Gestural Phasing as an Explanation for Vowel Devoicing in Turkish*

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Abstract: Recent work in phonetics has suggested that vowel devoicing or schwa deletion, observed in various languages, is a gradient process. This study provides evidence for the previously undocumented process of high vowel devoicing in Turkish. The prosodic and segmental factors *rate, stress, preceding environment, following enviornment, vowel type, and syllable type* were investigated. The factors are described, evaluated and ranked according to the results of a multiple regression (Variable Rule) analysis. Where applicable, results are contrasted with findings for i.e., Japanese and Korean. Furthermore, VOT (voice onset time) measurements of the three voiceless stops [p t k] were obtained, as well as duration measurements of vowels in open and closed syllables where vowels are significantly longer in Turkish. Generally, most devoicing occurred when the vowel was shorter (i.e., as a result of faster rates of speech, lack of stress, in closed syllables, ect.). These findings accord well with predictions made by a model assuming gradual gestural overlap of adjacent consonantal and vocalic gestures. It will be attempted to explain the findings with differences in phasing between articulatory gestures.

I. Introduction

In Turkish a syllable containing any of the four high vowels [i y ɨ u] can be realized without any audible traces of voicing. The phenomenon is demonstrated in Figure 1, which shows a contrasts between two words produced by the same speaker, one containing a fully realized vowel, the other containing a fully devoiced vowel. As becomes clear from these spectrograms, the endpoint of a continuum of vowel devoicing can be interpreted as vowel deletion. On the left we see a spectrogram and waveform of the word *tüfek* 'gun, rifle' spoken in a slow rate of speech. The vertical striations at the bottom of the spectrogram are the individual glottal pulses, showing that this first vowel is voiced. The presence of the vowel is also reflected in the waveform. The spectrogram on the right shows the same word produced in a normal rate of speech. Here, the vowel has completely disappeared, there are no voicing traces left so that this vowel is analyzed as completely devoiced. This phenomenon is previously undocumented for Turkish, but resembles a process noted for several other languages, including Svabian (Griffen, 1983), Canadian French (Cedergren & Simeneau, 1985; Cedergren, 1986), Korean (Jun & Beckman, 1993, 1994) and Japanese (McCawley, 1968; Jun & Beckman, 1993, 1994).

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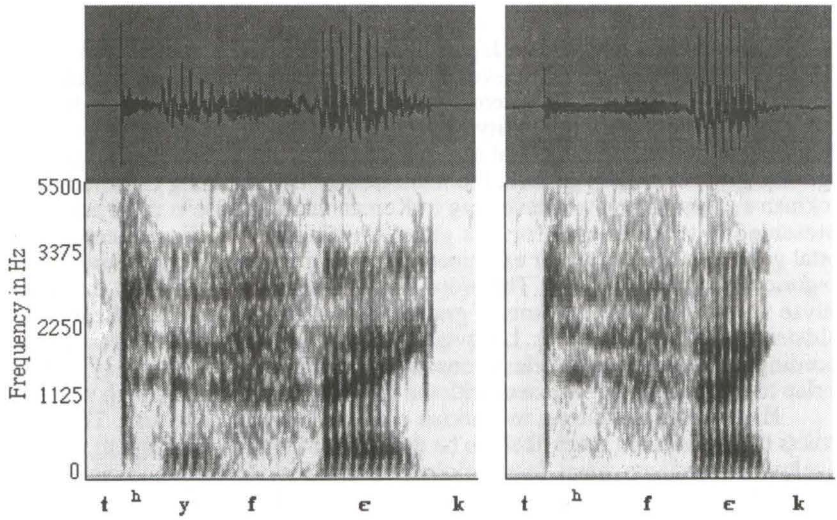


Figure 1: Spectrograms and waveforms of completely voiced and completely devoiced /y/ in [tyfek] 'gun, rifle'

Vowel devoicing has been discussed most thoroughly for Japanese, where it has traditionally been described in terms of a categorical feature changing rule. McCawley (1968:127), for example gives the following SPE-type rule by which the high vowels /i/ and /u/ in Japanese become devoiced between voiceless consonants or wordfinally after voiceless consonants:

(1)
$$\begin{bmatrix} \text{-cns} \\ \text{+voc} \\ \text{+dif} \end{bmatrix} \longrightarrow \text{[-voi] in env.} \begin{bmatrix} \text{[-voi]} \,\_\_\_\, \text{[-voi]} \\ \_\_\_\, \# \end{bmatrix}$$

However, there are reasons to suspect that such categorical phonological rules are inadequate to describe vowel devoicing in Japanese and other languages also previously studied for the phenomenon. Beckman & Shoji (1984) showed that in Japanese the initial syllable in the minimal pair /ʃikaN/ and /ʃyukaN/ is not completely neutralized in production. Rather, the fricative spectrum of the preceding "esh" [ʃ__] retains information about the vowel's quality to various degrees so that due to coarticulation, a contrast is preserved. In cases where no coarticulatory information is preserved in the consonant-vowel transitions, the end of the continuum of vowel devoicing can be interpreted as vowel deletion. The gradient nature of this effect is shown in production and confirmed by results of a perception experiment where listeners' identification responses show a high correlation with the amount of vocalic coloring of the fricative.

Jun & Beckman (1993) studied the behavior of the three high vowels [i ɨ u] of Korean, occurring as the first vowel in CVCV syllables with combinations of voiceless aspirated, lenis and fortis stops preceding and following the initial high vowel in the first open syllable. Duration measurement of the preceding aspirated and lenis stop consonants plotted against the duration of the vowel show that vowels preceded by aspirated consonants are generally shorter than vowels preceded by lenis stops. The authors also provide data that shows that the amount of completely and partially devoiced vowels was highest when it was preceded by aspirated, then lenis, then fortis stops, in ascending order of glottal openness of the three Korean stop types.

These previous studies on Japanese and Korean have shown that the change in specification from [+voice] to [-voice] is not categorical but rather gradual, there are intermediate stages found where a partially voiced vowel has only a few very weak glottal pulses. The probability of devoicing a vowel is, among other factors, dependent on the size of the glottal opening gesture of neighboring consonants, the larger the glottal opening gesture, the more frequently devoicing occurred. Jun & Beckman suggest that vowel devoicing in Korean and Japanese is more adequately represented in terms of more or less glottal overlap of the adjacent consonantal glottal gestures and thus, better explained in terms of gestural hiding rather than by categorical phonological rules. Therefore, Jun & Beckman (1993, 1994) propose to analyze vowel devoicing in terms of gradual glottal gestural overlap (Browman & Goldstein, 1990; Munhall & Löfqvist, 1992) where the glottal gestures for preceding and following voiceless consonants are phased in such a way that they overlap to a greater or lesser extent with the voicing gestures for the high vowels.

High vowel devoicing in Turkish can be explained similarly. The model predicts that vowels are more likely to be devoiced if they are short and the adjacent voiceless consonants have large glottal opening gestures. High vowels are particularly prone to be devoiced because the their intrinsically shorter duration. This study examines vowel devoicing in word initial and word medial position in Turkish and provides evidence for this previously undocumented process. The prosodic and segmental factors *rate, stress, preceding environment, following environment, vowel-* and *syllable type* are considered in the current study. The factors are described, evaluated, and ranked according to the results of a multiple regression (VARBRUL) analysis. Where applicable, results are contrasted with findings for other languages such as Montreal French, Korean or Japanese. Furthermore, VOT (voice onset time) measurements of the three voiceless stops [p t k] were obtained, as well as duration measurements of non-high vowels in open and closed syllables before geminates as well as heterorganic consonant clusters and single consonants.

I.2 Motivation for Duration Experiments in Turkish

Since not many instrumental phonetic studies of Turkish have been performed, there is a lack of basic knowledge of durational facts relevant to devoicing in Turkish. The Korean data suggests that the stronger the glottal gesture the more devoicing is triggered. Thus, basic durational facts such as the duration of the accompanying aspiration of voiceless stop consonants need to be established for Turkish so that the impact of stops can be evaluated and predicted better. For example, Turkish contrasts voiced and voiceless stops (Kornfilt, 1986, 1987; Lees, 1961; Underhill, 1986) and thus, a potentially important factor is the duration of VOT (voice onset time) which is a measure of the lag or delay of voicing onset of the following voiced segment. In order to explain patterns of devoicing as a function of the preceding environment, we need to know more about the duration of aspiration accompanying the release of voiceless stops. The larger and longer the glottal opening gesture is, the greater is the potential for the consonantal glottal gesture to extend into the vowel's glottal gesture and delay or prevent it's onset of voicing. Thus, in experiment one, the duration of VOT of word initial voiceless stops [p t k] before non-high vowels (appendix A) was measured to establish voice onset time measures for Turkish in a fairly independent and unaffected context to vowel devoicing.

