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A PHONETIC AND PHONOLOGICAL ANALYSIS OF FINAL DEVOICING IN TURKISH

by

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To my parents,

Veli and Saadet Kopkallı

for everything they have done for me

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ABSTRACT

A PHONETIC AND PHONOLOGICAL ANALYSIS OF WORD FINAL DEVOICING IN TURKISH

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This research investigates the phonetic realization of the phonological process of final devoicing in Turkish. Contrary to the traditional assumption that final devoicing is a neutralizing process, several previous phonetic studies have claimed that a distinction is maintained in languages such as German, Polish, Russian, and Catalan. This phonetic claim is controversial, as such results may be influenced by orthographic or semantic factors. Turkish avoids these difficulties because Turkish orthography does not preserve the underlying voicing contrast, and the Turkish lexicon does not generally contain relevant minimal pairs. Whether or not such rules are neutralizing has potential implications for phonological theory, as the phonological component may need to derive a three-way voicing contrast among final voiced, devoiced (underlyingly voiced), and voiceless obstruents. Within current theory, Underspecification Theory is most likely to derive a three-way surface voicing distinction, yet due to Turkish suffixation phenomenon, such analyses are highly complex and counterintuitive. However, the phonology has to be able to account for a three-way surface voicing if devoiced non-continuants are phonetically distinct from voiceless ones.

To determine the neutralizing status of final devoicing in Turkish, acoustic and perceptual tests were conducted. Although the focus of this study was on word-final

stops, intervocalic stops were first investigated to determine the acoustic correlates of the voicing contrast in Turkish stops. The four temporal parameters measured in this study were significantly different for voiced and voiceless intervocalic stops. The same four parameters which were measured for final stops showed no significant differences between devoiced and voiceless stops in word-final position.

To rule out the possibility that other acoustic (e.g., spectral) differences might be present and therefore cue the voicing distinction, identification and discrimination tests involving excised syllables with final devoiced or voiceless stops were presented to Turkish listeners. The results indicated that Turkish listeners were not able to identify or discriminate the underlying voicing contrast. The lack of acoustic or perceptual distinction between devoiced and voiceless stops suggests that final devoicing is neutralizing in Turkish.

CHAPTER 1
INTRODUCTION

In recent years, a growing body of research has focused on the interface between the phonetic and phonological components of the grammar. As viewed by Chomsky and Halle (1968; henceforth SPE), the output of the phonological component (and the input to the phonetic component) was a set of fully specified feature matrices. The implementation of these feature matrices within the phonetic component involved processes thought to be universal and biomechanical. But both of these positions concerning the phonetics-phonology relation have been called into question. Phonetic data suggest that processes generally recognized as phonetic in nature are not necessarily universal, but rather may exhibit language differences. Further, the nature of the phonetic data suggests that the output of the phonological component contains segments which are unspecified for certain features.

Data bearing on the question of surface underspecification of phonological features come from the investigation of two types of phonological processes, assimilation and neutralization. Selected studies of assimilatory processes are briefly reviewed below. Neutralization phenomena are considered more extensively, with special attention given to devoicing processes. That research provides the background to the present study.

This study focuses on the neutralization process of word-final devoicing in Turkish. It investigates the phonetic realization of word-final stops in Turkish to determine whether the devoicing process is fully neutralizing. The degree of neutralization shown by the phonetic data in turn bears on the surface phonological specification of final obstruents.

1.1 ASSIMILATORY PROCESSES

Phonetic investigation of assimilatory and spreading phenomena has suggested that certain segments have not acquired the feature values of the neighboring segment in the course of the phonological derivation, but rather surface unspecified for that feature (i.e., underspecified) at the output of the phonological component. The argument, as stated by Keating (1988), is that a phonologically underspecified segment should lack a phonetic target for an unspecified feature, and hence the phonetic realization of that feature will depend on that of adjacent segments. If the specification for that feature differs for flanking segments (e.g., the preceding segment is [+FEATURE] and the following segment is [-FEATURE]), then the corresponding phonetic property should continuously change throughout the duration of the segment. The glottal approximant /h/ in English, for example, has been traditionally described as acquiring the feature values of the following vowel by a phonological feature spreading rule, as "/h/ [itself] has no intrinsic oral feature values" (Keating, 1988a: 282). If /h/ were indeed assimilated to the following vowel via a phonological rule, then the formant frequencies of /h/ would be expected to be similar to those of the following vowel throughout most or all of the duration of /h/. But Keating's (1988a) investigation of the phonetic realization of intervocalic /h/ in English, Farsi, and Swedish showed that /h/ did not acquire the feature values of the following vowel, but rather the formant frequencies of /h/ depended on both preceding and following vowels. Keating (1988) argued that transitional, rather than static, formant trajectories of /h/ suggest that /h/ is underspecified for oral features at the output of phonology.

Cohn (1990) investigated nasal spreading in Sundanese (as well as in English and French). In Sundanese, both obstruents and liquids phonologically block spreading of the feature nasal. Tracings of nasal flow in lexical items containing oral stops and /l/ indicated that the phonetic realization of the feature [nasal] in these two types of consonants, however, was different. The sharp decrease in the amplitude of nasal flow in oral stops suggested that obstruents are specified as [-nasal] at the output of phonological component.

The change in the amplitude of nasal flow for /l/, on the one hand, was transitional, suggesting that it was not specified as [-nasal]. Gradual decrease, rather than steady nasal flow, on the other hand, indicated that it was not specified as [+nasal] at the output of phonological component. Thus Cohn concluded that liquids (namely /l/) are underspecified for the feature [nasal] at the output of Sundanese phonology.

1.2 NEUTRALIZATION PROCESSES

The above illustrations of assimilatory processes indicate that the transitional nature of phonetic data for certain segments supports surface underspecification of phonological features. Phonetic studies of neutralization processes have provided substantially different data in support of the same conclusion. In these studies, the phonetic evidence suggests that segments underlyingly specified for a particular feature are not identical to segments which receive the same feature specification through a neutralization process. That is, contrary to the traditional assumption, segments which undergo putative neutralization processes may not be completely neutralized. Non-neutralization of these segments then calls into question the surface specification of such segments. In Turkish, for example, long vowels derived by an intervocalic g-deletion rule are assumed to be identical with underlyingly long vowels. Rudin (1980) investigated the phonetic realization of these two types of long vowels and found that the underlyingly long vowels were shorter than long vowels derived by an intervocalic g-deletion rule (i.e., /VgV/ ≠ /V:/).

One of the more widely studied neutralization phenomena has been the phonological neutralization of voicing contrasts. Different studies have focused on the neutralization of voicing contrasts in different positions within a word. But phonetic findings have been similar, indicating a phonetic distinction is maintained even in environments described as phonologically neutralizing. For example, Fox and Terbeek (1977) investigated intervocalic flapping in English and found that the vowels preceding flaps were phonetically different depending on whether the flap was derived from underlying /d/ or /t/.

Similarly, Weismer, Dinnsen and Elbert (1981) found that final obstruents are often deleted in young children's speech, yet the underlying voicing contrast is maintained by the differences in the durations of vowels preceding the deleted obstruents.

One focus of recent phonetic research has been the process of phonological neutralization of a voice distinction of obstruents in word-final position. Word-final obstruent devoicing is formalized as a neutralization rule within the SPE framework, as in (1) whereby the phonological contrast between underlyingly voiced and voiceless obstruents is assumed to be lost word-finally.

(1) Neutralization rule

$$[\text{-sonorant}] \rightarrow [\text{-voice}] \; / \; \_\_\_ \; \#$$

This rule predicts that underlyingly voiced obstruents (specified as [+voice] in the underlying representation) receive [-voice] specification somewhere in the derivation and surface as [-voice] at the output of phonological component.

However, results of recent phonetic studies of word-final obstruent devoicing in German, Polish, Russian and Catalan claim that phonetic differences are maintained not only in environments of contrast but also in environments described as neutralizing. Such findings, if correct, contradict the prediction of the neutralization rule given in (1), as the [+voice] specification of an obstruent is not changed to [-voice] in the course of the derivation. Rather, the phonetic differences between devoiced (i.e., underlyingly voiced) and voiceless final obstruents suggest that devoiced segments surface with a different voicing specification than that of voiceless ones. These phonetic differences can be captured by allowing segments which undergo putative neutralization processes to surface underspecified for voicing at the output of the phonological component.

In the current study, the phonetic realization of the phonological process of word-final devoicing is investigated in Turkish. Two findings are possible. Turkish devoiced (underlyingly voiced) and voiceless non-continuants (i.e., stops and affricates) might be phonetically identical, suggesting that devoiced non-continuants surface with the same voicing specification as voiceless non-continuants (i.e., [-voice]). Or, the underlying voicing distinction between devoiced and voiceless non-continuants might be maintained phonetically, suggesting that devoiced obstruents are not specified for voicing at the output of phonology.

Turkish is chosen for several reasons. The acoustic differences between devoiced and voiceless obstruents reported for German, Polish, and Catalan have been claimed to be the result of orthographic and semantic motivation in these languages (Fourakis and Iverson, 1984; Jassem and Richter, 1989; Mascaró, 1987; respectively; discussed in detail in §1.2.1). In German, Polish, and Russian, the underlying distinction between devoiced and voiceless obstruents is represented in the orthography: devoiced obstruents are spelled with graphemes representing voiced obstruents and voiceless ones with graphemes representing voiceless ones. Unlike these three languages, Turkish reflects word-final devoicing in its orthography: word finally, graphemes representing voiceless segments are used for both devoiced and voiceless non-continuants, as seen in (2). Thus, in Turkish, any experimental artifact introduced by orthographic distinctions would be avoided.

(2) Orthography

Final Position	Non-Final position	
kap	kabı	'container, nom/acc'
sap	sapı	'stalk, nom/acc'
tat	tadı	'taste, nom/acc'
kat	katı	'layer, nom/acc'
çok	çoğu	'many, nom/acc'
tok	tokum	'full, stem/1st person'

Catalan, like Turkish, also reflects final devoicing in the orthography. However, Catalan contrasts words differing solely in the underlying voicing of final obstruents, such that devoicing results (in principle, at least) in homophonous words. Thus in Catalan, there is semantic motivation to maintain the underlying distinction. In contrast, Turkish does not (with very few exceptions) contrast words differing only in the underlying voicing of a final non-continuant, and so there is no apparent semantic motivation to preserve final voicing differences.

The following sections of this chapter discuss the methodologies and results of previous studies of final devoicing in German, Polish, Russian, and Catalan. These studies fall into two general categories with respect to the claim each study makes. On the one hand, some studies claim that final devoicing is non-neutralizing because these languages maintain consistent acoustic differences between final devoiced and voiceless obstruents, and these differences are perceptible. Alternatively, other studies claim that final devoicing is neutralizing because the differences found are artifacts of problems in the experimental design. The results of acoustic and perceptual studies for each language are discussed separately.

1.2.1 Acoustic Studies of Final Devoicing

In determining the neutralizing status of final devoicing, the studies discussed here have measured four (or a subset of these four) temporal parameters: duration of the vowel preceding the final obstruent, duration of voicing into constriction, overall duration of the obstruent itself, and duration of aspiration following constriction release (for stops, or duration of frication for fricatives). These measures were selected based on cross-linguistic evidence that the voicing distinction in obstruents may be cued by these temporal parameters. (The evidence to support these four parameters as acoustic correlates of voicing in obstruents is discussed in Chapter 3).

1.2.1.1 German

German final devoicing has been more widely studied than final devoicing in any other language. The reported differences between devoiced and voiceless obstruents were, in general, large for German (especially in the earlier studies). For example, Mitleb (1981) reported that the duration of vowels before devoiced obstruents was 20 ms (12%) longer than before voiceless ones, and that voicing into closure was 5 ms (100%) longer for devoiced than for voiceless obstruents. Both of these differences were significant, although closure duration was not (1 ms mean difference).

Port and O'Dell (1985) found a significant effect of underlying voicing in terms of all four temporal parameters. Vowel duration was approximately 20 ms (8%), and voicing into closure was 5 ms (42%), longer for devoiced than voiceless stops. Closure duration was 5 ms (4%), and aspiration duration was 16 ms (47%), longer for voiceless stops than for devoiced ones.

In both of these studies, as well as in other studies of German final devoicing, large differences may be due to a number of factors. One possibility, of course, is that final devoicing in German is non-neutralizing. Before this conclusion is reached, however, various factors concerning experimental design need to be considered. For example, in many of the German final devoicing studies, the number of test pairs was small: four pairs in Mitleb (1981) and Charles-Luce (1985); three pairs in Port and Crawford (1989). (In contrast, Port and O'Dell (1985) tested ten pairs, and Piroth, Schiefer, Janker and Johne (1991) tested nine pairs.) A small number of test pairs might reduce variability among pairs as compared to a larger set, possibly resulting in larger differences between devoiced and voiceless obstruents.

The large differences between devoiced and voiceless obstruents in German may also be due to an effect of orthography (Fourakis and Iverson, 1984). Such an effect may have been introduced by including unfamiliar test words and/or by the experimental paradigm. For example, two of the four word pairs tested by Mitleb (1981) contained members no longer used in German. The inclusion of such words may have drawn subjects' attention to the underlying voicing of the test pairs, and thus to the purpose of the experiment. This is particularly likely as there were no filler words to disguise the purpose of the experiment. Similarly, Port and O'Dell (1985) included rare lexical items, which presumably emphasized the underlying voicing of the test pairs. Furthermore, in that study, subjects were asked to read the test words in isolation, which may have encouraged subjects to give spelling pronunciation. In both studies, inclusion of uncommon words, and lack of filler words or a carrier sentence, may have provided clues as to the purpose of the experiment, and encouraged subjects to exaggerate the differences between devoiced and voiceless obstruents.

Fourakis and Iverson (1984), arguing that the differences between German devoiced and voiceless obstruents were due to orthography, conducted a study designed to eliminate the orthography effect. They used an elicitation task in which subjects were asked to conjugate (strong) verbs when orally prompted with the infinitive form. The overall results (based on five near-minimal pairs and four subjects) showed that there were no significant differences between devoiced and voiceless obstruents in terms of vowel and closure durations (the only parameters measured in their study). These results were contrasted by these authors to those obtained in a partial replication of the O'Dell and Port (1983) study[1]. In this replication, subjects were asked to read lists of isolated words. Although no significant effect of underlying voicing was found for either of the two parameters for the overall data, two of the four subjects maintained a distinction of underlying voicing for certain pairs. Fourakis and Iverson (1984) concluded that the differences between devoiced and voiceless obstruents reported by O'Dell and Port (1983) were an artifact of the experimental design.

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[1] This study is an earlier version of Port and O'Dell (1985).

Port and Crawford (1989), in an attempt to further address the orthography issue, conducted an extensive study in which one of the pairs (*seid/seit*) did not exhibit any morphophonemic alternation but rather formed a minimal pair supported only by orthography. As Port and Crawford (1989: 262) stated, " any [phonetic] differences for this pair would have to be due to orthography". The overall results (based on three pairs) showed that the *seid/seit* pair had the largest difference for vowel duration. Vowel duration was 11 ms (or 7%) longer for *seid* than for *seit*, in contrast to 1 ms for *Bund /bunt* and 4 ms in the wrong direction for *Rad/Rat.*

Port and Crawford (1989) also tested for the effect of experimental paradigm on preservation of the underlying voicing distinction. They designed five conditions. In Condition 1A, test words were embedded in a long sentence to disguise the purpose of the experiment so that subjects' attention was not drawn to the underlying voicing of the test words. In Condition 1B, subjects were asked to recite the sentences read by the experimenter from memory to eliminate the possibility of an orthographic artifact. In Condition 2, subjects were asked to contrast the members of a pair ("I said Rat as in 'bit of advice'; not Rad as in 'bicycle'"). Condition 3 was a dictation task in which subjects dictated sentences such as " I said Rat, not Rad", so that the experimenter could write down the intended word (i.e., Rat). In Condition 4, subjects were asked to read lists of words in isolation. Port and Crawford (1989) expected the largest temporal differences to be found in Conditions 2, 3, and 4, as the purpose of these conditions was to encourage subjects to exaggerate the distinction between devoiced and voiceless obstruents. The mean temporal differences between devoiced and voiceless members for the three pairs in all five conditions are presented in Table 1.1. (A minus (-) sign indicates that the difference between devoiced and voiceless members is in the wrong direction, i.e., the opposite of what is expected.)

	vowel duration			closure duration			burst duration		
	seid/seit	Rad/Rat	Bund/bunt	seid/seit	Rad/Rat	Bund/bunt	seid/seit	Rad/Rat	Bund/bunt
1A	16	-8	-1	9	-5	7	0	5	-4
1B	8	-6	2	-1	-5	-11	0	11	1
2	5	3	0	2	1	1	19	6	12
3	18	-1	1	-3	3	-9	49	61	38
4	10	-7	5	7	-1	-3	33	8	40

Table 1.1. Mean differences (in ms) between devoiced and voiceless members of three parameters in different conditions (based on the data presented in Port and Crawford, 1989).

As seen in Table 1.1, the mean difference in burst duration (burst + aspiration) increased substantially in Conditions 2, 3, and 4 for all three pairs. (Burst duration was the only parameter which showed a significant effect of underlying voicing for the overall data across word pairs, subjects, and conditions.) The mean differences were generally small or in the wrong direction (i.e., longer for devoiced stops) in Conditions 1A and 1B.

Thus, as Port and Crawford (1989) expected, differences between devoiced and voiceless members for all three parameters were generally larger when subjects were asked to maximally differentiate between devoiced and voiceless members (as in Conditions 2 and 3), and when asked to read isolated words (as in Condition 4). When the purpose of the experiment was not obvious (as in Conditions 1A and 1B), the differences were smaller (for *Rad/Rat* and *Bund/bunt*, although not for *seid/seit*).

Other studies of German final devoicing have focused on contextual (sentential and phonetic) effects to determine the neutralizing status of German final devoicing in "fluent, connected speech" (Charles-Luce, 1985: 311). Embedding the test words in different contexts helps to conceal the objective of the experiment (Piroth *et al.*, 1991). Charles-Luce (1985) examined the neutralizing status of four word pairs in four different contexts. Two of the test word pairs ended in a dental stop while the other two pairs ended in an alveolar fricative. Test words occurred in clause-final position in two carrier sentences, and in non-clause-final position in the other two carrier sentences. Within each sentential position, test words were followed by a vowel in one context, and by a voiced labio-dental fricative in the other context. For final stops, voicing into closure and closure duration did not have a significant effect of underlying voicing. Although Charles-Luce (1985) reported vowel duration differences to be significant, these differences were in the opposite direction of the predicted differences. For final fricatives, two temporal parameters -- preceding vowel duration and frication duration -- were measured. Vowel duration was significantly longer before devoiced members in clause-final position. Frication duration was not significant in any context. Charles-Luce (1985) concluded that final devoicing in German was not neutralizing. However, the data showed that any phonetic differences were highly restricted: significant differences were found only for fricatives in clause-final position.

Piroth *et al.* (1991) also investigated the neutralizing status of German final devoicing in different sentential positions and phonetic environments. Two subjects were asked to read nine (one minimal pair, and eight rhymes) test pairs with final stops in four contexts: utterance-final, word-final (but not utterance-final), morpheme-final followed by a voiced segment, and morpheme-final followed by a voiceless segment. Three temporal parameters -- vowel duration, closure duration, and release (burst+aspiration) duration -- were measured. Similar to Charles-Luce (1985), Piroth *et al.* (1991) found an effect of context on final voicing. In utterance-final position, release and closure durations were longer for voiceless members than for devoiced ones. In word-final position, only release duration showed an effect of underlying voicing. None of the three parameters showed significant differences between devoiced and voiceless stops morpheme-finally (in either phonetic environment). Vowel duration was not significant in any context. (The mean durations of the parameters measured for devoiced and voiceless stops were not reported, therefore the size of the differences is not clear.) Piroth *et al.* (1991) concluded that final devoicing in German was not completely neutralizing. However, final devoicing in that study was neutralizing at least in some contexts (e.g., morpheme-finally).

In summary, various experimental designs have been used in different studies of German final devoicing, leading to different results. Results were more consistent across word pairs and subjects in earlier studies in which subjects read test words in isolation. When the experimental design introduced tasks involving the production of test words in context, in different sentential positions, or in different phonetic environments, temporal differences between devoiced and voiceless obstruents were no longer consistently obtained. The number of parameters which showed a significant effect of underlying voicing decreased and these effects were restricted to certain environments for certain parameters. The results of the German final devoicing studies are summarized in Table 1.2. (Each study is given a number which will be used as a reference in Chapter 5.)

	1	2	3	4	5	6
	Mitleb (1981)	Fourakis & Iverson (1984)	Port & O'Dell (1985)	Charles-Luce (1985)	Port & Crawford (1989)	Piroth *et al.* (1991)
number of test pairs	4 minimal pairs	11 rhymes	10 minimal pairs	4 minimal pairs	3 minimal pairs	1 minimal pair 8 rhymes
experimental paradigm	embedded in a carrier sentence	elicitation task (verb conjugation)	reading of isolated words	4 contexts	5 conditions	4 contexts
significant parameters	(overall) vowel dur voicing closure	none	(overall) vowel dur voicing closure aspiration	vowel dur for clause-final fricatives	(overall) burst duration	release and closure dur utterance-finally; release dur word-finally

Table 1.2. Summary of the German final devoicing studies (vowel dur: vowel duration, voicing: voicing into closure, closure: closure duration, aspiration: aspiration duration, release dur: release duration).

1.2.1.2 Polish

The acoustic realization of Polish final devoicing has not been studied as extensively as that of German. The two published studies have substantially different findings and conclusions.

Slowiaczek and Dinnsen (1985) examined final devoicing in Polish using 15 minimal pairs ending in stops (bilabial, alveolar, velar), fricatives (labio-dental, dental), and affricates (dental). Subjects were asked to read the test words in two carrier sentences in which the test word was followed either by a vowel or by a voiceless stop consonant. In their study, the overall results showed the duration of the vowel preceding devoiced obstruents to be significantly longer (10%) than that preceding voiceless ones. When the data for individual subjects were analyzed separately, vowel duration was significant for four of the five subjects. Voicing into closure was significant for bilabial stops, although as only two word pairs ended in bilabial stops it is not clear how general this finding is. Similarly, based on four word pairs, closure duration was significant only for dental stops.

Similar to the results of the German studies, Slowiaczek and Dinnsen (1985) found an effect of context in Polish. Significant differences in vowel duration were found for dental stops and affricates when the test word was followed by a vowel but not when followed by a voiceless stop.

Jassem and Richter (1989) claimed that the findings reported in Slowiaczek and Dinnsen (1985) did not necessarily indicate that the underlying contrast is maintained in Polish, arguing that the obtained differences can be attributed to other factors such as the influence of English, orthographic pronunciation, and hypercorrection. Jassem and Richter (1989) claimed that hypercorrection was introduced by the carrier sentences as they were "of the 'metalinguistic' kind" ("Mary pronounces ____ correctly", and "Mary pronounces ____ terribly"; p.318). Jassem and Richter (1989) conducted an experiment in Polish which they argued eliminated these artifacts. To avoid an effect of orthography, utterances were elicited in a dialogue between the experimenter and the subject. In eliciting word pairs, two types of prompting were used to test for hypercorrection introduced by prompting. One type of prompting consisted of general questions such as "Which bird has the most beautifully colored tail?", while the second type consisted of "metalinguistic" questions, including such questions as "What is the diminutive form of 'mapa' ('the map')?" (Answer: Mapka). The test words consisted of 17 minimal pairs and 12 rhymes.

While Jassem and Richter (1989) found no overall significant differences between devoiced and voiceless obstruents (although the mean release difference was 15 ms), they did find an effect of type of prompting used in eliciting word pairs. The mean differences between devoiced and voiceless were larger for metalinguistic than for general prompts. For metalinguistic prompts, vowel duration was 9 ms (9%) longer before devoiced than before voiceless obstruents, and closure duration was 10 ms (5%) shorter for devoiced ones. For general prompts, on the other hand, the mean differences between devoiced and voiceless members were in the wrong direction (2 ms difference in vowel and closure durations).

The lack of an underlying voicing effect when Jassem and Richter (1989) elicited the test words in dialogues suggests that the productions elicited by Slowiaczek and Dinnsen (1985) may have been influenced by orthography. Furthermore, the substantial increase in temporal differences when subjects were prompted with metalinguistic questions suggests that subjects may have been influenced by the type of prompting such that they were encouraged to differentiate the underlying contrast when the focus was on linguistic knowledge.

The results of the two Polish studies are summarized in Table 1.3. Consecutive numbers are assigned to each study following the German studies.

	7	8
	Slowiaczek & Dinnsen (1985)	Jassem & Richter (1989)
number of test pairs	15 minimal pairs	17 minimal pairs 12 rhymes
experimental paradigm	2 carrier sentences	elicited in dialogues
significant parameters	vowel duration voicing for bilabial stops closure for dental stops	none

Table 1.3. Summary of the Polish final devoicing studies (voicing: voicing into closure, closure: closure duration).

1.2.1.3 Russian

One of the least studied languages with respect to final devoicing and its phonetic realization has been Russian. Although Chen (1970), in a cross-language study investigating vowel length as a function of consonant voicing, mentioned that vowels in Russian were longer before phonologically voiced obstruents than before voiceless ones, there is only one published experimental study investigating the phonetic realization of Russian final devoicing.

Pye (1986) investigated Russian final devoicing using 17 minimal pairs ending in stops (bilabial, palatalized and non-palatalized dental, and velar) and fricatives (dental and palato-alveolar). Russian, like German and Polish, maintains the underlying voicing contrast of obstruents orthographically. Subjects were asked to read the test words in two carrier sentences differing in sentence stress. Although in both contexts the test words occurred in sentence-final position, one context avoided possible emphasis on the test word while the other context did not. The results indicated that vowel duration and voicing into closure were longer for devoiced than for voiceless obstruents in both contexts. Conversely, closure duration was longer for voiceless obstruents than for devoiced ones, again in both contexts. The same general pattern was also found when individual subject data were analyzed separately. The results of this study are summarized in Table 1.4. (In this study, the data were not subjected to statistical analyses.)

	9
	Pye (1986)
number of test pairs	17 minimal pairs
experimental paradigm	2 carrier sentences
significant parameters	(no statistical analyses)

Table 1.4. Summary of the Russian final devoicing study.

