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**Is Tenseness in German a Segmental Feature or a  
Property of the Syllable?  
An Experimental Study.**

by

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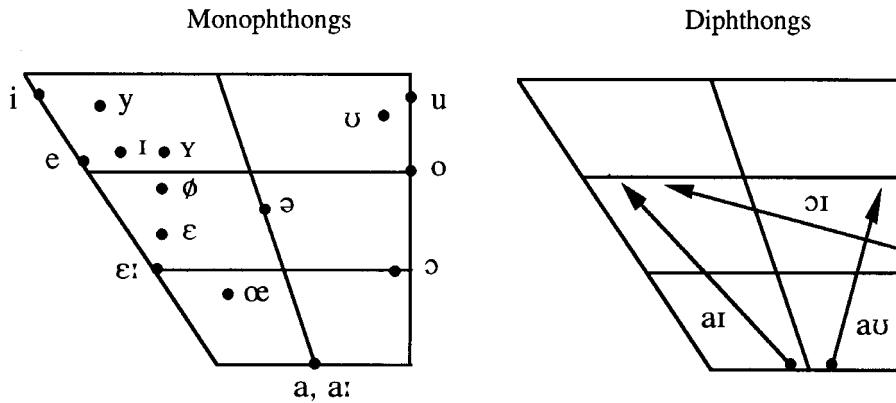
The title of this talk is "Is tenseness in German a Segmental Feature or a Property of the Syllable?". As you will see later, I unfortunately still don't know the answer.

The feature tenseness in Standard German, distinguishes the difference between the first vowel in *Miete* (rent) and in *Mitte* (center). In stressed position tenseness correlates with quantity, that is tense vowels are long and lax vowels short. There exist two different concepts: one assumes that tenseness is a segmental feature. First I'll give a short survey of phonological regularities for the distribution of tenseness and how they are described in the framework of auto-segmental phonology. Then I'll talk about some segmental phonetic correlates.

The second concept assumes that the domain of tenseness is the syllable. This so called Syllable Cut Theory dates back to the 16th century. After a short introduction I'll present the results of a production experiment which will be modelled in the framework of Articulatory phonology.

#### Overview

- I. German vowel inventory and phonological regularities of the feature tenseness in German
- II. Phonetic correlates
- III. Theory of Syllable Cut / Contact Prosodies
- IV. Articulatory Experiment
- V. Conclusions



## I. German vowel inventory and phonological regularities of the feature tenseness in German

The German vowel inventory consists of seven pairs of tense and lax vowels. For example

Table 1.1: Minimal pairs in stressed position

tense, long			lax, short			lax, long	
bieten	<i>offer</i>	i:	bitten	<i>beg</i>	ɪ		
Hüte	<i>hats</i>	y:	Hütte	<i>hut</i>	ʏ		
Beet	<i>bed, patch</i>	e:	Bett	<i>bed</i>	ɛ	bäten	<i>beg (subj.)</i> ε:
Höhle	<i>cave</i>	ø:	Hölle	<i>hell</i>	œ		
Mus	<i>mush</i>	u:	muß	<i>must</i>	ʊ		
wohne	<i>live (1.pers.sg.)</i>	o:	Wonne	<i>bliss</i>	ɔ		
Bahn	<i>train</i>	a:	Bann	<i>spell</i>	a		

There are two exceptions:

Acoustically the low vowels /ɑ:/ and /a/ are not distinguished by quality but only by quantity. Therefore the same symbol is often used and in some representations they are not specified for the feature tenseness.

The specification of the long vowel ä (ε:) is still a matter of debate because it is either assumed that this vowel has no short counterpart or its short counterpart is short /ε/. In the latter case there is no qualitative difference. Furthermore it is often realized as the long close-mid vowel /e:/ as in *Väter* (fathers).

Segmentally-based phonological theories differ with respect to which feature is assumed to be primary: quality or quantity or both. In the framework of autosegmental phonology quantity represented as number of slots on the skeletal tier is taken as the primary feature. The assignment of tenseness is then derived according to the number of timing slots by a default rule. The main argument for quantity as an underlying feature is the syllable structure, especially the complexity of the coda which depends on the nucleus.

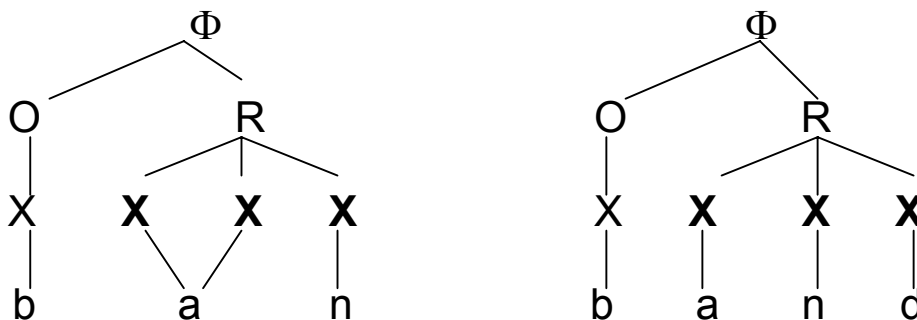
### a) Complexity of the coda

In German monosyllabic words there is a coda complexity restriction: only one consonant can follow after tense vowels and diphthongs, whereas after lax vowels the coda can consist of two consonants.

Table 1.2: Examples of the syllable structure of monosyllabic words in Standard German

long vowel		diphthong		short vowel	
viel	<i>many</i>	Pfeil	<i>arrow</i>	Film	<i>film</i>
doof	<i>stupid</i>	drauf	<i>then (sl)</i>	Dorf	<i>village</i>
schön	<i>beautiful</i>	neun	<i>nine</i>	gern	<i>gladly</i>
Stab	<i>stick</i>	Raub	<i>robbery</i>	halb	<i>half</i>
Bahn	<i>train</i>	Bein	<i>leg</i>	Bank	<i>bank</i>

Therefore the maximal rhyme can consist of three X positions: two positions for long vowels or diphthongs plus one X position for a consonant, that is VVC, or one position for a short vowel and one for each of the following two consonants, that is VCC.



There are regular exceptions concerning final coronal consonants.

Table 1.3: Examples of the syllable structure of monosyllabic words in Standard German with final coronal consonants.

long vowel		diphthong		short vowel	
Dienst	<i>service</i>	raubst	<i>rob (2.p.sg.)</i>	Herbst	<i>autumn</i>
Obst	<i>fruit</i>	läufst	<i>run (2.p.sg.)</i>	wirfst	<i>throw (2.p.sg.)</i>
lobst	<i>praise (2.p.sg.)</i>	streichst	<i>paint (2.p.sg.)</i>	denkst	<i>think (2.p.sg.)</i>

## b) Word final vowels

A second point concerns word final vowels: There are no lexical words in German with word final lax vowels.

Table 1.4: Word examples with open syllables

tense vowel		lax vowel		exceptions	
See	<i>sea</i>	*[zɛ]		bitte [ə]	<i>please</i>
Ski	<i>ski</i>	*[zɪ]		zäh [ɛ:]	<i>tough</i>
Schuh	<i>shoe</i>	*[ˈkɑ:mʊ]			

## c) Ambisyllabic consonants

Therefore, it is often assumed that lax vowels cannot occur in open syllables and that word medially an open syllable with a lax nucleus is closed by the following ambisyllabic consonant.

