,o-ɔ/) in stressed and unstressed positions. Stress alternations were fixed by morphologically conditioned word stress and contrastive stress. Thus the first test syllable in the sentence “Ich habe /ˈtVtɐ/, nicht /tVtˈal/ gesagt“ ("I said /ˈtVtɐ/, not /tVtˈal/") was always stressed and the second unstressed. All 14 sentences were repeated six times.

Tongue, lower lip and jaw movements were monitored by EMMA (AG100, Carstens Medizinelektronik). Four sensors were attached to the tongue, one to the lower incisors and one to the upper lip. Two sensors on the nasion and the upper incisors served as reference coils to compensate for helmet movements during the recording session. Simultaneously, the speech signal was recorded by a DAT recorder.

The audio data were transformed to Signalyze format and downsampled from 48 kHz to 16 kHz. Articulatory data were smoothed by a lowpass filter at 30 Hz, velocity and acceleration signals at 20 Hz.

Kinematic analyses of articulatory data of the tongue tip sensor were performed following [9] using a 20% threshold criterion of the tangential velocity of the tongue tip, see Fig. 1. The following durations were analyzed: CV (B-A), Nucleus (C-B), VC (D-C), and Movement cycle (D-A). Additionally, the ratio of the interval between velocity peaks (F-E) to movement cycle, and the acceleration phase of the opening gesture ((E-A)/CV) and of the closing gesture ((F-C)/VC) were computed.[2] Opening and closing movement amplitudes were calculated as Euclidian distances of horizontal and vertical tongue tip movements between on- and offsets of both gestures. Vowel target positions were measured using the minimum during the vowel of averaged tangential velocities of all tongue sensors (G).

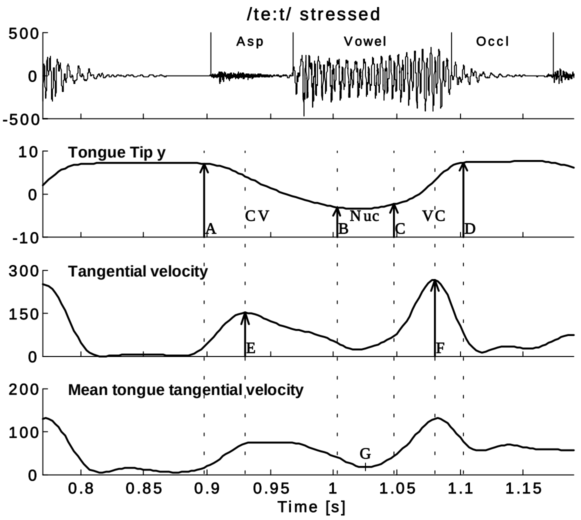

Fig. 1. Target word /teːtɐ/. Upper panel: speech signal, second panel: vertical tongue tip movement, third panel: tangential velocity of tongue tip movement, lower panel: mean tongue tangential velocity. A: begin of opening movement, B: end of opening movement, C: begin of closing movement, D: end of closing movement, E: peak velocity of opening gesture, F: peak velocity of closing gesture, G: moment for measuring vowel target position.

The following acoustical parameters were measured: aspiration duration (Asp) of the first consonant, vowel duration (vowel) and the closure duration (occl) of the following consonant. The on- and offsets of the second formant and the adjacent two bursts in /tVt/ served as relevant events for the segmentation of these temporal intervals.

Frequency measurements of the first and second formant were taken at the moments of the articulatorily determined vowel target position (G). In some cases this value occurred during the aspiration phase; then the next possible moment was used.

Statistical analyses of the acoustical parameter were performed with STATVIEW using ANOVA, the articulatory data were analyzed by SAS using GLM.

Since multidimensional positional articulatory data are highly correlated, the jaw influence was extracted using Arbitrary Factor Analysis [11] and the residuals were used as input for Canonical Discriminant Analysis [8]. Vowel identity combined with tenseness served as canonical variable. The resulting factor scores of stressed and unstressed vowels were compared by means of GLM.

3. RESULTS

3.1. Vowel Quality

To test if the centralization of formant values due to deaccentuation causes neutralization of the tenseness contrast, ANOVAs were carried out with post hoc Scheffé tests ($p<0.01$) split by speaker and vowel. The independent variable was a combination of tenseness and stress. With the exception of the low vowel /a/ the influence of stress on vowel quality was rarely significant, i.e. formant patterns of tense and lax vowels were not affected by accent. Formant values of the vowel /a/ changed only due to deaccentuation when it was tense. For this vowel all speakers neutralized the tenseness contrast when unstressed. For all other vowels the reduction patterns differed speaker dependently. The quality of /y/ was neutralized for three subjects, for speaker CM only two vowel categories showed significant differences.

To corroborate the acoustical results, movement amplitudes of opening and closing gestures were compared for differences due to accent and tenseness. Deaccentuation was produced as expected: syllables with stressed vowels displayed larger amplitudes than with unstressed vowels. For tenseness the results varied with speakers and vowel identity: two speakers showed higher amplitudes for front lax vowels in stressed position than their tense counterparts. The other two speakers exhibited no significant difference between tense and lax front vowels.