Secondly, durational information about vowels in closed and open syllables needs to be obtained. Generally, the assumption holds that the shorter the vowel, the greater the probability for the vowel to become devoiced. Maddieson (1985) summarized previous research on a variety of languages that have shorter vowels in closed versus open syllables, among these languages are English, Russian, Finnish, Korean, Chinese, and Thai. Maddieson (1985) also cites studies which established vowel duration to be shorter before geminate consonants (closed syllables) compared to singletons (open syllables), among these languages are Hausa, Italian, Norwegian, Finnish, Arabic, Bengali, Kannada and Amharic. These studies suggest that crosslinguistically, vowels are shorter in closed compared to open syllables. Lahiri and Hankamer (1988) measured vowel duration in Bengali and Turkish before geminates and single consonants and found an overall marginally significant effect for vowels to be shorter in closed syllables before geminates in Bengali, but did not find a significant effect for Turkish. In fact, in Turkish, mean duration of vowels was contrary to the predictions, slightly longer in closed syllables. Thus, according to their results, Turkish seems to be somewhat unusual in that vowel duration in open and closed syllables does not significantly differ but shows a small difference in the opposite direction. Han (1994) however reports vowels to be significantly longer (11% ~ 11ms) before geminate stop consonants in Japanese when running a 'simple binomial probability test ($p < 0.001$)', but not when doing a 'one-tailed difference t test ($t(9)=.054$, $p>0.05$)'. Maddieson (1985) refutes Japanese to be an apparent counterexample to what he calls *closed syllable vowel shortening*. He argues that in Japanese which is assumed to be organized temporally on the bases of the mora (Bloch, 1950; Han, 1994) the first part of the geminate does not close the preceding syllable but constitutes a mora by itself, leaving the preceding vowel in an open syllable.

A significant effect for vowel duration differences for open versus closed syllables with longer vowels in closed syllables in a language without a moraic temporal organization could show that vowel duration in closed syllables is either language specific (and thus, not a universal feature of language) or possibly an effect of the following consonantal environment. Three conceivable options to test are: vowels are generally longer before a) single consonants (CV.C) in open syllables versus b) geminates, one consonant belonging to the coda of the first syllable and the second consonant belonging to the onset of the second syllable ($CVC_i.C_i$) versus c) non-geminate heterorganic consonant clusters ($CVC_i.C_j$). In experiment two, duration of non-high vowels in open and closed syllables in disyllabic words (appendix A) was measured. Non-high vowels were chosen since they are more resistant (due to their intrinsically longer duration) of the dependent test variable (vowel devoicing). The corpus contained 'minimal pairs' that contrasted between a singleton (VC_1) and a consonant cluster containing that singleton immediately following the vowel ($VC_1.C_2$) in question. If longer vowel durations in closed syllables before heterorganic consonant clusters will be found then an explanation assuming vowel elongation only before geminates must be rejected and longer vowel durations in closed syllables are just another language specific factor a language chooses. As a control, words contrasting in having single consonants (and thus open syllables) CV•C and geminates $CVC_i{\cdot}C_i$ (closed syllables) used by Lahiri and Hankamer (1988) (see appendix B) were also recorded and vowel duration was measured.

In a third experiment, words with high vowels occurring in various prosodic and segmental contexts were elicited in three different speech rates. Based on categorization criteria similar to those used in Jun & Beckman (1994), the experimenter judged whether the vowel of interest was voiced, voiceless or partially voiced. The judgments were considered in a variable rule (VARBRUL) statistical analysis and conditioning factors were ranked according to the magnitude of their contribution to the process of devoicing.

Jun & Beckman (1993, 1994) suggest to interpret vowel devoicing in Japanese and Korean in terms of a gradual gestural overlap model (Browman & Goldstein, 1990) where the laryngeal gestures of the adjacent consonants to the left and right of the vowel overlap with the high vowel's glottal gesture.This suggestion will be taken up again and applied to the Turkish data. Generally, the gestural overlap model predicts that factors shortening the duration of vowels (i.e., a faster overall rate of speech) should increase the probability for vowel devoicing and factors that lengthen syllable duration (i.e., stress) should decrease the likelihood of devoicing.

II. Methods

1. The Duration Experiments

Two sets of data were used for the duration measurements: one set of 18 'minimal-' and 'near-' pairs (36 words) previously used by Lahiri and Hankamer (1988), contrasting intervocalic single consonants and geminates, displayed in appendix B, and a second set of 28 (56 words) 'minimal' and 'near-minimal' pairs selected for this study, displayed in appendix A.

Lahiri and Hankamer (1988) elicited these 18 pairs of words (illustrating the difference between single consonants and geminates), in citation in a normal rate of speech. They measured VOT of word medial singleton stops and geminates as well as vowel duration in open and closed syllables in Turkish. Mean VOT was 34 ms in closed and 45 ms in open syllables and significantly different. None of the 18 pairs of words contained a [p], thus, the mean VOT-values reported in Lahiri and Hankamer's study do not encompass all three voiceless stops of Turkish. Mean vowel duration in closed syllables (116 ms) was insignificantly longer than in open syllables (112 ms).

The 28 pairs of disyllabic words (fifteen disyllabic minimal and thirteen disyllabic near minimal pairs) selected for this study, contained non-high vowels and with a contrast in syllable type (open versus closed). The syllable type was confirmed by two native speakers. The non-high vowels [a e o] were preceded by all three types of voiceless stop consonants [p t k]. One pair contained a geminate, the rest contrasted intervocalic clusters and singletons.

Each word was presented on an index card and elicited in citation form in a normal rate of speech (three repetitions in different randomized orders) as well as in three different self selected speech rates (slow, normal, fast) absolute utterance initially in carrier phrases. All three carrier-phrases were presented on a single index card. (Although in this experiment we are only marginally interested in the effect of rate on the non-high vowel's duration or the VOT, durations for all three speech rates were measured). The words were embedded in the following carrier phrases:

1. "____" kelimesini yavaş şekilde söyle. The word "___" I say in a slow mode.
   word slow mode say

2. "____" kelimesini normal hizla söyle. The word "___" I say in a normal speed.
   word normal speed say.

3. "____" kelimesini hizli şekilde söyle. The word "___" I say in a fast mode.
   word fast mode say.

1.1 VOT (Voice Onset Time)

Five educated male native speakers of Istanbul Turkish read the words in the above described conditions. VOT for Turkish syllable initial voiceless stops [p t k] before unstressed non-high vowels in the initial syllable (appendix A) was measured from the release burst of the stop to the onset of voicing of the following vowel visible as a voice bar on the spectrogram. In the repetition of Lahiri and Hankamer's 1988 experiment (appendix B), VOT for the word medial voiceless stops [t k] was measured from waveforms from the release of the burst of the voiceless stop closure of the geminate or single consonant to the onset of voicing of the following vowel. Since Turkish words are generally stressed on the final syllable (Lees, 1961; Underhill, 1986; van der Hulst & van de Weijer, 1991), VOT in these cases was measured before stressed vowels. Figure 2 shows spectrograms and waveforms for two Turkish words, exemplifying the VOT measurement criteria.

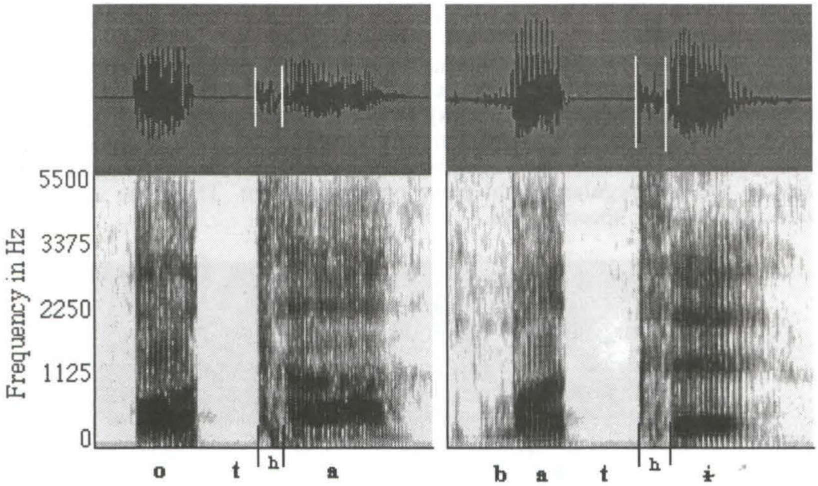


Figure 2. Spectrograms, waveforms and rms amplitude traces of the words [ota] 'grass' and [batɨ] 'west, western', demonstrating VOT measurement criteria.

For Lahiri and Hankamer's data, the total number of tokens was 180 (36 words x 5 speakers) tokens per speech rate in the phrasal condition and 540 (36 words x 5 speakers x 3 speech rates) in citation for the words where medial VOT was measured. For the words selected for this study, for the initial VOT measurements, 840 measurements were taken in the citation condition (56 words x 5 speakers x 3 speech rates) and 280 words in the phrasal condition (56 words x 5 speakers). In both corpora, several tokens had to be discarded from the study mainly because of incomplete stop closures.

1.2 Vowel-duration

The same 28 minimal and near minimal pairs (appendix A) contrasting open and closed initial syllables were used for the vowel duration measurements. Measurements were taken for the duration of the four non-high vowels [a e o] from the onset to the end of the vowel's formant structure. Measurements were made using wideband spectrograms generated on a KAY 5500-DSP real time sound spectrograph. 28 pairs of words contrasting open and closed syllable type generated 140 tokens (28 words x 5 speakers) that were elicited in the phrasal condition per rate per syllable type. In the citation condition, 420 tokens (28 words x 5 speakers x 3 rates) were elicited and analyzed.