Table 1.4: Words with ambisyllabic consonants

Masse	<i>mass</i>	[ˈmasə]	Maße	<i>measure</i>	[ˈma:.sə]
Robbe	<i>seal</i>	[ˈRɔbə]	Robe	<i>robe</i>	[ˈRɔ:.bə]
Mitte	<i>center</i>	[ˈmitə]	Miete	<i>rent</i>	[ˈmi:.tə]
Komma	<i>comma</i>	[ˈkɔma]	Koma	<i>coma</i>	[ˈko:.ma]

## d) Shortening of unstressed tense vowels

A further regularity concerns accent. Only tense vowels are shortened in unstressed position.

Table 1.5: Words with unstressed tense and lax syllables (after Moulton 1962, 63)

tense, short			lax, short		
D̄iner	<i>dinner</i>	i	d̄iffus	<i>diffuse</i>	ɪ
D̄etail	<i>detail</i>	e	D̄essert	<i>dessert</i>	ɛ
B̄alance	<i>balance</i>	a	B̄allade	<i>ballade</i>	a
K̄olumbus	<i>Columbus</i>	o	K̄ollege	<i>college</i>	ɔ
K̄urier	<i>courier</i>	u	sk̄urriel	<i>bizarre</i>	ʊ
S̄ynagoge	<i>synagogue</i>	y	(S̄ynapse	<i>synapse</i> )	ʏ
Ȫkonom	<i>economist</i>	ø	Ȫstrogen	<i>estrogen</i>	œ

In casual speech unstressed tense vowels are often pronounced as the lax counterparts, this is called pretonic laxing, for example /tɔˈta:l/

instead of /to'ta:l/.

Some theories assume that accent in German is assigned by syllable weight. But the algorithms don't work well and never without exceptions. Therefore I'm not going into this matter.

## II Phonetic correlates of the feature tenseness

### a) Vowel duration

The perceptually most prominent correlate for the tenseness distinction is vowel duration which is - depending on vowel category, especially on vowel height - approximately half as long for lax vowels compared to tense stressed vowels.

The vowel duration of tense vowels is more prone to suprasegmental variation than durations of lax vowels, that is tense vowels shorten when unstressed or for fast speech tempo whereas the durations of lax vowels tend to be more stable.

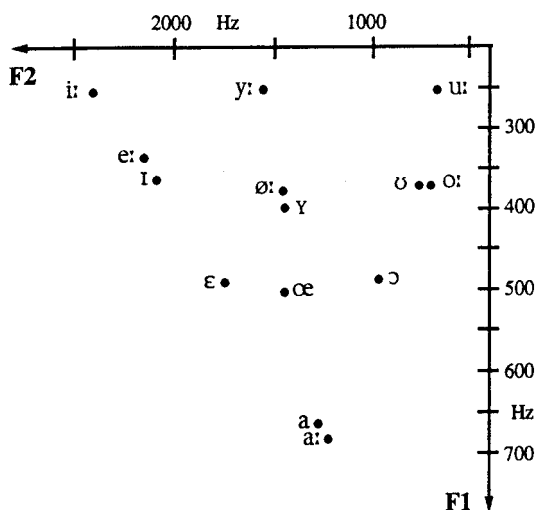


Figure 2.1: Average formant frequencies for German vowels in stressed position (Pompino-Marschall 1995, 124)

### b) Formant frequencies

In stressed position the frequency values of the first two formants are more centralized for lax vowels than for tense, i.e. formants of lax vowels are closer to the neutral vowel schwa than tense vowels.

Unstressed vowels are generally centralized. Depending on the style of speech the tenseness distinction can be neutralized, e.g. Politik. The degree of overlap between vowel types increases going from laboratory speech (e.g. Jessen and colleagues 1995) to spontaneous speech (e.g. Steriopolo 1994).

### c) Muscle tension

The term tenseness as an articulatory feature goes back to the intuition that tense vowels are produced by more muscle activity than lax vowels. For example in the beginning of the last century Sievers assumed that the more centralized tongue position and shorter durations of lax vowels are the result of the lower muscle activity. Several studies, measuring the muscle activity by means of Electromyography, couldn't confirm this assumption. For American English vowels no consistent differences were observed in tongue muscle activity for tenseness, which could not be explained by the diphthongization of long vowels. The only consistent result was a correlation between muscle activity and deviation of the tongue position from the neutral position.

d) Articulatory correlates:

- ( Tense vowels are produced with more extreme tongue positions. This property was described as a more convex tongue shape by Sidney Wood in 1975. He found that the jaw position is the same for tense and lax vowel pairs, but that they differ in tongue shape.
- ( He also found a more prominent lip rounding for tense rounded vowels and a lower larynx position for rounded tense back vowels.
- ( As Philip Hoole and Barbara Kühnert found, the target positions of lax vowels are more prone to contextual variability than tense vowels.

Now I come to some preliminary conclusions:

- Most phonological regularities in German concerning the feature tenseness have the syllable as their domain.
- There is no unique phonetic dimension for the tenseness distinction apart from vowel duration. Most phonetic correlates could be attributed to vowel duration, that is, for example the more centralized tongue positions of lax vowels could simply be the result of target undershoot due to the shorter duration, which also affects the formant frequencies.

### III Theory of Syllable Cut Prosody

The second group of phonological theories assumes that tenseness is a feature of the whole syllable and it therefore involves a prosodic contrast. Syllables with lax vowels are shorter because they are abruptly cut, that is: the following consonant cuts off the vowel before it reaches its sonority peak. Smoothly cut syllables with tense nuclei evolve and end during the vowel. This concept is usually attributed to Sievers 1901, but as David Restle found out it dates back to Valentin Ickelsamer in 1534.

The following table shows different terms and phonetic assumptions for the syllable cut distinction.

Sievers assumed that syllables with lax vowels don't have a decrescendo, that is abrupt syllables end in a crescendo whereas smooth syllables turn from crescendo to decrescendo.

Jespersen and Trubetzkoy attributed the cut distinction to the contact between the vowel and the following consonant. In syllables with loose contact the vowel can evolve fully before the following consonant is articulated. Vowels with close contact are cut off by the following consonant.

A less known concept stems from Forchhammer. He assumes that for a sequence like m-a-n (*Mann* or *mahn* like in *mahnen* that is urge) there exist two possibilities for the coordination of the pre- and post vocalic consonants. The opening movement for m can occur simultaneous with the closing movement for n. Because of this overlap of consonantal movements the vowel target is not reached, the syllable is short and produced with an abrupt cut syllable. Forchhammer calls this a bouncing or single beat articulation. The other possibility is that the n is produced some time after the release for m. This is what he calls a double beat or delayed articulation.

Author	Terms	Smooth Cut	Abrupt Cut
Sievers 1901	Pressure contour	smooth syllable accent Descrescendo within the vowel	strongly cut syllable accent No descrescendo
Jespersen 1913 Trubetzkoy 1939	Consonantal contact	loose contact vowel reaches its target	close contact vowel is cut off by the following consonant
Forchhammer 1939	Coordination of consonants at the syllable edge	double beat (delayed) articulation	single beat (bouncing) articulation

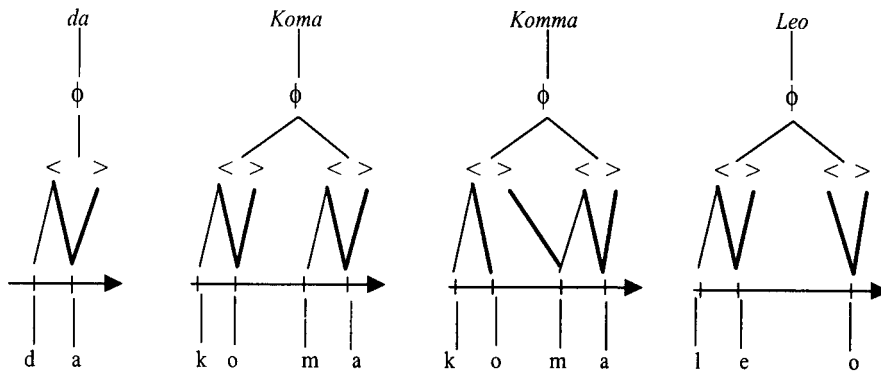
In the sixties some acoustical studies were carried out to confirm the intuition of Eduard Sievers, but as Eli Fischer-Jorgensen and Jorgensen pointed out in 1969 all possible correlates like the steepness of the decrease in volume can be attributed to the difference in vowel duration.

