ACOUSTIC CORRELATES OF WORD STRESS AND THE TENSE/LAX OPPOSITION IN THE VOWEL SYSTEM OF GERMAN

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ABSTRACT

Acoustic correlates of word stress and the opposition between tense and lax vowels were measured in the speech of ten speakers of German. F1- or F2-frequency was found to be a significant tense/lax correlate across stress conditions and for most sets of vowels. Significant correlates of stress across tense/lax differences and vowel sets are vowel duration and closure duration.

1. INTRODUCTION

The difference in German between stressed and unstressed syllables and the difference between tense vowels as in *Schote* [o:] 'pod' and lax vowels as in *Schotte* [ɔ] 'Scot' is expressed in part by the same acoustic correlates. Vowel duration, for example, encodes both stress and tenseness [4]. Other correlates are largely specific to the expression of either stress or tenseness. For example, F0 expresses stress, but not tenseness [3]. This situation calls for an investigation in which stress and tenseness are varied independently in the stimulus material and measured for the same set of acoustic parameters.

2. METHOD

The following near-minimal pairs involving tense and lax vowels were selected, in which the segmental context was [tʰ_l] throughout: *Ventil* [i:] 'valve' vs. *Tormentill* [ɪ] 'tormentilla', *Klientel* [e:] 'clients' vs. *Kartell* [ɛ] 'alliance', *Spital* [ɑ:] 'hospital' vs. *Metall* [a] 'metal', *Anatolien* [o:] 'Anatolia' vs. *Ayatollah* [ɔ] 'ayatollah', *Thulium* [u:] 'thulium' vs. *Schatulle* [ʊ] 'casket'. On the basis of each of the ten words both a variant with a stressed and one with an unstressed target vowel was triggered by appending the derivational suffixes *-isch* and *-ist*, respectively. For example, based upon *Klientel* and *Kartell* the following combinations of tenseness and stress were triggered (with stress marks added): tense stressed (*klientélisch*), lax stressed (*kartéllisch*), tense unstressed (*Klientelíst*), and lax unstressed (*Kartellíst*). These four combinations are referred to as 'e-vowels'. Analogously, four i-, a-, o-, and u-vowels were triggered. The resulting 20 target words were read twice each by ten speakers of German, five female and five male. The recordings were digitized and analyzed acoustically. A number of different acoustic parameters were measured. The temporal parameters measured are closure duration of [tʰ] (Clos), aspiration duration of [tʰ] (Asp), vowel duration of the tense and lax target vowel (Vdur), and the duration of the following consonant [l] (Cdur). Onsets and offsets of F2, as well as the moment of stop release, served as the relevant events for the segmentation of these adjacent temporal intervals. Selecting F2-onset as the right-hand boundary of aspiration duration is motivated in [2]. The frequency of the first (F1) and second (F2) formant was measured half way into the target vowel. Measurements were also made of the mean F0 of the target vowel (F0mean), the standard deviation of F0 over the span of the target vowel (F0sd), as well as of the mean RMS (RMSmean) and standard deviations of RMS (RMSstd) over the vowel span. As another parameter, vowel energy (Energ) was calculated as Vdur * (RMSmean + 100) in analogy to a procedure proposed in [1].

3. RESULTS

For the presentation of the results and the statistical analysis the data of all ten subjects are pooled together, except for the F0-parameters, that are evaluated separately for female and male speakers. The measurement results for the durational parameters Clos, Asp, Vdur, and Cdur are represented graphically in Figure 1. No results for Clos in [u] are available because the [tʰ] of the words *thulisch* and *Thulist* are not preceded by a segment (no more appropriate near-minimal pair could be found). The results of the vowel formant measurements, as well as of the measurements of F0, RMS, and energy are presented in Table 1.