For the replication of Lahiri & Hankamer's 1988 experiments (appendix B), the total number of tokens is 75 (15 words x 5 speakers) per speech rate in the phrasal condition and 225 (15 words x 5 speakers x 3 speech rates) in citation form. Three pairs of words were discarded from this set of data because of difficulties in applying consistent measurement criteria: for two pairs ([jata] - [jatta] 'Yacht' DAT and LOC; [jatɨ] 'Yacht ACC' and [jattɨ] 'lie down' PAST) no consistent segmentation landmarks could be found between the palatal glide and the low vowel; and the third pair because (contrary to Lahiri and Hankamer's assumptions) [saate] and [saatte] ('clock' DAT and LOC), are trisyllabic, with a syllable break in the middle of what Lahiri and Hankamer took as a long vowel. All five native speakers of Turkish analyzed the vowel sequence as having a syllable break in the middle.

To test the consistency of measurement criteria (demonstrated in figure 4 below) across measurement techniques (in this study spectrograms were used while Lahiri and Hankamer used waveforms), vowel duration measurements for a subset of five pairs of words (marked with a * in appendix B) was repeated from waveforms. The onset of the vowel was measured from the first regular glottal pulse to the last regular glottal pulse on a waveform. The same applies for measurements from spectrograms.

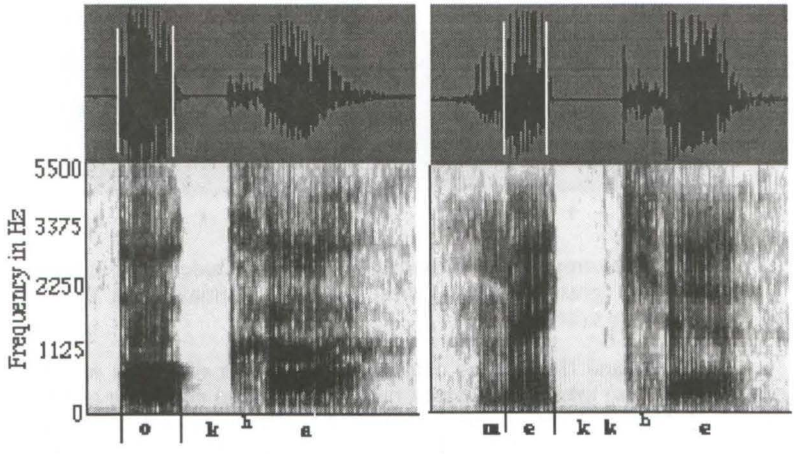


Figure 3. Spectrograms and waveforms of the words [oka] 'arrow' and [mek:e] 'Mecca', demonstrating vowel duration measurement criteria from waveforms and spectrograms.

2. Devoicing Experiment

Nine naive educated native speakers of Turkish (2 female, 7 male; 3 from Ankara and 6 from Istanbul) read 135 words positioned utterance initially positioned in carrier-phrases at three self-selected rates (slow, normal, fast). None of the words were monosyllables or contained [h] since the phonetic classification as fricative or approximant is not clear.

2.1 Devoicing Analysis

Each of the 3645 tokens (9 speakers x 135 words x 3 rates) was rated by the experimenter as containing either a voiced (clear voicebar with several glottal pulses), partially voiced (one or two faint glottal pulses) or completely devoiced vowel (no glottal pulses visible on spectrogram). Note that the dependent variable *voicing status* is continuous but by arbitrary criteria categorized into three discrete levels. The criteria for this categorization on a voicing continuum are similar to the ones used by Jun and Beckman (1994) for Korean.

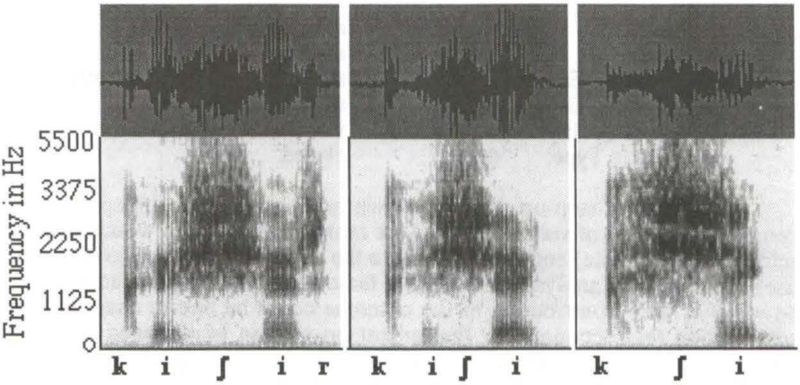


Figure 4. Spectrograms and waveforms of voiced, partially devoiced and completely devoiced vowel tokens in the word [**kiʃir**] 'crust, bark'.

2.2 Statistical Analysis

Varbrul (Variable Rule) analysis (Sankoff, 1988; Rand & Sankoff, 1990) was used to evaluate the relative importance to the distribution of devoicing of the different predictors *rate, stress, preceding-* and *following environment, vowel-* and *syllable type*. This analysis method uses step-wise multiple regressions on a logistic transform of the proportions of tokens which undergo a "rule" (in this case, vowel devoicing) for each combination of factors, with a maximum likelihood estimation criterion to accommodate imbalances (e.g., fewer token of words containing [y] than [i]; more unstressed syllables than stressed ones, etc.) of number of tokens within the various cells. In a logistic regression analysis, the sum of the factor effects does not equal the predicted percentage of a given choice but some quantity related to this percentage by the following formula:

(2) $\log\left(\frac{p}{1-p}\right)$ = "input"[1] + sum of factor effects

Because results are expressed as proportions, only binary oppositions for dependent factor groupings (i.e., *devoiced* vs. *voiced*) can be compared. Therefore,

[1]The "input" is the sum of all the averages that were subtracted from the different factor groups, also called *corrected mean*.

the factor *partially voiced* of the dependent variable was grouped with the *voiced token* and then compared to the *completely devoiced* ones. Since grouping the fully devoiced with the partially devoiced token generated exactly the same results in step-up and step-down VARBRUL analyses, the more conservative binary distinction between *voiced* (including *partially voiced*) and *completely devoiced* will be used to explain the ranking and the influence of prosodic and segmental factors on devoicing in Turkish.

Dependent Variable:

1.Voicing Status	:voiced	partially devoiced	voiceless

Independent Variables:

1. Rate:	slow	normal	fast	
2. Stress:	yes	no		
3. preceding Env.:	fricative	stop	zero-context	
4. following Env.:	ficative	stop		
5. Vowel Quality:	i	y	ɨ	u
6. Syllable Type:	open	closed		

In binomial step-up and step-down analyses, the six independent factor groups (with a total of sixteen factors) are ranked according to which independent factor group (variable) contributes most to the dependent effect (*devoicing,* in this case). In an step-up analysis, initially, all factor groups are evaluated separately to see whether their contribution to the outcome could be due to chance. After the factor group that accounts for the largest proportion of variance is found, the remaining factor groups are again evaluated for the most significant contribution that increases the likelihood of prediction maximally. This is done until no factor groups remain or until no group significantly contributes to the results anymore. The significance level of = .05 was adjusted by adding up the number of levels of applications (6+5+4+3+2+1 = 21) and dividing the original = .05 by the 21 levels of application. The calculation generates an adjusted significance level of $p < .002$ per factor group. This calculation is performed to adjust for the number of times the factor levels are compared with one another and to adjust the level of significance a factor needs to reach in these multiple comparisons in order to significantly contribute to the outcome. In the step-down analysis, the program starts out with all factor groups and eliminates those that contribute least to the outcome. Ideally, the same factors are discarded in the step-up and the step- down analysis.

III. Results

1. Proportions of Tokens within the Data

The following tables give an overview of the distribution of the various considered segmental and prosodic factors considered for the third experiment.

	slow	normal	fast	Total
item	45	45	45	135
token	1215	1215	1215	3645
%	33	33	33	~100

Table 1: Proportions of tokens in slow, normal and fast speech.

	stress	no stress	Total
item	128	7	135
token	3456	189	3645
%	95	5	100

Table 2: Proportions of stressed and unstressed tokens.

	zero	fricatives	stops	affricate	Total
item	40	37	46	12	135
token	1080	999	1242	324	3645
%	30	27	34	9	100

Table 3: Proportions of tokens with preceding zero-environment, fircatives, and stops and affricates.

	[zero]	[p]	[t]	[k]	[f]	[s]	[ʃ]	[tʃ]	Total
item	40	15	12	19	13	16	8	12	135
token	1080	405	324	513	351	432	216	324	3645
%	30	11	9	14	10	12	6	9	100

Table 4: Proportions of tokens with preceding [*zero*], [p], [t], [k], [f], [s], [ʃ], [tʃ] environment.

	fricatives	stops	affricate	Total
item	67	62	6	135
token	1809	1674	162	3645
%	50	46	4	100

Table 5: Proportions of tokens with following fricative- and stop, and affricate environment.