Theo Vennemann, who renewed the discussion in 1989, summarized the phonetic concomittants of the syllable cut prosody as following:

<i>smoothly cut syllables</i>		<i>abruptly cut syllables</i>	
vowel	peripheral	vowel	centralized
	tense		lax
	long under accent		short
	diphthongal under		monophthongal
	accent in certain dialects		

For the representation of the syllable cut he used the framework of autosegmental phonology. Here are some examples. The crescendo is represented with the sign for smaller (<) and the decrescendo with the sign for greater (>). For smoothly cut syllables the decrescendo is associated with the nucleus whereas for abruptly cut syllables it is associated with the post vocalic consonant.





The main advantages over the segmentally-based phonological approaches are:

- Integration of the features quantity and quality in one prosodic feature.
- Reduction of the German vowel inventory, that is instead of 15 vowels only eight are underlying.

gespannt	i	y	e	ɛ:	ø	ɑ	o	u
ungespannt	ɪ	ʏ	ɛ		œ	a	ɔ	ʊ

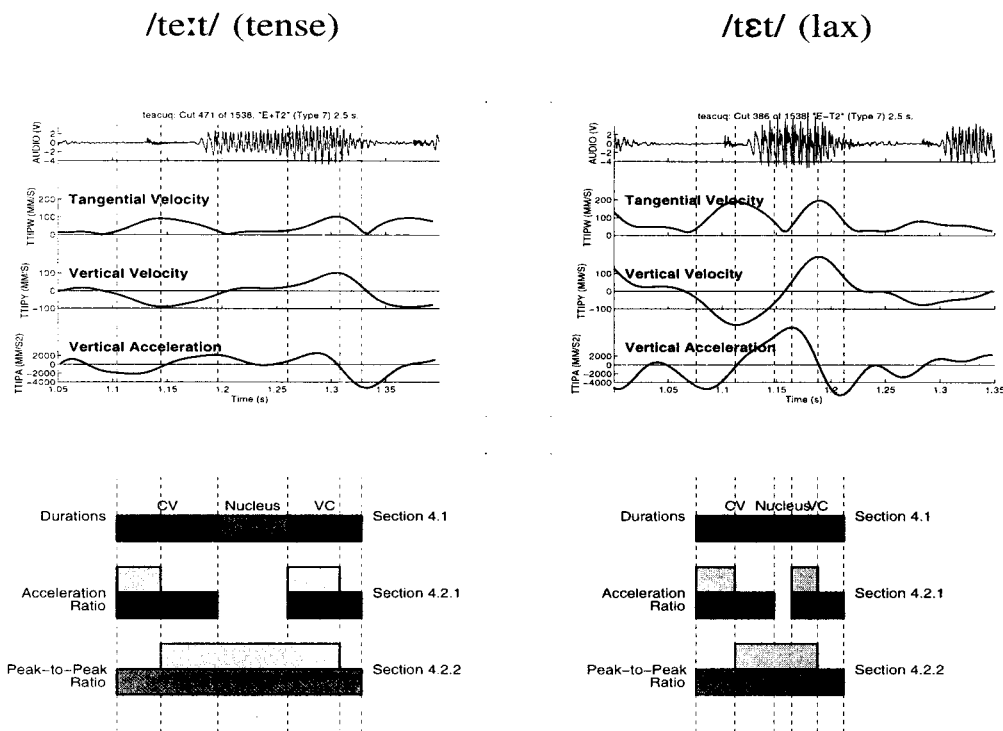
Silbenschnitt	i	ü	e	ä	ö	a	o	u
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- The distributional asymmetries follow simply from the type of syllable cut, that is the constraint that lax vowels don't occur in open syllables follows from the close consonantal contact.

As I mentioned before possible acoustical correlates of the syllable cut can always be attributed to vowel duration. But some newer articulatory studies by Phil Hoole, myself and Hans Tillmann in 1994 and Christian Kroos and colleagues in 1996 yielded a difference in the coordination of opening and closing movements independent of speech rate. They recorded tongue, lower lip and jaw movements of seven speakers by means of Electromagnetic articulography in normal and fast speaking rate. The target words were logatoms and consisted of CVC sequences with the 15 vowels of German and a symmetrical consonant context with p, t, k embedded in Schwa syllables, for example *gepaape*, *gepappe*, *getette*, *geteete* and so on.

Articulatory analysis was based on the sensor closest to the consonant

articulator. The procedure is shown in the following figure. The upper panel shows the speech signal of the sequence *teet* on the left and *tett* on the right. The next panels show the tangential velocity of the tongue tip sensor, the vertical velocity and the vertical acceleration signal. The CVC sequence is segmented according to a 20% threshold criterion of the tangential velocity peaks, that is onset and offset of the opening and closing movement start at 20% of corresponding velocity peak. The segment between the offset of the opening movement and the onset of the closing movement is called the nucleus segment.



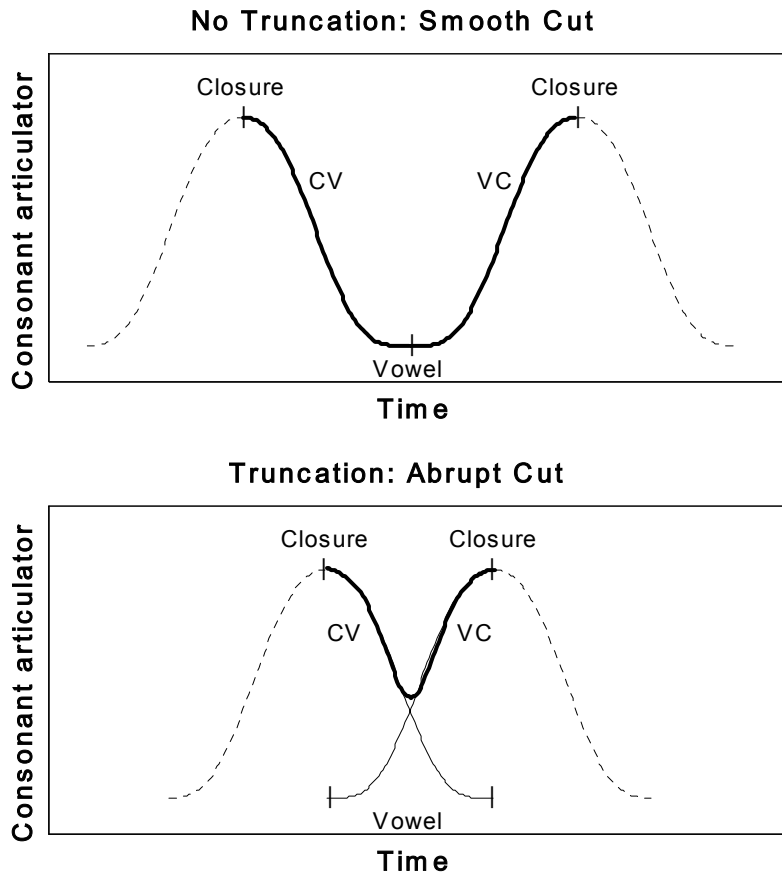
**Fig. 2:** Examples of tongue-blade velocity signals for tense vowel /e:/ in /t\_e\_t/ context (left) and corresponding lax vowel /ɛ/ (right). Below each set of velocity signals is a time-aligned schematic illustration of the kinematically-defined durational parameters used for analysis of the CV and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

Going from normal to fast speech rate 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.

