Working Papers of the Cornell Phonetics Laboratory
1993, vol. 8, pp. 1-27.

Stress conditions on vowel quality and quantity in German*

Michael Jessen

1. Introduction

German has a phonemic distinction between tense and lax vowels. For all vowels except the low ones this distinction is realized phonetically by both vowel quality (i.e. formant structure) and vowel quantity (i.e. duration). In acoustic terms, we find oppositions like in *Miete* [i:] 'rent' vs. *Mitte* [I] 'mid' differing both in formant structure, most noticeably F_1 and F_2, and in duration. This distinction in both quality and quantity is fully manifested under main stress. However, there is disagreement in the German phonetic literature about what happens under degrees of stress lower than main stress. There are two positions on this issue. Under the first view, both phonetic quality and quantity remain equally important as realizations of the tense/ lax opposition for any level of stress. Under degrees of stress lower than main stress the difference between tense and lax vowels is reduced compared to main stress position. This reduction affects both quality and quantity to the same proportion. Under the second view, reduction under low degrees of stress affects quantity more than quality, such that in some weak stress contexts, tense and lax vowels are claimed to differ in quality but to be equal in quantity. This paper provides acoustic-phonetic evidence that bears upon this issue. Duration and formant structure of German tense and lax vowels are evaluated with respect to these two different views, which will be defined more specifically as the "association hypothesis" and the "dissociation hypothesis" respectively. Following this empirical treatment, which constitutes the main body of the paper, the reader will be introduced to a classic issue in German phonology: is it quality or quantity that has distinctive status in the German vowel system. Results and implications from the present study, as well as other data will be discussed in light of this debate.

* Parts of this work were presented at the 14th Annual Meeting of the German Linguistic Society ("Deutsche Gesellschaft für Sprachwissenschaft"), February 25-28, 1992 in Bremen, Germany. I want to express my thanks to Wilbur Benware, Bernhard Hurch, Allard Jongman, Magnús Pétursson, Karl Heinz Ramers, and Linda Waugh for their helpful comments on an earlier manuscript that covers part of what is presented in this paper. Thanks also to Abigail Cohn, Ann Bradlow, Allard Jongman, and Linda Waugh for reviewing the present paper and to John Kingston for introducing me to the statistical methods used here. My presentation in Germany was supported by a travel grant from Cornell University, Sage Graduate School and the Department of Modern Languages and Linguistics.

2. German tense and lax vowels in main stress position

The opposition between tense and lax vowels[1] in main stress position is illustrated in (1). Tense vowels (left hand side) are both longer and of a more decentralized quality than lax vowels (right hand side). This difference in both quality and quantity is characteristic of nonlow vowels only (1a). The opposition between the two low vowels of German is reliably realized by quantity alone, as is indicated in the transcription of the example in (1b).

(1)	a.	Schiefer	[i:]	'slate'	vs.	Schiffer	[I]	'captain'
		stehlen	[e:]	'steal'	vs.	stellen	[ɛ]	'put'
		Schote	[o:]	'pod'	vs.	Schotte	[ɔ]	'Scot'
		spuken	[u:]	'haunt'	vs.	spucken	[ʊ]	'spit'
		fühlen	[y:]	'feel'	vs.	füllen	[ʏ]	'fill'
		Höhle	[ø:]	'cave'	vs.	Hölle	[œ]	'hell'
	b.	Haken	[a:]	'hook'	vs.	hacken	[a]	'chop'

The phonemic vowel system of German is presented in (2). The phonetic symbols represent the realization of the German vowels in main stress position, as in (1).[2]

(2)		front unrounded	front rounded	back
high	tense	i:	y:	u:
	lax	I	ʏ	ʊ
mid	tense	e:	ø:	o:
	lax	ɛ	œ	ɔ
low	tense			a:
	lax			a

The acoustic realization of German vowels in main stress position is the subject of a number of studies. For a more detailed overview of the literature the reader is referred to

---

[1]Some authors assume that the term tense/ lax implies the phonetic realization as a quality distinction, as opposed to a quantity distinction (e.g. Kloeke 1982: 9 who uses the feature [+/-tense] for vowel quality and [+/-long] for vowel quantity; cf. also Hall 1992 who uses [+/-ATR] for vowel quality and one vs. two x-slots for vowel quantity). For the purpose of this paper the tense/ lax distinction is used only as a convenient label to classify vowels into two groups based on phonological evidence, without a priori implying that phonetic realization is either in terms of quality or quantity.

[2]The inventory in (2) does not include the three diphthongs and the two schwa-vowels [ə] and [ɐ] that exist in German, because they don't form a tense/ lax opposition. The classification of [a:] and [a] as back is motivated phonologically, for example by the alternation of the dorsal fricatives [ç] and [x]. The vowel [ɛ:] was excluded from the chart, because not all subjects in my experiment used it spontaneously. It is known to be subject to strong dialectal variation (cf. Benware 1986 for an overview of German phonology).

Sendlmeier (1985) and the very comprehensive work of Ramers (1988). Measurements of vowel formants clearly show that *nonlow* tense and lax vowels (1a) are differentiated in terms of F_1, F_2, and to a certain extent F_3. Considering the first two formants only, nonlow lax vowels are generally realized at a more centralized position in a typical F_1 x F_2 chart (cf. Ramers 1988: 134f. for literature and chap. 3. for his own results). The tense/ lax distinction in nonlow (and low) vowels is also clearly realized in terms of vowel duration. Tense vowels are about twice as long as the corresponding lax vowels (cf. Ramers 1988: 73-78 for literature and chap. 3. for his own results; also Antoniadis & Strube 1984: 82f.).

The literature indicates that formant differences between the tense and lax *low* vowels [a:] vs. [a] (1b) are neither systematic nor substantive. Ramers (1988) shows considerable speaker and token variability in the realization of the [a:] vs. [a] opposition in his data. For his speakers, the difference in F_1 (in the example ***Bann*** [a] 'ban' vs. ***Bahn*** [a:] 'train') is very small (p. 179). Ramer's vowel charts show that F_2 is even less reliable than F_1 as a correlate of the opposition. For two of his speakers F_2 is higher in [a], for the other two it is higher in [a:] (pp. 181-192). Difficulties in differentiating the formant structure of [a:] and [a] are also reported by Jongman et al. (1989: 237). Earlier indications in the literature for nonregular differences between the low tense and lax vowel are given by Schindler (1974: 46-49; including further references) and Krämer (1978: 9). Thus, based on the findings of these authors, formant structure is not a reliable correlate of the tense/ lax opposition among the low vowels [a:] vs. [a]. However, these vowels are reliably differentiated in terms of duration, like all the other tense/ lax pairs (Antoniadis & Strube (1984: 82f.).

3. German tense and lax vowels in non-main stress position

Moulton (1962: 63f.) states that nonlow tense and lax vowels in "unstressed position" are distinguished in terms of vowel quality, but not vowel quantity when spoken in formal Standard German. As examples for nonlow vowels in unstressed position he provides the near-minimal pairs in (3ab).