1.2.1.4 Catalan

The main criticism of the studies of German and Polish has been the possible influence of orthography on subjects' productions. Fourakis and Iverson (1984) and Jassem and Richter (1989) argued that the temporal differences found in German and Polish, respectively, are due to spelling pronunciation of the devoiced obstruents which are written with graphemes representing voiced obstruents. To address this issue, Dinnsen and Charles-Luce (1984) investigated final devoicing in Catalan, a language which does not maintain the underlying voicing distinction in the orthography (i.e., only voiceless graphemes occur in word-final position).

Dinnsen and Charles-Luce (1984) examined the neutralizing status of final devoicing in Catalan using 10 minimal pairs differing only in the underlying voicing of the final obstruent. The Catalan results showed no overall differences between devoiced and voiceless stops for any of the three parameters measured. (The mean differences were small: 1 ms for vowel duration, no difference for voicing into closure, and a 3 ms reverse difference for closure duration.) Dinnsen and Charles-Luce (1984) argued that the small differences were due to individual subject variability. However, the data for individual subjects indicated that even at this level differences were not large, with mean differences for certain subjects for certain parameters being in the wrong direction. Only two of the five subjects showed a significant effect of underlying voicing, and for one of these subjects, the effect was in the wrong direction (as pointed out by Mascaró, 1987).

As a reply to Mascaró's (1987) criticisms, Charles-Luce and Dinnsen (1987) reexamined the Catalan data including only two of the ten original minimal pairs. (The other eight pairs were eliminated because of the problems in the characterization of the underlying representation, and segmentation due to gemination effects in certain contexts.) In the reanalysis, a significant effect of underlying voicing was obtained for voicing into closure. However, the mean difference between devoiced and voiceless stops was only 1 ms and this result was based on two pairs.

Charles-Luce (1987) conducted an extensive study of final devoicing in Catalan. In this study, nine test pairs occurred in three different sentential positions, and in two different phonetic contexts within two of the sentential positions (for a total of five contexts). The results were similar to the 1984 study: no main effect of underlying voicing was found for any of the three temporal parameters measured and the mean differences for the overall data were small in all contexts. When subject data were analyzed separately, only two of the five subjects showed significant differences between devoiced and voiceless obstruents for certain parameters in certain environments.

In the Catalan studies, Spanish glosses which preserve the underlying voicing contrast were given in order to signal the intended Catalan word. Charles-Luce (1987) argued that the presence of Spanish glosses may have resulted in the lack of significant differences between devoiced and voiceless obstruents, as subjects would not feel the need to distinguish the meanings of pair members when meanings were provided by the experimenter[2]. To test for this possibility, each of the five test words appeared in two different semantic contexts, one context containing semantic information which disambiguated the test word, and one which did not. Charles-Luce hypothesized that relatively large differences between devoiced and voiceless obstruents would be expected in contexts not providing information as to the meaning of the test word. This hypothesis was upheld: underlying voicing had an effect on vowel duration for test words in contexts not containing semantic information. This overall result, however, did not hold for all phonetic contexts. When phonetic contexts were analyzed separately, significant differences were found in the two assimilatory contexts where regressive assimilation, rather than final devoicing, applies. No differences between devoiced and voiceless obstruents were found utterance-finally, a position in which final devoicing applies. This

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2 Mascaró (1987), however, argued just the opposite: the presence of Spanish glosses which preserve the underlying voicing contrast in the orthography may have provided orthographic cues.

holds for individual as well as group data. Similarly, no individual word pair showed an effect of underlying voicing utterance-finally. (In the two assimilatory contexts, vowel duration was longer before devoiced members than before voiceless ones for three of the five pairs.)

In summary, it has been argued here that the results reported by Dinnsen and Charles-Luce (1984) and Charles-Luce and Dinnsen (1987) do not provide strong evidence of the non-neutralizing status of final devoicing in Catalan. The mean differences between devoiced and voiceless obstruents for the three parameters measured were not significant. While Charles-Luce (1987) found an effect of underlying voicing for vowel duration in one of the semantic contexts, this effect did not hold for utterance-final position, which was the context designed to test for final devoicing. The Catalan studies are summarized in Table 1.5. (The study by Charles-Luce and Dinnsen (1987) was not included in the table, as this was a reanalysis of a portion of the data reported in Dinnsen and Charles-Luce (1984), and the results of the reanalysis were not substantially different than those reported in the earlier study.)

	10	11
	Dinnsen & Charles-Luce (1984)	Charles-Luce (1987)
number of test pairs	10 minimal pairs	9 minimal pairs
experimental paradigm	2 carrier sentences	5 contexts 2 semantic contexts (3 environments)
significant parameters	none overall	vowel duration in semantically non-biasing contexts (in 2 assimilatory environments)

Table 1.5. Summary of the Catalan final devoicing studies.

1.2.1.5 Summary

The largest differences between devoiced and voiceless obstruents are found in languages which preserve the underlying voicing contrast orthographically. The influence of orthography on contrast preservation is evidenced by experimental designs which minimize or eliminate an orthographic contribution. In such designs, the temporal differences between devoiced and voiceless obstruents decrease substantially. Furthermore, when the experimental setting reflects more casual speech, as when test words are embedded in long sentences or elicited in dialogues, temporal differences also decrease.

1.2.2 Perceptual Studies of Final Devoicing

For three of the languages discussed above (German, Polish, and Catalan), perceptual tests have also been conducted to determine whether the acoustic differences between devoiced and voiceless obstruents found in these languages could be perceived by native speakers. Results of the perceptual experiments are discussed separately for each language.

1.2.2.1 German

Port and O'Dell (1985) conducted a perceptual test in which ten German listeners were asked to circle on an answer sheet the word they thought the speaker intended to say. The stimuli consisted of five of the original ten test pairs read in isolation by ten speakers in the acoustic study. Each listener responded to a randomized list of 400 stimuli. Listeners were able to distinguish the underlying contrast 59% of the time (see also Port, Mitleb, and O'Dell, 1981). (Chance was 50%.) Individual subject data showed that correct identification for each subject ranged from 51% to 65%; correct identification for each word ranged from 52% to 60%. Thus for certain subjects, and for certain pairs, correct identification was at chance level.

Port and Crawford (1989) also investigated perception of word-final devoicing in German to determine whether the acoustic differences they found were perceptible. The pairs selected for the perceptual experiment were from two of the tasks, dictation and reading (Conditions 3 and 4), designed to encourage the greatest possible differentiation of the words in each minimal pair. Utterances from two representative speakers (whose results showed neither the most nor the least differentiation) were selected, yielding a total of 288 stimuli which were presented to five German listeners. The overall results showed 69% correct identification -- significantly better than chance. Performance was generally better on the productions from the dictation task than on those from the reading task, regardless of speaker.

Port and Crawford's (1989) listeners were clearly able to identify underlying voicing with greater than chance accuracy. However, 69% correct identification suggests that listeners could not *consistently* use these differences as a cue to the phonological voicing distinction. As dictation and reading tasks are not representative of casual speech, the results of this experiment may not present conclusive evidence to the perceptibility of the underlying voicing contrast in German.

1.2.2.2 Polish

Slowiaczek and Szymanska (1989) investigated whether the acoustic differences found in Polish by Slowiaczek and Dinnsen (1985) were perceptible. The 26 test pairs which exhibited the largest vowel duration differences between pair members (mean vowel duration difference between pair members: 55%) were selected. Multiple randomizations of the 52 test words were presented to 21 native Polish and 18 native American English speakers for identification. Both groups of listeners were provided with an answer sheet containing minimal pairs for each trial. Overall performance was 61% correct identification for Polish listeners and 59% correct identification for English listeners.

The Polish perceptual data are similar to those for German in that listeners identified underlying voicing better than chance, but not at the level that might be expected if such temporal differences are consistently used by listeners as a cue to underlying voicing. In this study, both Polish and English listeners showed a bias towards voiceless members.

Polish listeners correctly identified voiceless members 69% of the time and devoiced members only 52% of the time. Similarly, English listeners correctly identified voiceless members 66% of the time, and devoiced members only 52% of the time. Identification of devoiced members, then, was at chance level[3].

Jassem and Richter (1989) conducted a perceptual test with ten monolingual Polish speakers in which all minimal pairs produced by all four subjects in the acoustic experiment were included. Overall accuracy was 53%. These authors also found a bias toward voiceless members: 67% of the voiceless members were correctly identified, while only 39% of the devoiced members were correctly identified.

In general, when overall performance was better than chance in the Polish studies, it was due to a voiceless bias. Neither study showed the voicing of underlyingly voiced members to be perceived better than chance. However, this is not to suggest that devoiced and voiceless obstruents showed the same patterns of identification. Underlyingly voiceless obstruents were identified as voiceless more often than were devoiced obstruents. Listeners were more certain of the voicing of voiceless obstruents than that of devoiced obstruents.

1.2.2.3 Catalan

Charles-Luce (1987) conducted a perceptual study in Catalan to determine whether the underlying voicing contrast was perceptible. Three of the five test pairs produced by one of the speakers in two semantic contexts were chosen. Multiple repetitions of 108 (for a total of 756) stimuli were presented to seven Catalan listeners and five English listeners. Catalan listeners were phonetically naïve whereas English listeners were phonetically sophisticated. Catalan listeners were asked to identify the word they heard while English

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[3] It is not clear whether there was a comparable bias in the German data given the way the data were presented.

speakers were asked to identify the voicing of the last consonant of a given word. Identification was at a chance level for both groups (51% correct identification for Catalan listeners and 48% for English listeners). When data were analyzed separately according to the semantic context in which the token originally occurred, performance was found to be better for word pairs excised from the context containing semantic information than for pairs excised from the context without semantic information. Thus the perceptual results run counter to what the acoustic differences would predict, as the temporal measures showed larger differences in the non-semantic context. However, the performance of each group was below chance regardless of semantic information in the context. When individual pairs were analyzed separately, there was no pair in which both devoiced and voiceless members were identified better than chance.

In Catalan, then, the underlying voicing contrast was not perceptible to either native Catalan or native English speakers. As in the Polish studies, there was a bias towards voiceless members by both groups of listeners, although this was a more general tendency for the English listeners.

1.2.2.4 Summary

The underlying voicing contrast between devoiced and voiceless obstruents is reported to be perceptible in German and Polish. Listeners identified final obstruents as voiced or voiceless with better-than-chance accuracy when stimuli involved relatively large temporal differences between devoiced and voiceless tokens. It has been suggested here that the perceptual findings for Polish reflect a bias in favor of voiceless obstruents, as percent correct identification was not better than chance for devoiced obstruents. Perceptibility of the German voicing contrast may also reflect a voiceless bias, at least in part. For example, the percentage of voiceless responses for one of the conditions tested by Port and Crawford (1989) was 60%. It is not clear if this is also true of Port and O'Dell

(1985) as performance for devoiced and voiceless members is not reported separately. The results of the perceptual experiments are summarized in Table 1.6.

	German		Polish		Catalan
	12	13	14	15	16
	Port & O'Dell (1985)	Port & Crawford (1989)	Slowiaczek & Szymanska (1989)	Jassem & Richter (1989)	Charles-Luce (1987)
selection of stimuli	------	from dictation and reading tasks	vowel duration differences	-------	3 pairs from 2 semantic contexts
overall performance	59%	69%	61% (for Polish listeners)	53 %	below chance
bias	?	voiceless ?	voiceless	voiceless	voiceless

Table 1.6. Summary of the perceptual studies in three languages. (A question mark (?) indicates that sufficient information was not available.)

1.2.3 General Summary of Final Devoicing Studies

The results of the acoustic and perceptual studies of German, Polish, Russian, and Catalan suggest that there are two types of languages with respect to the neutralizing status of word-final obstruent devoicing. German, Polish, and Russian pattern together, constituting one type of language. In these three languages, final devoicing is non-neutralizing, at least in certain environments. Catalan exemplifies the second type of language, in which final devoicing is neutralizing. Based on the four languages reviewed here, then, there appears to be a relation between orthography and the neutralizing status of final devoicing. Final devoicing seems to be non-neutralizing in languages which maintain the underlying voicing distinction in the orthography (i.e., German, Polish, and Russian), but neutralizing in a language which does not (i.e., Catalan).

Phonetic differences between devoiced and voiceless final obstruents in languages such as German, Polish, and Russian suggest that devoiced obstruents do not surface with the same voicing specification as voiceless obstruents. Rather, such findings suggest that devoiced obstruents may be unspecified for voicing at the output of the phonological component. The lack of phonetic differences between devoiced and voiceless final obstruents in languages such as Catalan, on the other hand, suggest that devoiced obstruents surface with the same voicing specification as voiceless ones (i.e., [-voice]). The differences in the surface specification of segments which undergo final devoicing allows for capturing cross-language differences.

In the present study, the neutralizing status of Turkish final devoicing is investigated. Turkish, like Catalan, does not maintain the underlying voicing distinction in the orthography. If there is a relation between orthography and the neutralizing status of final devoicing, then final devoicing in Turkish would be expected to be neutralizing. In this study, the phonology of Turkish word-final devoicing is discussed in Chapter 2. Chapter 3 presents an experimental study determining the acoustic correlates of the voicing contrast for Turkish non-continuants in intervocalic position. In Chapter 4, the phonetic realization of word-final non-continuants is investigated. In Chapter 5, the results of the present study are compared to those reported for other languages, and the implications of the current study for the relation between phonetics and phonology are explored.

CHAPTER 2

PHONOLOGY OF TURKISH FINAL DEVOICING

In this chapter, the phonology of final devoicing in Turkish is investigated in the SPE framework and in two versions of Underspecification Theory, Contrastive Specification and Radical Underspecification. Underspecification Theory is given a careful consideration because this theory, unlike SPE, can be extended to cover a three-way contrast if required (as discussed below)[1]. In addition, as is shown below, underspecification is independently motivated within Turkish phonology and provides an insightful account of Turkish final devoicing even if that process is shown to require only a two-way surface voicing contrast.

As discussed in Chapter 1, recent phonetic studies have argued that final devoicing is not neutralizing, at least in certain languages under certain conditions. If there is a phonetic difference between devoiced and voiceless obstruents, then a three-way voicing distinction is needed to capture the phonetic facts of obstruents in these languages: voiceless (for voiceless obstruents), devoiced (for underlyingly voiced final obstruents), and voiced (for intervocalic voiced obstruents). Within Underspecification Theory, underspecification of segments (i.e., omission of feature values) is permitted. Underspecification for a given feature can continue throughout the derivation and surface as underspecified at the output of the phonological component. For the feature [voice], for example, segments may surface as positively specified [+voice], negatively specified [-voice], or unspecified [Øvoice]. Recent studies investigating assimilation and nasal

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[1] Underspecification Theory is not intended to give rise to a three-way contrast, as Archangeli (1988) points out. But should a three-way contrast arise, Underspecification Theory can be extended to cover it.

spreading suggest that the phonetic realization of phonologically unspecified segments is distinct from that of phonologically specified segments (Keating, 1988a; Cohn, 1990). Consistent with this approach, a phonetic distinction between final devoiced and voiceless obstruents might be taken as evidence that devoiced obstruents are unspecified for voicing at the output of the phonological component.

Before presenting phonological analyses of Turkish final devoicing, syllable structure and suffixation in Turkish are discussed, as the process of final devoicing interacts with suffixation and hence with syllabification. For example, a vocalic suffix, when attached to a stem with a coda, alters the syllable structure of the stem: the final consonant of the stem syllabifies with the suffix (Ergin, 1962; Gencan, 1971; Göker, 1986). Consonant-initial suffixes, on the other hand, do not change the syllable structure of the stem.

2.1 TURKISH SYLLABLE STRUCTURE

In the representation of Turkish syllable structure, I assume the syllable has two immediate constituents, the onset and the rhyme (Selkirk, 1982; Harris, 1983; Goldsmith, 1990.) (The model of the syllable assumed here is immaterial to arguments presented here. See, for example, Clements and Keyser, 1983; Hayes, 1989, for other models of syllable structure.) Any consonantal segment of Turkish may constitute a one-segment onset[2], and the onset does not branch. The rhyme has two branches: the nucleus and the coda. The nucleus is a necessary constituent which is always a vowel. (Turkish does not have syllabic consonants.) The coda may contain any single consonant except a voiced non-

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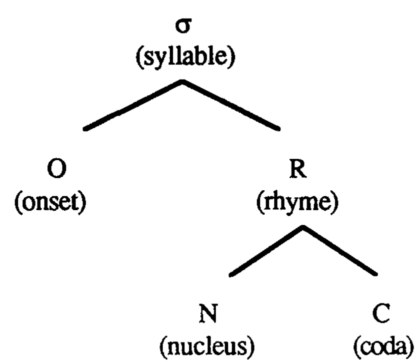
[2] The so-called 'soft g' (ğ in orthography) may constitute an onset except word initially, e.g., a-ğa 'brother'. The acoustic correlates of 'ğ' are controversial. In the literature, ğ is said to lengthen the preceding vowel (see Lees, 1961; Selen, 1979). Konrot (1981), on the other hand, argues that there is phonetic evidence that ğ is a velar consonant in certain cases as evidenced by spectrographic representations, but does not describe in detail its acoustic characteristics.

continuant obstruent (i.e., voiced stops and affricates), and may contain at most two consonants. The co-occurrence restrictions on these syllable-final consonant clusters are not relevant to final devoicing, and will not be discussed here. An arboreal representation of Turkish syllable structure is shown in (2).

(2) Turkish syllable structure



Given this basic syllable structure, the following syllable types are well-formed (Göker, 1986).

(3)	syllable types	examples	gloss
a.	V	o	'he,she,it'
b.	VC	on	'ten'
c.	CV	su	'water'
d.	CVC	kan	'blood'
e.	VCC	ilk	'first'
f.	CVCC	renk	'color'

Individual syllables of a longer string (i.e., a polysyllabic word) conform to the same basic syllable structure. Where more than one segmentation of a given string is possible, segmentation is consistent with the following principle.

(4) Maximal Syllable Onset Principle
In the syllable structure of an utterance, the onsets of syllables are maximized, in conformance with the other principles of basic syllable composition of the language (Selkirk 1982, p.359).

In conformance with the Maximal Syllable Onset Principle, an intervocalic consonant is syllabified with the vowel on its right, as exemplified in (5).

(5)	[ka.pɯ]	'door'
	[ma.sa]	'table'
	[ja.tak]	'bed'
	[a.nɯ]	'memory'
	[a.jak]	'foot'

Similarly, when a vocalic suffix is attached to a stem with a coda, the coda re-syllabifies with the suffix becoming the onset of the following syllable, as in (6)[3].

(6)	nominative	accusative	syllabification	gloss
	[on]	[onu]	o.nu	'ten'
	[kan]	[kanɯ]	ka.nɯ	'blood'
	[ilk]	[ilki]	il.ki	'first'
	[halk]	[halkɯ]	hal.kɯ	'people'

Consonant-initial suffixes, regardless of the stem-final segment -- whether a vowel or a consonant -- remain syllable onsets[4].

[3] The different forms of the accusative suffix are due to the process of vowel harmony in Turkish, whereby suffix vowels agree in backness (and rounding for high vowels) with the preceding vowel. See §2.4.1 for discussion.

[4] The alternation between [d] and [t] is the result of a voicing assimilation process by which certain suffixes, such as the dative suffix in (6), assimilate in voicing to the preceding segment.

(7) nominative	dative	syllabification	gloss
[on]	[on-da]	on.da	'ten'
[kan]	[kan-da]	kan.da	'blood'
[oda]	[oda-da]	oda.da	'room'
[ilk]	[ilk-te]	ilk.te	'first'
[halk]	[halk-ta]	halk.ta	'people'

Turkish suffixes are discussed in more detail in 2.3.

2.2 TURKISH FINAL DEVOICING

Final devoicing in Turkish is described as applying syllable-finally (e.g., Göker, 1986). Examples are shown in (8). The accusative forms illustrate the underlying voicing of the final stops; the nominative singular forms illustrate syllable-final devoicing that is also word final; the nominative plural forms show syllable-final devoicing before a sonorant-initial suffix.

(8) UR	accusative	nominative singular	nominative plural	gloss
/kab/	[kabɯ]	[kap]	[kaplař̥][5]	'container'
/sap/	[sapɯ]	[sap]	[saplař̥]	'stalk'
/kanad/	[kanadɯ]	[kanat]	[kanatlař̥]	'wing'
/sanat/	[sanatɯ]	[sanat]	[sanatlař̥]	'arts'

Syllable-final devoicing in Turkish applies to oral non-continuants (i.e., stops[6] and affricates) but not to fricatives. As shown in (9), voicing is contrastive for fricatives syllable-finally (as well as word-initially and intervocalically).

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[5] The phonetic realization of 'r' in Turkish is dependent on the position in which it occurs. Word-finally, it is realized as a voiceless alveolar fricative flap.

[6] In the present study, final devoicing is assumed to apply to stops representing all three places of articulation. Zimmer (1975) and Sezer (1981), however, argued that syllable-final /k/ alternates with Ø rather than /g/, based on examples such as /ajak/ -> /ajaɯ/. Lees (1961), Underhill (1976), and Rudin (1980), on the other hand, argued that the underlyingly voiced syllable-final /g/ surfaces as /k/, based on

(9) [af] 'pardon' [kas] 'muscle'
[av] 'hunting' [kaz] 'goose'

2.3 TURKISH SUFFIXES

In Turkish, suffixes may be divided into two groups based on whether the initial segment of the suffix is a vowel or a consonant. A vowel-initial suffix, when attached to a stem with a coda, causes the coda of the stem to syllabify with the suffix, as described by the Maximal Syllable Onset Principle. As stem-final non-continuants are not syllable-final in such forms (as in the accusative), final devoicing does not apply.

Consonant-initial suffixes do not alter the syllable structure of the stems to which they are attached, but the voicing of the initial consonant of a suffix may depend on the voicing of the stem-final segment. The consonant-initial suffixes may further be divided into two classes, sonorant- and obstruent-initial suffixes. When the initial consonant is a sonorant, voicing is not affected by the stem. Suffixes with initial obstruents, on the other hand, are of two types. Non-alternating suffixes are those whose initial obstruent is voiceless and remains voiceless regardless of the stem-final segment; alternating suffixes are those in which the voicing of the initial obstruent depends on that of the preceding segment. Examples in (10) illustrate the non-alternating suffixes.

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examples such as /reng/ ->[renk]. However, there is a separate process which deletes intervocalic /g/, resulting in /ajag/ -> /ajagɯ/ -> /ajaɯ/.

(10)	nominative	'in the state of'	gloss
	[sap]	[sapken]	'stalk'
	[af]	[afken]	'dismissal'
	[av]	[avken]	'hunting'
	[el]	[elken]	'hand'
	[aj]	[ajken]	'month'
	[kedi]	[kedijken][7]	'cat'

Examples in (11) illustrate the alternating suffixes, whose initial consonants assimilate in voicing to the stem-final segment:

(11)	nominative	locative	gloss
	[sap]	[sapta]	'stalk'
	[af]	[afta]	'dismissal'
	[av]	[avda]	'hunting'
	[el]	[elde]	'hand'
	[aj]	[ajda]	'month'
	[kedi]	[kedide]	'cat'

Whether or not a suffix-initial consonant is alternating is not rule-governed, but is rather an idiosyncratic characteristic of a given suffix. Although the majority of obstruent-initial suffixes are alternating, the number of suffixes with non-alternating initial consonants is not negligible.

The voicing of alternating suffix-initial obstruents depends on the voicing of the preceding segment (see (11) above). In words in which syllable-final devoicing applies to the stem, the initial consonant of alternating suffixes surfaces as voiceless, suggesting that final devoicing applies before voicing assimilation:

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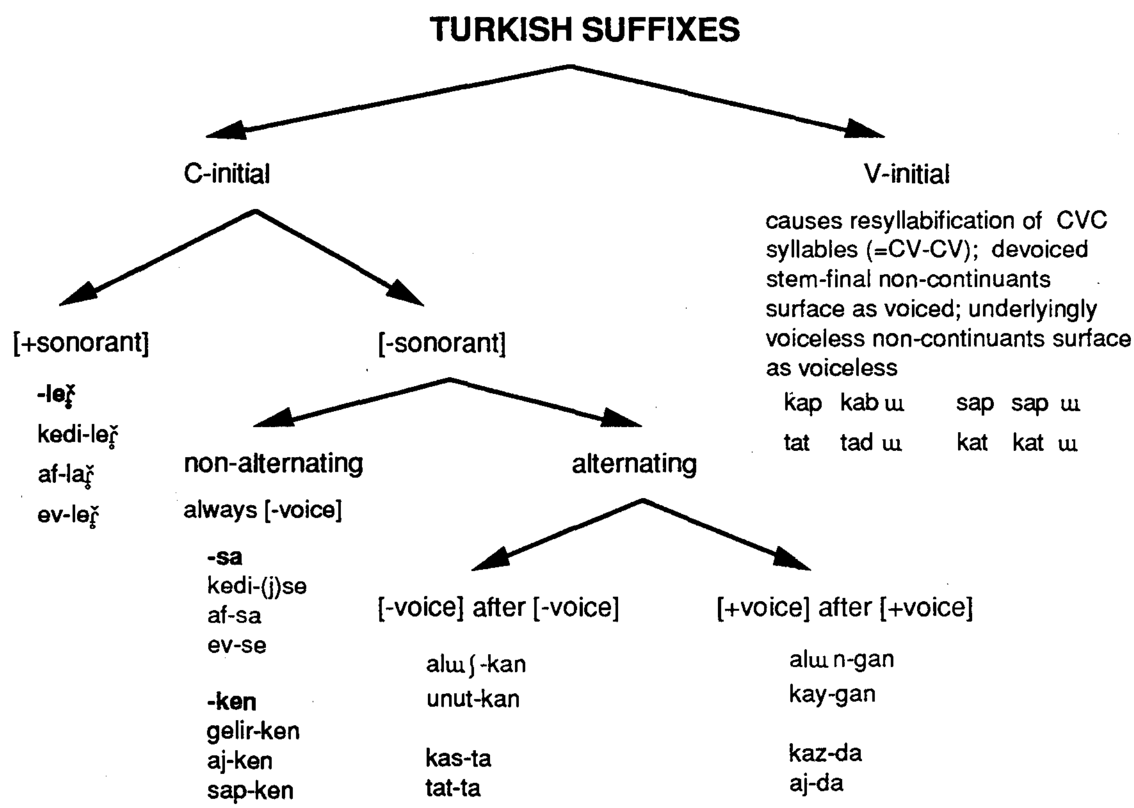
[7] An epenthetic glide is inserted after a stem-final vowel and before certain suffixes (see, for example, Underhill, 1976). The possible explanations are beyond the scope of this study and not relevant to the point made here.