Their hypothesis was that the opening movement is truncated by the closing movement when the nucleus is lax. This can be seen on the

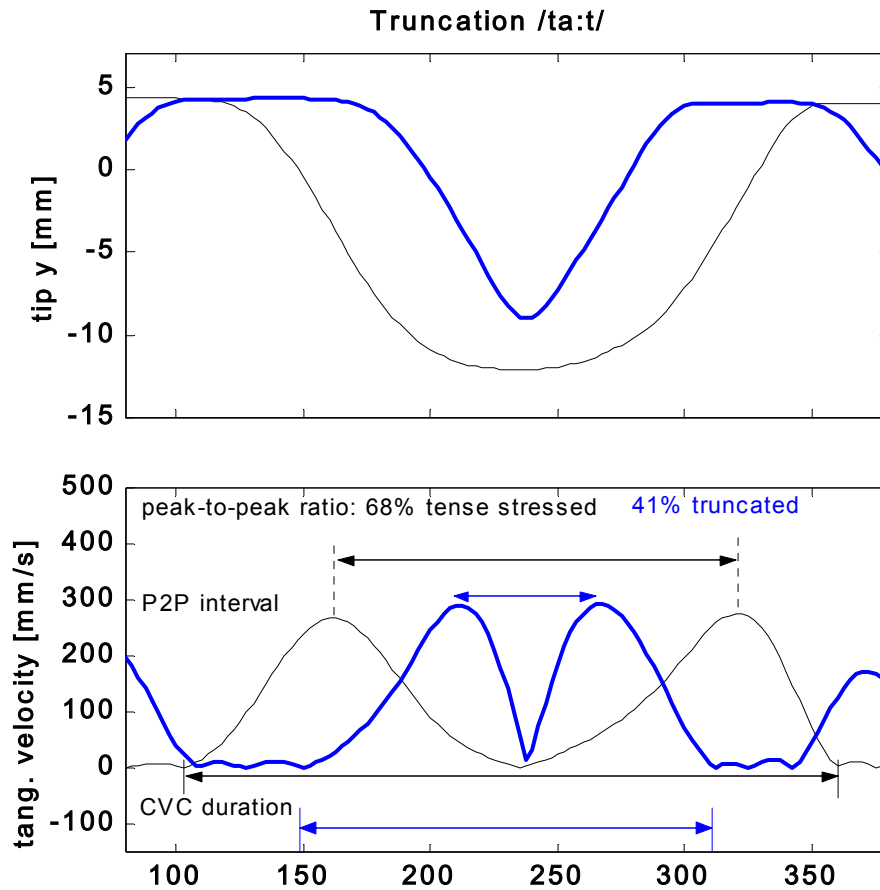
next slide. Both panels show schematic sequences of opening and closing movements of the consonantal articulator.

In the upper panel the opening and the closing gesture are adjacent, there is no overlap. The lower panel shows the truncation of the opening gesture by the closing gesture. This sequence is shorter and the movement amplitudes are smaller.

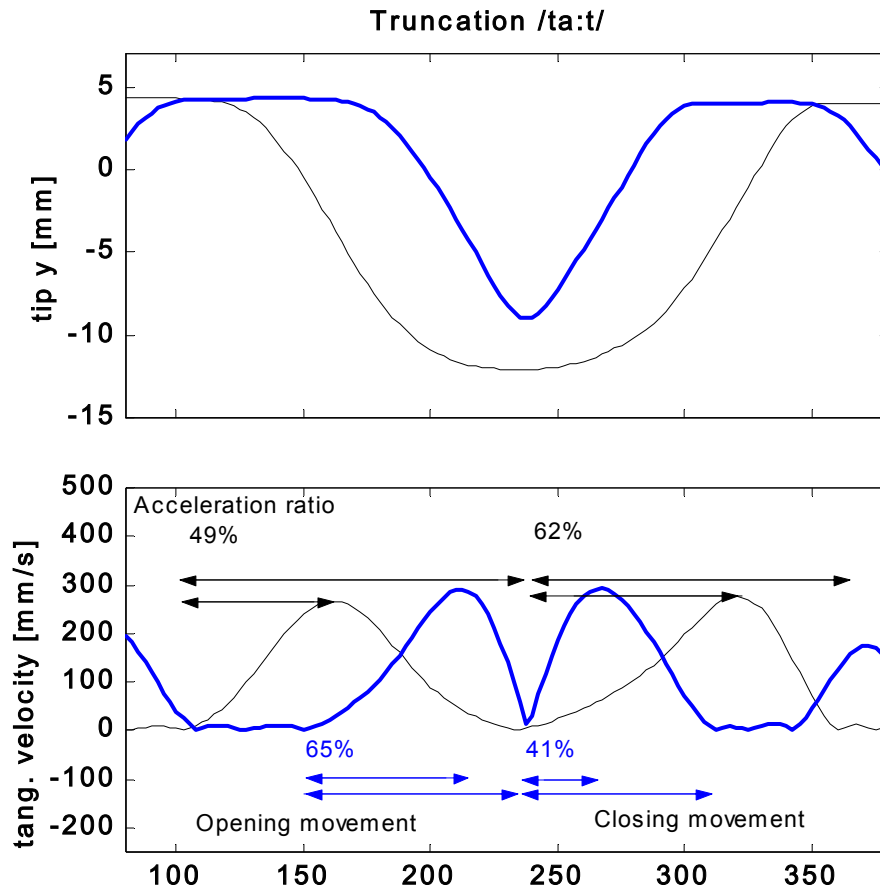


As was found by Jonathan Harrington and colleagues in 1995 there are several more kinematic parameters, which change due to truncation. I'll explain them by a simulation, that is I took the tongue tip signal of a tense stressed item, the black curve, and truncated it in 40 steps of 2.5 ms. The outcome is the curve printed in blue.