(3)a.	Dinér	[i]	'dinner'	vs.	diffús	[I]	'diffuse'
	Detáil	[e]	'detail'	vs.	Dessért	[ε]	'dessert'
	Kolúmbus	[o]	'Columbus'	vs.	Kollége	[ɔ]	'colleague'
	Kuríer	[u]	'courier'	vs.	skurríl	[ʊ]	'odd'
b.	Synagóge	[y]	'temple'	vs.	Synal'öphe	[ʏ]	'synaloepha'
	Ökonóm	[ø]	'economist'	vs.	Östrogén	[œ]	'estrogen'
c.	Balánce	[a]	'balance'	vs.	Balláde	[a]	'ballad'

As the phonetic transcription suggests, the tense/ lax pairs in (3ab) differ in phonetic quality, whereas the quantity difference present under main stress in (1a) has disappeared. For the low vowels (3c), Moulton claims not only the absence of a quantity difference, but also nondistinct vowel quality. What Moulton refers to as 'unstressed position' is the syllable immediately preceding main stress (3a) or 2 syllables preceding main stress (3b) (this classification into a. and b. is not given by Moulton). Some of the relevant literature, however, suggests that it is important to carefully differentiate between different positions of non-main stress, rather than grouping together all positions not under main stress as 'unstressed'. Vernon (1976) distinguishes three different non-main stress contexts, which he calls 'pretonic', 'posttonic-penultimate' and 'posttonic-final'. He concludes from his evidence that duration differences between tense and lax German vowels are neutralized in the pretonic and posttonic-penultimate syllable, but maintained in the posttonic-final syllable. That both quality and quantity differences between tense and lax vowels are found in the final syllable post-main stress, is supported by the transcription practice of the two most comprehensive German pronouncing dictionaries, Krech et al. (1982) and Mangold (1990). They, for example, transcribe the near-minimal pair ***Wérmut*** [u:] 'vermouth' vs. ***Pérlmutt*** [ʊ] 'mother of pearl' with differences in both vowel quality and quantity. Also consistent with Vernon, neutralization of vowel quantity while maintaining quality differences is claimed explicitly by Mangold (1990) for positions before main stress. Mangold transcribes e.g. the pair ***Kolúmbus*** vs. ***Kollége*** according to (3a). Mangold also seems to differentiate among pre-main stress contexts the syllable immediately preceding main stress (e.g. ***möblíeren*** [ø] 'furnish') from the syllable that precedes main stress with an intervening syllable (e.g. ***Blödeléi*** [ø:] 'kidding'; p. 35), where, as his transcriptions suggest, neutralization of vowel duration only occurs in the position immediately preceding main stress. However, Mangold doesn't seem to be consistent in this differentiation throughout his dictionary, since e.g. he transcribes ***Zölibát*** [ø] 'celibacy' with a short vowel despite an intervening syllable between target vowel and main stress; he also transcribes ***Ökonóm*** and *Synagóge* according to (3b); cf. also the first edition Mangold (1974: 38). In my experiments, to be introduced in sections 5 and 6, I will test whether there are systematic differences between these two pre-main stress positions. I will henceforth refer to the position one syllable before main stress as "pre-stress 1" context and to the position two syllables before main stress as "pre-stress 2" context.

Very little acoustic data on the realization of the tense/ lax opposition in non-main stress position is available in the literature. For the studies that address this issue at all, the general tendency is that the acoustic correlates of quality and quantity are not compared within the same experimental setting (Delattre 1969 investigates formant structure; Delattre & Hohenberg 1968, Vernon 1976 investigate duration), and that different subclassifications of non-main stress are not very systematic and fine-grained. None of the three sources explicitly makes a distinction between the two different pre-main stress contexts 'pre-stress 1' and 'pre-stress 2'.[3] Nevertheless, in a general sense, these sources confirm the claim made by Moulton that nonlow (but not low) tense and lax vowels before main stress (3ab) differ consistently in quality (results on formant structure by Delattre 1969), but not quantity (results on duration by Vernon 1976). The duration differences that are reported by Delattre & Hohenberg (1968) are of limited value for an evaluation of Moulton's claim, because they are obtained from a set that includes words with more than one syllable intervening between target and main-stress, e.g. in compounds. It remains unclear whether there are different patterns of quality and quantity in 'pre-stress 1' (3a) and 'pre-stress 2' (3b) position. The two experiments presented in this paper are meant to address this issue.

4. Quality and quantity in non-main stress position: two contrasting hypotheses

As made explicit by Ramers (1988: 92f.), two different hypotheses about the realization of quantity and quality under non-main stress emerge from the literature on German. The first hypothesis claims that with successively lower degrees of stress, differences in quantity between tense and lax vowels are more sensitive to reduction than quality differences. In other words, quality differences are more stable than quantity differences under stress lowering. As a consequence, there is a level of non-main stress at which tense and lax vowels are distinguished in terms of quality, but not in terms of quantity. The pairing of quality and quantity found for main stress position is dissociated in favor of quality at this level of stress. I will call this the *"dissociation hypothesis"*.

The second hypothesis is that the reduction of differences between tense and lax vowels that occurs with lower degrees of stress, affects vowel quality to the same extent as vowel quantity. Consequently, no level of stress will be found at which the tense/ lax opposition is realized solely by either quality or quantity. Put differently, vowel quality and quantity

[3]The exact contextual settings in Vernon's work remain somewhat unclear. Vernon (1976) gives no list of the words he investigated and it is therefore not clear whether his term 'pretonic' refers to pre-stress 1, pre-stress 1 and 2, or even all possible positions before main stress. Vernon (1976) only reports on duration values, not formant values.

are tightly associated and cannot be dissociated at any stress level.[4] I will refer to this as the *"association hypothesis"*.

As the discussion in section 3 made explicit, Moulton (1962) is a proponent of the 'dissociation hypothesis'. He claims that in the position one (3a) or two (3b) syllables before main stress, tense and lax (nonlow) vowels differ systematically in quality, but not in quantity. The acoustic evidence from the literature that was mentioned there could in a general sense confirm Moulton's claim. Notice that the dissociation hypothesis is not falsified by finding differences in both quality and quantity at higher degrees of stress, as long as at a lower degree of stress only quality differences remain. If, for example, acoustic studies showed both quality and quantity differences in the word-final post-main stress syllable (e.g. *Wérmut* vs. *Pérlmutt* above), this would not per se constitute evidence against the dissociation hypothesis.

Among the authors that argue for the association hypothesis are Meinhold & Stock (1982: 90) and Schindler (1974: 28). They claim that reduction due to decreasing degrees of stress affects quality and quantity to the same extent. Meinhold & Stock, in support for their claim, refer to work by Maack (they mention specifically Maack 1951), who shows clear quantity differences under low stress. In Maack (1951), or other relevant work by Maack that I know of (Maack 1949, 1954), the data are classified into 'stressed' and 'unstressed' without presenting a list of words or even representative examples to which these classificatory labels apply. It might be, for example, that the materials contain a considerable percentage of compound-like words, in which case the reported quantity differences in 'unstressed' context have the same limited value to our questions as in the study of Delattre & Hohenberg (1968) mentioned above. Maack states that he excludes 'foreign words' and specific names (1951: 292). This makes it likely that he did not investigate words of the kind in (3), which are very important for testing the two contrasting hypotheses discussed here. Moreover, Maack doesn't measure formant structure. Schindler (1974), who provides acoustic data, does not present sufficient data to support the association hypothesis. He gives formant values only for weak stress tense, but not weak stress lax vowels, and provides no duration values (cf. Ramers 1988: chap. 2.2 for more literature by the adherents of the two contrasting hypotheses in German).

Although up to this date, more acoustic evidence exists in favor of the dissociation hypothesis rather than the association hypothesis, much work is still needed to shed light on this controversy. Below, I present my two experiments, in which both formants and

[4] The third, logically possible hypothesis, is that quantity rather than quality is more stable across stress lowering. It has, to my knowledge, never been proposed in the literature, nor is there any evidence for it.

duration are measured under identical conditions and (with the exception of [ø, œ] in Experiment 1) for the complete set of tense/ lax pairs in German. I also control for the precise stress level under consideration, specifically the one realized immediately preceding main stress (Experiment 1; cf. 3a) and two syllables before main stress (Experiment 2; cf. 3b).