(12)

UR	nominative singular	locative (alternating)	gloss
/kab/	[kap]	[kap-ta]	'container'
/sap/	[sap]	[sap-ta]	'stalk'
/kanad/	[kanat]	[kanat-ta]	'wing'
/sanat/	[sanat]	[sanat-ta]	'arts'

The resulting classification of Turkish suffixes is given in (13).



(13) Classification of Turkish suffixes

In summary, obstruent-initial suffixes are of two types: those which assimilate in voicing to the coda of the stem, and those which are always voiceless regardless of the voicing of the coda. These two types of suffixes have implications for the underlying voicing specification of obstruents in the phonological analysis of Turkish final devoicing, as discussed in the following section.

2.4 PHONOLOGICAL ANALYSES OF TURKISH FINAL DEVOICING

Voicing alternations in segments which undergo final devoicing or voicing assimilation processes can be analyzed in two ways. In one approach, a given segment is assumed to have a value for the feature [voice] in the underlying representation and this value is changed by a rule (i.e., feature-changing rule) somewhere in the derivation (as in SPE). Alternatively, the segment is assumed to have no value for [voice] in the underlying representation and may receive a value during the course of the derivation or may surface with no voicing specification (as within Underspecification Theory). The phonological processes of final devoicing and voicing assimilation as represented by these two approaches are described below.

2.4.1 SPE Account

Final devoicing is analyzed within the SPE framework as follows. An underlyingly voiced obstruent would have a [+voice] specification in the underlying representation, as segments must be fully specified before the application of any phonological rules within this theory. Via a feature-changing rule, the [+voice] specification of the final obstruent is changed to [-voice] in syllable-final position. This formalization does not allow for any phonetic differences between devoiced and voiceless obstruents. Such an analysis, then, predicts that devoiced non-continuants are neutralized syllable-finally. If there are acoustic differences between devoiced and voiceless obstruents, as the results of recent phonetic studies have claimed, then the SPE account of final devoicing is not adequate.

Within SPE, the process of voicing assimilation would also be analyzed as a feature-changing rule. The alternating suffix-initial consonant would be specified as [+voice], and this value would change when preceded by a segment specified as [-voice]. In contrast, non-alternating suffix-initial consonants, specified as [-voice], do not change voicing values depending on the voicing of the preceding segment. An example is given in (14).

(14)

	Alternating suffix		Non-alternating suffix	
UR	af-da [-vce][+vce]	av-da [+vce][+vce]	af-ken [-vce][-vce]	av-ken [+vce][-vce]
Surface	af-ta [-vce][-vce]	av-da [+vce][+vce]	af-ken [-vce][-vce]	av-ken [+vce][-vce]

Thus, feature-changing results in an asymmetry in the assimilation process whereby the two features, [+voice] and [-voice], behave differently: [+voice] onsets assimilate in voicing to the coda, while [-voice] onsets do not.

In the following sections, analyses of Turkish final devoicing within Underspecification Theory are presented. Underspecification Theory, rather than SPE, is considered here as the framework of analysis, as underspecification of segments for Turkish is independently motivated. For example, the process of vowel harmony in Turkish, shown in (15), suggests that certain segments are unspecified for certain features (see, for example, Clements and Sezer (1982) for a detailed discussion).

(15)

	nominative singular	genitive singular	nominative plural	genitive plural
'work'	iʃ	iʃin	iʃleř̥	iʃleɾin
'girl'	kɯz	kɯzɯn	kɯzlař̥	kɯzlaɾɯn
'ash'	kyl	kylyn	kylleř̥	kylleɾin
'widow'	duɫ	duɫun	duɫɫař̥	duɫɫaɾın
'wire'	tel	telin	telleř̥	telleɾin
'snow'	kař̥	kaɾɯn	karlař̥	kařlaɾɯn
'village'	köy	köyün	köyleř̥	köyleɾin
'dust'	toz	tozun	tozlař̥	tozlaɾɯn

The [+high] vowel suffixes (as in the genitive suffix) and [-high] vowel suffixes (as in the plural suffix) behave differently in terms of the harmony process. [+high] vowel suffixes agree in backness and rounding with the stem vowel, whereas [-high] suffixes agree only in backness. The relevant features spread from stem vowels to suffix vowels across intervening consonants.

Within the SPE framework, each segment is represented as a fully specified matrix. Such a view raises two problems for vowel harmony. First, if every segment must be fully specified at all levels, one form of the suffix would have to be chosen arbitrarily as the underlying representation, requiring feature-changing rules to account for the harmony process. Separate rules have to be postulated for the two types of suffixes, as the feature [round] can change in the [+high] vowel suffixes, but not in the [-high] suffixes. Within Underspecification Theory, on the other hand, the harmony process is postulated not as 'feature-changing', but rather as 'feature-filling'. Underlyingly, the genitive suffix, for example, is specified as [+high], and the plural suffix is specified as [-high, -round]. The unspecified features (i.e., [back] and [round] in the genitive suffix and [back] in the plural suffix) are then filled in by the values of the preceding vowel.

Secondly, in SPE, as all segments must be fully specified, consonants and vowels would have values for the same features. An intervening consonant specified for a relevant feature would be expected to block the spreading of that feature from the preceding vowel onto the following vowel. However, intervening consonants do not block the harmony process, suggesting that consonants are not specified for the same features as vowels.

2.4.2 Underspecification Account

Within Underspecification Theory, a segment may lack specification for a given feature. If it is assumed that voiced obstruents are specified as [+voice] and voiceless obstruents are not specified for voicing underlyingly, then final devoicing could be analyzed as delinking of the voicing specification for voiced obstruents. If that segment does not receive a value for voicing during the course of the derivation, it will surface unspecified for voicing (i.e., [Øvoice]).

Voicing assimilation of obstruent-initial suffixes in Turkish can be analyzed such that an alternating suffix-initial obstruent is unspecified for voicing or [Øvoice] and a non-alternating suffix-initial obstruent is specified for voicing as [-voice]. The alternating suffix-initial obstruent receives a value for voicing in the course of the derivation due to spreading of [+voice] or [-voice] from the stem-final segment.

Two versions of Underspecification Theory are considered here: Contrastive Specification and Radical Underspecification. The two versions differ as to whether both values of voicing are specified underlyingly or whether just one value is specified. In the first two sections (§ 2.4.2.1 and § 2.4.2.2), Contrastive Specification and Radical Underspecification are explored, and within each of these versions two separate analyses of Turkish final devoicing are presented. The purpose of the first analysis is to determine whether obstruents are correctly assigned [+voice] and [-voice] specifications within a given version, assuming that only a two-way voicing distinction is needed. If voicing specifications are correctly assigned, then a second analysis is undertaken to determine whether a three-way distinction can be derived in that framework.

In earlier versions of both Contrastive Specification and Radical Underspecification, the feature [voice] is assumed to be binary-valued. Recently, Mester and Ito (1989) have argued that [voice] is a privative feature: only one value of [voice] is present. In the third section (§ 2.4.2.3), analyses of Turkish final devoicing in which [voice] is a privative feature are presented.

2.4.2.1 Contrastive Specification with binary [voice]

In Contrastive Specification, all values of a contrastive feature are specified in the underlying representation (Steriade, 1987). Turkish obstruents contrast in voicing in certain contexts, thus both [+voice] and [-voice] specifications need to be present in their underlying representation, as in (16).

(16)

b	d	g	dʒ	v	z	ʒ
|	|	|	|	|	|	|
[+voice]	[+voice]	[+voice]	[+voice]	[+voice]	[+voice]	[+voice]
p	t	k	tʃ	f	s	ʃ
|	|	|	|	|	|	|
[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]

Contrastive Specification requires all obstruents in Turkish to be specified underlyingly for voicing. Syllable-final non-continuants which are [+voice] underlyingly will receive [-voice] specification by a devoicing rule, as formalized in (17).

(17) Devoicing

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{+voice} \end{bmatrix} \rightarrow \text{[-voice]} \,/\, \underset{\substack{| \\ \text{coda}}}{\underline{\qquad}}$$

To distinguish non-alternating suffix-initial obstruents which are always voiceless (hence specified as [-voice]), from alternating suffix-initial obstruents, the latter are specified as [+voice] underlyingly. Voicing assimilation of these suffixes is accounted for by the spreading rule formalized below.

(18) Spreading

$$\text{[+voice]} \rightarrow \text{[-voice]} \,/\, \underset{\substack{| \\ \text{coda}}}{\text{[-voice]}}\ \underset{\substack{| \\ \text{onset}}}{\underline{\qquad}}$$

This rule has to be restricted to apply only across syllable boundaries (i.e., both the coda and the onset have to be specified in the environment). Otherwise, the voicing specification of a syllable-initial voiceless obstruent, for example, would spread to the coda of that syllable, or to the onset of the following syllable if the intervening coda is unspecified for voicing, as in (19).

(19)			
	Spreading	kaz [-vce][+vce]	kim - de [-vce] [+vce]
	Surface	* kas [-vce][-vce]	* kim - de [-vce] [-vce]

By the default rule in (20), which applies after the devoicing and spreading rules, segments unspecified for voicing receive a voicing specification. (The voicing specification of vowels is not indicated in the subsequent derivations.) In general, default rules apply at the end of a derivation to fill in the unspecified feature values.

(20) Default rule

$[\text{Ø}voice] \rightarrow [+voice]$

Sample derivations illustrating the behavior of alternating and non-alternating suffix-initial obstruents are given in (21a) and (21b), respectively. In (21a), the initial obstruent of the locative suffix assimilates in voicing to the preceding segment. In (21b), the initial obstruent of the suffix *'in the state of'* does not assimilate due to the (idiosyncratic) non-alternating status of the suffix.

(21) a. alternating suffix

UR	kab [-vce][+vce]	sap [-vce][-vce]	av [+vce]	af [-vce]	kim [-vce]
Suffixation	kab- da [-vce][+vce][+vce]	sap- da [-vce][-vce][+vce]	av- da [+vce][+vce]	af- da [-vce][+vce]	kim- de [-vce] [+vce]
Devoicing rule	kap- da[8] [-vce][-vce][+vce]	n/a	n/a	n/a	n/a
Spreading rule	kap- da [-vce][-vce][+vce]	sap- da [-vce][-vce][+vce]	n/a	af- da [-vce][+vce]	n/a
Default rule	n/a	n/a	n/a	n/a	kim- de [-vce][+vce][+vce]
Surface	kap- ta [-vce][-vce]	sap- ta [-vce][-vce]	av- da [+vce][+vce]	af- ta [-vce][-vce]	kim- de[9] [+vce][+vce]

---

[8] For alternating suffix-initial obstruents, and for word-final non-continuants, phonetic symbols representing the underlying voicing is used until after that voicing specification is changed by a rule.

[9] The voicing specification of word-initial obstruents is omitted in the surface form, as it is not relevant to the analysis here.

b. non-alternating suffix

UR	kab [-vce][+vce]	sap [-vce][-vce]	av [+vce]	af [-vce]	kim [-vce]
Suffixation	kab- ken [-vce][+vce][-vce]	sap- ken [-vce][-vce][-vce]	av- ken [+vce][-vce]	af- ken [-vce][-vce]	kim- ken [-vce] [-vce]
Devoicing rule	kap- ken [-vce][-vce][-vce]	n/a	n/a	n/a	n/a
Spreading rule	n/a	n/a	n/a	n/a	n/a
Default rule	n/a	n/a	n/a	n/a	kim- ken [-vce][+vce][-vce]
Surface	kap-ken [-vce][-vce]	sap-ken [-vce][-vce]	av-ken [+vce][-vce]	af-ken [-vce][-vce]	kim-ken [+vce][-vce]

As the derivations in (21) illustrate, both devoicing and spreading rules within Contrastive Specification are feature-changing rules: devoicing changes the [+voice] specification of syllable-final non-continuants and spreading changes that of suffix-initial obstruents preceded by a voiceless segment. As in the SPE analysis, there is an asymmetry between [+voice] and [-voice] in the Contrastive Specification analysis. Although [+voice] assimilates to a preceding [-voice], [-voice] does not assimilate to a preceding [+voice] in (21b) (as in [av-ken], not [*av-gen]). This asymmetry needs to be stipulated.

In these derivations, devoiced and underlyingly voiceless non-continuants surface with the same voicing specification, leading to the expectation that they are phonetically identical. The derivations in (21) yield the correct output if phonetic data indicate a two-way surface voicing contrast.

Can Contrastive Specification yield a three-way surface voicing contrast? In such an analysis, the devoicing rule would be a process which delinks [+voice] specification from syllable-final non-continuants[10]:

(22) Devoicing

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{+voice} \end{bmatrix} \rightarrow [\text{Øvoice}] \; / \; \underset{\substack{| \\ \text{coda}}}{\underline{\quad\quad}}$$

Alternating suffix-initial obstruents are again assumed to be specified as [+voice], as all obstruents must be specified for voicing underlyingly within this view. The process of [-voice] spreading from voiceless segments to alternating suffix-initial obstruents can be accounted for by the rule formalized in (23).

(23) [-voice] Spreading

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{Øvoice} \end{bmatrix} \rightarrow [\text{-voice}] \; / \underset{\substack{| \\ \text{coda}}}{[\text{-voice}]} \; \underset{\substack{| \\ \text{onset}}}{\underline{\quad\quad}}$$

---

10 It is not clear whether Contrastive Specification allows a rule such as (22), which may yield a three-way voicing contrast. For the sake of argument, it is assumed here that it does allow such a rule.

As in (18), Spreading in (23) needs to be restricted so that the spreading of voicing is from the coda of one syllable to the onset of the following syllable. Otherwise, the voicing of the stem initial obstruent in /kab-da/, for example, can spread to the suffix-initial stop as the syllable-final stop no longer has a voicing specification as a result of the devoicing rule, as shown in (24).

(24) Devoicing

kab - da
[-vce][+vce]

Spreading

* kab - da
[-vce]

The default rule in (20) has to apply before the devoicing rule so that devoiced non-continuants do not receive [+voice] specification[11]. The derivations are shown in (25).

[11] This ordering follows from the Redundancy Rule Ordering Constraint of Archangeli (1984), which requires an unspecified feature value to be filled before any rule that refers to that feature value applies.

(25) a. alternating suffix

UR	kab [-vce][+vce]	sap [-vce][-vce]	av [+vce]	af [-vce]	kim [-vce]
Suffixation	kab-da [-vce][+vce]	sap-da [-vce][-vce]	av-da [+vce]	af-da [-vce]	kim-de [-vce]
Default rule	n/a	n/a	n/a	n/a	kim-de [-vce][+vce]
Devoicing	kab-da | ǂ [-vce][+vce]	n/a	n/a	n/a	n/a
[-vce] spreading	n/a	sap- da [-vce][-vce][+vce]	n/a	af- da [-vce][+vce]	n/a
Surface	* kap- da [Øvce][+vce]	sap- ta [-vce][-vce]	av- da [+vce][+vce]	af- ta [-vce][-vce]	kim- de [+vce][+vce]

b. non-alternating suffix

UR	kab [-vce][+vce]	sap [-vce][-vce]	av [+vce]	af [-vce]	kim [-vce]
Suffixation	kab- ken [-vce][+vce][-vce]	sap- ken [-vce][-vce][-vce]	av- ken [+vce][-vce]	af- ken [-vce][-vce]	kim- ken [-vce] [-vce]
Default rule	n/a	n/a	n/a	n/a	kim- ken [-vce][+vce][-vce]
Devoicing	kab- ken [-vce][+vce][-vce]	n/a	n/a	n/a	n/a
[-vce] spreading	n/a	n/a	n/a	n/a	n/a
Surface	kap- ken [Øvce][-vce]	sap- ken [-vce][-vce]	av- ken [+vce][-vce]	af- ken [-vce][-vce]	kim-ken [+vce][-vce]

In these derivations, a ternary voicing contrast surfaces among voiced continuants ([+voice]), devoiced non-continuants ([Øvoice]), and voiceless obstruents ([-voice]). However, the initial consonant of the alternating suffix incorrectly surfaces as [+voice] after a devoiced non-continuant (25a).

Within Contrastive Specification, then, the analysis with a two-way surface voicing contrast correctly assigns plus and minus voice specifications to obstruents (as in (21)), but the analysis with a three-way voicing contrast does not (as in (25)). When voicing specification of obstruents is correctly assigned, devoicing and spreading rules are necessarily feature-changing rules whereby [+voice] specification becomes [-voice] for syllable-final non-continuants and initial obstruents of alternating suffixes (when preceded by a voiceless segment). As mentioned above, such an analysis is similar to that within the SPE framework where an asymmetry between [+voice] and [-voice] is present.

2.4.2.2 Radical Underspecification with binary [voice]

Radical Underspecification Theory allows all predictable values for a given feature to be absent in the underlying representation (Archangeli, 1988). For the feature [±voice], for example, only one value, either [+voice] or [-voice], is present for obstruents in the underlying representation, as the other value is predictable. The question, however, becomes which value to specify underlyingly for the feature [voice]. Both options will be considered here. First, it is assumed that [-voice] is unmarked and [+voice] is specified underlyingly. Thus, as shown below, voiced obstruents are assigned plus values for voicing whereas voiceless obstruents are unspecified:

(26)

p	t	k	tʃ	f	s	ʃ	b	d	g	dʒ	v	z	ʒ
							|	|	|	|	|	|	|
							[+voice]	[+voice]	[+voice]	[+voice]	[+voice]	[+voice]	[+voice]

The devoicing rule, as seen in (27), is a feature-changing rule whereby the [+voice] specification of devoiced non-continuants becomes [-voice]. If the devoicing rule were postulated as delinking of [+voice], then a default rule which fills in [-voice] specification would be necessary so that devoiced non-continuants receive voicing specification before the spreading rule applies. However, via such a default rule, vowels and sonorants would incorrectly receive [-voice] specification.

(27) Devoicing

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{+voice} \end{bmatrix} \rightarrow \text{[-voice]} \: / \: \underset{\substack{| \\ \text{coda}}}{\underline{\quad\quad}}$$

To distinguish alternating and non-alternating suffix-initial obstruents, alternating suffix-initial obstruents are underlyingly specified for voicing and non-alternating suffix-initial obstruents are underlyingly unspecified. Within this approach, a rule, shown in (28), which spreads [-voice] specification from the preceding segment to the alternating suffix-initial obstruents is necessary. As in (18), syllable coda and onset have to be specified as a necessary environment in (28). Otherwise, the voicing specification of syllable-initial obstruents would incorrectly spread to the syllable-initial obstruent of the following syllable (see (19)).

(28) [-voice] Spreading

$$\text{[+voice]} \rightarrow \text{[-voice]} \: / \: \underset{\substack{| \\ \text{coda}}}{\text{[-voice]}} \; \underset{\substack{| \\ \text{onset}}}{\underline{\quad\quad}}$$

The default rule in (29) applies at the end of the derivation so that segments unspecified for voicing receive [+voice] specification, as shown in (30).

(29) Default rule

[Øvoice] → [+voice]

(30) a. alternating suffix

UR	kab [+vce]	sap	av [+vce]	af	kim
Suffixation	kab-da [+vce][+vce]	sap-da [+vce]	av-da [+vce][+vce]	af-da [+vce]	kim-de [+vce]
Devoicing	kap-da [-vce][+vce]	n/a	n/a	n/a	n/a
Spreading	kap-da [-vce][+vce]	sap-da [-vce][+vce]	n/a	af-da [-vce][+vce]	n/a
Default	n/a	n/a	n/a	n/a	kim-de [+vce][+vce]
Surface	kap-ta [-vce][-vce]	sap-ta [-vce][-vce]	av-da [+vce][+vce]	af-ta [-vce][-vce]	kim-de [+vce][-vce]

b. non-alternating suffix

UR	kab [+vce] on b	sap	av [+vce] on v	af	kim
Suffixation	kab-ken [+vce] on b	sap-ken	av-ken [+vce] on v	af-ken	kim-ken
Devoicing	kap-ken [-vce] on p	n/a	n/a	n/a	n/a
Spreading	n/a	n/a	n/a	n/a	n/a
Default	n/a	n/a	n/a	n/a	kim-ken [+vce][-vce]
Surface	kap-ken [-vce][-vce]	sap-ken [-vce][-vce]	av-ken [+vce][-vce]	af-ken [-vce][-vce]	kim-ken [+vce][-vce]

In the derivations in (30), obstruents are correctly assigned voicing. However, this analysis is similar to that in the SPE analysis, as devoicing and spreading rules are feature-changing rules, consequently resulting in an asymmetry between [+voice] and [-voice].

In (30), voiced obstruents were specified for voicing in the underlying representation. Below, the second option is considered where voiceless obstruents, rather than voiced obstruents, are assumed to be specified for voicing underlyingly, as in (31) (compare (25) above).

(31)

p	t	k	tʃ	f	s	ʃ	b	d	g	dʒ	v	z	ʒ
|	|	|	|	|	|	|							
[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]							

As shown in (31), all voiced obstruents are unspecified for voicing underlyingly. However, voiced fricatives surface as [+voice] at the output of phonology, whereas voiced non-continuants devoice syllable-finally. Thus final devoicing applies to non-continuants unspecified for voicing. This rule, formalized in (32), assigns [-voice] specification to underlyingly unspecified non-continuants in syllable-final position.

(32) Devoicing

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{Ø voice} \end{bmatrix} \rightarrow [\text{-voice}] \ / \ \underset{\substack{| \\ \text{coda}}}{\underline{\quad\quad}}$$

The initial obstruent of alternating suffixes surfaces as voiceless when preceded by a voiceless segment. This voicing assimilation can be accounted for by a rule which assigns [-voice] to unspecified segments following [-voice], as in (33). Again, [-voice] spreading needs to be restricted so that it applies across syllable boundaries.

(33) [-voice] Spreading

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{Øvoice} \end{bmatrix} \rightarrow [\text{-voice}] \,/\, \underset{\text{coda}}{\underset{|}{[\text{-voice}]}} \;\; \underset{\text{onset}}{\underset{|}{\_\_\_\_}}$$

Then by the default rule, formalized in (34), segments still unspecified for voicing receive [+voice] specification.

(34) Default rule

[Øvoice] → [+voice]

The resulting derivation is shown in (35).

(35) a. alternating suffix

UR	kab	sap [-vce]	av	af [-vce]	kim
Suffixation	kab-da	sap-da [-vce]	av-da	af-da [-vce]	kim-de
Devoicing	kap-da [-vce]	n/a	n/a	n/a	n/a
[-vce] Spreading	kap-da [-vce]	sap-da [-vce]	n/a	af-da [-vce]	n/a
Default	n/a	n/a	av-da [+vce][+vce]	n/a	kim-de [+vce][+vce]
Surface	kap-ta [-vce][-vce]	sap-ta [-vce][-vce]	av-da [+vce][+vce]	af-ta [-vce][-vce]	kim-de [+vce][+vce]

b. non-alternating suffix

UR	kab	sap | [-vce]	av	af | [-vce]	kim
Suffixation	kab-ken | [-vce]	sap-ken | | [-vce][-vce]	av-ken | [-vce]	af-ken | | [-vce][-vce]	kim-ken | [-vce]
Devoicing	kap-ken | | [-vce][-vce]	n/a	n/a	n/a	n/a
[-vce] Spreading	n/a	n/a	n/a	n/a	n/a
Default	n/a	n/a	av-ken | | [+vce][-vce]	n/a	kim-ken | | [+vce][-vce]
Surface	kap-ken | | [-vce][-vce]	sap-ken | | [-vce][-vce]	av-ken | | [+vce][-vce]	af-ken | | [-vce][-vce]	kim-ken | | [+vce][-vce]

This analysis differs from the SPE analysis and that of Contrastive Specification in an important way; namely, there is no feature-changing rule, but feature-filling only. Consequently, there is no asymmetry between [+voice] and [-voice] spreading. In particular, [-voice] spreads because the target segments have no voicing specification. In contrast, [+voice] does not spread, not because it differs from [-voice] in some intrinsic way, but because segments already have a voicing value. This analysis is similar to the well-known process in tonology, where tone-spreading to toneless segments is common, but tonal replacement is rare (Williams, 1971/6; Pulleyblank, 1986).

The above analysis yields a binary surface voicing contrast. Is it possible, within this theory, to derive a three-way surface voicing contrast in syllable-final position (i.e., [+voice] for voiced fricatives, [Øvoice] for devoiced non-continuants, and [-voice] for voiceless non-continuants and fricatives)? As seen below, the rules needed to derive a three-way contrast are complex and in some cases counter-intuitive. First, a rule which fills in [+voice] specification on voiced continuants is necessary to distinguish voiced fricatives from devoiced non-continuants. This rule fills in [+voice] for vowels and sonorants as well.

(36) Feature-filling

$$\begin{bmatrix} \text{+cont} \\ \text{Øvoice} \end{bmatrix} \rightarrow \text{[+voice]}$$

A second rule, formalized in (37), is needed to spread [-voice] from voiceless obstruents to the initial obstruents of alternating suffixes.

(37) [-voice] Spreading

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{Øvoice} \end{bmatrix} \rightarrow \text{[-voice] /[-voice] \_\_\_\_\_}$$

Vowels must receive [+voice] specification (via (36)) at an early stage of the derivation, otherwise, [-voice] would incorrectly spread from a voiceless onset to an unspecified coda, as in (38).

(38)

UR	kab | [-vce]	sap | | [-vce][-vce]
Suffixation	kab-da | [-vce]	sap-da | | [-vce][-vce]
[-vce] spreading	kab-da |/ [-vce]	sap - da | |/ [-vce][-vce]
Surface	* kab-da | | [-vce][-vce]	sap - da | | | [-vce][-vce][-vce]

Vowels must also receive [+voice] specification at an early stage of the derivation so that unspecified stops which surface as [+voice] intervocalically (i.e., when a vocalic suffix is added) can receive their [+voice] specification from the preceding vowel.

A third rule, shown in (39), which spreads [+voice] from voiced obstruents to the initial obstruent of an alternating suffix, accounts for voicing assimilation. This rule is also restricted to apply across syllable boundaries. Vowels have received [+voice] specification by this point in the derivation, and can spread [+voice] to following devoiced non-continuants. This spreading, however, must be blocked from applying to syllable-final non-continuants (i.e., to consonants which undergo final devoicing).