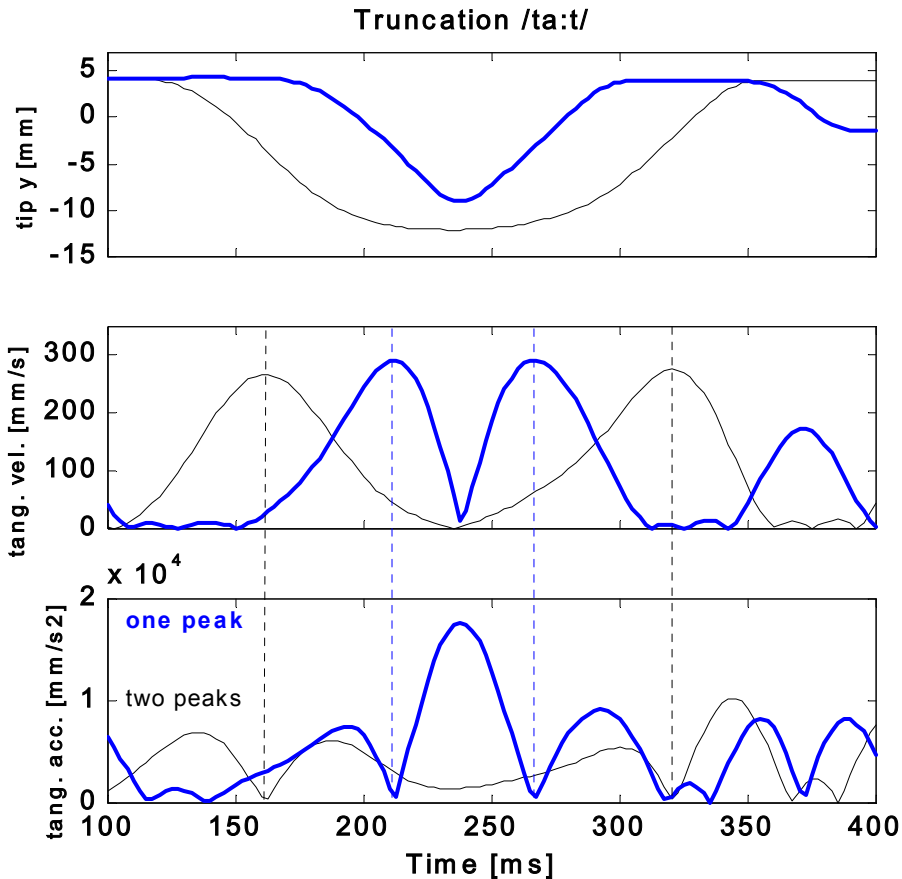
The first parameter is the ratio of the interval between velocity peaks to total movement duration (short peak-to-peak ratio).



The lower panel shows the tangential velocity signals. Below the signals the movement cycle durations are shown, above you see the peak-to-peak intervals. The peak-to-peak ratio is simply the ratio between these two durations in percent. It decreases proportional with degree of truncation.



The second temporal parameter for truncation is the skewness of the velocity profiles. This is measured as the ratio of the acceleration phase to movement duration in percent. The acceleration phase corresponds to the interval from movement onset to time of peak velocity. This value is divided by the duration of the opening or closing movement. A truncated opening gesture shows a later velocity peak, that is the velocity profile is skewed to the right with a value over 50%, whereas a truncated closing gesture is skewed to the left and has a value under 50%.



Truncation also influences the number of acceleration peaks between velocity peaks, that is for untruncated movement cycles there is at least one deceleration peak for the opening movement and one acceleration peak for the closing movement. For truncated movements deceleration of the opening movement and acceleration of the closing movement merge into a single peak.

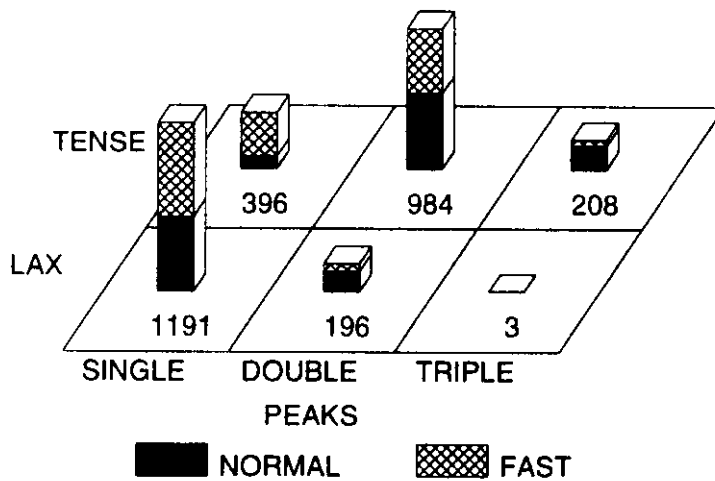
It was assumed by Jonathan Harrington and colleagues that there is no substantial change in peak velocities, but a small reduction of movement amplitudes for truncated syllables.

In their study they showed that jaw movements of unstressed /bæb/ sequences can be generated by truncation of stressed /bæb/ sequences.

Christian Kroos and colleagues measured the same kinematic parameters for the production of the tenseness distinction. The following table shows their results for the peak-to-peak ratio. For lax vowels this parameter is considerably reduced.

Ratios in %		P2P	sd	ACV	sd	AVC	sd
tense	normal	63.7	7.52				
	fast	58.3	8.23	47.6	11.10	53.6	8.68
lax	normal	49.5	6.61				
	fast	49.4	6.78	56.3	9.72	44.8	6.65

The acceleration phases of the opening movement were longer for lax vowels than for tense vowels, that is the velocity peak of the opening gesture occurred later relative to the opening duration for lax vowels. The pattern is reversed for the closing movement.



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

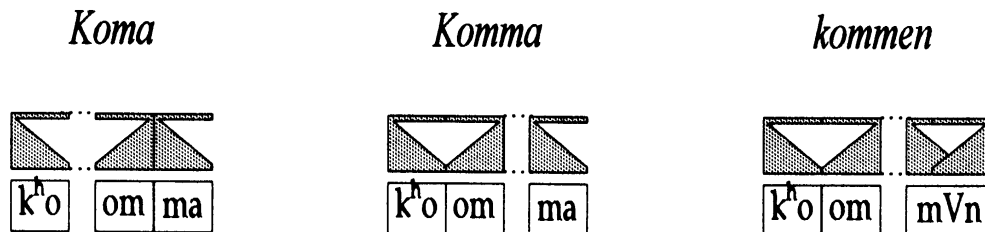
The number of acceleration peaks depends crucially on the category of the nucleus, that is sequences with lax vowels are usually produced with one acceleration peak between the velocity peaks.

Kroos and colleagues concluded:

The observable kinematic differences between tense and lax vowels can be explained by tighter CV-VC coupling for lax vowels.

This difference in innervocalic coupling of opening and closing movement which is **in**dependent of vowel duration suggests a prosodic base of the tenseness distinction in German.

David Restle took these results as starting point for his phonological theory of syllable oscillation. The basic elements are not phonemes but opening and closing phases, which are concatenated. A sequence of an opening and a closing phase is called oscillation syllable.



A loose innervocalic coupling is represented in the following way: The closing phase is not coupled with the opening phase, shown as dotted lines between the segments. This should represent the higher durational variability of tense vowel, for example lengthening due to stress or shortening due to increase in speech rate.

For tight vocalic coupling the opening and closing phase are timed with respect to each other. Therefore there is only little temporal variability for this coupling type.

As can be seen in the examples David Restle assumes, that there is a difference in coupling type for the consonantal area too. After a tight vocalic coupling a loose coupling of the closing and opening phase occurs and the other way around after loose vocalic coupling. We tested this hypothesis in a production experiment but the differences were very inconsistent for Standard German.