5. Experiment 1: tense and lax vowels in 'pre-stress 1' position

The purpose of this experiment was to determine whether tense and lax vowels in pre-stress 1 position differ significantly in both duration and formant structure or only in formant structure. The former result would lend support to the 'association hypothesis', introduced in section 4. The latter result would confirm the 'dissociation hypothesis'.

5.1 Stimuli

A list of words differing in tense and lax vowels in the word-final syllable was compiled that is similar to Moulton's list (3a). The words are near-minimal pairs. Alternations between pre-stress 1 and main stress vowels were created by using two different productive suffixes, one bearing main stress and the other requiring the preceding syllable to receive main stress. The main stress bearing suffix *-ist* derives nouns with a meaning of personification from, in most cases, other nouns. The suffix *-isch* derives adjectives from various word classes and has no common semantic result. Among other phonological effects, it requires main stress to fall on the syllable immediately preceding this suffix. The list is given in (4).[5]

(4)

main stress tense		main stress lax		pre-stress 1 tense		pre-stress 1 lax	
nitríl-isch	[i:]	mandríll-isch	[I]	Nitril-íst	[i]	Mandrill-íst	[I]
pakét-isch	[e:]	parkétt-isch	[ɛ]	Paket-íst	[e]	Parkett-íst	[ɛ]
korán-isch	[a:]	tyránn-isch	[a]	Koran-íst	[a]	Tyrann-íst	[a]
despót-isch	[o:]	kompótt-isch	[ɔ]	Despot-íst	[o]	Kompott-íst	[ɔ]
kabúl-isch	[u:]	abdúll-isch	[ʊ]	Kabul-íst	[u]	Abdull-íst	[ʊ]
acr´yl-isch	[y:]	ber´yll-isch	[ʏ]	Acryl-íst	[y]	Beryll-íst	[ʏ]

[5]The stems in (4) are glossed as follows: *Nitril* 'nitrile', *Paket* 'packet', *Koran* 'Koran', *Despot* 'despot', *Kabul* 'Kabul', *Acryl* 'acryl', *Mandrill* 'mandrill', *Parkett* 'parquet', *Tyrann* 'tyrant', *Kompott* 'compote', *Abdull* 'Abdul', *Beryll* 'berylium'. The stress marks that are added here and elsewhere in this paper are not part of German orthography. A morpheme-boundary is symbolized here by "-". Glosses for the stems in (6), below, that are not already given in (1) are: *beten* 'pray', *hüten* 'guard', *Höker* 'seller', *betten* 'make the bed', *Hütte* 'hut', *Höcker* 'bump'. For the sake of illustration, the transcriptions of quality and quantity in (4) and (6) give a preview on the results of Experiment 1 and Experiment 2, respectively.

In compiling the list in (4), I was not able to find an appropriate example for the vowels [ø, œ]. The stems to which the two suffixes are attached are mostly nonnative. Possibly because of that it was not possible to find true minimal pairs differing in vowel tenseness alone (cf. Ramers 1988: 89 on this issue). However, in pairs of word-stems with tense and lax vowels (e.g. *Nitril* vs. *Mandrill*) the number of syllables and the consonants surrounding the vowels in question were held constant (with the exception of *Kabul* vs. *Abdull*). Only a few of the stem plus suffix combinations in (4) occur in a dictionary, but they are all grammatical possible words.

5.2 Recording

Each word of the list in (4) was spoken twice by three speakers. The total number of word tokens analyzed in this experiment was 144 (24 words x 3 speakers x 2 repetitions). The words were presented in random order on index cards and spoken in isolation by the subjects at a normal speaking rate. Random order prevented the subjects from emphasizing differences in minimally contrasting word pairs. Recordings were made in a sound-proof booth, using a high-quality cassette recorder (Marantz PMD 222).

5.3 Subjects

The three subjects are all native speakers of Standard German, and none of them has any known history of speech or hearing disorders. Speaker BE is male, 30 years old, grew up in Olpe and studied in Köln. Speaker MA is female, 28 years old, grew up in Lemgo and studied in Bielefeld. Speaker MJ (the author) is male, 31 years old, grew up in Flensburg and studied in Bielefeld. Each speaker had been in the US for 2 years. I decided to include my own speech, since the results did not differ in any consistent way from those of the other speakers.

5.4 Measurements

The recordings were digitized on a SUN 3/160 computer with a sampling rate of 12000 Hz and were low-pass filtered at 6000 Hz. Acoustic analysis was performed with the commercial software package WAVES+. For each word, waveforms and wide-band spectrograms were aligned in time for comparison. The acoustic parameters that were measured are vowel duration and vowel formants 1, 2, and 3. Formant analysis was performed with the help of LPC-generated formant candidates that were superimposed on the regular spectrograms. LPC values were computed with the following default settings: preemphasis = .7, window size = 49 ms, number of poles = 12. *Vowel duration* was determined by looking at the realization of the second formant: vowels were defined as being realized with an F_2 that is fully voiced and with energy at the range of average vowel amplitude. The three *vowel formants* F_1, F_2, and F_3 were measured at a single point in time during the vowel. Preferably, the point was during the steady state portion of the vowel. Some vowels, especially the lax, were transitional throughout; in such a case the center of the vowel was chosen, provided that both the preceding and following consonant imposed their formant locus on the vowel (e.g. an alveolar consonant following [u] imposes a rising F_2 transition out of the vowel). If either of the consonants was known to impose no specific formant locus (e.g. [h], or g/k adjacent to vowels other than [a]) and the vowel was transitional throughout, the measurement point was chosen closer to the 'neutral' than to the transition-imposing consonant. The LPC-analysis did not always yield adequate formant candidates for every point in time during the vowel; this was quite often the case for F_3. In those cases, a point in time close to the one dictated by the criteria was chosen. If this was not possible, formant structure was determined directly from the spectrogram without making use of formant candidates provided by the LPC-analysis. Everything else being equal, as a matter of convention, earlier points in time were preferred over later ones.

5.5 Analysis

For the statistical analysis, 1-factor ANOVA's were calculated using the computer program Statview SE+. Tenseness (tense, lax) is the independent variable and vowel duration, F_1, F_2, and F_3 are the dependent variables. In the statistical analysis front and back vowels were grouped separately, because the front vs. back distinction determines whether F_2 in tense vowels is higher or lower than the one in lax vowels: in my results, tense vowels with front articulation have a higher F_2 than lax front vowels, tense vowels with back articulation have a lower F_2 than lax back ones. Separate analysis was also performed for vowels in main stress position on the one hand and in pre-stress 1 position on the other. The data from all 3 speakers were pooled together.

5.6 Results

In (5) the results for front and back vowels in main stress position (5ab) and pre-stress 1 position (5cd) are presented in tabular form. The first two columns give the means for duration and formants of tense and lax vowels, respectively. The results separated for each pair of tense and lax vowel are provided in Appendix A. Since the absolute number of tokens in this experiment is relatively small, it was not possible to perform ANOVA's for each tense/ lax pair individually. Therefore, in Appendix A only average values are given without further statistics.