(39) [+voice] spreading rule

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \\ \text{Øvoice} \end{bmatrix} \rightarrow [\text{+voice}] \,/\, \underset{\text{coda}}{\underset{|}{[\text{+voice}]}} \; \underset{\text{onset}}{\underset{|}{\_\_\_\_}}$$

Underlyingly unspecified non-continuants which do not receive voicing specification by a rule in the derivation surface unspecified for voicing. The derivations are shown in (40).

(40) a. alternating suffix

<table>
<tr><td>UR</td><td>kab
|
[-vce]</td><td>sap
| |
[-vce][-vce]</td><td>av</td><td>af
|
[-vce]</td><td>kim
|
[-vce]</td></tr>
<tr><td>Suffixation</td><td>kab-da
|
[-vce]</td><td>sap-da
| |
[-vce][-vce]</td><td>av-da</td><td>af-da
|
[-vce]</td><td>kim-de
|
[-vce]</td></tr>
<tr><td>Feature-filling</td><td>kab-da
| | |
- + +</td><td>sap-da
||| |
-+- +</td><td>av-da
| | |
+ + +</td><td>af-da
|| |
+- +</td><td>kim-de[12]
| | |
- + +</td></tr>
<tr><td>[-vce] Spreading</td><td>n/a</td><td>sap-da
||/ |
- +- +</td><td>n/a</td><td>af-da
|/ |
+- +</td><td>n/a</td></tr>
<tr><td>[+vce] Spreading</td><td>n/a</td><td>n/a</td><td>av-da
|/ |
++ +</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Surface</td><td>kab-da
| || | |
- +Ø Ø+</td><td>sap-ta
||| | |
-+- - +</td><td>av-da
| | | |
+ + + +</td><td>af-ta
|| ||
+- - +</td><td>* kim-de
||| ||
- +Ø Ø -</td></tr>
</table>

12 Due to lack of space, voicing is indicated as (-) for voiceless, (+) for voiced, and left blank or as (Ø) for unspecified segments.

b. non-alternating suffix

<table>
<tr><td>Suffixation</td><td>kab-ken
|
[-vce]</td><td>sap-ken
| |
[-vce][-vce]</td><td>av-ken
|
[-vce]</td><td>af-ken
| |
[-vce][-vce]</td><td>kim-ken
|
[-vce]</td></tr>
<tr><td>Feature-filling</td><td>kab-ken
| | | |
- + - +</td><td>sap-ken
| | | | |
-+- - +</td><td>av-ken
| | | |
+ + -+</td><td>af-ken
| | | |
+- -+</td><td>kim-ken
| | | |
- + -+</td></tr>
<tr><td>[-vce] Spreading</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td>[+vce] Spreading</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Surface</td><td>kab-ken
| | | | | |
- +Ø - +Ø</td><td>sap-ken
| | | | | |
-+- - +Ø</td><td>av-ken
| | | | |
+ + - +Ø</td><td>af-ken
| | | | | |
+- + +Ø</td><td>* kim-ken
| | | | | |
- +Ø - +Ø</td></tr>
</table>

In this analysis, devoiced non-continuants surface unspecified for voicing not as a result of a devoicing rule, but rather as a result of the failure of either the feature-filling rule or spreading rules to apply. That is, voiced non-continuants do not receive voicing specification by rule (36) or by subsequent rules, and thus underspecification of voiced non-continuants continues throughout the derivation. Syllable-initial voiced non-continuants also remain unspecified for voicing throughout the derivation, and hence surface as [Øvoice] (as in the derivation for [kabda] in (40a)). Consequently, alternating suffix-initial non-continuants, when preceded by a devoiced non-continuant, surface unspecified for voicing.

Nasal stops also surface unspecified for voicing -- the same as devoiced non-continuants -- as rule (36) assigns voicing values only to continuants. Nasal stops, like oral stops and affricates, are non-continuant consonants. Thus, rule (36) has to be revised to assign [+voice] specification to nasals but not to syllable-final non-continuants.

Thus, in (40), a ternary surface voicing contrast is derived, but nasals surface with incorrect voicing specification. The incorrect specification for nasals can be handled by complicating the feature-filling rule. However, whether underspecification of syllable-initial non-continuants is the correct surface form is an empirical question that would need to be resolved by phonetic analysis.

2.4.2.3 [voice] as a Privative Feature (Inherent Underspecification)

When [voice] is assumed to be a privative feature, analyses of Turkish final devoicing are the same within Contrastive Specification and Radical Underspecification.

Mester and Ito (1989) argue that [voice] is universally a privative feature, whereby only one value of the feature [voice] is specified underlyingly. An unspecified segment is assumed to have the feature value opposite of the specified value, not allowing a three-way contrast. Within Inherent Underspecification, default rules which fill in the absent value of a given feature are not allowed. Thus, if an underspecified segment does not receive a value for a given feature during the course of the derivation, no reference to that segment can be made. For example, the derivations in (30) would yield incorrect outputs within Inherent Underspecification, as voiceless obstruents would not receive a voicing value. The derivations in (30) are repeated below in (43), with the default and the spreading rules omitted. Omission of the spreading rule is a consequence of no default rules. That is, the environment for this spreading rule cannot be specified, as voiceless segments do not receive a voicing value during the course of the derivation[13].

---

[13] A phonetic interpretation rule will be needed to realize segments unspecified for voicing as voiceless.

As in (30), in Mester and Ito's (1989) approach, [voice] is specified for voiced rather than voiceless obstruents because [-voice] is the universally unmarked value for obstruents. Under this approach, the underlying specification for [voice] for Turkish obstruents would be as in (41).

(41)

p	t	k	tʃ	f	s	ʃ	b	d	g	dʒ	v	z	ʒ
							|	|	|	|	|	|	|
							[voice]	[voice]	[voice]	[voice]	[voice]	[voice]	[voice]

Devoicing of syllable-final non-continuants is accounted for by a delinking rule, formalized in (42).

(42) Delinking

X	→	X	/	___	
|		ǂ		|	
[voice]		[voice]		coda	where X is [-cont, -son]

Derivations are shown in (43). (To distinguish the two types of suffixes in the underlying representation, alternating suffix-initial obstruents are assumed to be specified for voicing whereas non-alternating suffix-initial obstruents are unspecified. Underspecification of both types of suffixes would not yield the correct outputs, as the different behavior of these suffixes cannot be captured.)

(43) a. alternating suffix

UR	kab | [vce]	sap	av | [vce]	af	kim | [vce]
Suffixation	kab-da | | [vce][vce]	sap-da | [vce]	av-da | | [vce][vce]	af-da | [vce]	kim-de | | [vce][vce]
Delinking	kab-da ǂ | [vce][vce]	n/a	n/a	n/a	n/a
Surface	* kap-da[14] | [vce]	* sap-da | [vce]	av-da | | [vce][vce]	*af-da | [vce]	kim-de | | [vce][vce]

[14] In this analysis, lack of [voice] specification means voiceless.

b. non-alternating suffix

<table>
<tr><td>UR</td><td>kab
|
[vce]</td><td>sap</td><td>av
|
[vce]</td><td>af</td><td>kim
|
[vce]</td></tr>
<tr><td>Suffixation</td><td>kab-ken
|
[vce]</td><td>sap-ken</td><td>av-ken
|
[vce]</td><td>af-ken</td><td>kim-ken
|
[vce]</td></tr>
<tr><td>Delinking</td><td>kab-ken
ǂ
[vce]</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Surface</td><td>kap-ken</td><td>sap-ken</td><td>av-ken
|
[vce]</td><td>af-ken</td><td>kim-ken
|
[vce]</td></tr>
</table>

In (43a), the locative suffix *-da* incorrectly surfaces with voicing specification regardless of the voicing of the preceding segment. Thus, [+voice] as a privative feature does not derive the correct outputs in Turkish.

Alternatively, within Inherent Underspecification (but contrary to Mester and Ito's approach), suppose that voiceless obstruents, rather than voiced obstruents, are specified for voicing underlyingly, as in (44) (compare (41) above). (To avoid confusion with the previous analysis, [-voice] is used to represent the voicing specification of voiceless obstruents.)

(44)

p	t	k	tʃ	f	s	ʃ	b	d	g	dʒ	v	z	ʒ
[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]	[-voice]							

In this analysis, two rules are needed: devoicing and [-voice] spreading. The devoicing rule applies to syllable-final non-continuants unspecified for voicing:

(45) Devoicing

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \end{bmatrix} \rightarrow \text{[-voice]} \; / \; \underset{\substack{| \\ \text{coda}}}{\underline{\quad\quad}}$$

By rule (45), syllable-final non-continuants receive [-voice] specification. Then, a spreading rule applies to assign voicing specification to alternating suffix-initial obstruents following voiceless codas. The spreading rule is formulated as follows.

(46) [-voice] Spreading

$$\begin{bmatrix} \text{-son} \\ \text{-cont} \end{bmatrix} \rightarrow \text{[-voice]} \; / \; \underset{\substack{| \\ \text{coda}}}{\text{[-voice]}} \; \underset{\substack{| \\ \text{onset}}}{\underline{\quad\quad}}$$

Derivations are given in (47).

(47) a. alternating suffix

UR	kab	sap [-vce]	av	af [-vce]	kim
Suffixation	kab-da	sap-da [-vce]	av-da	af-da [-vce]	kim-de
Devoicing	kap-da [-vce]	n/a	n/a	n/a	n/a
[-vce] Spreading	kap- da [-vce]	sap- da [-vce]	n/a	af- da [-vce]	n/a
Surface	kap- ta [-vce][-vce]	sap- ta [-vce][-vce]	av-da	af- ta [-vce][-vce]	kim-de

b. non-alternating suffix

UR	kab	sap | [-vce]	av	af | [-vce]	kim
Suffixation	kab-ken | [-vce]	sap-ken | | [-vce][-vce]	av-ken | [-vce]	af-ken | | [-vce][-vce]	kim-ken | [-vce]
Devoicing	kap-ken | | [-vce][-vce]	n/a	n/a	n/a	n/a
[-vce] Spreading	n/a	n/a	n/a	n/a	n/a
Surface	kap- ken | | [-vce][-vce]	sap- ken | | [-vce][-vce]	av-ken | [-vce]	af- ken | | [-vce][-vce]	kim-ken | [-vce]

Within this analysis, obstruents are assigned correct voicing specification, assuming that a binary surface voicing contrast is sufficient. As seen in (34), devoiced and voiceless non-continuants surface with the same voicing specification as a result of the devoicing rule. The devoicing rule is needed to distinguish the behavior of syllable-final non-continuants from that of fricatives. Similarly, due to the [-voice] spreading rule, alternating suffix-initial obstruents surface with the same voicing specification as non-alternating suffix-initial obstruents (i.e., [-voice]), following both devoiced and voiceless non-continuants. The spreading rule is necessary because the alternating suffix-initial obstruents are voiced following voiced codas (e.g., *av-da*) and voiceless following voiceless codas (e.g., *af-ta*). As there is no way of representing the voicing contrast between [Øvoice] and [+voice] underlyingly within privative theory, both devoiced and voiceless non-continuant codas, as well as alternating suffix-initial obstruents following these codas, surface with the identical voicing specification (i.e., [-voice]).

To summarize, within Inherent Underspecification, [+voice] as a privative feature for obstruents does not derive the correct surface forms for a binary voicing contrast in Turkish. [-voice] as a privative feature, on the other hand, derives a two-way surface voicing distinction -- voiced fricatives surface as voiced, devoiced and voiceless non-continuants surface as voiceless. As mentioned above, a three-way surface voicing distinction is not possible within this approach. In (47), for example, segments with voicing specification at the end of the derivation are voiceless obstruents, whereas unspecified segments are assumed to be voiced.

2.4.3 Summary

In the phonological analysis of final devoicing in Turkish, two versions of Underspecification Theory were explored. Within each version, analyses with [voice] as a binary-valued feature and as a privative feature were presented. Assuming a two-way surface voicing distinction is adequate, Contrastive Specification and Radical Underspecification with both binary [voice] and privative [voice] yield the correct outputs. Thus, final devoicing in Turkish does not argue for either a privative or binary feature theory. Although within both Contrastive Specification and Radical Underspecification the correct outputs are derived, the presence of only one voicing specification in the underlying representation may be preferred, as the presence of both [+voice] and [-voice] specification as in Contrastive Specification requires feature-changing rules which result in an asymmetry between [+voice] and [-voice]. Within Radical Underspecification, on the other hand, when [-voice] is specified underlyingly, devoicing and voicing assimilation processes are described as filling and spreading of the feature [-voice].

When only one value of the feature [voice] is present, underlying [-voice] rather than [+voice] specification is preferred for Turkish obstruents. In Radical Underspecification with binary [voice], underlying [+voice] specification requires devoicing and spreading rules to be feature-changing rules, which results in an asymmetry between [+voice] and [-voice]. When [voice] is considered to be a privative feature, underlying [+voice] specification does not derive the correct surface forms.

A ternary surface voicing contrast can be derived within Radical Underspecification when the feature [voice] is assumed to be binary-valued. However, the rules necessary to derive a three-way surface voicing contrast appear to be ad hoc and counter-intuitive.

2.5 CONCLUSION

Within Underspecification Theory, final devoicing of Turkish can be analyzed as yielding both binary and ternary surface voicing contrasts. The phonetic predictions of an analysis with a binary surface voicing contrast are substantially different from those with a ternary surface voicing contrast. In an analysis which derives a binary surface voicing contrast, both devoiced and voiceless non-continuants surface with [-voice] specification, suggesting that the underlying voicing distinction of devoiced non-continuants is neutralized in syllable-final position. Consequently, devoiced and voiceless non-continuants are expected to be phonetically identical.

In an analysis in which a ternary surface voicing contrast is derived, devoiced non-continuants surface unspecified for voicing ([Øvoice]) at the output of the phonological component. A devoiced obstruent constituting a distinct phonological voicing category from [+voice] and [-voice] might be expected to be phonetically different from voiced and voiceless obstruents. Thus, the underlying voicing distinction of devoiced non-continuants would not be neutralized. Keating (1988) and Cohn (1990) present phonetic evidence suggesting that certain segments surface unspecified at the end of the phonological component, and that their phonetic realization is distinct from that of fully specified segments.

The phonetic realization of final devoiced non-continuants will address the question of which phonological analysis is correct for Turkish. If devoiced and voiceless non-continuants surface with the same voicing specification, then a two-way surface voicing is adequate. If, however, the phonetic structure of Turkish indicates that devoiced non-continuants are acoustically distinct from voiceless ones, then the phonology has to be able to account for a three-way surface voicing. The results of the phonetic investigation of Turkish final devoicing are presented in Chapter 4.

CHAPTER 3

ACOUSTIC CORRELATES OF VOICING CONTRAST OF INTERVOCALIC STOPS IN TURKISH

Previous studies have determined the acoustic correlates of the voicing contrast in obstruents in such languages as English (e.g., Halle, Hughes and Radley, 1957; Chen, 1970; Zue, 1976), Spanish (Zimmerman and Sapon, 1958), French, Russian, and Korean (Chen, 1970). Other studies have demonstrated cross-language differences in the relevant acoustic properties (e.g., Lisker and Abramson, 1964; Mitleb, 1984; Keating, 1984, 1985). This chapter investigates the acoustic correlates of voicing in Turkish stops in intervocalic position. Although the acoustic characteristics of word-final stops are of primary interest in this study, the acoustic correlates of stops in environments of contrast (as in intervocalic position) need to be identified in order to determine which properties should be investigated in an environment of potential neutralization.

The voicing contrast in obstruents is determined by the presence or absence of vocal cord vibration during the production of the obstruent or, in the case of stops, by the presence or absence of aspiration following the release of stop closure, or both (Lisker and Abramson, 1964, 1967). Early cross-linguistic phonetic studies have also shown that voicing of obstruents influences the duration of the preceding vowel (Belasco, 1953; House and Fairbanks, 1953; Zimmerman and Sapon, 1958; Peterson and Lehiste, 1960; House, 1961; Delattre, 1962; Chen, 1970; Umeda, 1975) and the duration of the constriction itself (Lisker, 1952, 1972; Umeda, 1977). Traditionally, then, studies have recognized that the voicing distinction in obstruents may be cued by one or more of four temporal parameters: duration of voicing into constriction, duration of aspiration following constriction release (for stops), duration of the vowel preceding the obstruent and overall duration of the constriction itself. In general, the duration of voicing into constriction and the duration of the preceding vowel are longer before voiced obstruents than before voiceless. Aspiration and overall constriction durations, on the other hand, are generally shorter for voiced than for voiceless obstruents.

To determine whether one or more of these four temporal parameters are acoustic correlates of the voicing contrast in Turkish obstruents, intervocalic voiced and voiceless stops are investigated. In Turkish, voicing of stops is contrastive word-initially as well as intervocalically. The selection of intervocalic stops in the current study is motivated by two considerations. First, the measures taken here will be compared with those for word-final stops, and intervocalic stops are more similar to word-final ones in terms of phonetic context (both being in post-vocalic position). Second, post-vocalic position is preferred as cross-language studies have shown the duration of vowels preceding obstruents to be one of the salient cues to obstruent voicing.

3.1 METHOD

3.1.1 Subjects

2 female and 2 male adult monolingual speakers of Modern Standard Turkish served as subjects in this experiment. All 4 subjects were undergraduate students (between the ages 18 and 20) at Anadolu University in Turkey. None of the subjects had a known speech and/or hearing impediment. All 4 subjects were phonetically naïve, and were unaware of the purpose of this study. None had lived outside of Turkey.

3.1.2 Materials and Design

The test words consisted of 27 disyllabic word pairs containing intervocalic stops (10 bilabial, 10 dental, 7 velar). The test words are given in Appendix A. Whenever possible, minimal pairs differing only in voicing of the medial stops were chosen. This was possible for all ten bilabial pairs and for eight of the ten dental pairs. The members of the two remaining dental pairs differed in terms of the final consonant as well. For velars, finding minimal pairs was more difficult as [g] does not commonly occur intervocalically in Turkish (Underhill, 1976). Therefore, the members of the pairs with velar stops differed in other properties as well, although efforts were made to minimize these differences. All of the pairs for the velars had the syllable structure CV-CVC. The vowel preceding the medial consonant was the same for all the pairs, and the word-initial consonant was the same in five of the seven pairs. In the remaining two pairs, the manner and the voicing of the word-initial consonant were the same (voiceless obstruents). The vowel following the medial stop and the final consonant was the same when possible. In addition to the 27 word pairs (or 54 test words), 58 filler words were included to distract the subjects from the purpose of the experiment. All the words are lexical items in Turkish.

The 112 words were randomized seven times resulting in seven different lists. The words were embedded in the carrier sentence:

Bir ______________ istiyorum.
[biɾ̥̌ ______________ istijoɾʊm]
I want ______________.

In this experiment, five of the seven randomizations were analyzed acoustically, the first and the last lists being excluded from the analysis. The experiment, therefore, was a 2 (voicing: voiced/voiceless) x 27 (pairs of test items) x 5 (repetitions) x 4 (subjects) factorial design. Thus, a total of 1080 tokens were analyzed.

3.1.3 Procedure

This section of the experiment was the second part of a three-part (2 hour) recording session. The tasks in the first and the last parts were recorded for the purposes of the final devoicing experiments. (The recordings of the first and the last parts for these subjects were not used in the current study.)[1] Subjects were encouraged to take breaks after each part of the experiment. At the beginning of this part (Part II), subjects were given the seven randomizations. Each randomization was typed in Turkish orthography on a separate sheet. Subjects were instructed to read the lists of words in the carrier sentence '*bir* ____ *istiyorum*'. Subjects were familiar with the carrier sentence and the task from the previous session. Subjects were instructed to read the words with normal speaking tempo. All the instructions were given in Turkish.

Recordings were done in a radio studio at Anadolu University in Turkey using an AKG CK3 studio microphone, an Ampex Atr 800 reel-to-reel tape recorder for three subjects, and a NAGRA 4.2 portable reel-to-reel tape recorder for one subject.

3.1.4 Measurements

The tokens were digitized and analyzed on a Kay Elemetrics DSP Sona-Graph (Model 5500) in the University of Michigan Phonetics Lab. Acoustic measurements were based on wide-band spectrographic and waveform representations. In the spectrographic representation, a transform size of 100 points, with an effective analysis filter bandwidth of 300 Hz, was used. The time axis (total screen time) was 500 ms. The transform size for the waveform was 512 points, with a 59 Hz filter bandwidth, and the time axis was 31.2 ms. (The 500 ms waveform display in Figures 3.1a, 3.1b, 3.3, and 3.4 below is used for illustration purposes and is not that used in the actual measurements.) In the spectrographic representation, accuracy of measurement was within 0.8 ms (i.e., cursor movements were in 0.8 ms increments).

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[1] Due to the chronology of this study, recordings of only the second part (voiced/voiceless distinction in intervocalic position) were analyzed. The data for the final devoicing experiment were gathered and analyzed prior to this experiment from a separate group of subjects.

Four temporal measures were taken for each token. These four measures are illustrated in Figures 3.1a and 3.1b using a token of each member of the pair [k^hat^{h}aṛ̆/k^hadaṛ̆] produced by one of the female subjects (Subject 1).

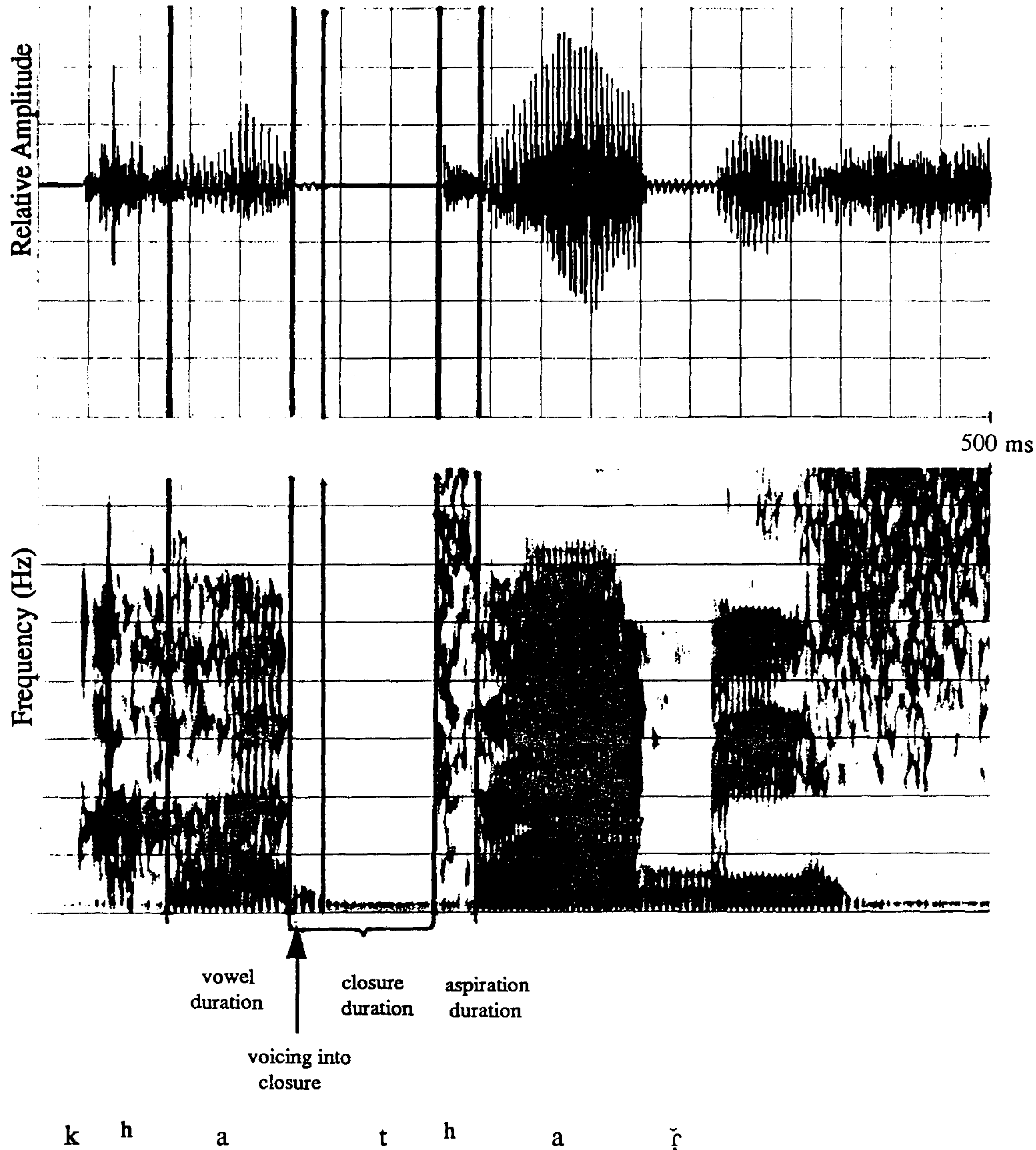

Figure 3.1a. Segmentation of waveform and spectrographic representations of [k^hat^{h}aṛ̆] according to the four temporal parameters (see text). The token was produced by a female subject (Subject 1).