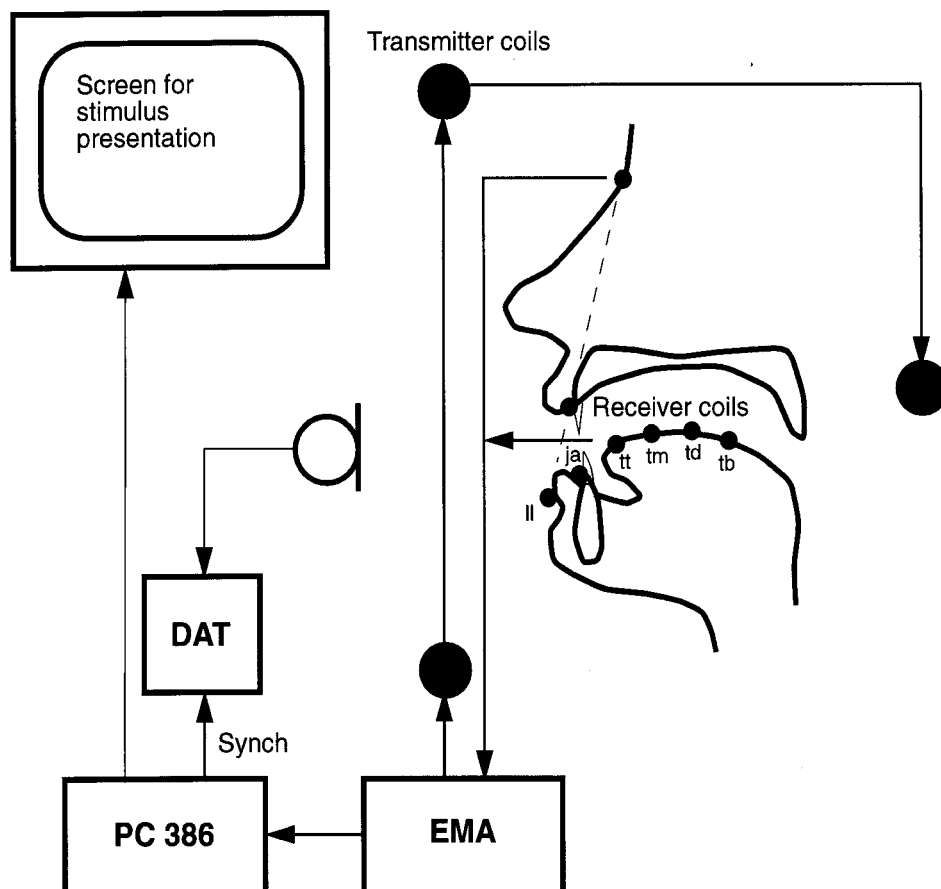


## IV Production Experiments

In the production experiment, I'm going to present here, my colleague Susanne Fuchs and I varied stress instead of speech rate. Since both, tenseness and accent are characterized by a change in intergestural timing, we were interested in a comparison of the nature and extent of these mechanisms.

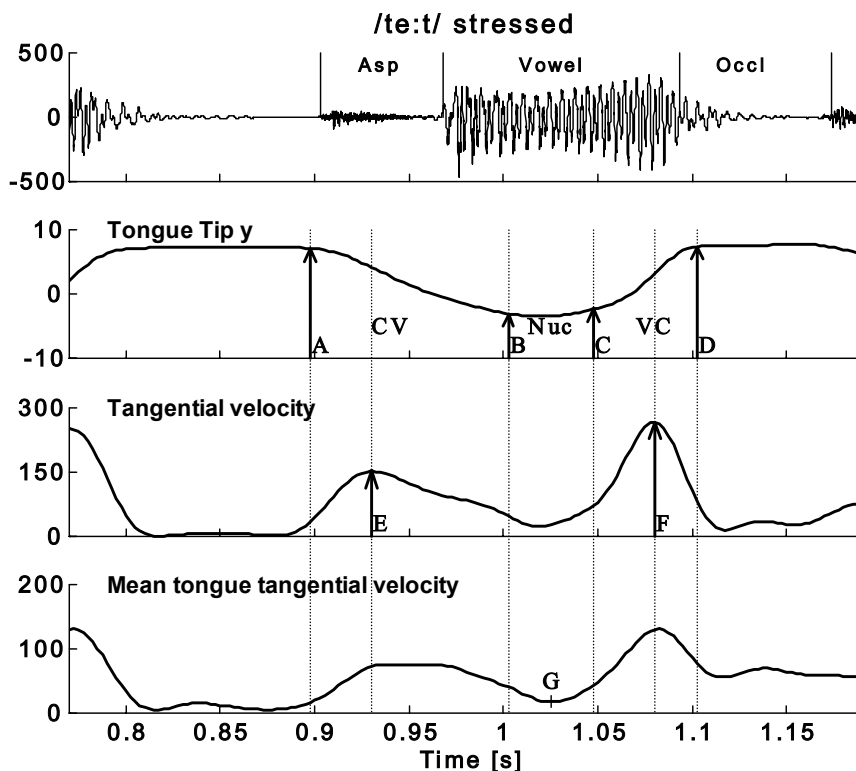
For the first experiment we recorded four native speakers of German by means of Electromagnetic Articulography. The speech material consisted of words containing /tVt/ syllables with tense and lax nuclei in stressed and unstressed position. Stress alternations were fixed by morphologically conditioned word stress and contrastive stress. Thus the first test syllable in the sentence "Ich habe /'tVtə/, nicht /tV'ta:l/ gesagt" was always stressed and the second unstressed. All sentences were repeated six to ten times.

### Experimental setup



Tongue, lower lip and jaw movements were monitored by the magnetometer AG100. Four sensors were attached to the midsagittal plane of the tongue, one to the lower lip and one to the lower incisors. Two sensors on the nasion and the upper incisors served as reference coils to compensate for helmet movements during the recording sessions. Simultaneously, the speech signal was recorded by a DAT recorder.

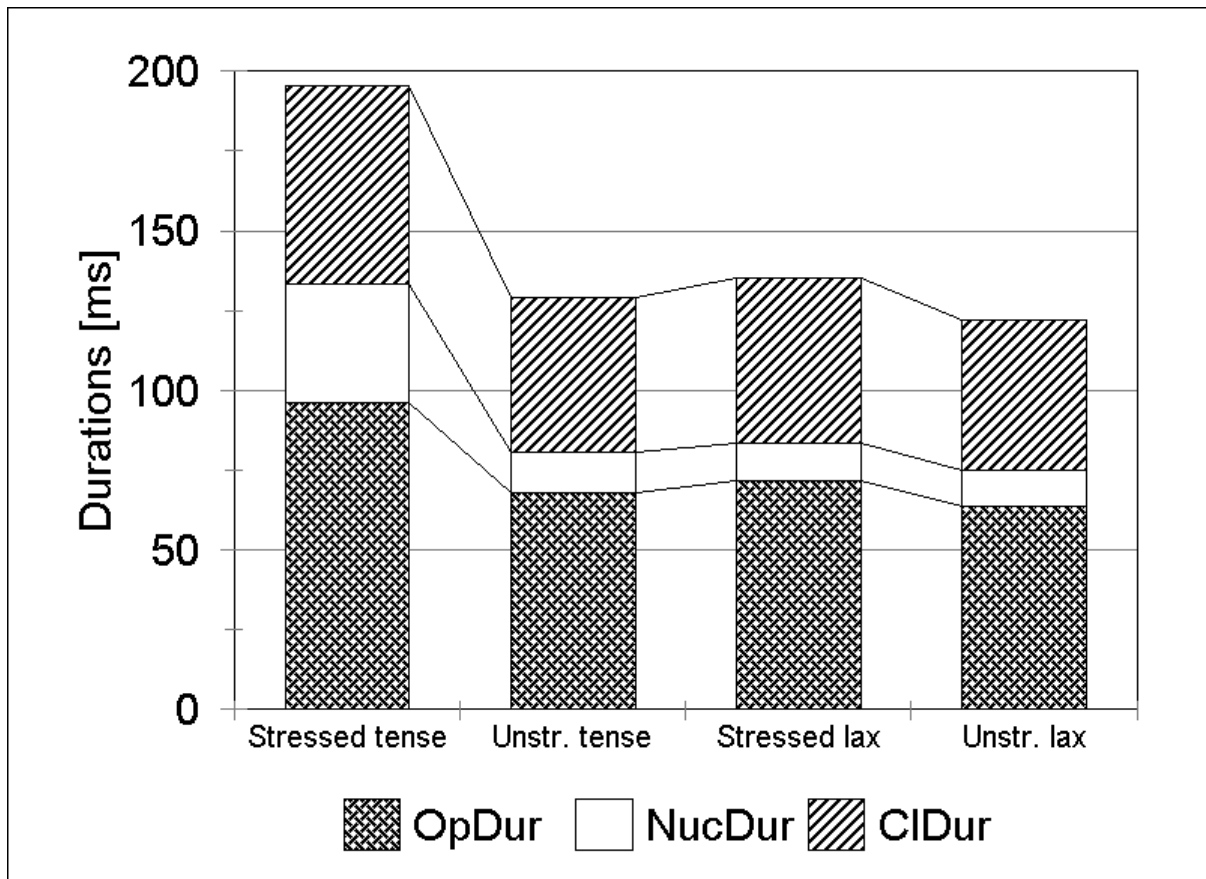
The analyses procedure we used, is analogue to the one used by Christian Kroos and colleagues as explained before.