(5) a. Front vowels in main stress position (from the two lefthand columns of (4)):

	tense	lax	F-test	P-value
duration	115 ms	66 ms	55.232	p=.0001
F_1	354 Hz	475 Hz	19.23	p=.0001
F_2	1956 Hz	1583 Hz	14.431	p=.0006
F_3	2670 Hz	2606 Hz	0.604	p=.4426

b. Back vowels in main stress position (from the two lefthand columns of (4)):

	tense	lax	F-test	P-value
duration	144 ms	85 ms	89.41	p=.0001
F_1	450 Hz	552 Hz	3.17	p=.0839
F_2	877 Hz	1214 Hz	21.344	p=.0001
F_3	2397 Hz	2405 Hz	0.01	p=.9117

c. Front vowels in pre-stress 1 position (from the two righthand columns of (4)):

	tense	lax	F-test	P-value
duration	65 ms	59 ms	2.027	p=.1637
F_1	347 Hz	456 Hz	66.067	p=.0001
F_2	1929 Hz	1658 Hz	12.223	p=.0013
F_3	2650 Hz	2570 Hz	1.686	p=.2029

d. Back vowels in pre-stress 1 position (from the two righthand columns of (4)):

	tense	lax	F-test	P-value
duration	74 ms	69 ms	0.671	p=.4184
F_1	459 Hz	521 Hz	1.13	p=.2952
F_2	1058 Hz	1295 Hz	11.808	p=.0016
F_3	2396 Hz	2415 Hz	0.056	p=.8148

These statistical results indicate that tense and lax vowels in main stress position (5ab) differ significantly (p-values equal to or smaller than .05) both in duration and in at least one formant. In pre-stress 1 position (5cd), on the other hand, tense and lax vowels differ significantly in at least one formant, but not in duration. If significant differences in at least one of the three formants (F_1 and F_2 for front vowels, F_2 for back vowels) are taken as evidence for a significant quality difference, the evidence speaks in favor of the dissociation hypothesis: there is a level of non-main stress, the pre-stress 1 position, at which tense and lax vowels differ significantly in quality, but not in quantity.

6. Experiment 2: tense and lax vowels in 'pre-stress 2' position

This experiment tests whether the dissociation hypothesis also holds for the 'pre-stress 2' position, or in other words, whether 'pre-stress 2' position is another context at which tense and lax vowels differ significantly in formant structure but not duration.[6]

To elicit the realization of vowels in main stress position, a list of minimal pairs (except *hüten* vs. *Hütte*, which is a near-minimal pair) was created, with a tense or lax vowel in the position of main stress followed by a schwa-vowel (cf. footnote 2). This is the canonical structure of bisyllabic words in German. The words chosen have the same structure as the ones given in (1) above (e.g. *Schiefer* [i:] 'slate' vs. *Schiffer* [I] 'captain'). These pairs are presented in the two lefthand columns of (6). To these words the main stress bearing derivational suffix *-ei* was attached that is used in German to derive nouns of abstract meaning from either nouns or verbs (this suffix has the two allomorphs *-éi* and *-eréi*). This way the same vowels that occur in main stress position when monomorphemic now occur two syllables before main stress, that is in pre-stress 2 position (the two righthand columns of (6)). The suffix *-ei* is highly productive in German, therefore the words derived by this suffix appear completely normal to the native speaker (glosses of the stems are given in footnote 5).

(6)

main stress tense		main stress lax		pre-stress 2 tense		pre-stress 2 lax	
Schíefer	[i:]	Schíffer	[I]	Schiefer-éi	[i:]	Schiffer-éi	[I]
béten	[e:]	bétten	[ɛ]	Bet-eréi	[e:]	Bett-eréi	[ɛ]
Háken	[a:]	hácken	[a]	Hak-eréi	[a:]	Hack-eréi	[a]
Schóte	[o:]	Schótte	[ɔ]	Schot-eréi	[o:]	Schott-eréi	[ɔ]
spúken	[u:]	spúcken	[ʊ]	Spuk-eréi	[u:]	Spuck-eréi	[ʊ]
h´üten	[y:]	H´ütte	[ʏ]	Hüt-eréi	[y:]	Hütt-eréi	[ʏ]
H´öker	[ø:]	H´öcker	[œ]	Höker-éi	[ø:]	Höcker-éi	[œ]

Each word of the list in (6) was spoken twice by the two speakers MA and MJ who also acted as subjects in Experiment 1. The total number of word tokens analyzed in this experiment was 112 (28 words x 2 speakers x 2 repetitions). Procedures for recording, measurements, and analysis were identical to Experiment 1. The results are given in (7) in a format that is the same as in (5).

[6]Chronologically, Experiment 2 was performed before Experiment 1. After I found that no dissociation between formant structure and duration took place at the level of stress investigated in Experiment 2, I went on to investigate in Experiment 1 if dissociation occurs at a lower degree of stress. Since Experiment 2 functions as a pilot study, there were fewer tokens investigated.

(7) a. Front vowels in main stress position (from the two lefthand columns of (6)):

	tense	lax	F-test	P-value
duration	138 ms	77 ms	159.45	p=.0001
F1	307 Hz	462 Hz	20.301	p=.0001
F2	1978 Hz	1697 Hz	9.563	p=.0043
F3	2629 Hz	2536 Hz	0.682	p=.4155

b. Back vowels in main stress position (from the two lefthand columns of (6)):

	tense	lax	F-test	P-value
duration	157 ms	81 ms	91.269	p=.0001
F1	465 Hz	577 Hz	1.467	p=.2386
F2	908 Hz	1178 Hz	6.147	p=.0213
F3	2289 Hz	2331 Hz	0.163	p=.6900

c. Front vowels in pre-stress 2 position (from the two righthand columns of (6)):

	tense	lax	F-test	P-value
duration	89 ms	62 ms	27.878	p=.0001
F1	309 Hz	437 Hz	13.809	p=.0008
F2	1938 Hz	1676 Hz	11.448	p=.0020
F3	2579 Hz	2518 Hz	0.450	p=.5077

d. Back vowels in pre-stress 2 position (from the two righthand columns of (6)):

	tense	lax	F-test	P-value
duration	109 ms	66 ms	35.189	p=.0001
F1	476 Hz	561 Hz	1.235	p=.2783
F2	973 Hz	1184 Hz	4.603	p=.0432
F3	2280 Hz	2355 Hz	0.516	p=.4802

These statistical results indicate that tense and lax vowels differ significantly in duration and formant structure (F1 and F2 for front vowels, F2 for back vowels), both in the position of main stress (7ab) and in the pre-stress 2 position (7cd). This result from Experiment 2 alone does neither confirm nor falsify the dissociation hypothesis. It doesn't confirm it, because at the stress level that is investigated here (pre-stress 2 position) there is a significant difference between tense and lax vowels in both quantity (duration) and quality (formant structure). It doesn't falsify it either as long as another stress level can be found at which tense and lax vowels only differ significantly in quality. This was found in Experiment 1 to be the pre-stress 1 position.

7. Conclusion from the experiments

The results from both experiments taken together confirm the dissociation hypothesis. In Experiment 1 it was shown that pre-stress 1 position is a context that dissociates vowel quality and vowel quantity, in the sense that differences in quality but not quantity between tense and lax vowels are significant. Experiment 2 showed that this dissociation does not take place at all levels of non-main stress. One syllable intervening between the target vowel and the main stress bearing vowel of the word is sufficient to result in significant differences that involve both quality and quantity. The results from Experiment 1 and 2 are also consistent with the transcriptions *möblíeren* [ø] (cf. pre-stress 1 position in Experiment 1) compared to *Blödeléi* [ø:] (cf. pre-stress 2 position in Experiment 2) given by Mangold (1990: 35), and with the general acoustic results obtained by Delattre (1969) and Vernon (1976), all of which were discussed in section 3.