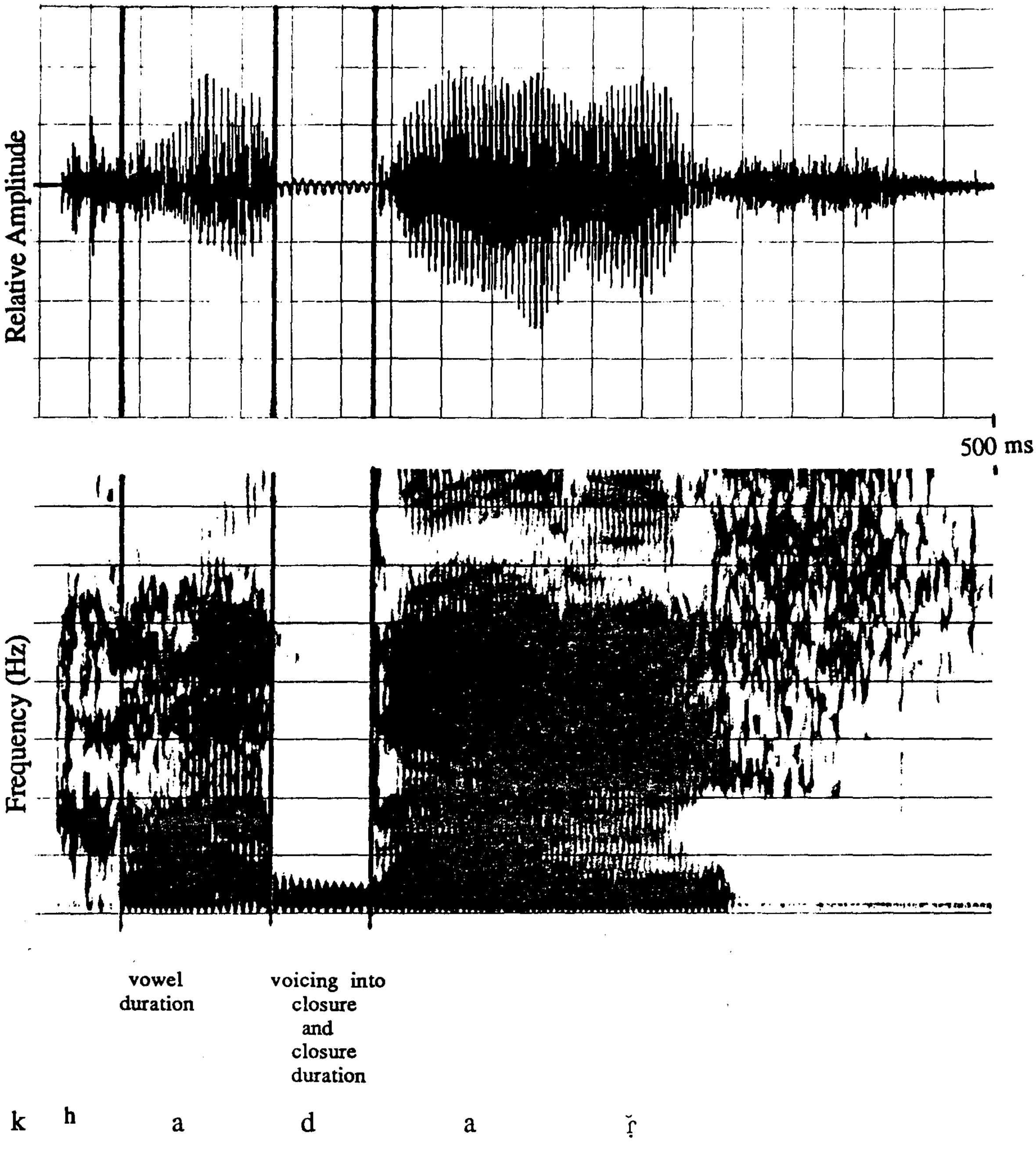

Figure 3.1b. Segmentation of waveform and spectrographic representations of [kʰadaɽ̆] according to the four temporal parameters (see text). The token was produced by a female subject (Subject 1).

The segmentation criteria were defined as follows:

1. *Vowel duration*: Vowel duration was defined as the interval from onset of periodicity in the waveform (as measured at the zero crossing) to substantial decrease in waveform amplitude corresponding to stop closure (see Figures 3.1a and 3.1b). As periodicity onset is not obvious in the 500 ms waveform display in Figure 3.1, Figure 3.2 illustrates placement of the onset cursor in [k^{h}at^{h}ař̥] with the 31.2 ms display used in the actual measurements.

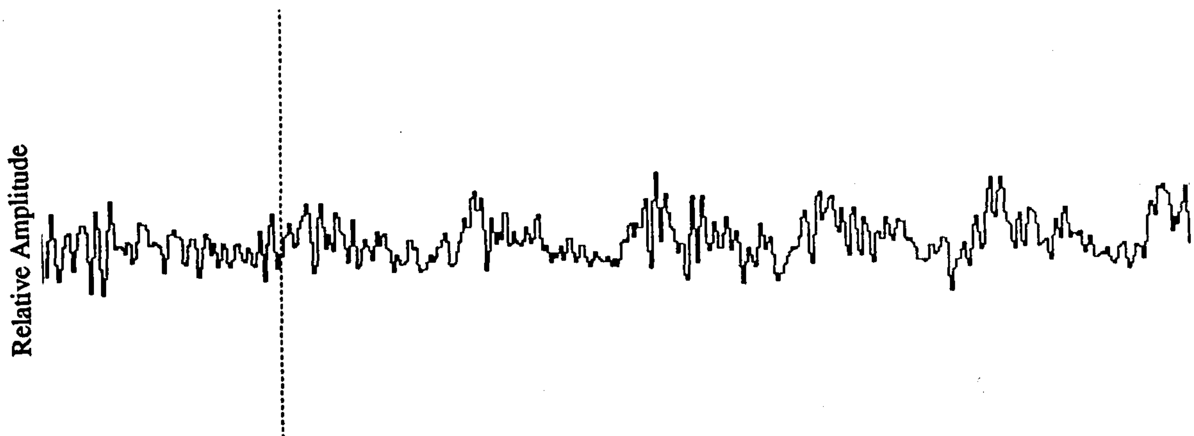

Figure 3.2. Expanded waveform representation used in the actual measurements (31.2 ms) illustrating cursor placement corresponding to the onset of the initial vowel in [k^{h}at^{h}ař̥].

For a subset of the data, a second measure of vowel duration was taken in which vowel onset was re-defined as the release of the closure for the preceding stop. Both types of measurements gave identical values for vowels preceded by voiced stops; for vowels preceded by voiceless stops, the second measure was longer, as initial voiceless stops are somewhat aspirated in Turkish. In the statistical analyses, the periodic vowel duration measure was arbitrarily selected. However, the second measure showed the same pattern of results, as word pairs were balanced with respect to voicing of the preceding segment.

For vowels following an approximant, vowel onset was signalled by an increase in waveform amplitude and an increase in formant intensity in the spectrographic representation.

The high vowels [i] and [u] following voiceless obstruents were sometimes realized as voiceless, as illustrated in Figure 3.3. In cases of an aperiodic vowel, the duration of the vowel was primarily determined from the spectrographic representation.

2. *Voicing into stop closure*: This measure was defined as the interval from offset of the preceding vowel (defined above) until either a visible fading in spectrographic striations or cessation of periodicity in the waveform (see Figures 3.1a and 3.1b).

3. *Stop closure duration*: The duration of stop closure was taken to be the interval from offset of the preceding vowel to the release burst (see Figures 3.1a and 3.1b). In the case of tokens lacking a clear burst, offset of stop closure was taken to be the onset of noisy aspiration for voiceless stops, and the onset of the following vowel for voiced stops.

In some tokens, there was weak random noise throughout most of the closure (i.e., fricative-like closure), as seen in Figure 3.4. For these tokens, the closure duration was measured as described above, ignoring the noise during closure.

4. *Aspiration duration*: Aspiration was defined as the interval between the release burst (or the onset of noisy aspiration if no clear burst) and the onset of periodicity of the waveform for the following vowel (see Figure 3.1a).

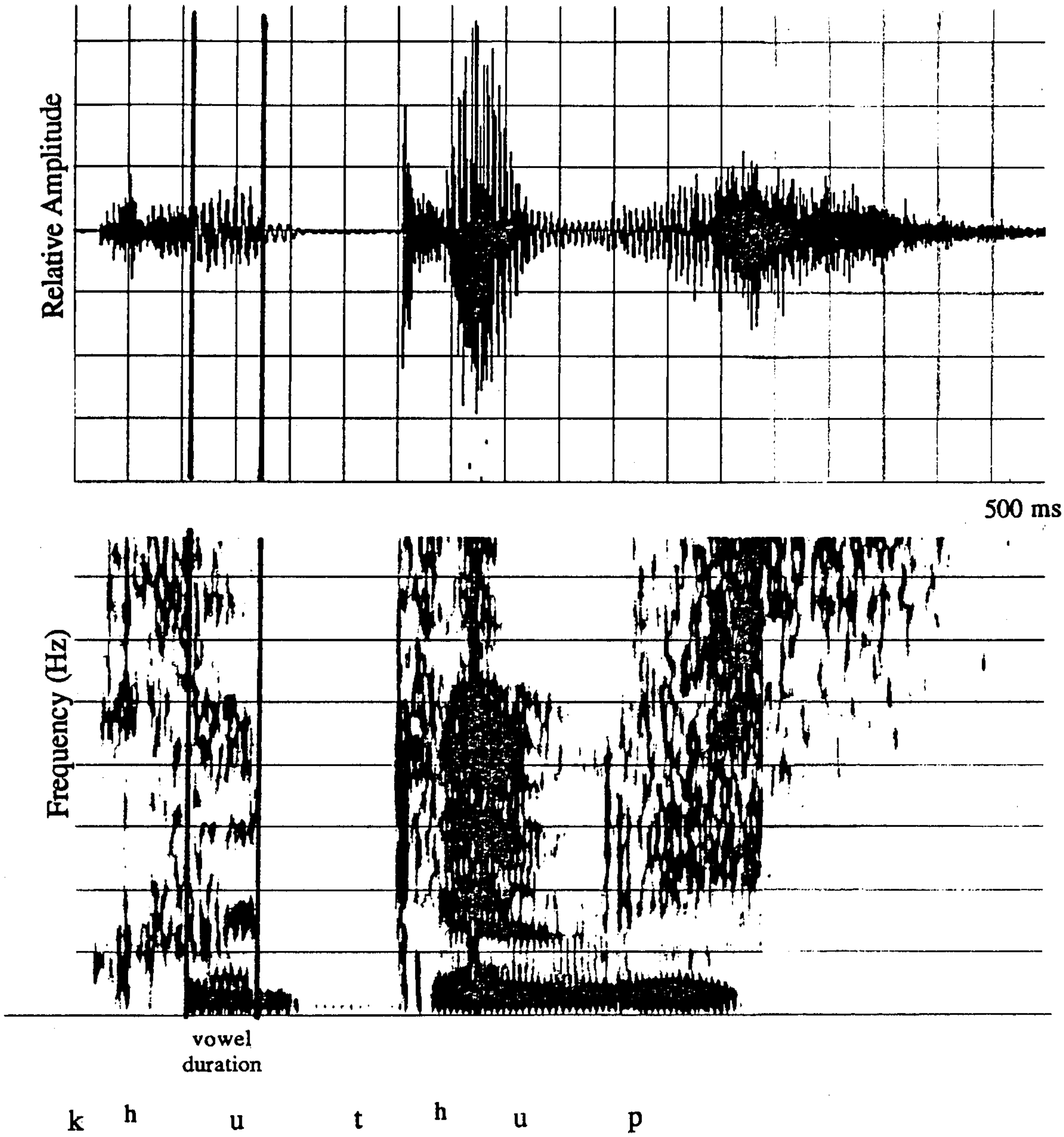

Figure 3.3. An example of a fricated high vowel [u] when preceded by a voiceless stop in the word [kʰutʰup]. The token was produced by a female subject (Subject 1).

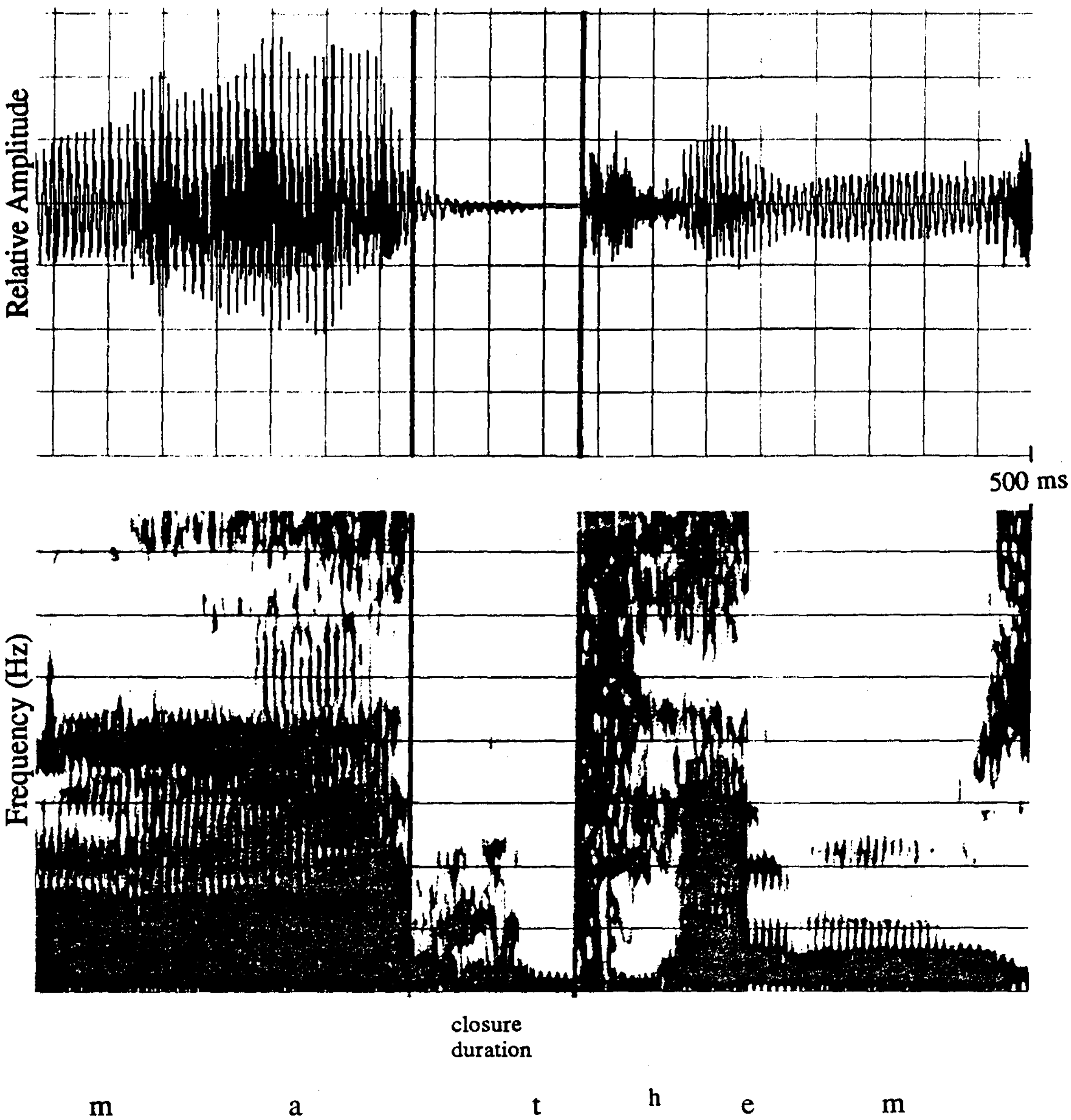

Figure 3.4. An example of a token [matʰem] in which there is random noise after the cessation of periodicity of [a]. The token was produced by a female subject (Subject 2).

For a small number of tokens (18 tokens), it was not possible to measure one or more of these temporal parameters. In such cases, the corresponding word pair in the last randomization (if possible; first if not possible) was analyzed. In the two instances in which a pair from two different lists was not measurable, that pair was taken from the first and the last list.

For Subject 1, the aspiration durations of three tokens were not measurable, and thus the mean values of aspiration for these words were based on four, rather than five, repetitions. For Subject 2, vowel duration measurements of the word [hadim] were discarded because, in all repetitions, it was incorrectly pronounced with a long vowel whereas its counterpart [hat^{h}im] was pronounced with a short vowel. For Subject 4, temporal parameters for two tokens were not measurable. The mean values of all four temporal parameters for these two words were based on four, rather than five, repetitions.

3.2 RESULTS

In the statistical analysis of the data, a Mixed Model Analysis of Variance with Likelihood Ratio Test of Significance was used. The Mixed Model Analysis was chosen because the data consisted of both fixed and random effects. Four factors were defined as fixed effects: voicing (voiced/voiceless), temporal parameter (vowel duration, voicing into closure, closure duration, and aspiration duration), context (isolation/context) and place of articulation (bilabial/dental/velar). In the analyses, the effect of word was also considered as a factor. Word was defined as a random effect, as the findings for the word pairs used here as a sample are expected to hold for all voiced and voiceless intervocalic stops.

The data for each subject were analyzed separately because the number of factors and degrees of freedom of each factor resulted in a model requiring more computer memory capacity than was feasible.

Therefore, the data for each subject were analyzed within each temporal parameter. Results of the statistical analyses for each parameter are discussed separately.

3.2.2 Vowel duration

Chi-Square and p-values for the factors and interactions for vowel duration for individual subjects are presented in Table 3.1.

		Subject 1		Subject 2		Subject 3		Subject 4	
	df	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value
voicing	1	56.610	0.000	60.591	0.000	73.305	0.000	63.639	0.000
place	2	1.198	0.549	1.232	0.540	0.105	0.949	3.114	0.211
voicing*place	2	7.511	0.023	7.939	0.019	5.987	0.050	2.418	0.298
word (place)	1	69.559	0.000	59.299	0.000	70.534	0.000	61.963	0.000
word(place)*voicing	1	3.235	0.072	2.071	0.150	0.000	0.995	3.972	0.046

Table 3.1. Chi-Square and p-values of the factors and interactions for each subject for vowel duration.

As expected, voicing showed a significant main effect for all subjects (row 1). Vowel duration was longer for voiced stops than for voiceless ones for all four subjects, as seen in Figure 3.6. The mean differences between voiced and voiceless stops ranged from 16 to 20 ms across subjects.

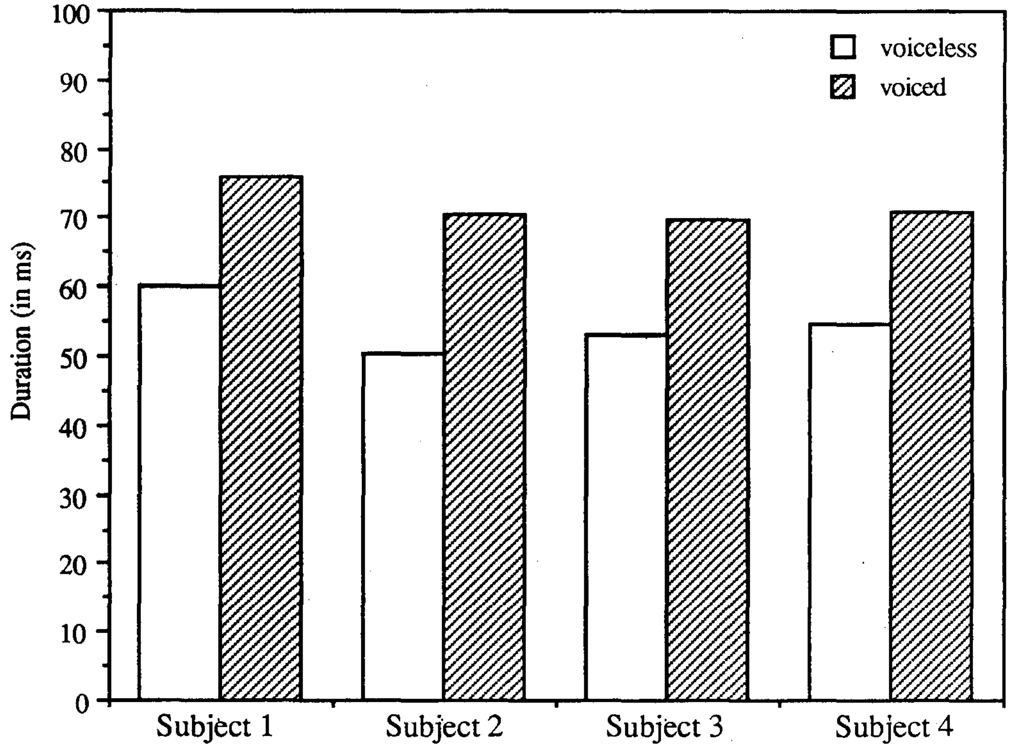

Figure 3.6. Mean vowel duration (in ms) for individual subjects.

Place of articulation did not show a significant main effect for vowel duration for any of the subjects (Table 3.1, row 2), although the interaction between voicing and place was significant for two of the subjects (row 3). Significance of this two-way interaction suggests that the size of the difference between voiced and voiceless stops for vowel duration varied as a function of place of articulation. Within each place, the differences in the vowel duration between voiced and voiceless stops were significant for all four subjects as determined by pairwise tests[2] (see Appendix C). This pattern is also seen for the data pooled across subjects. The mean vowel duration for each place of articulation across subjects is shown in Figure 3.7.

2 The pairwise test used in Mixed Model Analysis of Variance is a t-like ratio. It is not corrected for simultaneous comparison, and it is asymptotically correct for a large population.

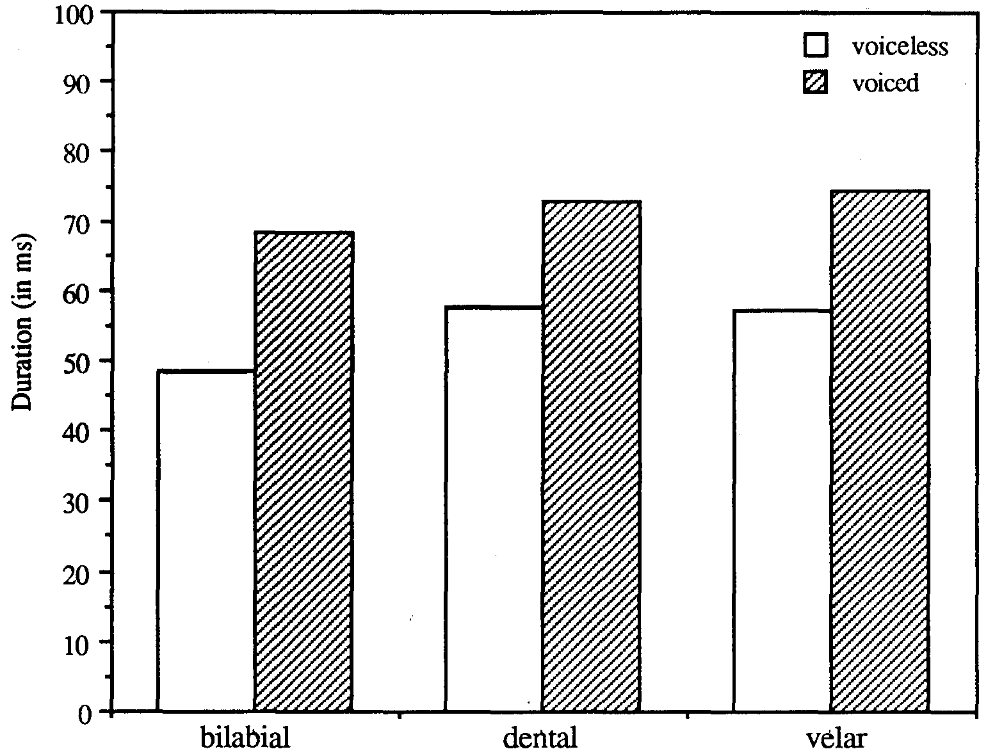

Figure 3.7. Mean vowel duration (in ms) for each place of articulation, summing across subjects.

Word had a significant main effect of vowel duration for all 4 subjects, suggesting that each word pair behaved differently. However, the two-way interaction between word and voicing was not significant except for one subject (Subject 4). For this subject, the difference between voiced and voiceless stops for vowel duration depended on individual words. The mean durations of the four temporal parameters for each word are given in Appendix D.

3.2.3 Voicing into Closure

Chi-Square and p-values for the factors and interactions for voicing into closure for individual subjects are presented in Table 3.2.

	df	Subject 1		Subject 2		Subject 3		Subject 4	
		ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value
voicing	1	123.143	0.000	114.951	0.000	107.420	0.000	100.636	0.000
place	2	2.679	0.262	3.618	0.164	3.801	0.150	11.837	0.003
voicing*place	2	3.733	0.155	2.511	0.285	8.005	0.018	8.551	0.014
word (place)	1	0.046	0.831	0.019	0.891	0.123	0.726	0.000	0.989
word(place)*voicing	1	0.835	0.361	18.126	0.000	13.861	0.000	20.376	0.000

Table 3.2. Chi-Square and p-values of the factors and interactions for each subject for voicing into closure.

Voicing into closure was significantly longer for voiced stops than for voiceless stops for all four subjects (row 1). The mean values of voiced and voiceless stops for each subject are plotted in Figure 3.8. Although voicing continued through a small portion of the closure duration for voiceless stops, voicing was present throughout closure for voiced stops. The mean differences in voicing into closure between voiced and voiceless stops ranged from 28 ms to 34 ms across subjects.

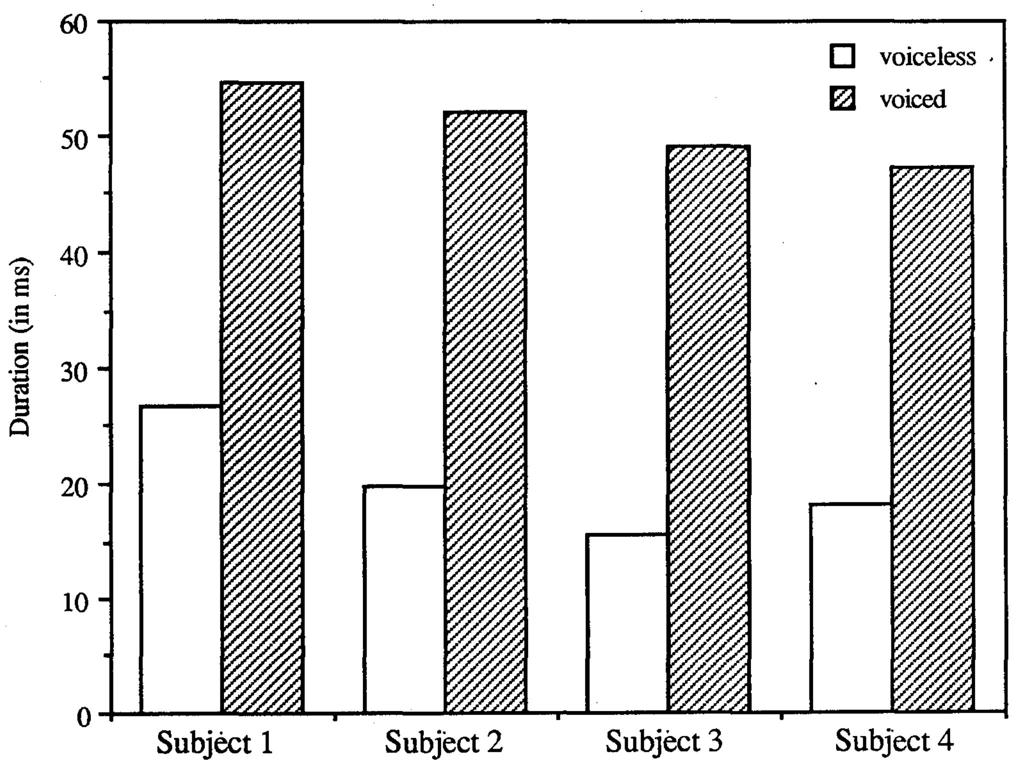

Figure 3.8. Mean voicing into closure (in ms) for individual subjects.