	[p]	[t]	[k]	[f]	[s]	[ʃ]	[tʃ]	Total
item	16	23	23	17	32	18	6	135
token	432	621	621	459	864	486	162	3645
%	12	17	17	13	24	13	4	100

Table 6: Proportions of tokens with following [p], [t], [k], [f], [s], [ʃ], [t] environment.

	Unround		Round		Total
	i	ɨ	y	u	
item	51	35	21	28	135
token	1377	945	567	756	3645
%	38	26	16	21	100

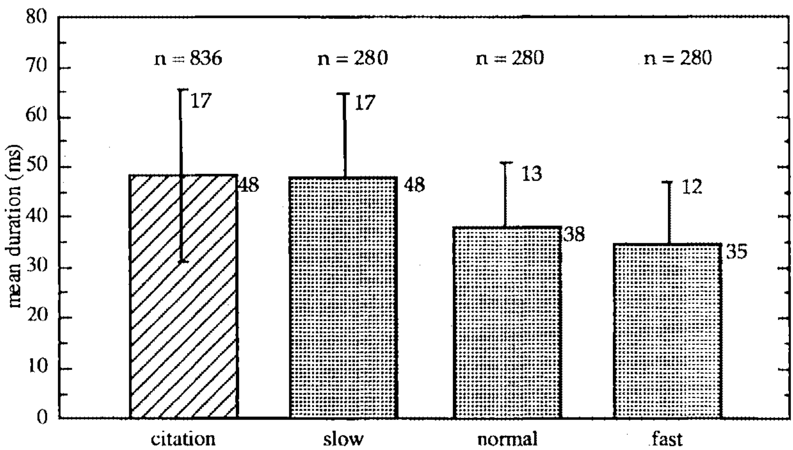
Table 7: Proportions of tokens containing the four different high vowels.

	open	closed	Total
item	69	66	135
token	1863	1782	3645
%	51	49	100

Table 8: Proportions of tokens containing open and closed syllables.

II. VOT Duration

The graphs (with standard deviation bars) in figure 5 display obtained VOT values in citation and in three different rates in carrier phrases for both sets of data. Note that the upper graph does not encompass data for VOT values for [p].



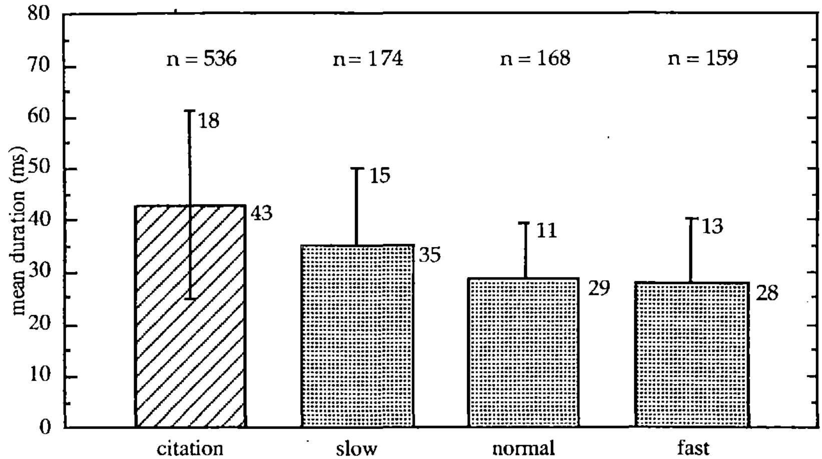


Figure 5.: Upper graph: mean duration of word initial VOT (in ms) of words in citation form and positioned utterance initially in carrier phrases in slow, normal, and fast speech collapsed over all three Turkish voiceless stops (appendix A). Lower graph: mean duration of word medial VOT (in ms) of words in citation form and positioned utterance initially in slow, normal, and fast speech (appendix B).

The mean VOT duration is indicated by the number next to the bar, standard deviation is displayed next to the standard deviation bar. The total number of tokens is given above the individual bars. In both sets of data in the citation condition (total: 840 tokens in the upper graph and 540 tokens in the lower graph), 4 tokens could not be measured due to incomplete stop closures. In the lower graph, in the phrasal condition (180 tokens total), 6 tokens had to be discarded due to incomplete closures during the stop production. In the normal and fastest rates 12 and 21 tokens were not measured because of incomplete stop closures or because the vowel following the stop was devoiced so that the data would have been confounded with these measurements.

Homma (1981:276) reports the mean VOT for initial voiceless unaspirated stops [p t k] in Japanese to be 37ms and for medial stops to be 16ms. The comparable results for Turkish in a phrasal condition in a normal rate of speech show a mean VOT of 38ms (collapsed over all three places of articulation) in initial position and 29ms in medial position. According to these results, Turkish initial voiceless stops have about the same amount of accompanying aspiration as the Japanese ones. The Turkish word medial values for VOT are slightly longer compared to the ones stated by Homma. Thus, we might expect a slightly different pattern for the preceding stops and fricatives in comparison to Japanese.

The results by place show that Turkish VOT durations are longer than the comparable values[2] for wordinitial voiceless unaspirated stops in sentence initial position (Lisker & Abramson, 1964) in Dutch (one speaker), Puerto Rican Spanish (two speakers), Hungarian (two speakers), or Cantonese (one speaker), languages that all contrast voiced and voiceless unaspirated stops. Korean (one speaker)

[2]The data from Lisker and Abramson reported in the table are VOT values for word initial stops in sentence initial position.

contrasts three stop categories, among them voiceless unaspirated stops. Hindi and Marathi (both one speaker) contrast four stop categories and also have voiceless unaspirated stops. The data for Japanese VOT was calculated based on the individual means for word medial stops [p t k] for words embedded in carrier phrases, reported in Han (1994:76-77). English values for voiceless stops by place [p t k] are also reported in Lisker and Abramson (1964).

mean VOT	[p]	[t]	[k]	[pʰ]	[tʰ]	[kʰ]
1. Turkish	**28**	**35**	**49**	--	--	--
2. Dutch	11	16	34	--	--	--
3. Spanish	4	7	25	--	--	--
4.Hungarian	0	20	28	--	--	--
5.Cantonese	11	15	34	58	62	68
6. Korean	7	11	20	89	100	125
7. Hindi	12	11	16	63	63	84
8. Marathi	0	11	21	35	54	73
9. Japanese	8	12	18	--	--	--
10 English	--	--	--	28	39	43

Table 9: Mean VOT values for voiceless unaspirated and voiceless aspirated stops for ten languages. (Data in 2 through 8 and 10 from Lisker and Abramson, 1964; values for Japanese calculated from Han's (1994) data).

The cross-language comparison of voice onset time values for voiceless unaspirated stops shows that Turkish VOT duration for the three voiceless stops in utterance initial position falls in between the values established for languages with comparable two way contrasts between voiceless unaspirated and voiceless aspirated stops. Note however, that Turkish and English show very similar values for VOT in sentence initial position[3]. For a wider comparison, values for voiceless unaspirated and voiceless aspirated stops in Korean, Hindi, and Marathi are given as well. These values confirm that the accompanying aspiration of Turkish voiceless stops is slightly longer compared to other language's voiceless unaspirated stops, but shorter than values for aspirated stops. Throughout all three different speech rates, VOT in Turkish was longest for [k], and shortest for [p], thus decreasing with distance from the glottis. Figure 5 shows VOT values of word initial voiceless stops before low vowels utterance initially positioned in carrier phrases in three different speech rates, displayed by place of articulation.

[3]The results of the VOT-experiments might reflect that four out of five consultants had been living and studying in the United States for at least a year prior to recording and that all of them had learned English in school prior to their arrival. Thus, the prolonged durations of the VOT values for Turkish voiceless stops might be due to interference from English.

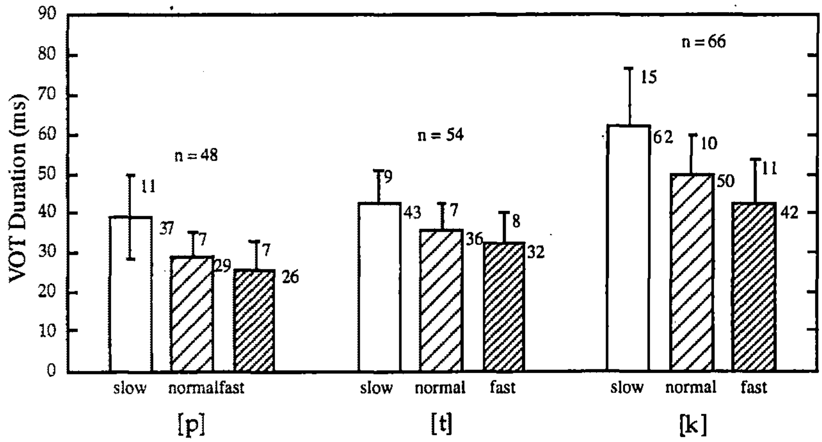


Figure 6: Mean duration of VOT (in ms) of word initial voiceless stops in slow, normal, and fast speech for all three places or articulation.

It is relevant to note that VOT in Turkish is slightly longer than in Japanese, thus we might expect a slightly different devoicing pattern for preceding stops compared to preceding fricatives in Turkish, in comparison to Japanese, Montreal French or Korean.