Since the amplitudes were computed using the consonantal articulator and not the vowel articulators, the speaker variability could be due to a differential timing between vowel and consonant articulators. Thus vowel target positions of tongue, jaw and lower lip were extracted using a criterion related to all tongue sensors, namely the minimum of the average tongue velocity.

The vowel target positions were subjected to factor analysis. The first factor was generated by computing Arbitrary Factor Analysis to extract the influence of jaw movements on the tongue. The residuals were used for computing the second and third factor by Canonical Discriminant Analysis.

As shown in Figure 2, upper panel, the factor scores of the first factor represented the differential jaw influence. Changes from stressed to unstressed, shown as black lines, were mainly significant for the first factor with higher "jaw positions" for unstressed vowels. The difference was often not significant for high vowels. The second factor discriminated front and back vowels and resembled the "front raising" factor by Harshman, Ladefoged and Goldstein [5]. There was a tendency for unstressed vowels to be more centralized, meaning here values closer to zero. The third factor can be interpreted as "back raising". With the exception of the low vowels /a/, and for one speaker /ø-œ/, this factor differentiated between tense and lax vowels with lower values for lax vowels. Factor scores of unstressed tense vowels and lax vowels were always significantly different for at least one factor. Here again, the vowel /a/ was an exception.

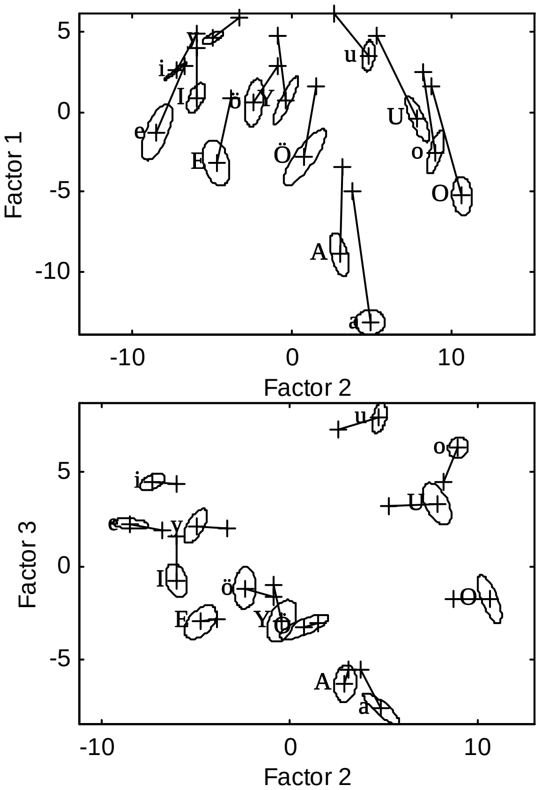

Fig. 2. Factor scores of vowel positions of Speaker PJ. Upper panel: second factor vs. first (arbitrary) factor; lower panel: factor 2 vs. factor 3. Upper letters indicate tense vowels, lower letters lax vowels. Axes of the ellipses represent one standard deviation in the main direction of variation. Crosses represent the means of unstressed vowels and lines the changes due to deaccentuation.

Together with the results of formant measurements, there was no evidence for a complete neutralization of the tenseness opposition in unstressed syllables.

For all speakers the first and the third factor showed high negative correlations with F1 but not with F2, on the other hand the second factor correlated negatively with F2. These results confirm the traditional view that jaw and tongue height (first and third factor) influence the values of the first formant, and that the second formant is mainly affected by horizontal tongue position.

3.2. Kinematic and acoustical segment durations

Articulatorily defined nucleus durations of unstressed tense vowels were compressed more prominently than the CV and VC segments (54 ms to 22 ms), whereas for lax vowels all segments shortened by a comparable ratio. A similar pattern was observed for the tenseness contrast: the nucleus durations were compressed only for stressed vowels. Thus, nucleus duration stayed essentially the same for tense unstressed and lax stressed vowels. Compared to the results of [9], the nucleus duration of tense vowels was reduced more due to accent variation than due to speech rate increase. The compression pattern for lax vowels were alike for deaccentuation and speech rate increases.

The opening gesture was more sensitive to the influence of both phonological features than the closing gesture, which can be attributed to the fact that consonantal closing gestures are controlled more ballistically than opening gestures [3]. It can be concluded that there is no differential influence of deaccentuation and laxness on the compression patterns of CV, Nucleus and VC durations, starting from tense stressed vowels.

Analyses of acoustical durations confirmed the articulatory results, in particular concerning vowel duration: The duration of tense vowels was influenced by accent variation (119 ms stressed to 49 ms unstressed). The tenseness contrast had a significant effect on stressed vowels; changing from tense to lax, an averaged ratio of 2.27 was observed. The vowel durations showed no significant differences between unstressed/tense and stressed/ lax (all speakers) as well as unstressed/tense and unstressed/lax (3 speakers).