Place of articulation did not show a significant main effect except for one subject (Subject 4; row 2), suggesting that the duration of voicing into closure was generally similar for the three places of articulation. The interaction between voicing and place was not significant for any of the subjects (at .01 significance level), as the mean differences between voiced and voiceless stops were similar for all places of articulation. (.01 was chosen as significance level to avoid significance due to chance, as a large number of statistical tests were performed.) For all four subjects, differences between voiced and voiceless stops within each place of articulation were significant (see Appendix C).

The mean values of voiced and voiceless stops for each place of articulation across subjects are represented in Figure 3.9. The overall mean differences reflect the pattern for each subject.

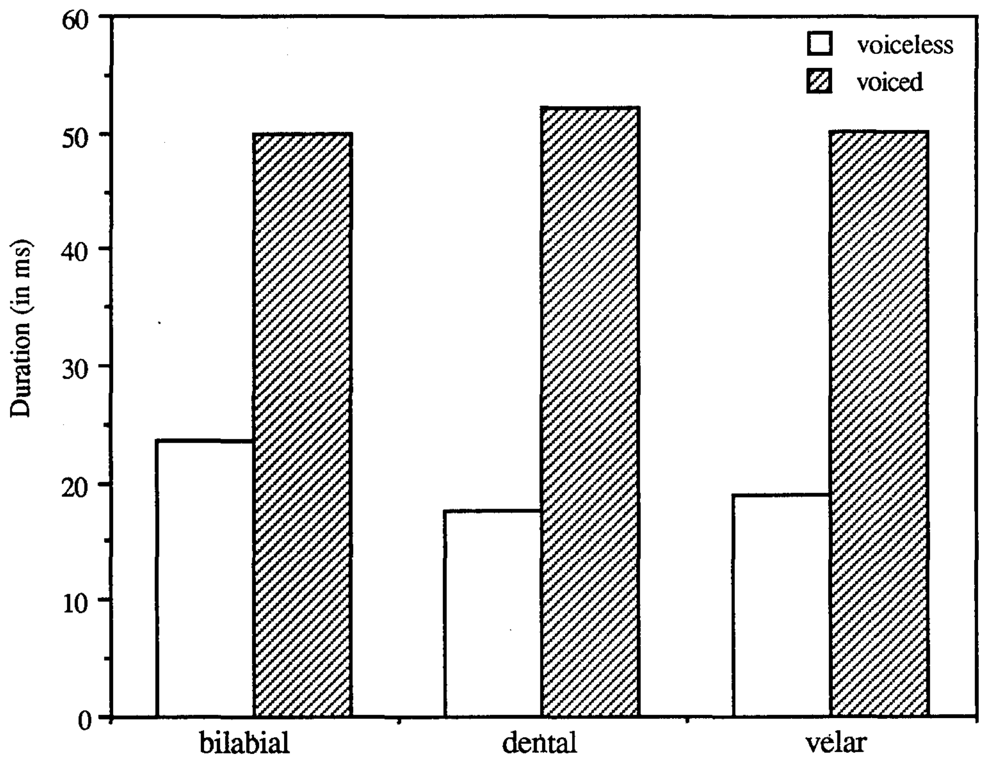

Figure 3.9. Mean voicing into closure (in ms) for each place of articulation, summing across subjects.

Word did not show a significant effect for voicing into closure for any of the subjects (Table 3.2, row 4). The two-way interaction between word and voicing was significant for all but one subject (last row). The mean duration of voicing into closure for each word is given in Appendix D.

3.2.4 Closure Duration

Chi-Square and p-values for the factors and interactions for closure duration for individual subjects are presented in Table 3.3.

		Subject 1		Subject 2		Subject 3		Subject 4	
	df	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value
voicing	1	103.877	0.000	93.136	0.000	64.507	0.000	100.950	0.000
place	2	10.732	0.005	2.413	0.299	3.578	0.167	15.758	0.000
voicing*place	2	26.520	0.000	10.252	0.006	22.692	0.000	15.711	0.000
word (place)	1	8.758	0.003	6.681	0.010	4.947	0.026	7.402	0.007
word(place)*voicing	1	1.593	0.207	1.675	0.196	8.511	0.004	5.686	0.017

Table 3.3. Chi-Square and p-values of the factors and interactions for each subject for closure duration.

As seen in Table 3.3, voicing showed a significant main effect for all subjects (row 1), indicating that closure duration was significantly longer for voiceless than for voiced stops. This temporal difference was maintained by each subject, as shown in Figure 3.10. The mean differences ranged from 21 ms (42%; Subject 3) to 33 ms (70%; Subject 4).

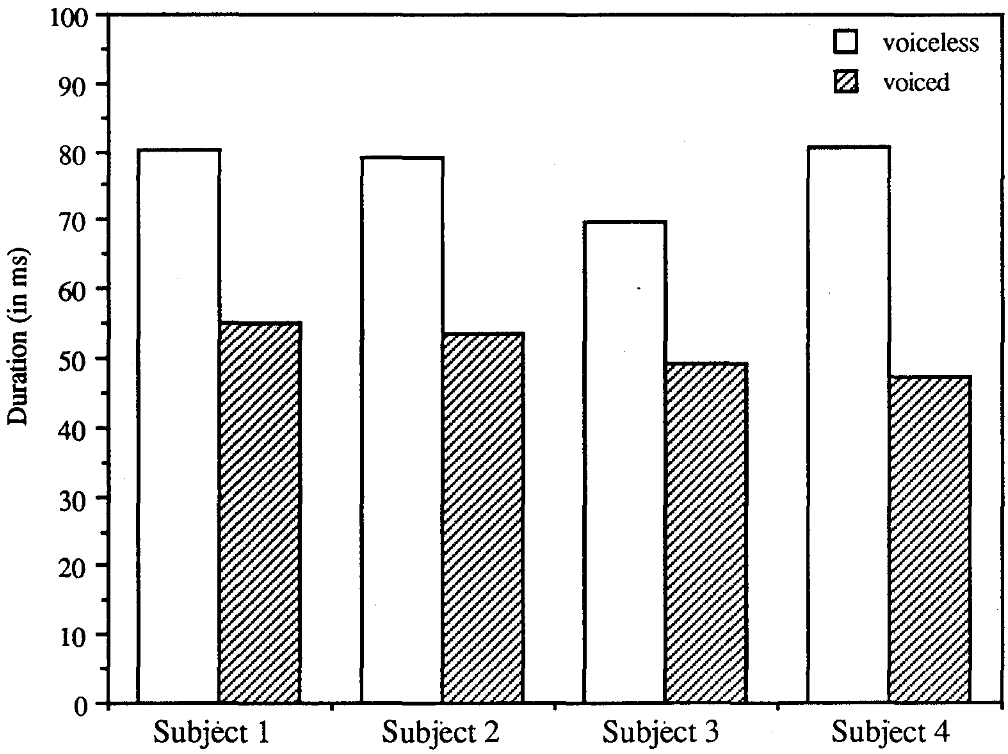

Figure 3.10. Mean closure duration (in ms) for individual subjects.

Place of articulation showed a main effect of closure duration for two subjects (Table 3.3, row 2), suggesting that, for these subjects, closure duration behaved differently within each place of articulation. The interaction between place and voicing was, however, significant for all subjects, due to the greater closure duration differences for bilabials than for the other two places. Mean closure duration for voiced and voiceless stops within each place for each subject is presented in Appendix C. In Figure 3.11, the mean closure duration (across subjects) within each place of articulation is shown.

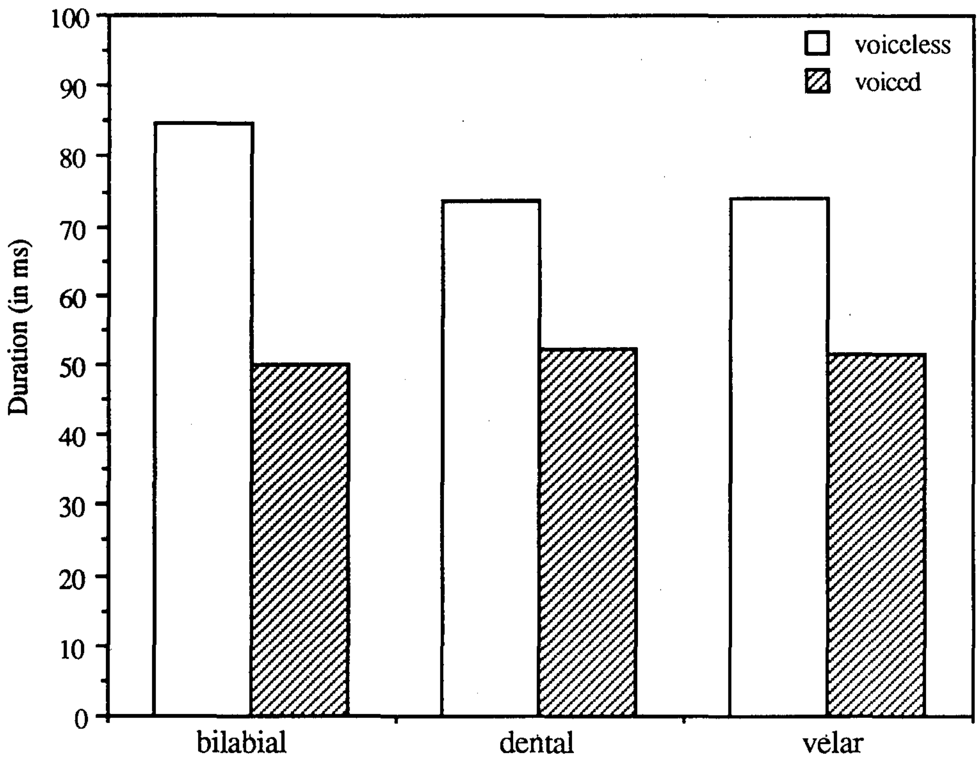

Figure 3.11. Mean closure duration (in ms) for each place of articulation, summing across subjects.

Word showed a significant main effect for place of articulation for all subjects (Table 3.3, row 4), although the interaction between word and voicing was significant for only two subjects (last row). Thus, for these two subjects, the difference in the closure duration of voiced and voiceless stops depended on the particular word pair. The mean duration of this parameter for individual words for each subject is presented in Appendix D.

3.2.5 Aspiration Duration

Chi-Square and p-values for the factors and interactions for aspiration duration for individual subjects are presented in Table 3.4.

	df	Subject 1		Subject 2		Subject 3		Subject 4	
		ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value	ChiSquare	p-value
voicing	1	143.528	0.000	102.758	0.000	116.544	0.000	107.014	0.000
place	2	15.294	0.000	25.352	0.000	26.223	0.000	24.501	0.000
voicing*place	2	6.343	0.042	3.007	0.222	11.006	0.004	13.920	0.001
word (place)	1	0.022	0.881	0.665	0.415	0.000	0.983	2.767	0.096
word(place)*voicing	1	2.335	0.127	8.687	0.003	14.460	0.000	3.116	0.078

Table 3.4. Chi-Square and p-values of the factors and interactions for each subject for aspiration duration.

As with the other three temporal parameters, a significant main effect of aspiration duration was found for voicing, with aspiration duration being significantly longer for voiceless stops. As seen in Figure 3.12, voiced stops were slightly aspirated (with mean duration ranging from less than 2 ms to 9 ms). Nonetheless, aspiration duration was at least 266% longer for voiceless than for voiced stops.

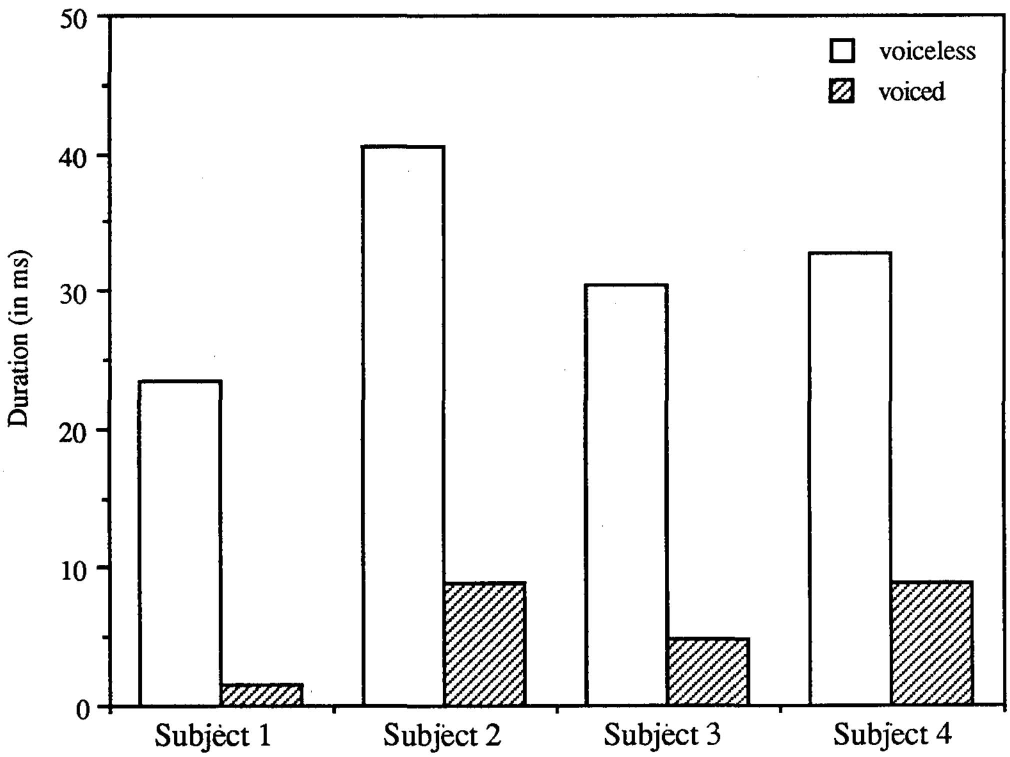

Figure 3.12. Mean aspiration duration (in ms) for individual subjects.

Place of articulation showed a significant main effect for all four subjects, with dentals and velars exhibiting longer aspiration than bilabials. This difference is shown by the mean aspiration durations plotted in Figure 3.13. The interaction between place and voicing was significant for all but one subject (Subject 2). Specifically, bilabials showed a smaller voiced/voiceless difference in aspiration duration than that shown by dentals and velars. The mean aspiration duration for each subject for the three places of articulation is given in Appendix C.

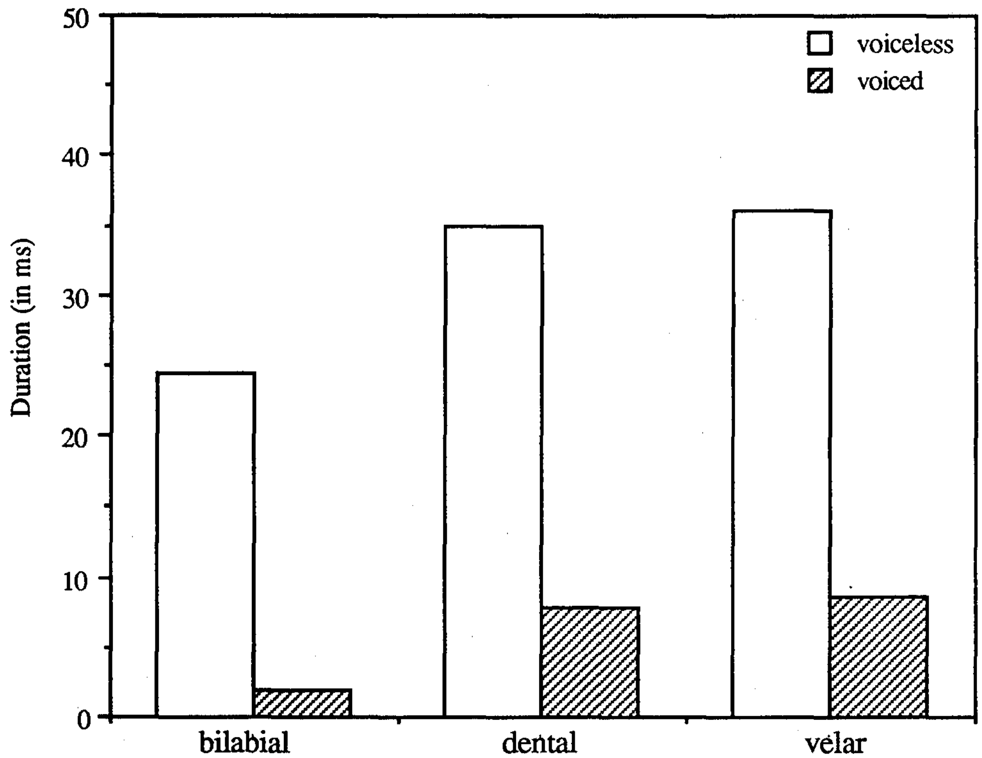

Figure 3.13. Mean aspiration duration (in ms) for each place of articulation, summing across subjects.

Word did not show a significant main effect for this parameter for any of the subjects. The two-way interaction between word and voicing was significant for two of the subjects, indicating that the difference in the aspiration duration between voiced and voiceless stops differed for each word. Aspiration durations of individual words for each subject are given in Appendix D.

3.3 SUMMARY AND CONCLUSION

In this experiment, four temporal parameters (vowel, voicing into closure, closure, and aspiration durations) were measured for Turkish intervocalic stops to determine whether these parameters are acoustic correlates of the voiced/voiceless distinction. The overall results showed that the differences between voiced and voiceless stops were significant for all four temporal parameters. Vowel duration and voicing into closure were significantly longer for voiced stops than for voiceless ones. Closure and aspiration durations, on the other hand, were significantly longer for voiceless stops than for voiced stops.

The data for individual subjects conformed to the overall results. Each subject showed consistently large differences between voiced and voiceless stops for all four parameters.

Within each place of articulation, all four parameters were significant for all four subjects. For certain subjects, the duration of certain parameters varied depending on the place of articulation of the intervocalic stop. However, no direct association was found between the duration of a given parameter and place of articulation, for all subjects.

In conclusion, then, all four parameters measured here are acoustic correlates of the voicing contrast in Turkish stops in intervocalic position.

CHAPTER 4

PHONETIC INVESTIGATION OF TURKISH FINAL DEVOICING

In determining the neutralizing status of the process of final devoicing in Turkish, two questions need to be addressed: (1) Are there acoustic differences between devoiced and voiceless stops? (2) Is the underlying voicing of these stops perceived by Turkish listeners? To answer the first question, the temporal characteristics of devoiced and voiceless stops are investigated to determine whether the underlying voicing contrast between these two types of stops is neutralized. This is discussed in § 4.1. Even if the acoustic data fail to show temporal differences between devoiced and voiceless stops, question (2) still needs to be addressed as there may be consistent acoustic differences not measured in this study. To determine whether the underlying voicing distinction between devoiced and voiceless stops is perceptible, perceptual tests were conducted. These tests and their results are reported in § 4.2.

4.1 ACOUSTIC REALIZATION OF TURKISH DEVOICED STOPS

4.1.1 Method

4.1.1.1 Subjects

3 female and 2 male adult native speakers of Modern Turkish served as subjects in this experiment. The subjects were graduate students at, or otherwise affiliated with, the University of Michigan. The ages of the subjects ranged from 22 to 27 years (with a median age of 24 years). All subjects were born and educated in Turkey and none of them had lived outside of Turkey more than 2.5 years. None of the subjects had a known speaking or hearing impediment. All 5 subjects were phonetically naïve, and were unaware

of the purpose of the study. Subjects were paid $10 for their participation in the experiment.

4.1.1.2 Materials and Design

The test words consisted of 30 pairs of words ending in stop consonants (9 bilabial, 11 dental, 10 velar). The underlying voicing of the final stops was determined on the basis of morphophonemic evidence. If a word-final stop surfaces as voiced in prevocalic position, then it was taken to be underlyingly voiced. Otherwise, it was taken to be underlyingly voiceless. As noted, Turkish has no commonly occurring word pairs differing only in the underlying voicing of final non-continuants. As a result, the members of each of the 30 pairs differed from each other in other properties as well, although efforts were made to minimize these differences. Specifically, in each pair, the vowel preceding the final consonant was the same, and in disyllabic pairs, the consonant preceding that vowel was the same as well. For monosyllabic (CVC) pairs, the manner (when possible) and voicing of the initial consonant were the same. All the words are lexical items in Turkish, although some are not as commonly used as others. The 30 word pairs are listed in Appendix E. In addition to the 60 test words, 60 filler words were included in order not to direct the attention of the subjects to the focus of the experiment.

The 120 words were randomized three times, resulting in three different lists of words. Each list occurred in two contexts: in isolation and embedded in the carrier sentence. The carrier sentence used in this experiment was the same as that used in the experiment described in Chapter 3.

Bir ______________ istiyorum.
[biř̥ ______________ istijoɾum]
I want ______________.

In this experiment, two randomizations for tokens in isolation and two for tokens in context were analyzed acoustically. The lists used for analysis were the second and third randomizations. The experiment, therefore, was a 2 (underlying voicing: voiced/voiceless) x 30 (pairs of test items) x 4 (repetitions: 2 in isolation+2 in context) x 5 (subjects) factorial design. A total of 1,200 tokens were analyzed.

4.1.1.3 Procedure

Prior to recording, each subject was encouraged to read the lists to become familiarized with the words and the task. Subjects were also encouraged to ask the meanings of the words they did not know. The number of words for which subjects asked the meanings ranged from 0 to 8 (up to 13%). The definitions of the words as well as all instructions were given in Turkish.

Subjects were recorded reading the list of words first embedded in a carrier sentence, then in isolation. As roughly 30% of the words used in this study are relatively uncommon lexical items, one concern was whether the underlying forms of test words for each subject were consistent with prescriptive grammar (i.e., underlying forms as indicated in dictionaries). Therefore, to determine the underlying voicing of the final stop for each word for each subject, subjects also performed a conjugation task. In this task, subjects were presented with the root form of the 120 words, and were asked to give the present tense forms for words which were verbs, and the accusative form for nouns (both forms resulting in prevocalic stem-final stops; see Appendix F). This task was done orally and subjects' productions were recorded. Again, three randomizations of the 120 words were used in the recordings. These tokens were not submitted to acoustic analysis; instead, the voicing of the stem-final stop of each of the 180 test words for each subject was judged impressionistically by two listeners, a native speaker of Turkish (the author) and a phonetician. Based on these responses, each of the 30 test pairs was defined as either familiar or unfamiliar for each subject. The list of familiar pairs was different for each subject. A pair was classified as familiar if the voicing of both members of a pair was consistent with prescriptive grammar in all three repetitions. If the voicing of one member of a pair was incorrectly identified (according to prescriptive grammar) in any of the repetitions, then that pair was treated as unfamiliar for that subject. The voicing status of a stem-final stop for a given subject is important in that, if a prescriptive voiced member is not voiced for the subject, then no acoustic distinction would be expected for that pair.

The subjects were instructed to read the lists of words with normal speaking tempo. The recordings were done in a sound-attenuated room at the University of Michigan Phonetics Laboratory using an Otari MX-5050 reel-to-reel tape recorder and an Electro-Voice 631B microphone.

4.1.1.4 Measurements

The acoustic analyses of intervocalic stops reported in Chapter 3 showed that the four parameters measured -- vowel duration, voicing into closure, closure duration, and aspiration duration -- were temporal correlates of the voicing distinction. The same four temporal parameters were measured here to determine whether the underlying voicing of final devoiced stops is maintained to some degree.

The tokens in this experiment were digitized and analyzed in the same manner as described in § 3.1.4. The criteria used for segmenting the acoustic signal into the four temporal measures are also as reported in that section, except that, in this experiment, words occurred in isolation as well as in context. For words in isolation, aspiration duration was defined as the interval from the release burst to the termination of any noise.

For a small number of tokens (33, or 3%), it was not possible to measure one or more of these temporal parameters. In such cases, the corresponding word in the first randomization of the same type (i.e., either in isolation or in context) was analyzed. In those instances in which one or more parameters were not measurable from either the original or the first list, the mean temporal values for that word for that subject were based on three rather than four word tokens. (This occurred for 19 tokens, or less than 2% of the data.)

4.1.2 Results

In the statistical analysis of the data, a Mixed Model Analysis of Variance with Likelihood Ratio Test of Significance was used. As before, the Mixed Model Analysis was chosen because the data consisted of both fixed and random effects. Four factors were defined as fixed effects: underlying voicing (voiced/voiceless), temporal parameter (vowel duration, voicing into closure, closure duration, and aspiration duration), context (isolation/context) and place of articulation (bilabial/dental/velar). Word was again defined as a random effect.

Due to insufficient computer memory, the data for each subject were analyzed separately. As not all interactions could be included in one analysis, several permutations of the factors were used to reduce the number of interactions from one analysis to the next. The approach taken was to include an interaction in the subsequent analysis if that interaction was significant for all five subjects. All factors and interactions which showed significance in previous analyses were included in the final model. Exclusion of non-significant interactions in a model did not distort the results of that model. Although the estimates and standard deviations may vary from one model to another, the variations are not substantial, and the general pattern holds in all models for all subjects (see Appendix G). The results obtained from the final model are reported here. The results of other models are presented in Appendix G.

4.1.2.1 Group Data

The overall mean values (i.e., across subjects, word pairs) for the four parameters are plotted for devoiced and voiceless word-final stops in Figure 4.1.