III. Vowel Duration

According to duration measurements of non-high vowels in 28 open and closed syllable "minimal pairs" (see Appendix A), vowels are, contrary to findings for many other languages (Maddieson, 1985) significantly longer in closed syllables than in open syllables. This result was confirmed in a replication of an experiment (15 [minimal]-pairs of words contrasting open syllables with syllables closed by geminates) described in Lahiri & Hankamer (1988) who found non-significantly longer vowels in closed syllables. The following tables display mean vowel durations, standard deviation, and total number of tokens and the significance level at which vowel duration is different between open and closed syllables in citation form and when uttered phrase initially. The following tables show the mean vowel duration and standard deviation (in ms), the total number of tokens and the significance level for the data in appendix 1 (upper table) and appendix 2 (lower table) in citation form and embedded in phrases in three different rates of speech for open and closed syllable types.

V-duration	**citation**		**slow**		**normal**		**fast**	
appendix A	**closed**	**open**	**closed**	**open**	**closed**	**open**	**closed**	**open**
mean Dur.	77	66	69	60	57	48	51	44
std. Dev.	17	19	13	13	12	10	13	13
total n	419	419	140	140	140	140	138	138
sig. level	sig. diff. p < .001							

V-duration	citation		slow		normal		fast	
appendix B	**closed**	**open**	**closed**	**open**	**closed**	**open**	**closed**	**open**
mean Dur.	87	78	81	71	70	58	61	51
std. Dev.	24	23	21	17	16	14	16	15
total n	222	222	74	74	72	72	67	67
sig. level	sig. diff. p < .001							

Table 10: Upper table: Vowel duration for words in citation form and for words positioned utterance initially in carrier phrases (appendix A). Lower table: Vowel duration for words in citation form and for words positioned utterance initially in carrier phrases (appendix B).

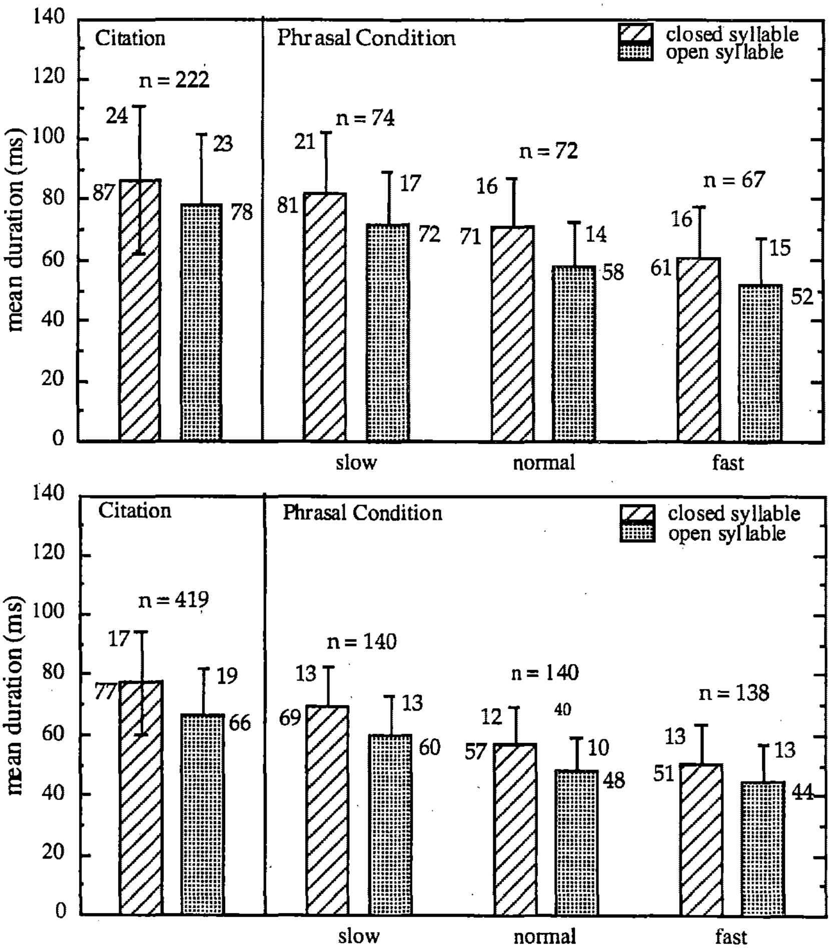


Figure 7. Upper graph: mean duration of non-high vowels in closed and open syllables in citation (left), and phrase initially in slow, normal, and fast speech (right) for 28 syllable type minimal-pairs.

Lower graph: mean duration of (mainly non-high) vowels in closed and open syllables in citation (left), and phrase initially in slow, normal, and fast speech (right) for 15 syllable type minimal-pairs.

Since Lahiri and Hankamer originally measured vowel duration from waveforms and not spectrograms, measurements for five pairs of their 15 words were repeated from waveforms and correlated with the measurements for the identical token obtained from spectrograms. The correlation was $r = .82$ for open and $r = .85$ for closed syllables. A paired t-test showed that even with a relatively small total *n* of 75, mean differences in vowel duration in open and closed syllables were highly significant regardless of measurement tool (spectrogram: $t = -8.84$, $p < .001$; waveform: $t = -6.86$; $p < .001$). Significantly longer vowels in closed syllables in Turkish are a robust effect.

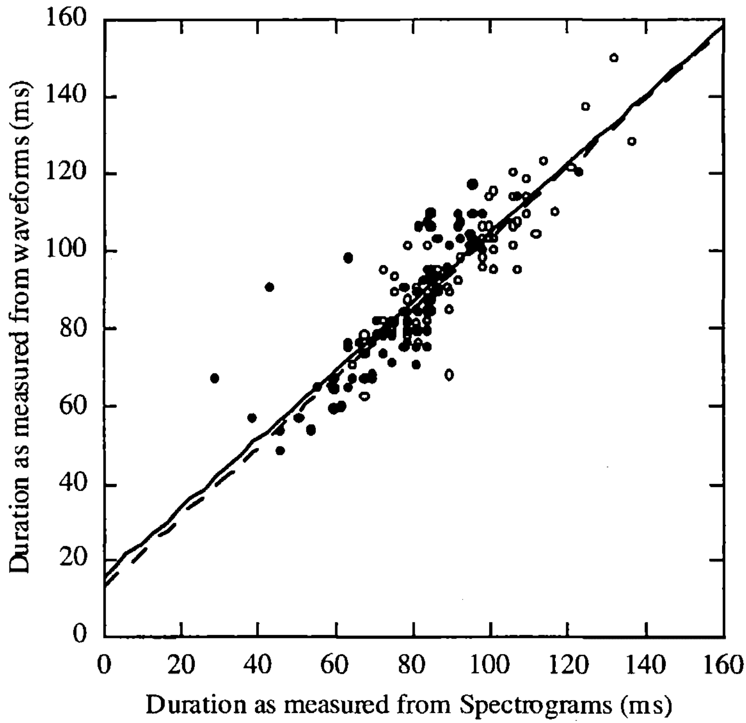


Figure 8.: Left: correlation of vowel duration measurements obtained from spectrograms (x-axes) and waveforms (y-axes) in open and closed syllables.

4. Devoicing

Grouping the partially devoiced with the fully voiced vowels generates the overall rankings of the factor groups as displayed in the following tables. The first table shows the slightly different ranking of the factors when considering each preceding and following consonant type separately. The second table shows the ranking of the factors when collapsing the preceding and the following environment by consonant manner (stops vs. fricatives vs. affricates vs. no onset).The value for the maximum-likelihood is an estimator of the effectiveness of the factor in accounting for the pattern of vowel devoicing. The significance levels reflect the probability that this factor is selected by chance.

Ranking	Factor Groups	maximum-likelihood	significance level
1	Rate	-1548.65	p < 0.001
2	Preceding Env.	-1475.95	p < 0.001
3	Stress	-1442.69	p < 0.001
4	Following Env.	-1419.02	p < 0.001
5	Syllable Type	-1406.47	p < 0.001
6	Vowel Type	-1399.82	p = 0.006

Ranking	Factor Groups	maximum-likelihood	significance level
1	Rate	-1548.65	p < 0.001
2	Preceding Env.	-1479.91	p < 0.001
3	Stress	-1449.16	p < 0.001
4	Syllable Type	-1438.75	p < 0.001
5	Following Env.	-1432.98	p = 0.005
6	Vowel Type	-1426.97	p = 0.009

Table 11: Ranking of factors according to the binomial step-up analysis with maximum-likelihood values indicating most to least contribution to complete vowel devoicing.

The factor group *rate* was initially selected in the step-up analysis indicating that this factor group contributed most significantly to the complete devoicing of the four high vowels. Adding the factor group *preceding environment* raises the likelihood again most significantly compared to all other remaining factor groups. This calculation and procedure is repeated until no factor groups remain or the contribution of the factor groups is insignificant. In the first analysis, all prosodic and segmental factor groups but *vowel type* contributed significantly at the adjusted probability level of $p < .002$. In the second analysis, all but the *following environment* and*vowel type* contributed significantly at the adjusted alpha level to vowel devoicing. The factor groups and their contribution will first be displayed and then discussed.