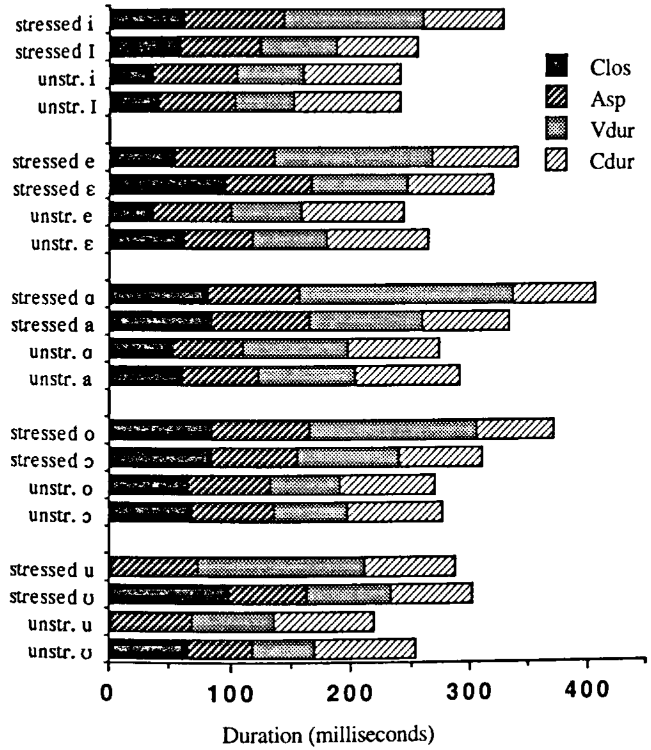

Figure 1. Mean results for the parameters Clos, Asp, Vdur, and Cdur pooled across the data from ten speakers. Duration values in milliseconds are presented horizontally, the conditions of tenseness and stress are presented vertically, divided into five separate blocks each for i-vowels (above) to u-vowels (below).

Table 1. Mean results for different acoustic parameters (horizontally) and different conditions (vertically), divided into five different vowel sets as in Figure 1. F1, F2, and F0 values are expressed in Hertz, RMS values are expressed in decibels.

target vowel	F1	F2	RMS mean	RMS sd	Energ	F0mean female	F0sd female	F0mean male	F0sd male
stressed i	299	2485	-20.8	1.1	9.0	218	5.6	149	5.0
stressed ɪ	414	2150	-19.5	1.2	4.9	233	3.1	145	2.6
unstr. i	354	2369	-22.3	1.0	4.1	203	3.7	116	3.9
unstr. ɪ	378	2192	-22.8	1.1	3.7	214	3.8	117	1.9
stressed e	381	2228	-19.6	0.9	10.5	231	11.8	129	5.6
stressed ɛ	569	1917	-17.8	1.5	6.5	217	8.6	129	2.3
unstr. e	407	2031	-22.2	1.1	4.4	207	8.8	115	4.8
unstr. ɛ	451	1878	-21.5	0.9	4.8	210	8.7	115	2.7

stressed ɑ	827	1375	-18.0	1.5	14.5	214	7.4	124	7.2
stressed a	807	1443	-18.0	1.7	7.6	215	7.6	118	2.4
unstr. ɑ	669	1606	-20.6	1.2	6.8	195	10.9	113	3.8
unstr. a	680	1590	-20.9	1.2	6.3	200	11.3	113	2.9
stressed o	363	738	-19.1	1.2	11.2	229	13.0	131	6.2
stressed ɔ	563	1086	-18.2	1.4	6.9	216	12.8	131	2.9
unstr. o	414	1138	-22.1	0.9	4.4	207	4.1	116	3.0
unstr. ɔ	453	1242	-21.9	0.9	4.7	203	9.4	118	2.9
stressed u	290	699	-19.7	1.2	10.9	226	5.8	143	6.9
stressed ʊ	406	1045	-18.2	1.2	5.7	224	3.7	145	2.7
unstr. u	354	1033	-21.3	1.3	5.2	199	3.9	122	2.5
unstr. ʊ	367	1207	-22.0	1.1	3.9	205	2.3	123	2.0

For the set of i-vowels four separate t-tests were calculated for each parameter. In the first t-test tenseness was the independent variable and the test was run on the stressed tokens, in the second it was run on the unstressed tokens, in the third t-test stress was the independent variable and the test was run on the tense tokens, and finally on the lax tokens. The same classes of t-tests was carried out on the other sets of vowels. Conditions for t-tests were proven correspondingly, and the data were found to meet the conditions. We present the statistical results by reporting only those parameters that were found to be significant (probability of t-statistics<.05). Table 2 lists for every set of vowels the parameters that were found to be significant in each of the four classes of t-tests.