It is possible that German has some form of alternating stress, such that every second syllable is realized with at least secondary stress. This is a common assumption in the literature on German stress in the framework of Metrical Phonology (e.g. Giegerich 1985). Unfortunately, there exists to my knowledge no phonetic study addressing that issue for German, and the pronouncing dictionaries Krech et al. (1982) and Mangold (1990) don't provide information about secondary stress in monomorphemic words. But if alternating stress was present in German, differences in quantity in pre-stress 2 position could be attributed to secondary stress and the absence of quantity differences in pre-stress 1 position to the absence of stress. Quality differences, on the other hand are independent of the degree of stress. Taken from another perspective, this would mean that vowel quantity is a reliable correlate of stress in German, but vowel quality is not.

The set of vowels for which the dissociation hypothesis has been originally conceptualized (cf. Moulton 1962) are all the nonlow vowel pairs, but not the low vowels [a:] and [a].[7] As the discussion in section 2 suggested, the tense and lax low vowels show

---

[7]The low vowels have been pooled with other back vowels in Experiments 1 and 2. The reason for that was purely methodological: I intended to have an equal (Experiment 1) or almost equal (Experiment 2) number of front and back vowels to make statistical analysis more straightforward. To the extent that it is problematic to pool low vowels with nonlow vowels (in light of the following discussion), I want to emphasize that all the front vowels that have been pooled are nonlow. The results for front vowels (5ac, 7ac) can alone confirm the dissociation hypothesis. Pooling low vowels with other back vowels might also have contributed to the result that F_1 was not significant for back vowels in any of the experimental conditions. This is specifically suggested from the results given in Appendix B-1 and B-2, to be explained

no reliable difference in formant structure. My data for each vowel pair provided in Appendix A confirm that formant differences between tense [a:] and lax [a] are minimal, even for main stress position. Obviously, more research is necessary concerning the quality of low vowels. But until more extensive acoustical studies are available, it is reasonable to infer from the existing evidence that the tense and lax low vowels in German differ consistently only in duration, but not in formant structure. I will base the following phonological discussion in section 8 upon this assumption. Given this assumption, low vowels are not subject to the dissociation hypothesis for the following reason: the dissociation hypothesis presupposes that there is both a reliable quality and quantity distinction in main stress position and requires upon this presupposition that at a given degree of non-main stress only quality differences remain. This presupposition is not met in low vowels if, as I assume, reliable quality differences between tense and lax low vowels don't exist at any level of stress. Thus low vowels don't form an exception to the dissociation hypothesis, but rather are irrelevant to it. In fact, as little of a quality difference as there is between [a:] and [a] in main stress position, it is not more reduced in pre-stress 1 position as there is quality reduction between other tense/ lax pairs in this position (cf. the formant chart in Delattre 1969: 86 and the results from Experiment 1 in Appendix A). Also, quantity reduction is similar in low vowels and nonlow vowels. Thus, low vowels don't seem to have a reduction pattern with respect to quality (F_1, F_2) and quantity (duration) that differs from that of other vowels, which also shows that they are not exceptional to the dissociation hypothesis. What makes low vowels different from nonlow vowels, however, is that they 'start out' with only minimal and inconsistent quality differences in main stress position, whereas nonlow vowels have clear and consistent quality differences in that context. This difference in patterning between low and nonlow vowels will become one of the important points in the following phonological discussion.

8. Phonological implications: What is distinctive, quality or quantity?

One of the classic issues in German phonology is the question of whether the distinctive feature that distinguishes tense and lax vowels in pairs like (1) is in terms of vowel quality or vowel quantity. There is almost a complete consensus in the literature that only one of these dimensions can be distinctive, whereas the other has to have the status of being redundant. The issue arises with the question of how to evaluate and weigh

---

below, in which low vowels are excluded and in which F_1 is always significant. In a more extensive investigation, comprising more speakers and tokens, I would avoid this kind of pooling and instead perform statistics on each tense/ lax pair individually.

arguments in favor of either distinctive quality or distinctive quantity. There exists an about equal number of phonological analyses arguing for distinctive quality on the one hand and quantity on the other. For the purpose of this paper, I will concentrate on those arguments that are based on the kind of phonetic evidence that has been presented in the two experiments above. For discussions of a more comprehensive set of arguments, including some that are based on evidence from phonotactic constraints or morpho-phonemic alternations the reader is referred to Ramers (1988). Other, more recent contributions that address the issue form the point of view of nonlinear phonology include Hall (1992). Since primary importance is given to phonotactic evidence in Hall's analysis, it will not be further discussed here. During this section I will introduce to an argument that has been made in favor of distinctive quality on the basis of evidence for the dissociation hypothesis. I will extend this argument by making the proposal that the quality/ quantity debate isn't a question of either/ or. It will be argued specifically, that vowel quality is distinctive for nonlow vowels, whereas vowel quantity is distinctive for low vowels.

The primary argument for the distinctive status of vowel quality found in the literature is the type of phonetic evidence that has been expressed and confirmed under the term 'dissociation hypothesis' in this paper. According to this argument, that has been made explicit by Reis (1974: chap. 3.4.1.1), but that is also found implicitely in Moulton (1962: 62-64), vowel quality, rather than vowel quantity, is distinctive, because in syllables that are not under main stress only quality differences remain, whereas quantity differences disappear. It is not stated by Reis (1974) or, as far as I know of, other proponents of distinctive quality why this type of evidence should constitute an argument for the distinctive status of vowel quality. One approach to phonology and phonetics that can provide a theoretical basis for the argument by Reis and Moulton is the functional-structural framework of Jakobson, Fant & Halle (1952), Jakobson & Halle (1968), and Jakobson & Waugh (1987). According to this framework a distinctive feature is determined on the basis of a phonetic property that is generalized as a relational invariant across contextual variation (cf. Jessen, to appear, for more about the theoretical background). In determining the distinctive features that characterize the opposition between tense and lax vowels in German, this procedure would require determining a concrete phonetic property (in the context of this study an acoustic property) that realizes the tense/ lax opposition in every context where this opposition is found in the language. With the outcome from Experiment 1 we saw that there exists a context (pre-stress 1 position) where the opposition is realized only as a significant difference in acoustic quality (formants 1 and 2), but not in acoustic quantity (duration). Dissociation between quality and quantity in this context is the crucial diagnostic for determining the appropriate invariant property. Since it is quality that is the only reliable (statistically significant) acoustic cue for the tense/ lax opposition in pre-stress 1 position, it is the invariant.[8]

As was mentioned in sections 2 and 3, there is no consistent difference in formant structure between the low tense and lax vowels [a:] vs. [a]. Therefore the classification of vowel quality as the invariant of the tense/ lax opposition in all contexts would hold only for nonlow vowels, but not for low ones. This, of course, would weaken the proposal of quality as the invariant, since we would expect all tense/ lax pairs to be differentiated by quality, not just the nonlow ones. The exceptionality of low vowels with respect to a quality distinction has been adduced as an argument for the distinctive status of vowel quantity, rather than quality (Wiese 1988: 64; cf. also Reis 1974: 182). According to this argument, quantity is considered distinctive, because it is the only dimension that differentiates all pairs of tense and lax vowels, including the low ones. This solution, however, cannot be satisfactory either given that we take cross-contextual invariance as the criterion for distinctivity. We saw that quantity does not qualify as the invariant because there exists a context (pre-stress 1 position) in which no quantity difference is found to cue the tense/ lax opposition. This leaves us with the following dilemma: vowel quantity cannot be the distinctive correlate of the tense/ lax opposition in German because it is not an invariant across contextual variation; vowel quality cannot be the distinctive correlate either, because it does not operate for the whole set of tense and lax vowels, but only for the subset of nonlow vowels. The only way out that I can think of is to reject the widespread assumption, mentioned above, that only one of the dimensions - quality or quantity - can be distinctive, whereas the other has to have the status of being redundant. If this assumption, which probably arises from a concern about simplicity in phonology, is no longer maintained, it becomes possible for me to suggest the following: vowel quality is distinctive for the set of nonlow vowels; vowel quantity is distinctive for the set of low vowels.