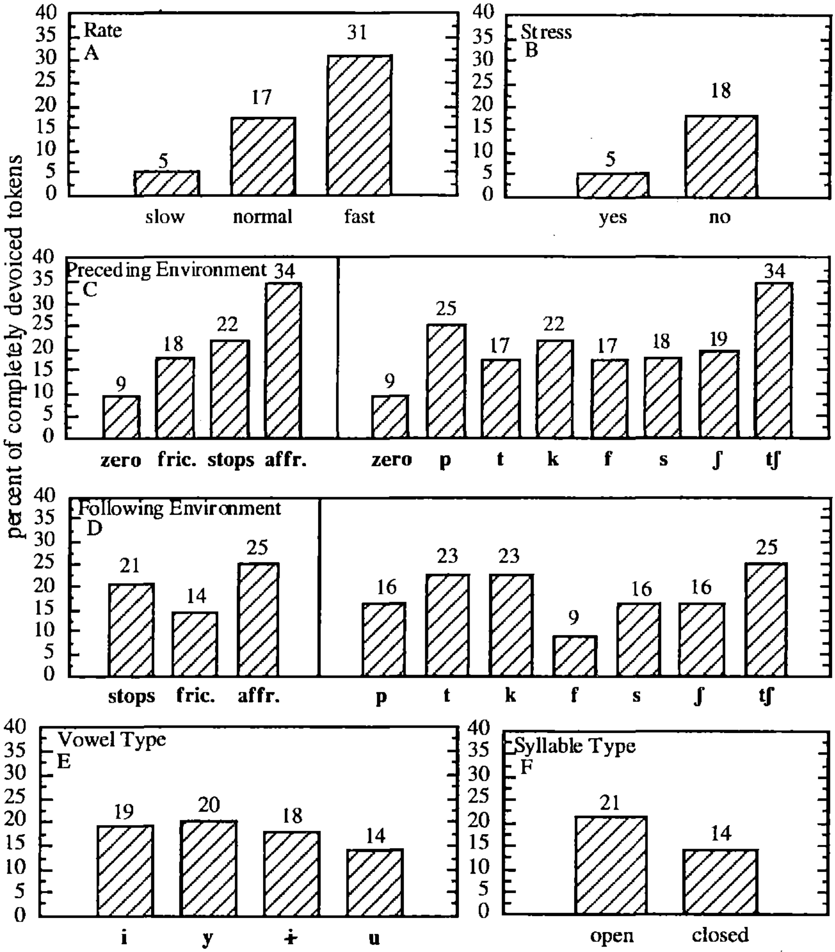


Figure 9.: Influence of rate, stress, segmental environment, vowel- and syllable type on the process of high vowel devoicing in Turkish.

In Turkish, high vowels were more frequently devoiced at faster speaking rates. Graph A in figure 12 shows the contribution of different rates of speech to the process of vowel devoicing by showing the percent of completely devoiced tokens averaged over all nine speakers and all 3645 tokens. The number of tokens that are devoiced as an effect of speech rate increases from slow (5%) to normal (17%) to fast (31%).

Only 5% of all stressed syllable token underwent vowel devoicing, whereas 18% of the vowels devoiced when the syllable was unstressed. Graph B in figure 12 shows a plot of the percent of token that were fully devoiced in stressed and unstressed position.

Stops, fricatives and affricates in the preceding environment were more closely associated with the devoicing of the vowel than no consonant in the onset. Graph C in figure 12 shows the effect of a *null-context* (9%) and the contribution of *stops* (22%) and *fricatives* (18%) and affricates (34%) on high vowel devoicing.

Because grouping all fricatives and all stops together averages out all differences in behavior among the two manners of articulation, a separate analysis was done to provide data for each individual preceding consonant type (on the right of graph C). Most devoicing occurs after the affricate [tʃ] (34%). From the individual plots (in the right of figure 8C) it appears that somewhat more devoicing occurs after stops than fricatives: [p] 25% > [k] 22% > [t] 17% versus [ʃ] 19% > [s] 18% > [f] 17%.

Graph D in figure 9 shows the influence of the consonant's manner following one of the four high vowels. The affricate [tʃ] accounts fpr 25% of the devoicing, the group of stops [p t k] accounts for 21% of the devoicing, and the group of fricatives [f s ʃ] accounts for 14%. The individual plots show that most devoicing (25%) is found before the affricate, alveolar and the velar stops [t k] (both 23%). The coronal and palatal fricatives [s] and [ʃ] and the bilabial stop [p] (16%) account for more devoicing than the labiodental fricative [f] (9%).

Graph E in figure 9 shows that the high rounded back vowel [u] is more resistant to devoicing compared to the other three high vowels [i y ɨ].

As graph F in figure 9 shows, there is less devoicing found in closed syllables (14%) where vowels were found to be significantly longer than in open syllables. The devoicing rate in open syllables was 21%.

IV. Discussion

1. Rate

Faster rates of speech reduce the duration of words and segments, that is, word duration and especially vowel duration is to some degree compressed in time (Klatt, 1976; Lehiste, 1970). Increased speech rate for example can result in phonetic target undershoot (Lindblom, 1963). In Lindblom's view gestures are sequences of temporally invariant motor-plan movements. In case of phonetic undershoot, a vowel gesture is truncated by the onset of following consonantal gesture before the vowel gesture has reached its target (Beckman et. al, 1992). In acoustic terms, a vowel gesture is truncated when the vowel formants assimilate to locus values of the neighboring consonants rather than hit their vowel target.

The gestural score model can explain gestural *undershoot* alone with changes in phasing among the articulatory gestures. In faster rates of speech for example, consonantal and vocalic gestures vary the relative onsets of gestures to each other and thus, as a result, overlap or blend. Overlap and blending of gestures can result in hiding a gesture so that acoustically no output is generated (Beckman, et al., 1992; Munhall & Löfqvist, 1992). Vowel devoicing can nicely be explained by this model, too. It is predicted to occur with greater frequency at faster rates of speech because the glottal gestures of neighboring consonants overlap the vowel's laryngeal gesture to greater or lesser extend. In a C_1VC_2 sequence for example, a vowel's laryngeal gesture can be partially or completely overlapped by adjacent voiceless consonantal gestures only by modifying the phasing between the gestures: C_1's glottal gesture extends into the vowels gesture and C_2's glottal gesture sets on earlier than in normal or slower rates of speech. The figure below illustrates this gestural reorganization resulting in undershoot of the voicing gesture.

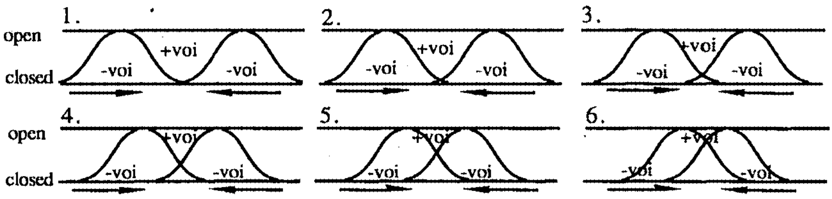


Figure 10: Hypothetical changes in gestural phasing on the glottal tier due to rate. Two voiceless gestures gradually overlap an intervening voiced gesture.

A gestural overlap interpretation of the results of this study regarding the impact of speech rate on glottal gestures is supported much by a study conducted by Munhall and Löfqvist (1992). The authors elicited multiple renditions of the phrase *Kiss Ted* in different speech rates ranging from slow to fast. In the slowest renditions they found two distinct glottal opening and closing movements at the word boundary between the [s] in *Kiss* [kɪs] and the aspirated [t] in *Ted* [t^hɛd]. With increasing rate of speech (in intermediate tempi) the two glottal gestures blended and the gesture for [s] became a shoulder of the gesture for the aspirated [t^h]. In the fastest rates, Munhall and Löfqvist interpret the two gestures as completely overlapped and blended into one glottal opening, whereby the [t] acoustically lost its aspiration due to gestural reorganization resulting in a change in timing of the glottal gesture in relation to the oral gesture for the [t]. These results show that faster tempi trigger overlap of two adjacent glottal gestures, and thus, by analogy, more devoicing of high vowels should be found in faster rates where the preceding and the following voiceless consonant's glottal gesture are predicted to overlap with the vowel's glottal gesture.

2. Stress

Since the 1940s it was debated in the literature (Benzing, 1941; Collinder, 1939; Duda, 1940; Grønbech, 1940) if there is *stress* in Turkish and how it is distributed. Newer literature and phonological descriptions report Turkish as regularly having stress on the final syllable (Lees, 1961; Underhill, 1986; Van der Hulst & Van der Weijer, 1991), whether the word is derived or not.[4] This appears to be the most widely held position. A perception study testing the bias to perceive stress at a particular location in synthesized non-sense words with constant f0, amplitude, duration and target formant values for the syllable nucleus (Konrot, 1987) does not show consistent results. Except for one study by Boyce (1978) the question of what the phonetic correlates of *stress* in Turkish are is practically unaddressed. In contrast to English, where stressed vowels are longer compared to unstressed vowels, Boyce found the durational differences between stressed and unstressed syllables in Turkish to be less striking. Nevertheless, we need to explain why stressed vowels in Turkish are more resistant to devoicing than unstressed ones. Although the influence of stress on vowel duration in English and Turkish is incomparable, data from Montreal French (Cedergren and Simeneau, 1986; Cedergren, 1985) suggests that vowels in rhythm group final syllables are particularly resistant to vowel syncope due to the stress placement on the final syllable.