Table 2. List of acoustic parameters that are significant according to t-tests in five different vowel sets (horizontally) and four different classes of t-tests (vertically) in the order mentioned in the text. Female and male are abbreviated as [f] and [m], respectively.

	i-vowels	e-vowels	a-vowels	o-vowels	u-vowels
tense vs. lax on stressed tokens	Asp, Vdur, F1, F2, Energ	Clos, Vdur, F1, F2, RMSstd, Energ, F0std [m]	Vdur, Energ, F0std [m]	Vdur, F1, F2, Energ, F0std [m]	Vdur, F1, F2, Energ, F0std [m]
tense vs. lax on unstressed tokens	no significant parameter	Clos, Asp, F1	no significant parameter	F2	Asp, Vdur, F2, Energ
stressed vs. unstressed on tense tokens	Clos, Asp, Vdur, Cdur, F1, Energ, F0mean [m]	Clos, Asp, Vdur, F2, Energ, F0mean [m]	Clos, Asp, Vdur, F1, F2, Energ, F0mean [m], F0std [m]	Clos, Vdur, Cdur, F1, F2, RMSmean, Energ, F0std [f], F0mean [m], F0std [m]	Vdur, F1, F2, Energ, F0mean [m], F0std [m]
stressed vs. unstressed on lax tokens	Clos, Vdur, Cdur, RMSmean, Energ, F0mean [m]	Clos, Asp, Vdur, Cdur, F1, RMSmean, RMSstd, Energ, F0mean [m]	Clos, Asp, Vdur, Cdur, F1, F2, RMSmean , RMSstd, Energ	Clos, Vdur, F1, F2, RMSmean, RMSstd, Energ, F0mean [m]	Clos, Asp, Vdur, Cdur, F1, F2, RMSmean, Energ, F0mean [m]

4. DISCUSSION

The results show that depending on the specific set of vowels involved and the tense/lax distinction, word stress in German is expressed by a variety of different correlates. The parameters that emerge from the results as the most reliable correlates of word stress, evaluated in terms of the occurrence of a significant effect across different conditions, are vowel duration (Vdur) and the duration of a stop closure (Clos) in the stressed vs. unstressed syllable. Since the energy index (Energ) includes Vdur, Energ patterns statistically with Vdur. The dependence of aspiration duration (Asp) on stress is not substantial and reliable enough to justify the existence of a phonological rule in German that assigns a feature category like [aspirated] to stops before stressed vowels (cf. [5]). Rather, the results suggest that aspiration depending on stress in German is a gradient phenomenon and part of phonetic implementation. The fact that consonant duration (Cdur) is smaller, while Clos, Asp, and Vdur are larger in the stressed than in the unstressed conditions indicates that lengthening due to stress is limited to the domain of the syllable (the consonant [l] belongs to the following syllable, which is unstressed if the preceding syllable is stressed). The F0 and intensity (RMS) parameters do not contribute with much reliability to the expression of stress. Although examination of the results for the individual speakers reveals that stressed vowels are consistently produced with higher F0mean than unstressed ones, the effect is not significant in several conditions. Significant effects for F1 and F2 in a number of conditions indicate that vowel quality is another correlate of stress in German. Among the set of tense vowels, vowels realized with stress are more peripheral in the vowel space than unstressed vowels. Among the lax vowels no clear similar nor opposite tendency can be observed.

In the evaluation of the different correlates of the tense/lax opposition in German it is important to realize that unstressed position imposes a strong constraint for the expression of the tense/lax difference. While, for example, vowel duration (Vdur) is significant across all stressed vowel conditions, it is significant for unstressed vowels only in the case of u-vowels. Formant structure (F1 or F2), on the other hand, is not only significant under stress, but remains significant in most conditions involving unstressed vowels. Similar results with an analogous set of target words are reported in [4]. As argued by [7], the stability of vowel quality across stress conditions speaks for the distinctive status of vowel quality, as opposed to vowel quantity in German. A-vowels behave differently from other sets of vowels. While all other vowel sets show significant effects for F1 and F2 in stressed position, a-vowels do not differ significantly in the expression of the tense/lax difference with respect to formant structure (cf. [6]). It is proposed in [4] that for low vowels (i.e. a-vowels) vowel quantity functions distinctively in German, while for nonlow vowels the distinctive property is vowel quality. A similar conclusion has been reached with results from vowel perception in German by [8]. We hope that further research will clarify why F0std for male speakers depends significantly on tenseness in most conditions involving stressed vowels.

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