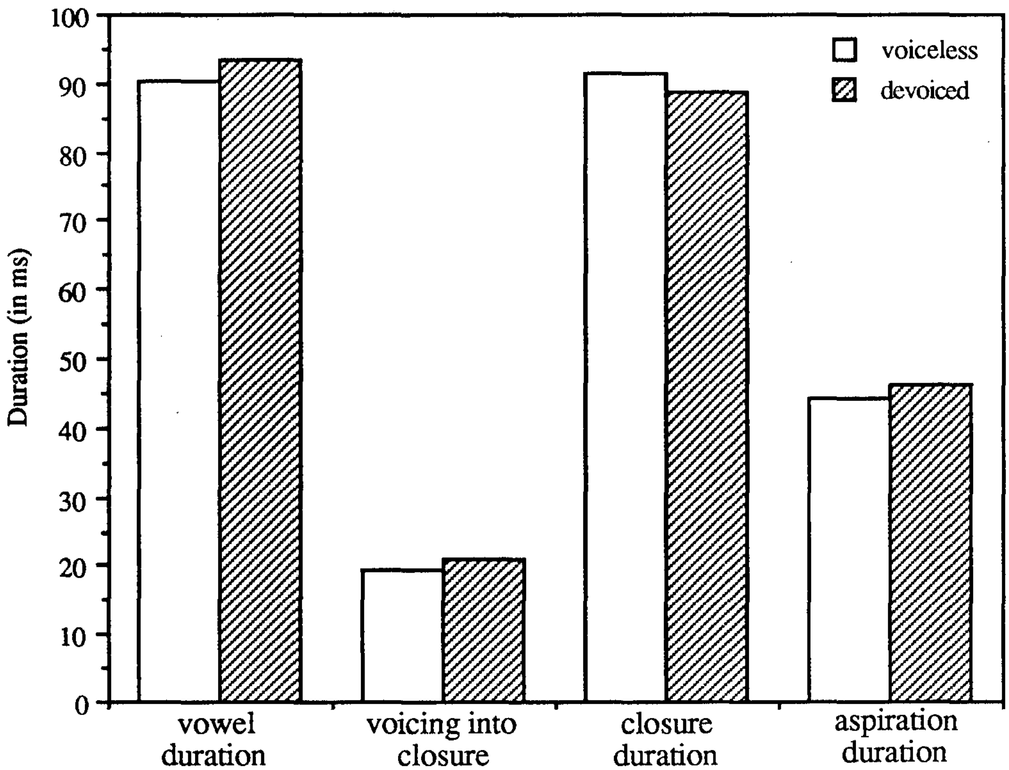

Figure 4.1. The overall mean values for each temporal parameter averaged across subjects.

The differences between devoiced and voiceless stops for the first three parameters, although in the expected direction, were very small. The mean vowel duration preceding devoiced stops was 3 ms (3%) longer than that of vowel duration preceding voiceless stops. Voicing into closure was 1 ms (7%) longer for devoiced stops than for voiceless ones. The mean stop closure was 3 ms (3%) shorter for devoiced stops than for voiceless stops. The difference between devoiced and voiceless stops for aspiration duration was not in the expected direction. Aspiration duration was longer for devoiced than for voiceless stops (2 ms or 4%).

The mean values for each parameter for each subject are presented in Table 4.1.

	vowel duration		voicing into closure		closure duration		aspiration duration	
	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless
Subject 1	93	93	21	21	87	87	46	45
Subject 2	75	71	22	20	79	83	38	32
Subject 3	93	91	24	22	106	107	27	27
Subject 4	111	108	20	19	95	100	48	47
Subject 5	90	89	17	15	76	81	72	70

Table 4.1. Mean values (in ms) of each temporal parameter for each subject.

The mean differences between devoiced and voiceless stops were very small for all five subjects. The largest mean difference for vowel duration was approximately 4 ms or 5.6% (Subject 2). The largest mean difference between devoiced and voiceless stops for voicing into closure was approximately 2 ms or 9-13% (Subjects 2, 3, and 5). For closure duration, the mean difference was 5 ms for Subjects 4 (5%) and 5 (6%). The difference in the aspiration duration was not in the expected direction: it was generally longer for devoiced than voiceless tokens. For Subject 2, this difference was approximately 6 ms (or 16% longer for devoiced stops).

That the mean differences between devoiced and voiceless stops for individual subjects did not increase when compared to those of the overall data indicates that the small overall differences are generally representative of the productions of individual subjects. Results of the statistical analyses indicated that the differences between devoiced and voiceless stops were not significant. These results are presented in Table 4.2, which gives the Chi-Square and p-values for the factors and interactions for individual subjects. (Estimates and standard deviations for each factor and interaction are in Appendix G, Model 3.)

		Subject 1		Subject 2		Subject 3		Subject 4		Subject 5	
	d.f	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value
UL voicing (alt)	1	0.890	0.345	2.316	0.128	1.005	0.316	0.553	0.457	0.020	0.887
parameter (par)	3	219.272	0.000	210.951	0.000	267.767	0.000	234.596	0.000	234.552	0.000
context (cont)	1	490.478	0.000	165.691	0.000	0.150	0.698	440.169	0.000	646.453	0.000
place (pl)	2	3.381	0.184	1.886	0.389	1.916	0.384	2.430	0.297	0.448	0.799
alt*par	3	0.863	0.834	10.026	0.018	2.554	0.466	15.663	0.001	7.005	0.072
par*cont	3	159.418	0.000	101.265	0.000	5.907	0.116	218.634	0.000	356.171	0.000
alt*pl	2	0.180	0.914	1.259	0.533	1.890	0.389	0.019	0.991	0.410	0.815
par*pl	6	13.844	0.031	24.006	0.001	30.358	0.000	38.533	0.000	25.981	0.000
cont*pl	2	7.069	0.029	5.474	0.065	5.423	0.066	10.868	0.004	3.695	0.158
alt*par*pl	6	10.620	0.101	5.019	0.541	4.272	0.640	8.758	0.188	2.170	0.903
alt*cont*pl	2	1.249	0.536	1.689	0.430	0.142	0.932	0.515	0.733	1.517	0.468
par*cont*pl	6	7.746	0.257	21.872	0.001	8.258	0.220	18.835	0.004	39.202	0.000
alt*par*cont*pl	6	3.550	0.737	5.513	0.480	5.645	0.464	2.882	0.824	7.260	0.297
word(pl)	1	0.109	0.741	1.384	0.239	0.058	0.809	0.000	0.091	0.011	0.918
word(pl)*par	1	152.053	0.000	89.031	0.000	315.914	0.000	305.041	0.000	120.548	0.000

Table 4.2. Chi-Square and p-values of the factors and interactions in the final model for each subject

The effects of the four different factors are discussed separately in the following sections.

4.1.2.2 Underlying Voicing

As seen in Table 4.2, there was not an overall effect of underlying voicing (top row) for any of the subjects ($p>.10$ for all subjects). In the analyses, all four temporal parameters -- vowel duration, voicing into closure, closure duration, and aspiration duration -- were included. Parameter showed a main effect for all subjects, indicating that each parameter behaved differently. This is expected as the duration of each parameter is different; vowel and closure durations, for example, are generally much longer than voicing into closure and aspiration. The interaction between underlying voicing and parameter was significant for two of the subjects (Subjects 2 and 4), indicating that the differences between devoiced and voiceless stops for these subjects varied depending on the parameter. Because this two-way interaction between underlying voicing and parameter was significant only for two of the five subjects (and because the mean differences between devoiced and voiceless stops for individual parameters were small for all five subjects; see Table 4.1), the data for each temporal parameter were not submitted to statistical analysis.

4.1.2.3 Temporal Parameter

The raw data for each subject were examined under the hypothesis that the small overall differences might be due to a subject's having maintained the underlying voicing distinction in terms of different parameters for different words. However, this hypothesis was not upheld. The temporal differences between devoiced and voiceless stops were not consistently in the expected direction for the majority of word pairs for any of the parameters for any one subject. To illustrate, Figures 4.2-4.5 show for each of the dental-final word pairs produced by Subject 4, the actual values of vowel duration, voicing into closure, closure duration, and aspiration duration, respectively. The first two repetitions were produced in context, while the other two were produced in isolation. These figures are generally representative of the data for word pairs ending in bilabial and velar stops, and for the data from other subjects.

In Figures 4.2 and 4.3, where values for devoiced stops should be longer than those for voiceless stops if a voicing distinction is maintained, the squares should be consistently above the corresponding circles. In Figures 4.4 and 4.5, the reverse pattern should hold if a voicing distinction is preserved. Neither pattern, however, is found. Across the four measures, the predicted direction of difference holds in only 51% of the cases (the range being 41-61%).

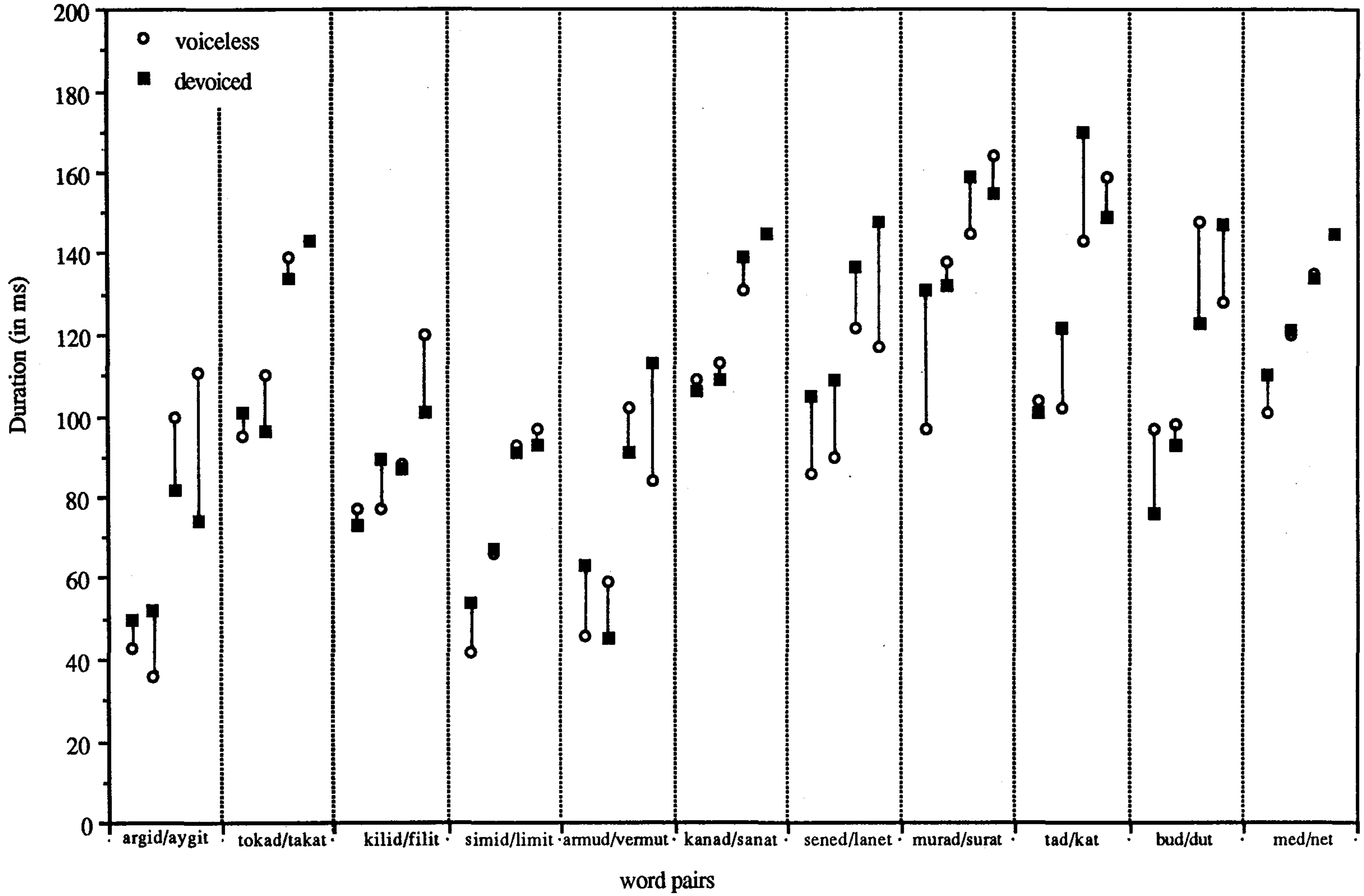

Figure 4.2. Vowel durations for voiceless/devoiced pairs (ending in a dental stop) in each repetition for Subject 4.

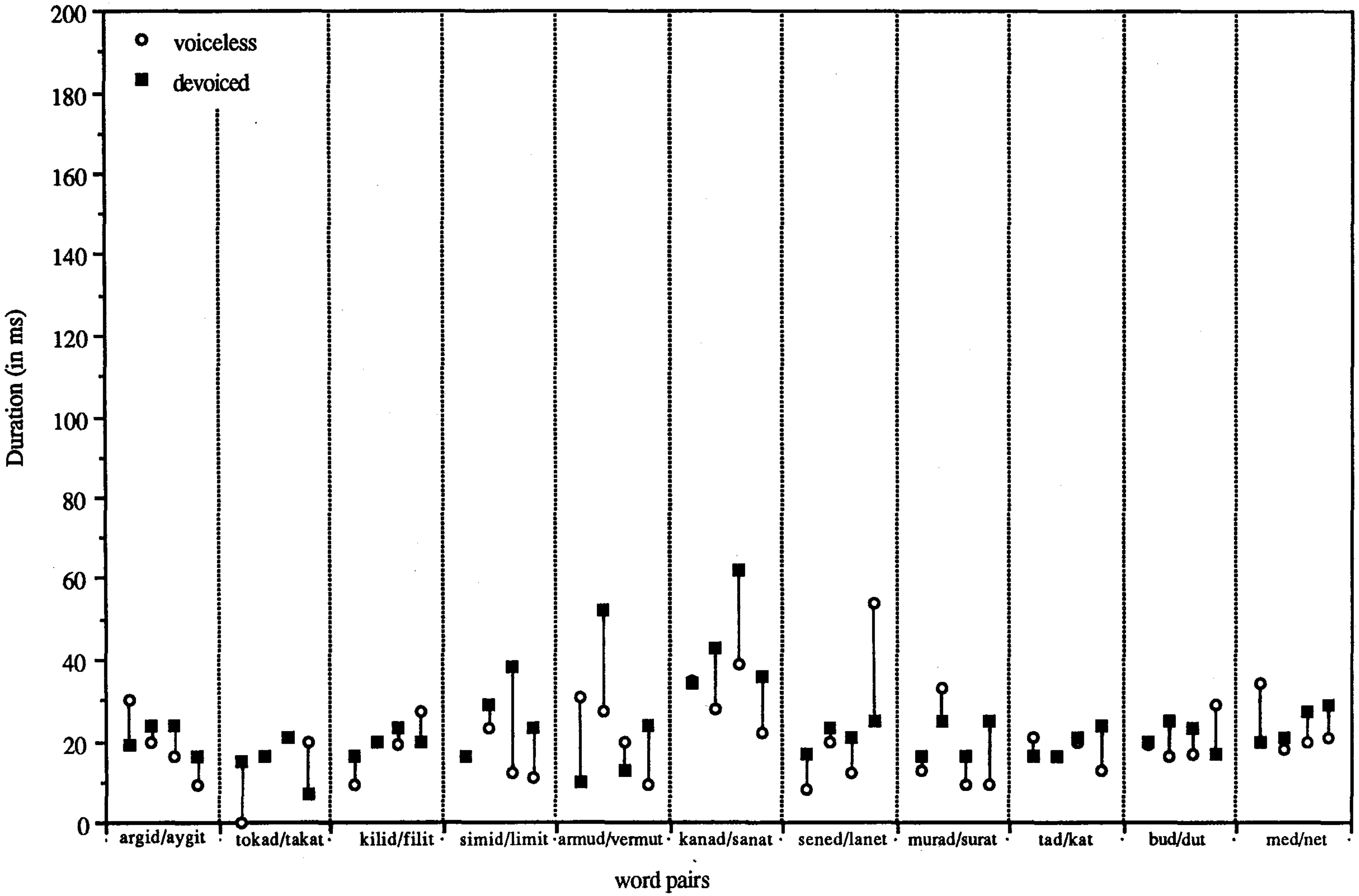

Figure 4.3. Voicing into closure durations for voiceless/devoiced pairs (ending in a dental stop) in each repetition for Subject 4.

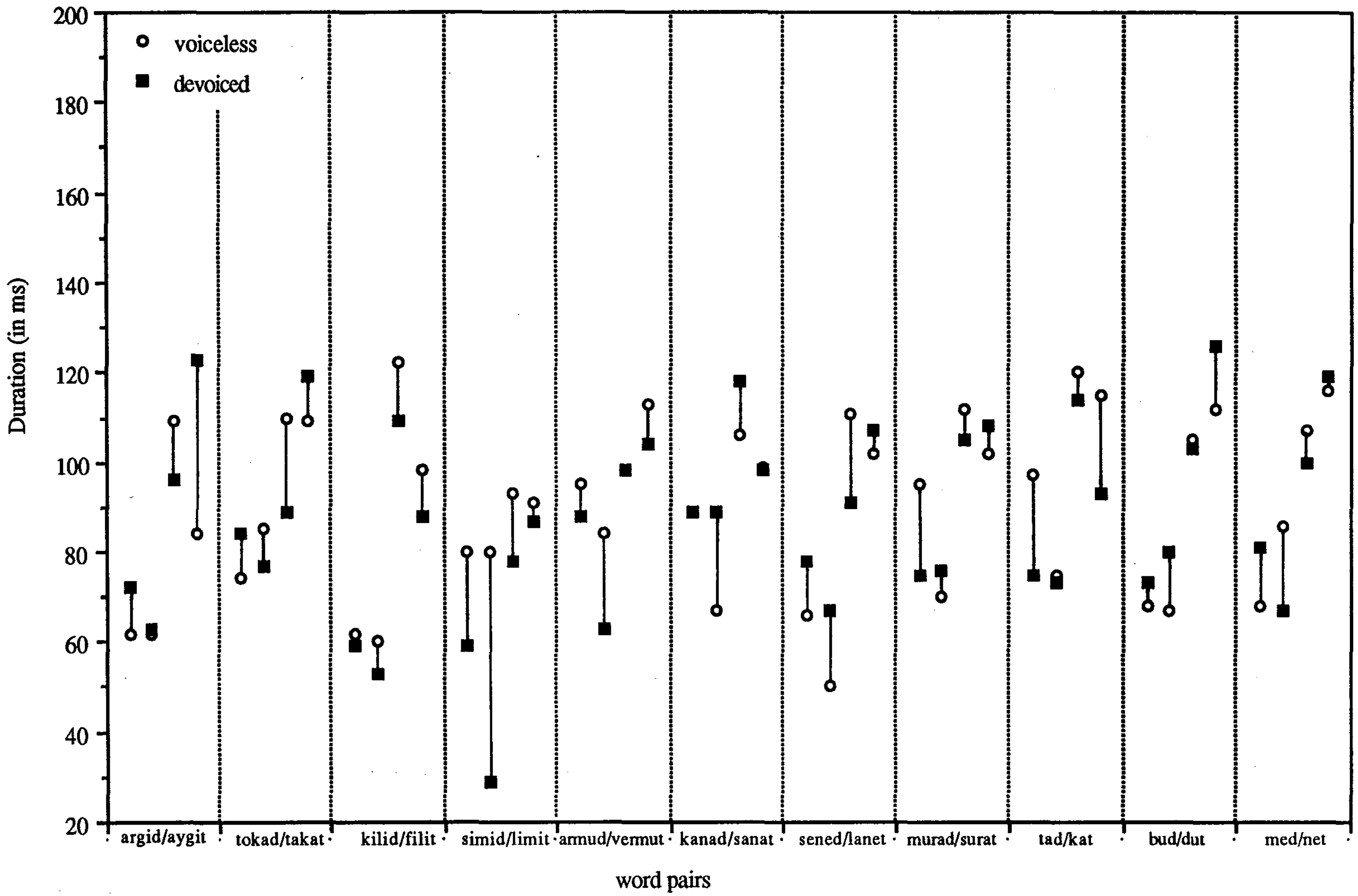

Figure 4.4. Closure durations for voiceless/devoiced pairs (ending in a dental stop) in each repetition for Subject 4.

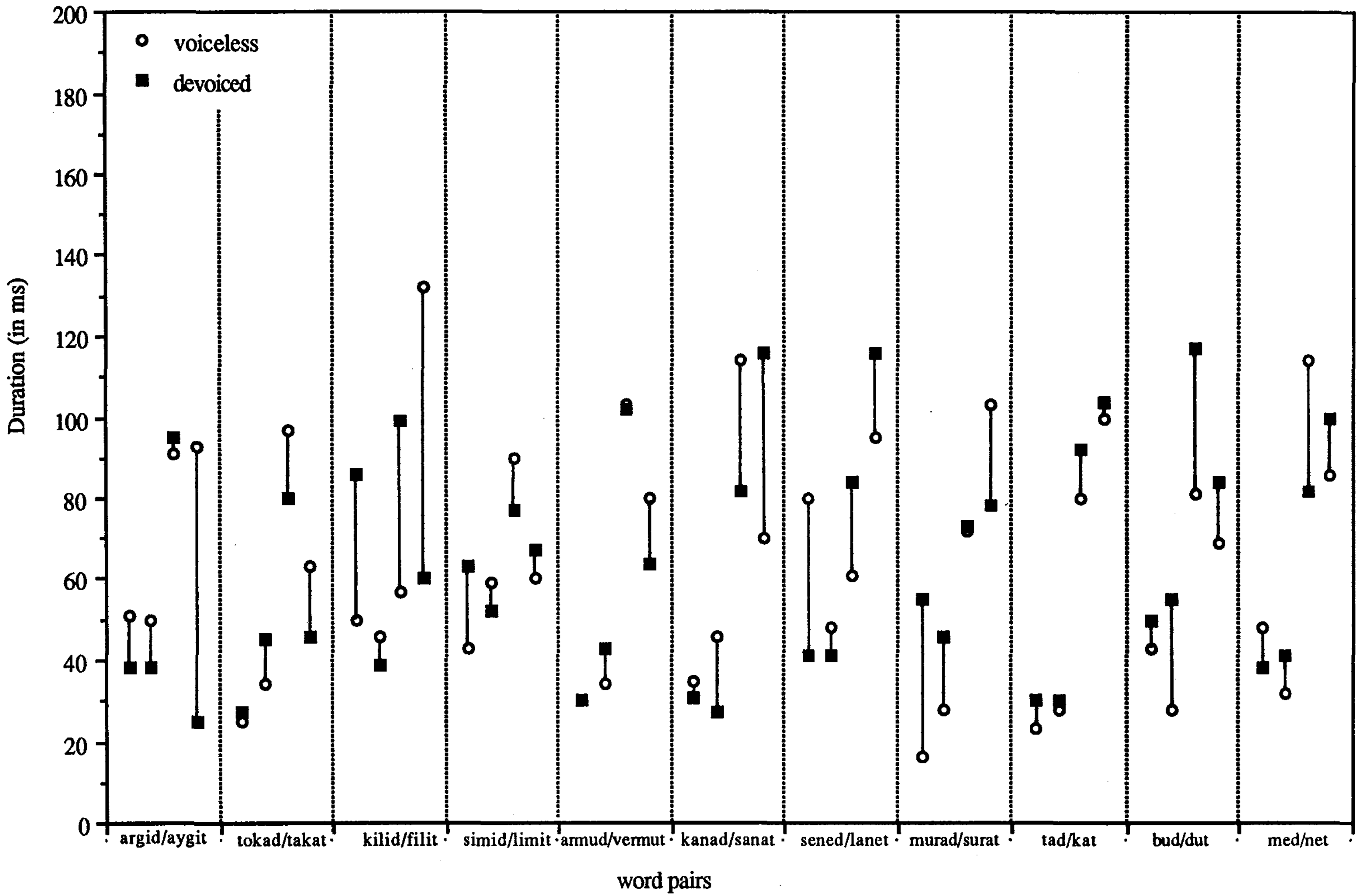

Figure 4.5. Aspiration durations for voiceless/devoiced pairs (ending in a dental stop) in each repetition for Subject 4.

4.1.2.4 Context

The context of production, isolation versus carrier sentence, had a main effect for four of the subjects (i.e., all but Subject 3; see Table 4.2, row 3) with tokens produced in isolation being significantly longer than tokens produced in sentence context. This is expected, as temporal measures are generally longer for words produced in isolation than for those produced in a sentence. These values, as well as the results of pairwise tests[1], are given for each subject in Appendix H.

Context did not interact with underlying voicing except for Subject 3 (see Appendix G, Model 1), suggesting that the difference between devoiced and voiceless stops generally did not vary across contexts. Furthermore, the three-way interaction among underlying voicing, temporal parameter, and context was not significant for any of the subjects (see Appendix G, Model 1), indicating that the differences between devoiced and voiceless stops for a given context did not show different patterns for different temporal parameters.

4.1.2.5 Place of Articulation

The mean values of each temporal parameter within each place of articulation for devoiced and voiceless stops (across context) are presented in Table 4.3. For some temporal parameters, the differences between devoiced and voiceless stops are longer for certain places of articulation, but these differences are generally not substantial. Further, the devoiced-voiceless temporal differences are not always in the expected direction.

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[1] The pairwise test used in the Mixed Model Analysis of Variance is a t-like ratio. It is not corrected for simultaneous comparison, and it is asymptotically correct for a large population.

	vowel duration		voicing into closure		closure duration		aspiration duration	
	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless
Subject 1								
Bilabial	99	93	28	29	97	100	36	38
Alveolar	96	89	20	20	86	85	49	51
Velar	92	97	18	15	81	79	50	45
Subject 2								
Bilabial	74	70	32	29	87	92	27	26
Alveolar	75	67	17	16	78	79	43	37
Velar	76	76	19	17	73	79	43	33
Subject 3								
Bilabial	91	90	27	26	123	129	17	17
Alveolar	91	89	22	20	100	101	36	34
Velar	96	94	23	21	99	95	26	28
Subject 4								
Bilabial	116	105	20	22	113	118	26	29
Alveolar	108	106	23	20	87	90	63	63
Velar	111	120	18	14	91	97	47	42
Subject 5								
Bilabial	88	86	21	17	84	90	59	60
Alveolar	92	89	15	14	71	75	84	81
Velar	91	92	17	15	75	79	69	68

Table 4.3. Mean values (in ms) of each temporal parameter for each subject within each place of articulation.