[4]There are irregular word stress rules which will not be discussed here. See Van der Hulst & Van der Weijer (1991) for a discussion of *stress* in Turkish.

When lack of stress causes vowels to be shorter, then the vowel's laryngeal voicing gesture will be shorter as well, and thus, time allowed to get the vocal folds into regular vibration necessary for voicing may not be not sufficient. Also, gestures associated with unstressed and thus shorter vowels are more prone to overlap by gestures of neighboring voiceless consonants. The predictions in terms of overlap of adjacent consonantal laryngeal gestures with the unstressed vowel's glottal gesture are consistent with the findings in Turkish, that is, more unstressed and thus shorter vowels were more frequently devoiced than stressed ones. Figure 14 shows hypothetical gestural phasings within stressed and unstressed CVC syllables in which both flanking consonants are assumed to be voiceless.

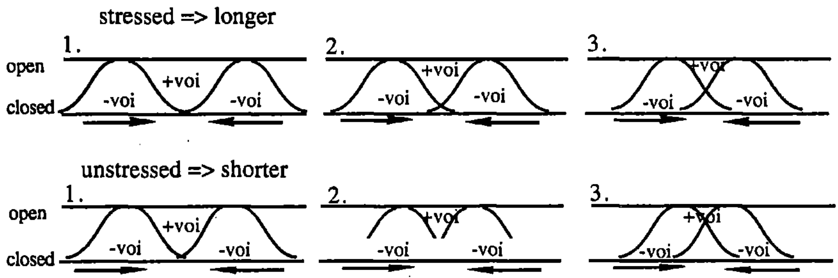


Figure 11: Hypothetical changes in gestural phasing in stressed and unstressed environment.

3. No preceding consonant (Zero Onset)

Turkish does not readily allow word initial consonant clusters (Kornfilt, 1987) since they are a violation of the phonotactic constraints of that language (van der Hulst & van der Weijer, 1991). Some borrowings into Turkish, mainly words of western origin (Özen, 1985; Kornfilt, 1987) contain syllable initial consonant clusters. To break up these disfavored consonant clusters, the languages uses two different mechanisms: one is vowel epenthesis (Lees, 1961; Clements and Sezer, 1982; van der Hulst & van der Weijer, 1991) between two cluster consonants, and the other is prothesis (van der Hulst & van der Weijer, 1991) by which a vowel becomes inserted before word initial consonant clusters such as *sp-*, *st-*, and *sk-*:[5]

spanak	'spinach'
statistik	'statistics'
iskelet	'skeleton'

The prothesized initial vowel causes resyllabification resulting in the resolution of the violation of the constraint against onset clusters. Although these word initial consonant clusters are undesirable in Turkish, we find cases where this phonological rule of prothesis is revoked by the phonetics, that is, the vowel is completely devoiced and (in effect perceptually) deleted with no formant structure in the fricative spectrum so that a word initial consonant cluster resurfaces[6].

[5] These examples are given by Van der Hulst & Van der Weijer (1991:14).

[6] The language- and alphabet reform, propagated by Atatürk in 1928 prescribed the usage of Turkish words over foreign words (i.e., *istanbul* for *Constantinople*) as well as the conversion of the Arabic writing system to the Roman alphabet (Brendemoen, 1990). Grønbech (1940) writes that one of his colleagues retuned from *Stambul* where he did field work on Turkish. This

Vowel devoicing in word- or utterance initial position occurred in 9% of the vowel initial cases. This is less easy to interpret in terms of the gestural score model, because only the following laryngeal gesture (the one to the right of the vowel) can overlap with the vocalic gesture to cause it to be devoiced. A simple overlap explanation predicts that devoicing will be less frequent when no consonantal onset precedes the vowel. The glottal gesture of the consonant following the vowel must be phased with the vowel's laryngeal gesture in such a way that the following consonantal gesture must completely overlap with the preceding vowel gesture so that the vowel's target cannot be realized. This is represented in Figure 15 below.

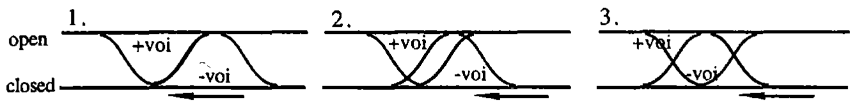


Figure 12: Hypothetical gestural phasing of vowel gesture and following consonantal gesture.

It is noteworthy that disobeying the phonological constraint, still 9% of the vowels with zero-onset devoiced. There is evidence, that at least in some cases, the utterance initial vowel is preceded by a glottal stop onset. But even sequences like *ʔ-V-*C_1•C_2 cannot be readily explained since the devoicing of the vowel between the glottal stop and C_1 should cause a *ʔ-C* sequence to appear which also is also a violation of the constraint against syllable initial consonant clusters in Turkish.

4. Preceding Consonant Type

Two observations are to be made with regard to the preceding consonantal environment: generally, in Turkish, preceding stops appear to account for more devoicing than fricatives, contrary to Jun and Beckman's (1994) findings for Korean, Cedergren and Simeneau's (1985) counts for Montreal French, and a report by Nagano-Madsen (1994:120) citing studies on Japanese unavailable in English. Fricatives in Korean and Japanese have a longer peak glottal opening than stops (Kayaga, 1974; Yoshioka et. al., 1986) but Japanese data provided by Sawashima & Hirose (1983) shows no delay in voicing onset after either voiceless fricative or unaspirated stop.

A higher devoicing rate in the presence of prevocalic stops versus fricatives in Turkish can maybe be explained by the slightly longer aspiration phases of Turkish voiceless stops compared to those of Japanese (and Montreal French, although no VOT data is available here) which have roughly three times less accompanying aspiration at the release of the unaspirated voiceless stops than the Turkish stops. Interestingly, most devoicing is found after the least aspirated stop [p] which suggests that there is some other overlooked contributing factor. How this can be explained remains unclear at this point since no data on glottal opening is available for Turkish. The hypothetical differences in phasing for unaspirated stops with more and less aspiration is shown in the next figure.

annecdotal evidence of Benzing's orthographic representation of this city name hints at how (at least Bechman) perceived the name of Turkey's capitol city.

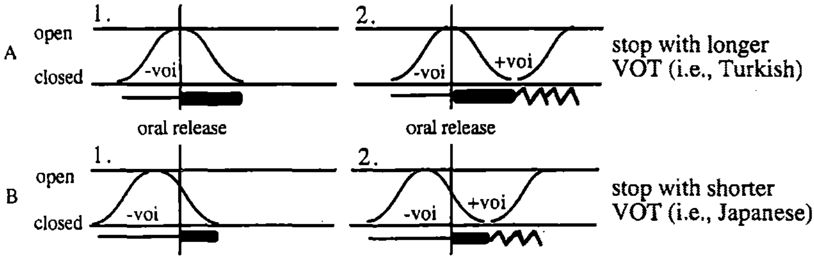


Figure 13: Hypothetical gestural phasing of more and less aspirated stops with following voiced gesture (dark bar: aspiration; jagged line: voicing).

Secondly, in Japanese coronal stops do not surface before high vowels. That is, /ti/ surfaces as [tʃi] and /tu/ surfaces as [tsu]. Underlying coronal stops before high vowels surface as affricates and not as stops. In Japanese, manner (stop versus fricative) is confounded with place, thus, we might expect coronal consonants with their faster oral gestures to show glottal overlap more easily independently of oral overlap. Affricates preceding vowels should behave more like fricatives. Observing the overall pattern of how affricates pattern in comparison to stops and fricatives, they appear to act more like stops when preceding vowels since slightly more devoicing is found after stops than fricatives. However, in Turkish, preceding stops and fricatives account for very similar amounts of devoicing for following high vowels. One could speculate that duration of peak glottal opening during consonant articulation and even possibly the size of the glottal opening might be language specific. Dixit (1989:228) states that unaspirated voiceless plosives in Dutch, French, Japanese and other languages, show "a considerable variability in the degree of glottal opening and the positioning of glottal peak during the initial unvoiced unaspirated plosives across languages; [...]". Also, it is conceivable that affricates like [t] are single phonological entities with their own intergestural timing properties. Even though acoustically, one might think of affricates as being a combination of a stop and a fricative, that is, a stop with a fricative release, it is not outrageous to assume that in production, the closure and release phases of affricates have different phase relations than a stop closure followed by a fricative. In other words, a single segment affricate might not just simply be a combination of two gestures with different manners.

5. Following Consonantal Environment

As for the impact of the following environment on vowel devoicing, results for Turkish are consistent with findings of Jun & Beckman (1994) for Korean where more devoicing was found before stops than fricatives. As data by Sawashima & Hirose (1983) show for Japanese, vocal fold vibration ceases abruptly in *V-stop* sequences compared to *V-fricative* sequences where vocal fold vibration ceases gradually: in order to sustain frication at a constriction in the upper vocal tract, airflow needs to be maintained, whereas a following stop requires a complete blockage of the airstream (Ohala, 1983). This is schematized in the following figure. Thus, more devoicing is expected for vowels followed by stops than by fricatives. Cedergren and Simoneau (1985) report generally less devoicing before voiceless fricatives than before voiceless affricates and voiceless stops in Montreal French. Also, in terms of the gestural overlap model and as shown previously by Munhall and Löfqvist (1992), gestural overlap can just as effectively occur across syllable boundaries as within syllables.