The hybrid character of this solution, allowing for both quality and quantity to be distinctive for a different subset of vowels, builds upon a proposal made by Weiss (1977), who suggests: "High vowels are distinguished primarily by quality (length is secondary).

---

[8]The term 'relational' in Jakobson and collegues' account means that it is the differences within a given context that are relevant for invariance, not absolute values. Applied to the tense/ lax oposition the notion of relationality would mean that e.g. a F_2 value for a lax vowel in main stress position might be identical to a F_2 value for a tense vowel in pre-stress 1 position. This situation called "overlap" (Jakobson, Fant & Halle 1952:5f.) would not invalidate relational invariance of quality as long a significant difference in F_2 is found within each context taken separately.

Low vowels are distinguished primarily by length (quality is secondary). Mid-vowels [sic] are distinguished both by length and quality factors" (p. 275). This proposal derives from his intensive work on vowel perception in German (cf. Weiss 1977 for more references to his work). Weiss shows that for example lengthening the *high* lax vowel [ɩ] doesn't result in the percept of high tense [i:], no matter how much lengthening is applied. The [I] to [i:] change in perception is made possible only by changing the formant structure. For *low* vowels, on the other hand, the perceptual shift between lax [a] and tense [a:] is achieved predominantly by changing duration, rather than formant structure. The perception of tense and lax *mid* vowels is subject to both quality and quantity factors.[9]

My proposal, which is based on acoustic, rather than perceptual evidence, starts from the same hypothesis that the selection of a distinctive feature depends on vowel height. The difference between Weiss' and my account lies in the role ascribed to mid vowels and in the issue of whether vowel height is divided gradually or categorically. Mid vowels in Weiss' account are seen as a set that behaves differently from that of high and low vowels, in that this set involves both quality and quantity as distinctive factors. Vowel height is thus seen as a gradient dimension in which the importance of quality as the distinctive factor increases by going from low to high articulation, and the importance of distinctive quantity increases by going from high to low. In my account mid vowels are grouped with high vowels, such that the vowel-height space is seen as divided categorically with respect to the distinctive correlates of tense and lax.

To decide between Weiss' and my hypothesis on a purely acoustic basis, it is necessary to group tense/ lax pairs of vowels according to vowel height and to determine whether there are salient differences in the realization of the tense/ lax opposition between mid and high vowels (that low vowels are different from both mid and high vowels is assumed both by Weiss and me and thus is not crucial to differentiate the two hypotheses). According to Weiss' vowel height conception there should be differences, such that for example, the formant differences of high vowels are more substantial than the formant differences of mid vowels, because formant structure is by Weiss considered more influential as a cue to the tense/ lax opposition for high vowels than for mid ones. My hypothesis of a categorical

[9]Another, very different, argument for the 'both quality and quantity' view is based on the fact that Standard German has a three-way opposition among mid front unrounded vowels (e.g. *stehlen* [e:] 'steal' vs. *stählen* [ε:] 'steel (verb)' vs. *stellen* [ε] 'put'). This three-way opposition is unstable and absent in many dialects, but its standard status cannot be easily denied (Wiese 1988: 63f.). As the transcriptions suggest, these three vowels are minimally distinguished by both vowel quality ([e:] vs. [ε:]) and vowel quantity ([ε] vs. [ε:]). However, this three-way opposition isn't matched by any other group of vowels, and it might be the result of a "spelling pronunciation" (Kloeke 1982: 11), which would mean that it is governed by the orthography rather than being integrated in the phonemic system of the speaker. These considerations make this a rather marginal argument for the 'both-and' view (cf. also footnote 2).

low vs. nonlow division of vowel height would predict that high and mid vowels do not differ in the way the tense/ lax opposition is realized. In order to provide the information that is crucial to address this issue, I carried out statistical analysis over high and mid vowels separately. For this calculation, I grouped front and back vowels together, because the absolute number of tokens would otherwise be too small for statistical analysis. As a consequence, I could not evaluate F_2, because as mentioned above, F_2 patterns differently for front and back vowels with respect to the tense/ lax opposition. I therefore only considered duration and F_1. F_1 clearly is an important correlate of the tense/ lax opposition, and probably even more reliable than F_2 (cf. Fischer-Jørgensen 1990: 108f.). The results are given in Appendix B-1. They show that the significance patterns for duration and F_1 are the same for high and mid vowels. For example, tense and lax vowels from Experiment 1 in main stress position differ significantly in duration and F_1; this is the case for both high and mid vowels (a., b.). For the vowels in Experiment 1 that occur in pre-stress 1 position there is a significant tense/ lax difference in F_1, but not duration; again this is the case for both high and mid vowels c., d.). Parallelism in the significance patterns between high and mid vowels is also found in the results from Experiment 2 (e.-h.).

In order to determine if F_2 behaves the same way as F_1 with respect to the high vs. mid distinction, I carried out statistics for F_1 and F_2 just among front vowels (front rather than back vowels were chosen because due to the rounded-unrounded distinction that in German exists only for front vowels, sufficient tokens for a reasonable statistical analysis were available only among the front vowels). The results are given in Appendix B-2. In the results from Experiment 1 (a.-d.) F_2 patterns like F_1 in being a significant correlate of the tense/ lax distinction for both high and mid vowels. However, in the results from Experiment 2, only F_1 but not F_2 differs significantly between tense and lax among the mid vowel, whereas among the high vowels both and F_1 and F_2 are significant. The results from Experiment 2 suggest that if F_2 is taken as an index of vowel quality, there is a difference in the influence of vowel quality between high and mid vowels to the extent that for high vowels quality is a more reliable correlate of the tense/ lax distinction than for mid vowels; this is in line with Weiss' hypothesis. On the other hand, this asymmetry between high and mid vowels is only found in the results from Experiment 2, not Experiment 1. Furthermore, if F_1 is taken as the index of vowel quality for the tense/ lax opposition, as is suggested by Fischer-Jørgensen (1990), mentioned above, the results from both experiments speak in favour of my hypothesis that high vowels pattern with mid vowels for the purpose of the tense/ lax opposition.

Considering the results from both Appendix B-1 and Appendix B-2 together, it appears that the majority of the evidence speaks in favor of my hypothesis that the vowel height dimension is divided into low vs. nonlow with respect to the tense/ lax distinction, and that consequently the influence of vowel quality and quantity does not differ between high and mid vowels. I conclude by repeating my view on the quality/ quantity debate that was motivated during this section: vowel quality is distinctive for the set of nonlow vowels; vowel quantity is distinctive for the set of low vowels.[10]

References

Antoniadis, Z. & Strube, H.W. 1984. Untersuchung zur spezifischen Lautdauer deutscher Vokale. *Phonetica* 41: 72-87.