Target word /te:tə/. 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.

First I'll present the durational parameters.

As for speech rate there is a very prominent compression of the nucleus duration due to deaccentuation and laxness but deaccentuation affects the nucleus durations to a greater extent than increase in speech rate, that is there is no significant difference between tense unstressed, lax stressed and lax unstressed nucleus durations.



According to Jonathan Harrington and colleagues the ratio of the interval between velocity peaks to total movement duration is reduced for truncated articulatory gestures. As can be seen in the following table there is a considerable reduction of this parameter. Again the influence of deaccentuation is stronger than the influence of an increase in speech rate.

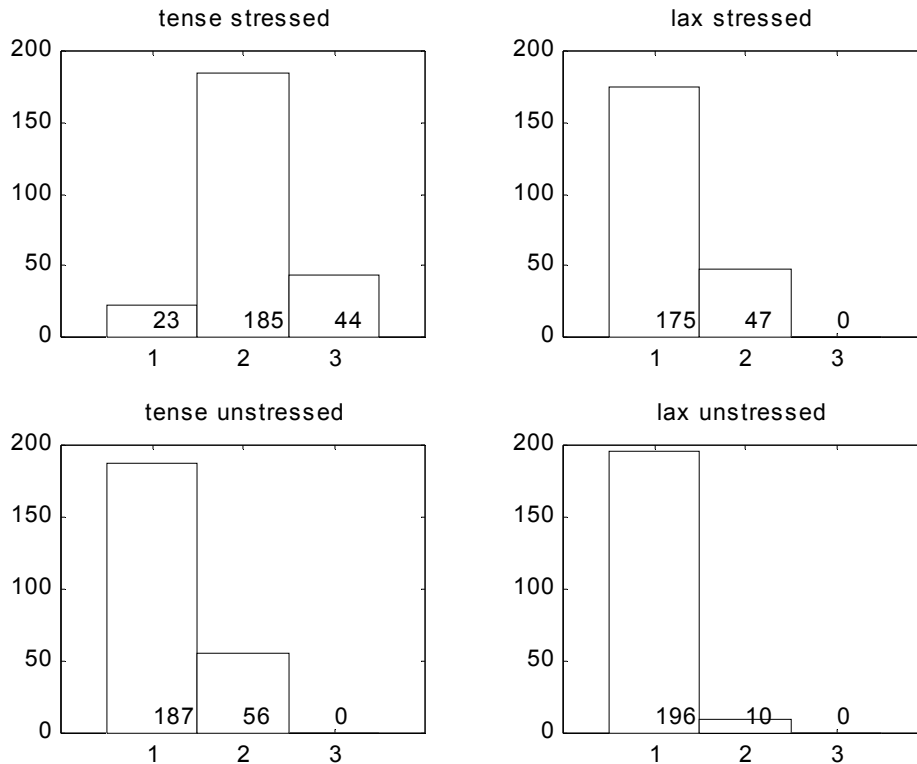
The other temporal parameter for truncation is the acceleration phase ratio. As can be seen in the table the value of the acceleration phase of the opening gesture, abbreviated with ACV, increases going from tense stressed to lax unstressed. AVC, that is the acceleration phase of the closing gesture, is decreasing as predicted.

Ratios in %		N	P2P	sd	ACV	sd	AVC	sd
tense	stressed	252	61.5	5.99	49.1	7.93	55.7	5.47
	unstressed	243	51.9	5.34	54.0	7.68	47.7	3.78
lax	stressed	222	50.4	5.44	56.4	7.21	48.5	3.93
	unstressed	206	48.8	4.75	58.1	6.96	46.2	3.78

Truncation also influences the number of acceleration peaks between velocity peaks. As can be seen from the following figure the majority

of tense stressed items have two or more peaks while tense unstressed, lax stressed and lax unstressed sequences tend to have only one acceleration peak.

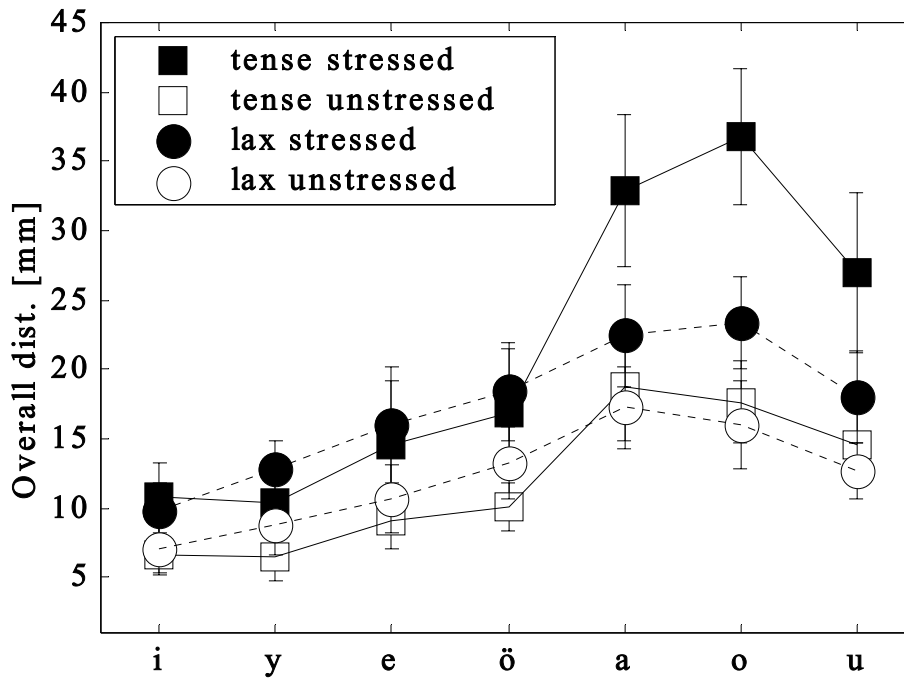
### Number of acceleration peaks



Taken together all temporal parameters and the number of acceleration peaks give strong evidence for a truncation of the opening gesture by the closing gesture going from tense to lax and from stressed to unstressed. Contrary to speech rate increase, deaccentuation is also produced by truncation. Lax vowels are further truncated by deaccentuation.