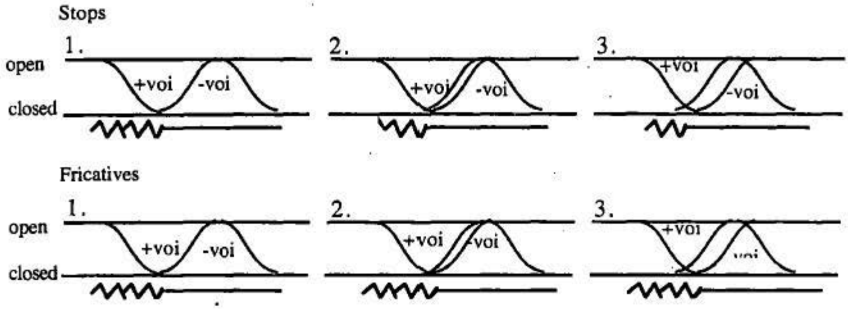


Figure 14: Hypothetical gestural phasing of following stop- and fricative environments with preceding vowel.

The exception among the Turkish stops in the following environment seems to be the bilabial voiceless stop [p] that shows somewhat less devoicing than [k] and [t]. Both labial sounds [f] and [p] show the least amount of impact on the devoicing process, possibly because in the articulation of labials the jaw is involved as an articulator. The affricate, which should behave like a stop following a vowel, is ranked second highest right after the voiceless non-labial stops.

6. Syllable Type

Unlike in most other languages, vowel duration is significantly shorter in open syllables ($p < .001$) than in closed ones. Durational differences of vowels in open and closed syllables have also been noted by Boyce (1978). The current study showed that greater vowel duration in closed syllables is a robust effect true for vowels before geminates as well as heterorganic consonant clusters. Whether the statistically significant difference in duration of vowels in production is perceptually salient, is currently under investigation. Since more devoicing is expected for shorter vowels, the outcome is just as we might expect: more vowels are devoiced in open than in closed syllables.

The occurrence of longer vowels in closed syllables through different experimental conditions (read in different speech rates, within a carrier phrase, in isolation, measurements from spectrogram and waveform) is interesting in itself. One might hypothesize phasing relationships of articulatory gestures to be language specific to explain this finding: possibly, in Turkish, consonantal gestures following a vowel within a syllable have a later onset phase target with regard to the preceding vowel in comparison to when a syllable boundary is intervening between the vowel and the consonant.

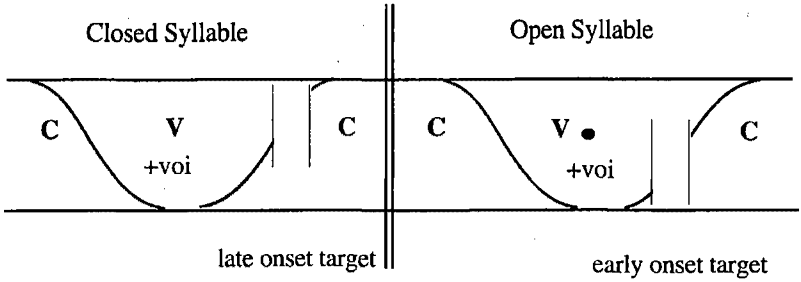


Figure 15: Hypothetical gestural score showing the phasing between vowel and consonant gestures within a syllable and across a syllable boundary in Turkish.

Phonotactic constraints on the possible shape of a syllable appear to be important as well: the complete devoicing of a syllable initial vowel in words like *spanak* 'spinach' or *Istanbul* 'Istanbul (city)' generates undesired and less frequent syllable onset clusters (attested in some western loan words), and thus devoicing or complete deletion in this position is possible but fairly rare. Vowels might be longer in closed syllables with a $C_1VC_2{\bullet}C_3$ structure so that consonant clusters or consonant sequences like $C_1C_2{\bullet}C_3$ or $C_1{\bullet}C_2C_3$ are prevented after devoicing or deletion and resyllabification.

Although Maddieson (1985) reports languages with longer vowels in closed syllables to be fairly unusual, Han (1994) provides data on Japanese, showing that in minimal pairs, differing in the openness and closedness of the first syllable, less devoicing occurs in the closed syllables (vowels before geminates) than in open syllables (vowel before single consonant) because the vowel in the closed syllable is generally longer. If indeed this finding can be explained with the moraic structure in Japanese, Turkish might be temporally organized on the basis of the mora too. However, there is no evidence for this assumption as of now.

7. Vowel Type

The impact of vowel type is statitically insignificant. All four Turkish high vowels can become devoiced, however [u] is slightly more resistant to devoicing than [i y ɨ]. This resistancy of [u] is difficult to explain, without more knowledge about the articulation of the sounds.

V. Conclusions

The presented data showed that various prosodic and segmental factors influence the process of high vowel devoicing in Turkish. As proposed by Jun & Beckman (1993, 1994), these findings can be explained in terms of gestural overlap where the laryngeal gestures of consonants overlap or blend with the glottal adduction gesture of the preceding or following vowel. The data also suggest language specific timing relations between glottal gestures. When comparing devoicing patterns in i.e., Japanese and Turkish, we find that Turkish VOT durations of voiceless stops are roughly three times as long in comparison to Japanese. Thus, language specific differences (like VOT-duration or vowel duration differences in open and closed syllables) play a role in explaining the overall pattern of devoicing in languages.

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Appendix A:

1. pata	*'wave hand in greeting'*	patla	*'burst, torn open'*
2. peki	*'very good'*	peklik	*'firmness'*
3. potuk	*'puckered'*	potluk	*'bagginess in garment'*
4. taka	*'small sailing boat'*	takla	*'somersault'*
5. tekil	*'singular'*	teklil	*'crowning'*
6. tepe	*'hill, summit'*	tepke	*'reflex'*
7. tetik	*'quick, sharp'*	tetkik	*'close examination'*
8. toka	*'shaking hands'*	tokta	*'to fix, settle, establish'*
9. topu	*'in all'*	toplu	*'tidy (place); having a round head'*
10. kakir	*'dry, rustling'*	kaktir	*'of'*
11. kapan	*'to shut, close'*	kaptan	*'captain'*
12. katan	*'loin, lumber'*	katlan	*'to bear, tolerate'*
13. kekik	*'thyme'*	keklik	*'partrige'*
14. köke	*'obsolete kind of ship'*	kökle	*'to tune'*
15. kota	*'quota'*	kotra	*'cutter'*
16. paket	*'package'*	pakla	*'to clean'*
17. pasak	*'dirty untidy clothes'*	paskal	*'comic of old. Turk. theatre'*
18. pesek	*'tartar (of teeth)'*	peste	*'pistachio nut'*
19. peşiz	*'very small coin'*	peşkir	*'table napkin'*
20. petek	*'honeycomb'*	petgir	*'hair sieve'*
21. tapu	*'written survey of province'*	tapkur	*'row, line'*
22. tatar	*'courier'*	tatla	*'to sweeten'*
23. topak	*'roundish lump'*	toplat	*'of'*
24. kepez	*'rock, cliff, hill'*	kepçe	*'laddle, scope'*
25. ketal	*'starched'*	kettan	*'flax'*
26. köpür	*'to froth, foam'*	köprü	*'(dent.) bridge'*
27. kokart	*'cockade'*	koklat	*'cause to smell'*
28. kopar	*'to pluck'*	kopsar	*'ring of iron'*

Appendix B:

1. yati	*'yacht (ACC)*	yatti	*'lie down' (PAST)*
2. bati*	*'west'*	batti*	*'sink' (PAST)*
3. ati*	*'horse' (ACC)*	atti*	*'throw' (PAST)*
4. aki*	*'white' (ACC)*	akki*	*'right' (ACC)*
5. raket	*'raquet'*	takke	*'skull-cap'*
6. sakal*	*'beard'*	bakkal*	*'grocer'*
7. oka*	*'arrow'*	okka*	*'measure of weight'*
8. leke	*'spot'*	Mekke	*'Mecca'*
9. eti	*'meat' (ACC)*	etti	*'do' (PAST)*
10. ete	*'meat' (DAT)*	ette	*'meat (LOCATIVE)*
11. ata	*'horse' (DAT)*	atta	*'horse'*
12. saate	*'clock' (DAT)*	saatte	*'clock' (LOCATIVE)*

13. demete*	*'bunch' (DAT)*	demette*	*'bunch' (LOCATIVE)*
14. ota	*'grass' (DAT)*	otta	*'grass' (LOCATIVE)*
15. batar	*'sink'*	battaniye	*'blanket'*
16. yata	*'yacht' (DAT)*	yatta	*'yacht' (LOCATIVE)*
17. catal	*'fork'*	hatta	*'line' (LOCATIVE)*
18. diken	*'thorn'*	sikke	*'Dervishe's cap'*