Bennett, D.C. 1968. Spectral form and duration as cues in the recognition of English and German vowels. *Language and Speech* 11: 65-85.

Benware, W.A. 1986. *Phonetics and phonology of Modern German. An introduction.* Washington, D.C.: Georgetown University Press.

Delattre, P. 1969. An acoustic and articulatory study of vowel reduction in four languages. In Malmberg, B. (ed.) 1981. *Pierre Delattre. Studies in comparative phonetics. English, German, Spanish and French.* Heidelberg: Groos. 63-93.

Delattre, P. & Hohenberg, M. 1968. Duration as a cue to the tense/ lax distinction in German unstressed vowels. In Malmberg, B. (ed.) 1981. *Pierre Delattre. Studies in comparative phonetics. English, German, Spanish and French.* Heidelberg: Groos. 39-62.

Fischer-Jørgensen, E. 1990. Intrinsic F_0 in tense and lax vowels with special reference to German. *Phonetica* 47: 99-140.

Giegerich, H.J. 1985. *Metrical phonology and phonological structure. German and English.* Cambridge etc.: Cambridge University Press.

Hall, T.A. 1992. *Syllable structure and syllable-related processes in German.* Tübingen: Niemeyer (= Linguistische Arbeiten 276).

---

[10] There are also some indications from other perception studies on German than Weiss' that all nonlow vowels pattern together, such that tense and lax nonlow vowels are distinguished primarily by vowel quality and low vowels primarily by quantity. Bennett (1968) investigates the perception of the pair of mid vowels [o:] vs. [ɔ] and concludes that "spectral form" is a "more important cue" for this tense/ lax pair than duration (p. 70; he doesn't investigate other tense/ lax pairs in German). This result is consistent with my hypothesis that nonlow vowels have a distinctive quality distinction, but inconsistent with Weiss, who assumes that for mid vowels quality and quantity is of equal perceptual importance. Also consistent with my hypothesis are the perceptual results of Sendlmeier (1981) who shows that both high and mid vowels cannot generally be perceptually shifted from tense to lax by shortening nor from lax to tense by lengthening the vowel, whereas low vowels can.

Jakobson, R., Fant, G. & Halle, M. 1952. *Preliminaries to speech analysis* (sixth printing 1965). Cambridge, Mass.: MIT Press.

Jakobson, R. & Halle, M. 1968. Phonology in relation to phonetics. In Malmberg, B. (ed.) *Manual of Phonetics* Amsterdam: North Holland. 411-449.

Jakobson, R. & Waugh, L.R. 1987[2]. *The sound shape of language.* Berlin etc.: Mouton de Gruyter.

Jessen (to appear). Functional differences between consonants and vowels in German. In Ramers, K.H., Vater, H. & Wode, H. (eds.) *Universale phonologische Strukturen und Prozesse* (preliminary title). Tübingen: Niemeyer (= Linguistische Arbeiten).

Jongman, A., Fourakis, M. & Sereno, J.A. 1989. The acoustic vowel space of Modern Greek and German. *Language and Speech* 32: 221-248.

Kloeke, W.U.S. van Lessen. 1982. *Deutsche Phonologie und Morphologie. Merkmale und Markierheit.* Tügingen: Niemeyer (= Linguistische Arbeiten 117).

Krämer, W. 1978. Acoustic variations of German /a/ and /a:/ under varied speaking attitude. In Wodarz, H.W. (ed.) *Frankfurter Phonetische Beiträge 2* Hamburg: Buske (= Forum Phoneticum 16). 1-21.

Krech, E.-M. et al. (Autorenkollektiv) 1982. *Großes Wörterbuch der deutschen Aussprache.* Leipzig: VEB Bibliographisches Institut.

Maack, A. 1949. Der Einfluß der Betonung auf die Lautdauer deutscher Sonanten. *Zeitschrift für Phonetik und allgemeine Sprachwissenschaft* 3: 341-356.

Maack, A. 1951. Die Variation der Lautdauer deutscher Sonanten. *Zeitschrift für Phonetik und allgemeine Sprachwissenschaft* 5: 287-340.

Maack, A. 1954. Die Korrelation Akzent/ Quantität. *Zeitschrift für Phonetik und allgemeine Sprachwissenschaft* 8: 226-238.

Mangold, M. 1974[2]. *DUDEN Aussprachewörterbuch.* Mannheim etc.: Bibliographisches Institut.

Mangold, M. 1990[3]. *DUDEN Aussprachewörterbuch.* Mannheim etc.: Bibliographisches Institut.

Meinhold, G. & Stock, E. 1982[2]. *Phonologie der deutschen Gegenwartssprache.* Leipzig: VEB Bibliographisches Institut.

Moulton, W.G. 1962. *The sounds of English and German.* Chicago: The University of Chicago Press.

Ramers, K.H. 1988. *Vokalquantität und -qualität im Deutschen.* Tübingen: Niemeyer (= Linguistische Arbeiten 213).

Reis, M. 1974. *Lauttheorie und Lautgeschichte. Untersuchungen am Beispiel der Dehnungs- und Kürzungsvorgänge im Deutschen.* Fink: München (=Internationale Bibliothek für allgemeine Linguistik 14).

Schindler, F. 1974. *Beiträge zur deutschen Hochlautung.* Hamburg: Buske (= Forum Phoneticum 9).

Sendlmeier, W.F. 1981. Der Einfluß von Qualität und Quantität auf die Perzeption betonter Vokale des Deutschen. *Phonetica* 38: 291-308.

Sendlmeier, W.F. 1985. Die Beschreibung der deutschen Vokale in betonter Stellung. Ein forschungsgeschichtlicher Überblick. In Borowsky, V. & Köster, J.-P. (eds.) *Neue Tendenzen in der angewandten Phonetik 1.* Hamburg: Buske (= Beiträge zur Phonetik und Linguistik 49). 167-198.

Vernon, J.-P. 1976. La neutralisation de l'opposition de durée et de timbre des voyelles de l'allemand. *Cahiers de'Allemand* 11: 110-126.

Weiss, R. 1977. The phonemic significance of the phonetic factors of vowels length and quality in German. In Dressler, W.U. & Pfeiffer, O.E. (eds.) *Phonologica 1976.* Innsbruck: Innsbrucker Beiträge zur Sprachwissenschaft. 271-276.

Wiese, R. 1988. *Silbische und lexikalische Phonologie. Studien zum Chinesischen und Deutschen.* Tübingen: Niemeyer (= Linguistische Arbeiten 211).

Appendix A.

The average values of duration and formant structure from Experiment 1 and 2 are presented for each pair of tense and lax vowels separately. In sections 5 and 6 only results pooled for all front and all back vowels were presented. Giving quality and quantity values for each vowel pair separately allows the reader to see, for example, the small differences in F_1 and F_2 for tense and lax low vowels, compared to the larger and more consistent differences for nonlow vowels.