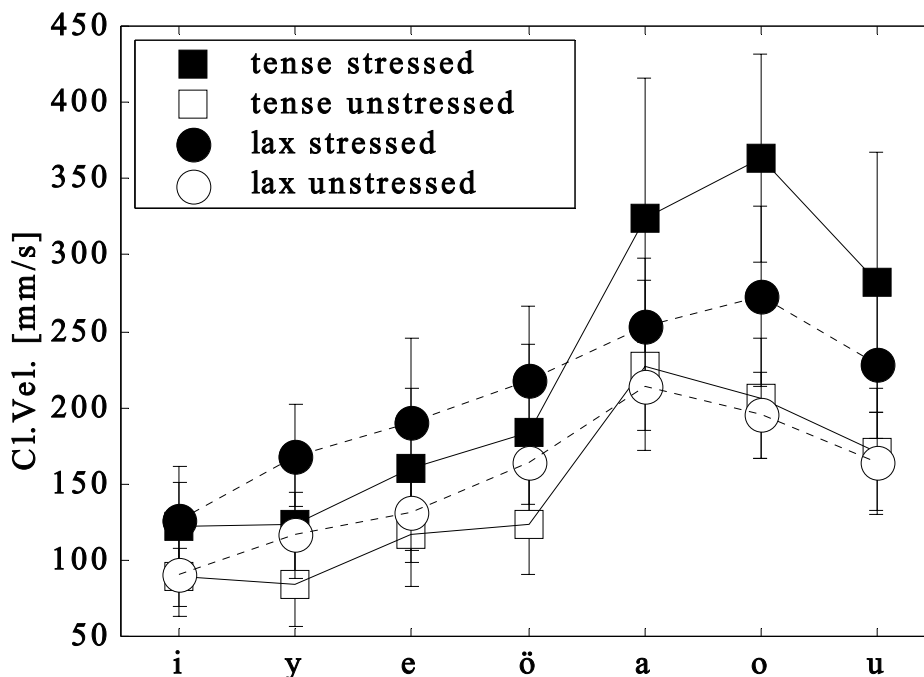
As Jonathan Harrington predicts, truncation involves a small reduction of movement amplitudes but no substantial changes of velocity peaks.

Movement amplitudes here were computed as the integral of the tangential velocity between movement onset of the opening gesture and offset of the closing gesture. This figure shows the overall distances for all vowels averaged over speakers.



As can be seen there is a considerable reduction going from stressed items - shown as filled squares and circles - to unstressed items that is the empty symbols. Therefore tongue tip movements of unaccented syllables could be generated by truncating the opening gesture by the closing gesture.

For the tenseness distinction this is only true for central and back vowels. Front lax vowels have a somewhat higher distance than tense vowels which is contrary to the prediction.



The peak velocities of the closing movement show a similar pattern.

Deaccentuation can be attributed to truncation but not laxness, at least not for the front vowels. But contrary to the prediction of Jonathan Harrington there are substantial changes in peak velocities which are probably due to the strong positive correlation between movement amplitude and peak velocity.

Summarising the results so far the purely temporal and the other kinematic parameters speak for a difference in gestural overlap for the stressed unstressed contrast. Laxness cannot be attributed to truncation since at least the movement amplitudes of the tongue tip for front lax vowels cannot be generated by truncating the opening movements of tense vowels.

## **V Conclusions**

There are different possible explanations for this result:

The first one is that truncation can only be measured at the jaw movements as was done for stress by Harrington and colleagues. Therefore the next thing we are going to do is analyse jaw movement amplitudes.

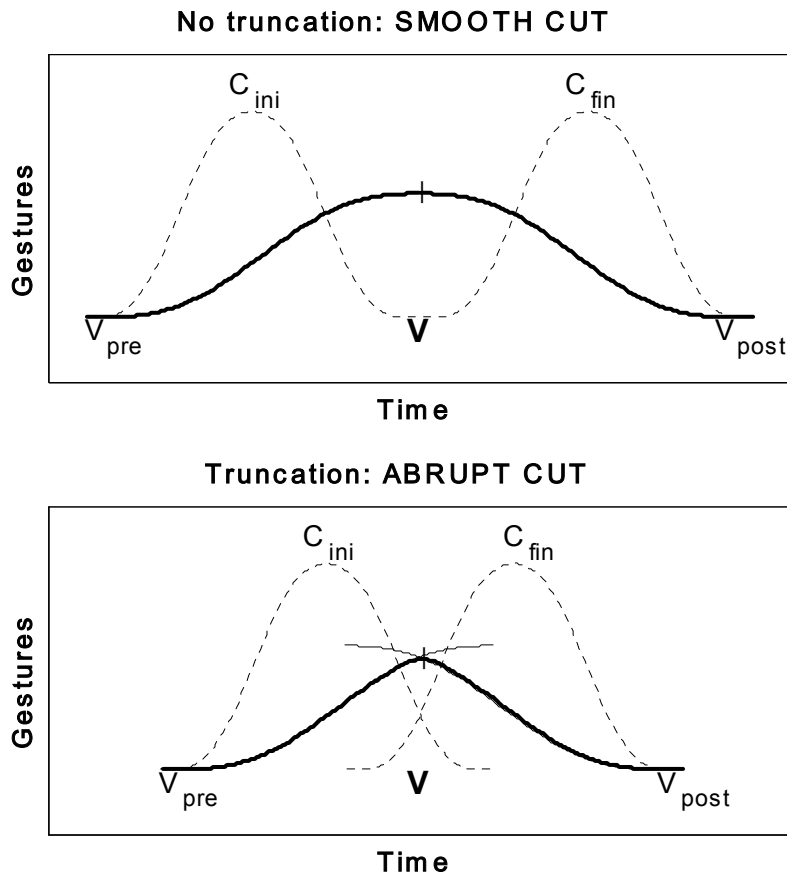
The second possibility is that targets of tense and lax vowels are specified with different values. As a consequence the assumption that the articulatory correlate of the syllable cut prosody is a difference in temporal organization must then be rejected.

The third explanation is that not the opening and the closing gestures differ in their temporal timing but the vowel gesture. This needs some more detailed description.

Based on Sven Öhman, Carol Fowler suggested in 1980 that vowels and consonants are produced autonomously. Vowels are articulated in the background as continuous quasi diphthongal vowel cycles. The production of consonants is supposed to be discrete and superimposed on the underlying vowel cycle. Therefore during the consonant phases vowels and consonants are co-produced.

In this last section I'm going to model the phonetic correlates of the syllable cut prosody in the framework of Articulatory Phonology.

The minimal sequence to model the intergestural timing of the syllable cut consists of a pre-consonantal vowel, an initial consonant, the vowel to be modelled, a final consonant and a post-consonantal vowel. The first and the last vowels are supposed to be the reduction vowels schwa.



For the smooth cut the vowel gestures don't overlap whereas for abrupt cut the first vowel gesture is truncated by the second.

Therefore the vowel target of the abruptly cut syllable is more centralized meaning it is closer to the neutral vowel schwa and not closer to the consonantal constriction location as for the truncation of the opening gesture. The whole sequence is shortened and the consonant gestures overlap which fits quite well to the assumptions of Forchhammer.

Unfortunately this model cannot be evaluated by real data. The problem is that measured articulatory data are concatenated opening and closing gestures. Even for a consonant context produced with the tongue tip, the tongue body movements are passively influenced during the consonant production. Therefore the underlying vowel cycle cannot be measured or extracted by different methods.

Thus I conclude that we still don't know the answer to the question posed in the title of this talk.