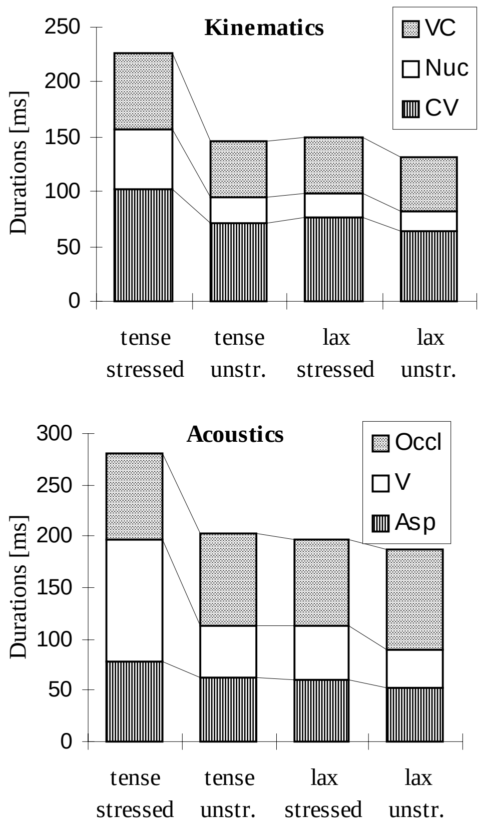

Fig. 3. Articulatory and acoustical durations of all speakers. Upper panel: durations of CV, Nucleus and VC segments. Lower panel: acoustical durations of aspiration, vowel and occlusion.

Variations of stress and tenseness rarely affected aspiration and occlusion durations and differed speaker dependently. In opposition to vowel length and aspiration, there was often a complementary relationship between vowel and occlusion duration: for 3 speakers occlusion durations in unstressed syllables increased opposed to the stressed vowels. Since the syllable duration (burst-to-burst interval) decreased going from stressed to unstressed the complementary relationship could be the consequence of a difference in interarticulator timing between tongue tip and laryngeal activity (see e.g. [10]), i.e. phonation ceases earlier relative to oral closure for unstressed vowels.

3.3. Peak-to-peak ratio and acceleration phases

Truncation is indicated by a prominent reduction of the peak-to-peak ratio. As shown in Table 1 (column P2P) this ratio was significantly longer for tense stressed vowels. No difference between tense unstressed and lax stressed vowels was observed, but lax unstressed vowels displayed significantly lower values.

Ratios in %		P2P	sd.	ACV	sd.	AVC	sd.
tense stressed	166	65.4	6.85	47.9	11.95	58.2	7.49
unstressed	191	53.7	6.58	55.8	9.65	47.6	5.05
lax stressed	166	53.1	8.13	57.2	13.05	48.9	4.34
unstressed	167	50.6	5.77	59.1	8.74	45.0	3.23

Table 1. Means and standard deviations of the ratio of the interval between velocity peaks and movement duration (P2P); and acceleration phases of opening (ACV) and closing gestures (AVC).

A further indicator of truncation is the asymmetry of acceleration phases: truncated syllables show later velocity peaks for the opening gesture (Table 1, column ACV) and earlier peaks for the closing gesture (AVC), relative to the overall movement durations. Again no significant differences between tense unstressed and lax stressed vowels occurred.

These results suggest that tense unstressed and lax stressed vowels are produced with the same amount of truncation. Unstressed lax vowels show a small but significant greater degree of truncation.

4. CONCLUSIONS

Except for /a/ the tenseness opposition was generally not completely neutralized in unstressed position, confirming other acoustical studies e.g. [7]. Since the neutralization normally occurs in casual speech, new recordings with a more natural corpus are planned.

Acoustically and articulatorily measured durational parameters gave clear evidence for a truncation of the opening gesture, starting from tense stressed vowels to tense unstressed and lax stressed vowels, the latter two displaying approximately the same degree of truncation. There was evidence for small but significant further truncation of lax unstressed vowels.

However, truncation not only involves changes in the temporal organization of opening and closing gestures, but also a reduction of movement amplitudes with relatively stable velocity peaks (see [4]). On the one hand, deaccentuation causes a reduction of movement amplitudes for unstressed vowels compared to their stressed counterparts. Therefore the patterns of movement amplitude reduction confirm the results of the temporal data, i.e. deaccentuation can be attributed to truncation.

On the other hand, for the tenseness opposition two speakers increased their movement amplitudes for front lax vowels when stressed compared to the tense stressed counterparts. The other two speakers showed no significant difference between these vowels. Thus the vowel target positions of the tongue for lax vowels cannot be generated by truncating the opening movement of tense vowels. Probably vowel targets for tense and lax vowels are specified with different values.

ACKNOWLEDGMENTS

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NOTES

1. There are two exceptions concerning tenseness: /aː-a/ are usually supposed to be only distinguished by duration [14], and /ɛː/ is often produced as /eː/. Thus the latter is not considered here.
2. Both female speakers quite frequently showed double velocity peaks for the opening gestures of tense high vowels. These items were deleted from the data. Still their durational parameters are much more variable than for the male subjects.

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