1. Duration values (milliseconds)

Results from:		Experiment 1	Experiment 1	Experiment 2	Experiment 2
position:		main stress (5ab)	pre-stress 1 (5cd)	main stress (7ab)	pre-stress 2 (7cd)
tense	i:	121	69	139	81
lax	ɪ	68	57	73	57
tense	y:	113	70	123	75
lax	ʏ	69	66	61	54
tense	e:	110	56	155	103
lax	ɛ	60	53	93	76
tense	ø:	-	-	135	95
lax	œ	-	-	83	61
tense	u:	146	88	134	96
lax	ʊ	100	72	73	61
tense	o:	131	56	165	103
lax	ɔ	73	63	88	74
tense	a:	154	78	171	126
lax	a	82	72	81	63

2. F_1 values (Hertz)

Results from: position:		Experiment 1 main stress (5ab)	Experiment 1 pre-stress 1 (5cd)	Experiment 2 main stress (7ab)	Experiment 2 pre-stress 2 (7cd)
tense	i:	324	336	245	261
lax	I	474	471	356	302
tense	y:	389	349	283	285
lax	ʏ	427	449	342	354
tense	e:	350	356	343	341
lax	ɛ	524	449	555	549
tense	ø:	-	-	357	350
lax	œ	-	-	596	545
tense	u:	309	289	306	299
lax	ʊ	417	351	384	404
tense	o:	350	384	315	373
lax	ɔ	540	528	538	549
tense	a:	691	705	775	757
lax	a	701	684	810	731

3. F_2 values (Hertz)

Results from: position:		Experiment 1 main stress (5ab)	Experiment 1 pre-stress 1 (5cd)	Experiment 2 main stress (7ab)	Experiment 2 pre-stress 2 (7cd)
tense	i:	2165	2045	2292	2212
lax	I	1583	1592	1819	1755
tense	y:	1547	1671	1727	1814
lax	ʏ	1298	1477	1648	1627
tense	e:	2157	2070	2253	2144
lax	ɛ	1869	1907	1765	1750
tense	ø:	-	-	1639	1585
lax	œ	-	-	1558	1571
tense	u:	718	852	762	740
lax	ʊ	1191	1346	864	919
tense	o:	711	967	697	876
lax	ɔ	1086	1180	1255	1249
tense	a:	1203	1354	1266	1305
lax	a	1367	1360	1416	1383

4. F3 values (Hertz)

Results from: position:		Experiment 1 main stress (5ab)	Experiment 1 pre-stress 1 (5cd)	Experiment 2 main stress (7ab)	Experiment 2 pre-stress 2 (7cd)
tense	i:	2872	2738	3110	2910
lax	I	2655	2622	2603	2561
tense	y:	2347	2456	2286	2338
lax	ʏ	2540	2458	2465	2463
tense	e:	2793	2756	2779	2708
lax	ɛ	2624	2629	2647	2642
tense	ø:	-	-	2341	2361
lax	œ	-	-	2428	2407
tense	u:	2280	2281	2247	2239
lax	ʊ	2262	2250	2222	2270
tense	o:	2330	2363	2117	2076
lax	ɔ	2446	2453	2425	2407
tense	a:	2581	2542	2505	2526
lax	a	2506	2544	2347	2388

Appendix B-1.

Results of a set of ANOVA's with tense/ lax as the independent variable and duration and F_1 as the dependent variables. In the statistical analysis high and mid vowels are grouped separately (cf. chart (2) for the high/ mid classification). Separate analysis was carried out for the results from Experiment 1 (a.-d.) and Experiment 2. (e.-h.) and for main stress position and non-main stress position. For example, in a. the difference in duration and F_1 between on the one hand [i:, y:, u:] and on the other hand [I,ʏ, ʊ] was calculated from all the tokens under main stress of Experiment 1 (two lefthand columns of (4)); significant differences were found for both duration and F_1.

a. High vowels in main stress position (from Experiment 1):

	tense	lax	F-test	P-value
duration	127 ms	79 ms	34.323	p=.0001
F1	340 Hz	439 Hz	10.858	p=.0023

b. Mid vowels in main stress position (from Experiment 1):

	tense	lax	F-test	P-value
duration	121 ms	67 ms	79.599	p=.0001
F1	350 Hz	532 Hz	129.594	p=.0001

c. High vowels in pre-stress 1 position (from Experiment 1):

	tense	lax	F-test	P-value
duration	76 ms	65 ms	3.139	p=.0854
F1	325 Hz	424 Hz	28.363	p=.0001

d. Mid vowels in pre-stress 1 position (from Experiment 1):

	tense	lax	F-test	P-value
duration	56 ms	58 ms	0.173	p=.4184
F1	370 Hz	488 Hz	35.164	p=.0001

e. High vowels in main stress position (from Experiment 2):

	tense	lax	F-test	P-value
duration	132 ms	69 ms	242.708	p=.0001
F1	278 Hz	360 Hz	21.437	p=.0001

f. Mid vowels in main stress position (from Experiment 2):

	tense	lax	F-test	P-value
duration	152 ms	88 ms	89.311	p=.0001
F1	338 Hz	563 Hz	45.572	p=.0001

g. High vowels in pre-stress 2 position (from Experiment 2):

	tense	lax	F-test	P-value
duration	84 ms	57 ms	38.562	p=.0001
F1	282 Hz	353 Hz	9.652	p=.0051

h. Mid vowels in pre-stress 2 position (from Experiment 2):

	tense	lax	F-test	P-value
duration	101 ms	70 ms	32.922	p=.0001
F_1	355 Hz	548 Hz	68.458	p=.0001

Appendix B-2.

Results of a set of ANOVA's with tense/ lax as the independent variable and F_1 and F_2 as the dependent variables. Only front vowels are considered, because F_2 in tense vs. lax vowels is sensitive to the front-back distinction. In the statistical analysis high and mid vowels are grouped separately. Separate analysis was carried out for the results from Experiment 1 (a.-d.) and Experiment 2. (e.-h.) and for main stress position and non-main stress position. For example, in a. the difference in F_1 and F_2 between on the one hand [i:, y:] and on the other hand [I,ʏ] was calculated from all the tokens under main stress of Experiment 1 (two lefthand columns of (4)); significant differences were found for both F_1 and F_2.

a. High front vowels in main stress position (from Experiment 1):

	tense	lax	F-test	P-value
F_1	356 Hz	450 Hz	6.147	p=.0213
F_2	1856 Hz	1441 Hz	12.581	p=.0018

b. Mid front vowels in main stress position (from Experiment 1):

	tense	lax	F-test	P-value
F_1	350 Hz	524 Hz	47.128	p=.0001
F_2	2157 Hz	1869 Hz	58.298	p=.0001

c. High front vowels in pre-stress 1 position (from Experiment 1):

	tense	lax	F-test	P-value
F_1	343 Hz	460 Hz	44.807	p=.0001
F_2	1858 Hz	1534 Hz	13.827	p=.0012

d. Mid front vowels in pre-stress 1 position (from Experiment 1):

	tense	lax	F-test	P-value
F_1	356 Hz	449 Hz	19.207	p=.0014
F_2	2070 Hz	1907 Hz	9.105	p=.013

e. High front vowels in main stress position (from Experiment 2):

	tense	lax	F-test	P-value
F_1	264 Hz	349 Hz	22.652	p=.0003
F_2	2009 Hz	1733 Hz	4.934	p=.0433

f. Mid front vowels in main stress position (from Experiment 2):

	tense	lax	F-test	P-value
F_1	350 Hz	576 Hz	91.944	p=.0001
F_2	1946 Hz	1661 Hz	4.237	p=.0587

g. High front vowels in pre-stress 2 position (from Experiment 2):

	tense	lax	F-test	P-value
F_1	273 Hz	328 Hz	5.131	p=.0399
F_2	2013 Hz	1691 Hz	13.351	p=.0026

h. Mid front vowels in pre-stress 2 position (from Experiment 2):

	tense	lax	F-test	P-value
F_1	345 Hz	547 Hz	55.959	p=.0001
F_2	1864 Hz	1660 Hz	2.522	p=.1346