To investigate possible differences among bilabial, dental, and velar stops, place of articulation was included as a factor in the statistical analyses. Place did not have a significant effect for any of the subjects ($p>.10$ for all subjects; see Table 2, row 4), indicating that the behavior of bilabials, dentals, and velars was similar. Further, place did not interact with underlying voicing for any of the subjects, nor was the three-way interaction (place*underlying voicing*parameter; place*underlying voicing*context), or the four-way interaction (place*underlying voicing*context*parameter) significant. Thus devoiced and voiceless stops behave similarly for each place of articulation within each context for each parameter. The mean values for devoiced and voiceless stops for each parameter within each context and place of articulation are given in Appendix I.

4.1.2.6 Word

The factor of word pair did not have a main effect for any of the subjects ($p>.09$ for all subjects; see Table 4.2, next-to-the-last row). The interaction between word and parameter was significant for all five subjects, indicating that each word pair behaved differently within each parameter. The three-way interaction among word, parameter, and underlying voicing was not significant (see Appendix G; Model 3), suggesting that the differences between devoiced and voiceless members of a pair were not dependent on parameter.

4.1.2.7 Familiarity

As noted above, due to efforts to preserve as much phonetic similarity as possible between members of a word pair, certain test words were relatively uncommon. This raises the possibility that the underlying voicing of the final stops for some words might have been unknown to some subjects, perhaps accounting for the small mean differences in the temporal measures. The results of the conjugation task designed to test for word familiarity showed that the underlying forms of approximately 50% of the test pairs were known to the subjects. The percent of unfamiliar pairs is high because a given pair was discarded as unfamiliar if the underlying voicing of one of the pair members (in any of the three randomizations) was not consistent with the prescriptive grammar. Thus 25% word unfamiliarity could give rise to up to 50% pair unfamiliarity.

In Figure 4.6, the mean values (across subjects) of the four temporal parameters for familiar pairs are plotted. The mean differences do not increase substantially when compared with the overall mean differences (see Figure 4.1).

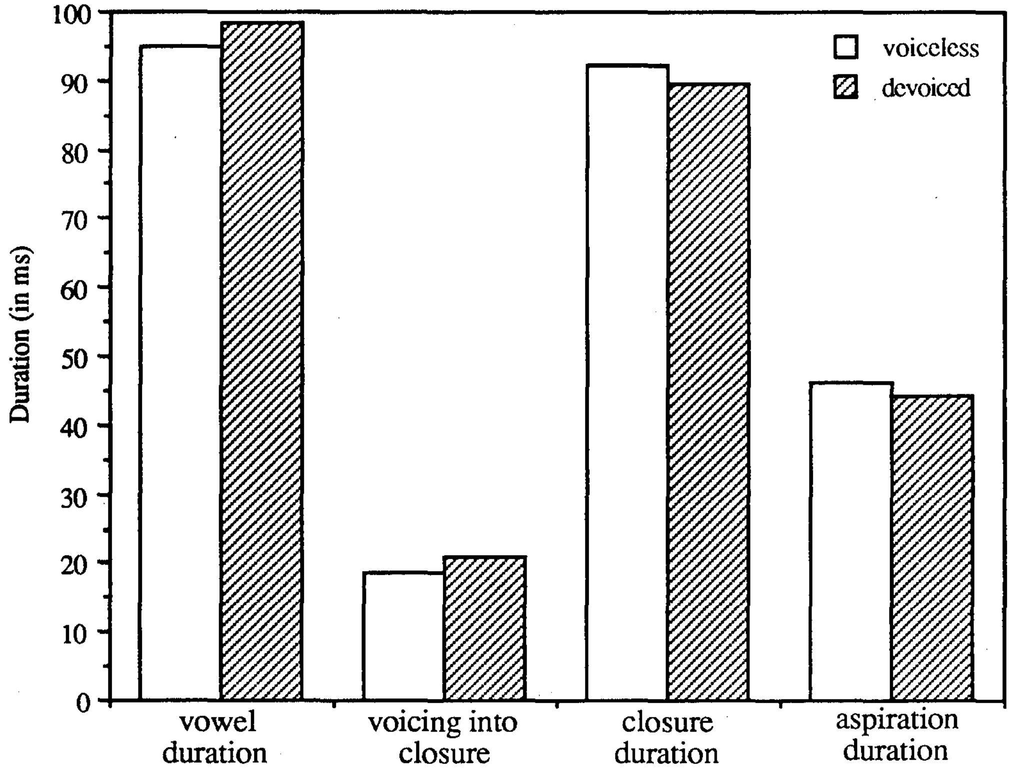

Figure 4.6. The mean values (in ms) of temporal parameters for familiar pairs (across subjects).

The mean values for the familiar word pairs were computed for each subject to determine if temporal differences increased for some subjects. But comparison of the values in Table 4.4 with the overall (familiar and unfamiliar) values in Table 4.1 shows the same pattern of results. This comparison is made explicit in Table 4.5, which gives the mean devoiced/voiceless differences for the overall data and for familiar pairs for each temporal measure. The differences between devoiced and voiceless stops should increase when unfamiliar pairs are omitted if small overall differences are due to subjects' lack of familiarity with certain lexical items. However, while the differences in the means increase for some of the temporal parameters for some subjects, these increases are not substantial. Furthermore, as shown in Table 4.5, the mean differences decrease about as often as they increase.

	vowel duration		voicing into closure		closure duration		aspiration duration	
	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless	devoiced	voiceless
Subject 1	95	92	20	19	88	83	47	50
Subject 2	74	70	23	23	79	85	39	30
Subject 3	99	93	23	21	103	104	28	25
Subject 4	115	112	20	17	94	101	48	46
Subject 5	102	102	18	14	76	80	74	72

Table 4.4. Mean values (in ms) of each temporal parameter for each subject for familiar pairs.

	vowel duration		voicing into closure		closure duration		aspiration duration	
	overall	familiar	overall	familiar	overall	familiar	overall	familiar
Subject 1	0	3	0	1	0	-5	-1	-3
Subject 2	4	4	2	0	4	6	-6	-9
Subject 3	2	6	2	2	1	1	0	-3
Subject 4	3	3	1	3	5	7	-1	-2
Subject 5	1	0	2	4	5	4	-2	-2

Table 4.5. Mean differences (in ms) between devoiced and voiceless stops for the overall data and for familiar pairs for each temporal parameter. (A minus (-) sign indicates a difference in the unexpected direction.)

A different statistical model (Appendix G, Model 4) was designed to include familiarity as a factor. The results of this analysis showed that the overall results were almost unchanged (compare to Table 4.2). The results are summarized in Table 4.6.

		Subject 1		Subject 2		Subject 3		Subject 4		Subject 5	
	d.f	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value	ChiSquare	p value
UR voicing (alt)	1	1.010	0.315	2.791	0.095	0.505	0.477	1.006	0.316	0.000	0.990
parameter (par)	3	219.565	0.000	211.251	0.000	264.931	0.000	226.984	0.000	268.088	0.000
context (cont)	1	492.785	0.000	165.399	0.000	0.373	0.542	387.468	0.000	656.177	0.000
place (pl)	2	3.471	0.176	1.778	0.411	2.540	0.281	3.741	0.154	0.034	0.983
familiarity (fam)	1	0.247	0.619	0.241	0.624	0.589	0.443	1.536	0.215	7.346	0.007
alt*fam	1	0.165	0.684	0.018	0.892	3.595	0.058	0.553	0.457	0.164	0.685
alt*fam*param	3	6.901	0.075	3.791	0.285	5.320	0.150	1.597	0.660	0.812	0.847
alt*fam*cont	1	0.332	0.565	1.384	0.239	0.708	0.400	0.165	0.684	1.942	0.163
alt*fam*par*cont	3	5.068	0.167	1.953	0.582	0.375	0.945	0.104	0.991	0.709	0.871

Table 4.6. Chi-Square and p-values of the factors and interactions for each subject in the model including familiarity.

Familiarity did not have a significant effect for four of the subjects (i.e., all but Subject 5). The interactions between familiarity and other factors were not significant, suggesting that the effect of other factors was not dependent on the familiarity criterion.

The general lack of an effect of the familiarity of the word pairs indicates that the small differences in the means of durations of the four parameters cannot be attributed to unfamiliarity of a word to a given subject.

4.1.3 Summary and Conclusion

Although the data for each subject were analyzed separately, the results of the statistical analyses were generally consistent for all five subjects. This suggests that subjects in this study behaved similarly. Underlying voicing did not have a significant effect for any of the subjects. The mean differences between devoiced and voiceless stops, for each subject, were small (the largest difference being 6 ms for vowel duration, 4 ms for voicing into closure, and 7 ms for closure duration), and the mean difference for aspiration duration was in the wrong direction. The mean differences got even smaller when the data for all subjects were combined. For the overall data, the mean difference for vowel duration was 3 ms, for voicing into closure, 1 ms, and for closure duration, 3 ms. The mean differences remained almost unchanged when each place of articulation was analyzed separately. Furthermore, the familiarity criterion did not change the results of the data in any considerable way, suggesting that the small differences are not due to subjects' unfamiliarity with the underlying voicing of the word-final stops.

In summary, the lack of statistical significance of underlying voicing, the small mean differences between devoiced and voiceless stops, the lack of at least one parameter with a large mean difference, and the lack of consistent differences in the expected direction across tokens for all word pairs or for the familiar pairs suggest that final devoicing in Turkish is neutralizing as measured by these four temporal parameters for these subjects.

While these acoustic data point toward neutralization of the final voicing contrast in Turkish, it is possible that other acoustic differences, not measured in this study, consistently differentiate final devoiced and voiceless stops. It is recognized, however, that no study could identify all possible acoustic differences. Yet, if such differences are present and are sufficiently large as to be perceptible, then perceptual investigation of devoiced and voiceless final stops with native speakers of Turkish should yield positive results. This possibility is tested in the following section.

4.2 PERCEPTUAL TEST

A perceptual test was conducted to determine whether Turkish listeners can identify and/or discriminate the underlying voicing distinction of devoiced and voiceless stops. Although no consistent differences were found for the four temporal measures, it is still possible that the underlying voicing distinction of devoiced and voiceless stops is maintained in other parameters, perhaps leading to an identifiable and/or discriminable difference. The four temporal parameters measured here (vowel duration, voicing into closure, closure duration, and voicing into closure) were selected because they were found to be acoustic correlates of the voicing contrast in intervocalic stops (see Chapter 3). However, phonetic studies suggest that spectral, rather than durational, properties may be more perceptually salient as cues to the voicing distinction of post-vocalic stops (Walsh and Parker, 1984, and references therein). Results of perceptual studies with English listeners suggest that while formant transitions alone are a perceptually significant cue to voicing, vowel duration, for example, is not (Wolf, 1978; Walsh and Parker, 1984).

The experimental design used here was constrained by the general lack of minimal pairs differing only in the underlying voicing of final stops in Turkish. In the perceptual studies using German and Polish, for example, listeners were asked to identify the word they heard. This was possible because in both of these languages, there are word pairs whose members differ only in the underlying voicing of final obstruents. As Turkish has no such commonly occurring pairs involving final non-continuants, near-minimal pairs whose members differed in other properties as well (see Appendix E) were used in the acoustic analysis of final stops. Due to these multiple differences, the original test pairs from the acoustic study could not be used in the perceptual tests. Monosyllabic words (CVC) from the acoustic study could not be used as stimuli because the pair members differed both in underlying voicing of the final consonant and in the manner of the initial consonant. In disyllabic pairs, although the first syllables were different, the second syllables (i.e., the -CVC portions) were always the same for each member, as the examples in (1) illustrate.

(1)	/dolab/	do.lap	/tʃalap/	tʃa.lap
	/kanad/	ka.nat	/sanat/	sa.nat
	/gurub/	gu.rup	/turup/	tu.rup

A subset of disyllabic pairs was chosen as test stimuli, based on two criteria[2]. First, pairs were selected based on the place of articulation of the final non-continuant so that each place was represented. Second, within each place of articulation, priority was given to pairs whose members were commonly occurring lexical items. Subject 4 was selected as the speaker because she showed the largest mean differences between devoiced and voiceless stops for three of the four parameters. This was done to maximize the possibility of perceptible differences.

The perceptual test consisted of two tasks; identification and discrimination. The purpose of the identification test was to determine whether Turkish listeners can classify devoiced stops as different from voiceless ones. The discrimination test was conducted to determine whether the differences between devoiced and voiceless stops could be detected even if the stops were not classified as different.

Two separate identification tests were conducted. The difference between these two tests was the presence or absence of sentential context for the test stimuli.

4.2.1 Perceptual Experiment I: Identification in Isolation

In this experiment, test stimuli consisted only of the second syllable of a disyllabic word. Although the original words were produced in a carrier sentence, the entire carrier was eliminated from the test stimuli.

4.2.1.1 Method

Subjects: 7 adult native speakers of Turkish served as subjects. 4 had participated in the acoustic study. None was the speaker. Subjects were acquaintances of the author and

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[2] The temporal differences between devoiced and voiceless stops were similar for both monosyllabic and disyllabic pairs. Thus, disyllabic pairs are representative of all the test pairs.

were contacted by phone. Subjects were not paid for their participation in the perception experiments.

Stimuli: 15 disyllabic pairs produced by a female speaker (Subject 4) for the acoustic experiment were selected. The pairs are presented in Appendix J, along with the values for each pair member for each of the four temporal parameters. As noted above, Subject 4 was chosen as the speaker in this experiment because she showed larger mean differences between devoiced and voiceless stops for three parameters. The pairs were selected from the second repetition of words embedded in the carrier sentence.

The second syllables of test words were excised from the original sentences. While the CV portion of these syllables consisted of the same segments for both pair members, one concern was that the first syllable (which differed across pair members) might have had a coarticulatory influence on the second syllable. (For example, the second syllable of /tokad/ and /takat/ might differ due to the influence of the preceding vowel.) To minimize such possible coarticulatory influences, the initial cut for each stimulus was placed not at the onset of the syllable-initial (intervocalic) consonant, but rather at the offset of the consonant (e.g., at the offset of /k/ in both /tokad/ and /takat/). The offset of intervocalic stops was defined as the onset of periodicity of the following vowel. For intervocalic liquids and nasals, increase in the waveform amplitude was taken to be the consonant offset. (Transitions of intervocalic consonants into the following vowel were included in the stimuli.) The end of the test stimulus was determined to be the onset of periodicity in the waveform for the following word. Onsets and offsets were placed at the zero crossings in the waveform. The waveform editing routine was from Haskins Laboratories, and was implemented on a Vax Workstation GPX II.

Procedure: 30 excised syllables were randomized three times in three separate blocks, resulting in 90 trials. The interstimuli interval (ISI) was 2.5 seconds. Listeners were told that they would hear stimuli in which the first syllable of real Turkish words had been deleted, and that their task was to identify the original word. On the score sheet, next to each trial number, full word (disyllabic) forms of both members of the pair were written. For each trial, listeners were asked to circle the member of the pair that the stimulus was taken from.

The stimuli were presented on-line. Speakers were placed in a quiet room, and the volume was adjusted to a comfortable listening level. All three experiments were conducted in the same recording session, and in the order reported here. The duration of Experiment I was approximately 10 minutes.

4.2.1.2 Results

The percent correct identification for the group as well as for each subject is shown in Table 4.7.

Subject	devoiced	voiceless	**overall**
	% correct	% correct	**% correct**
1	47	53	**50**
2	53	49	**51**
3	49	36	**42**
4	53	51	**52**
5	58	36	**47**
6	80	22	**51**
7	56	47	**51**
Group	**57**	**42**	**49**

Table 4.7. Percent correct identification of devoiced and voiceless pairs according to subject.

The group results suggest that identification of devoiced and voiceless final stops is about chance (49%). For individual subjects, percent correct identification ranged from 42% to 52%. When devoiced and voiceless stops were analyzed separately, however, devoiced stops were, in general, identified better than chance (57%) while identification of voiceless stops was below chance (42%).

The percentages from Table 4.7 are shown in graphic form in Figure 4.7. This representation makes it clear that identification hovered around chance for those subjects who showed no bias in their responses; for subjects who showed a bias (especially Subjects 5 and 6), performance was above chance on devoiced stops and below chance on voiceless ones.

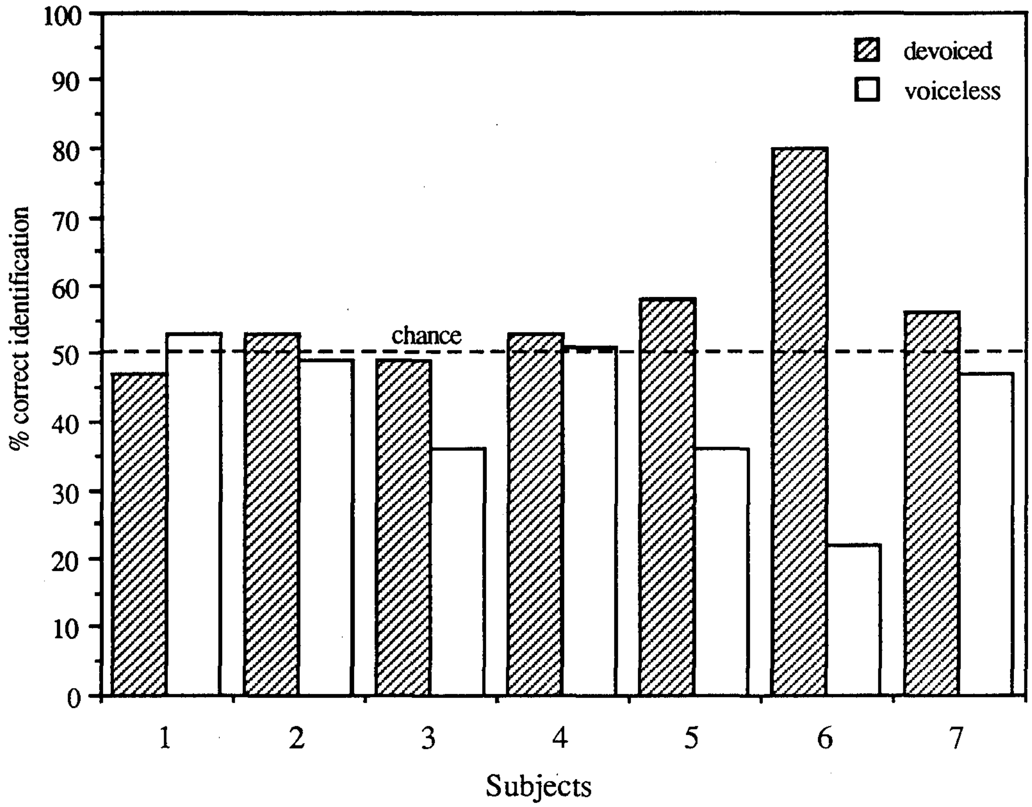

Figure 4.7. Percent correct identification of devoiced and voiceless pairs for each subject.

This bias was also evident when each pair was analyzed separately (summing across subjects), as shown in Figure 4.8. In the majority of the pairs, devoiced stops were identified more accurately than their voiceless counterparts.

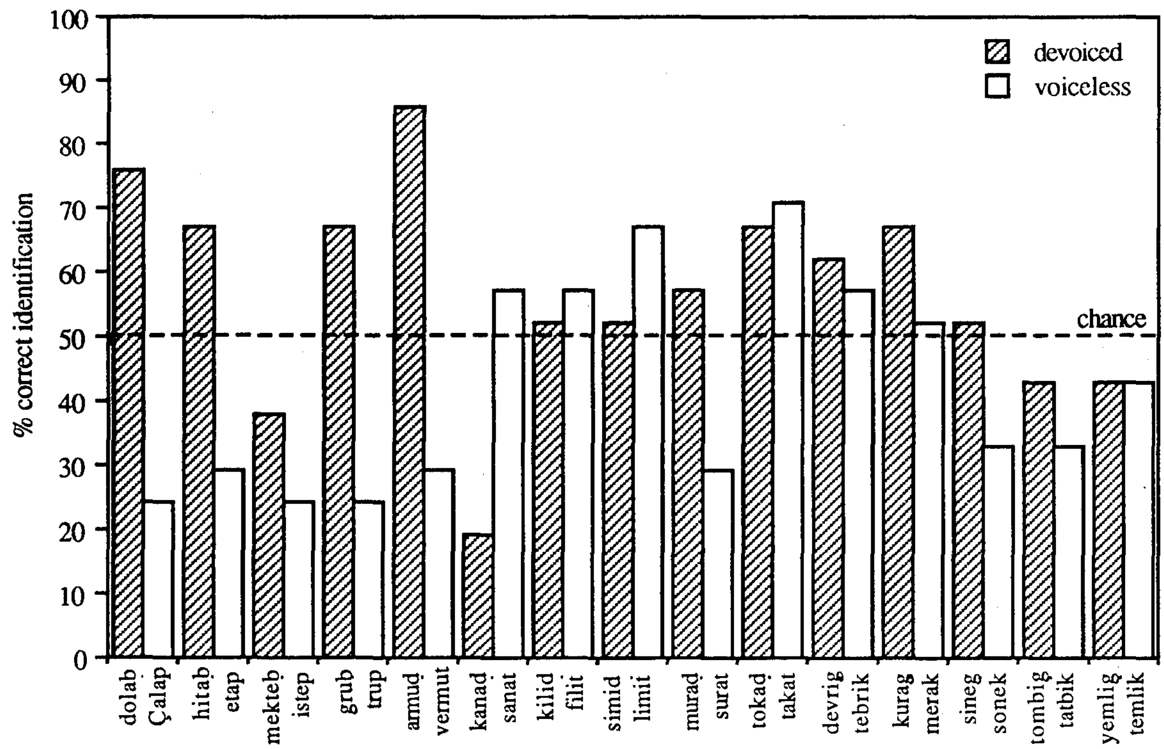

Figure 4.8. Percent correct identification for each pair (across subjects).

This preference for the devoiced member runs counter to what would be expected based on the acoustic measures. The acoustics show that devoiced stimuli are not phonetically distinct from voiceless ones, yet there is a bias in favor of the devoiced member. In previous studies, on the other hand, there was a tendency to select the voiceless member (Port and Crawford, 1989; Slowiaczek and Szymanska, 1989; Jassem and Richter, 1989; Charles-Luce, 1987). However, in Turkish, in those pairs in which one member was more common than the other, the more common member contained a devoiced final stop. These seven pairs are shown in (2), where the more common member is in the left-hand column. All seven of these are pairs in which the devoiced member was identified more accurately (compare Figure 4.8).

(2)	dolab	'closet'	Çalap	'God (old Turkish)'
	hitab	'address'	etap	'lap (e.g., in swimming)'
	mekteb	'school'	istep	'steppe'
	grub	'group'	trup	'troupe'
	armud	'pear'	vermut	'vermouth'
	sineg	'fly'	sonek	'suffix'
	tombig	'cute'	tatbik	'putting (something) into effect'

It seems likely, then, that the devoiced bias is actually a bias towards the more common member of a pair. For the remaining eight pairs in which both members are equally common lexical items, there was no clear pattern to the perceptual responses. For four of the pairs, the percentage of correct identification was approximately the same for both devoiced and voiceless member (*kilid/filit, tokad/takat, devrig/tebrik, yemlig/temlik*). For two pairs, the voiceless member was chosen (*simid/limit, kanad/sanat*) while for the other two pairs, the devoiced member was chosen (*murad/surat, kurag/merak*).

In this experiment, there were two pairs in which both members were identified better than chance: *tokad* 67%, *takat* 71%; *devrig* 62%, *tebrik* 57%. (There were three other pairs (*kilid/filit, simid/limit, kurag/merak*) for which both members were identified correctly more than 50% of the time, but in all three, the percentage of correct identification for one of the members was only 52%.) However, comparison with acoustic measures shows no clear correlation between percent correct identification and size of the temporal differences between pair members. For example, the pairs *tombig/tatbik*, and *mekteb/istep* showed differences in the expected direction for all four temporal parameters (see Appendix J), yet the members of both pairs were identified correctly less than 50% of the time.

These findings suggest that Turkish listeners are generally not able to distinguish devoiced and voiceless stops when presented with excised syllables differing only in the underlying voicing of the final stop.

4.2.2 Perceptual Experiment II: Identification in Context

The stimuli presented in Experiment I were relatively short, with the average duration being 201 ms (ranging from 153 ms to 261 ms). A second experiment was conducted to determine whether the inclusion of the following word from the original sentential context would provide additional cues for the identification of the final stop.

4.2.2.1 Method

Subjects: The same 7 adult native speakers of Turkish served as subjects.

Stimuli: The 15 pairs used in Experiment I were taken from the second and third repetitions of words embedded in the carrier sentence. The speaker in this experiment was the same as in Experiment I. Thus, half of the stimuli (from the second repetition) were the same as in Experiment I (but presented in context), and the other half were new (from the third repetition). Word pairs from two different repetitions were included so that the identification of a given pair could be compared across repetitions, assuming that the temporal differences between members of a pair would be different for each repetition.

All stimuli consisted of the second syllable of the selected test words followed by the word '*istiyorum*'. Again, the offset of the syllable-initial consonant was marked as stimuli onset. The end of the stimulus was the end of the original utterance.

Procedure: The 30 words from Repetitions 2 and 3 comprised two separate lists. Each list of 30 words was randomized three times in three separate blocks. The two different repetitions were kept as two separate lists because the differences in the temporal parameters for each pair differed from one repetition to another. Since one purpose was to determine whether there was any correlation between temporal differences and correct response, the two lists were analyzed separately as well.

There were 180 trials in this experiment (30 words x 2 repetitions x 3 randomizations). Stimuli were separated by a 2-second ISI. In this experiment, listeners were told that they would hear the second syllables followed by '*istiyorum*', but their task was the same as in the first experiment. (Experiment II followed Experiment I.) Again, listeners were asked to circle the word they thought the syllable was taken from.

The stimuli were presented on-line as in Experiment I. The duration of Experiment II was approximately 20 minutes.

4.2.2.2 Results

Table 4.8 shows percent correct identification for devoiced and voiceless members for each subject as well as for the group. (Subjects are assigned the same subject numbers as in Experiment I.)

Subject	devoiced	voiceless	**overall**
	% correct	% correct	% **correct**
1	50	41	**46**
2	58	43	**51**
3	54	41	**48**
4	54	56	**55**
5	49	31	**40**
6	72	26	**49**
7	54	41	**48**
Group	**56**	**40**	**48**

Table 4.8. Percent correct identification of devoiced and voiceless pairs according to subject.

There was some variation among subjects' overall performance, with Subject 4 at 55% correct identification and Subject 5 at 40%. Overall identification of devoiced and voiceless members was about chance for the group (48% correct identification).

In this experiment, 15 pairs were taken from two different repetitions. As temporal differences between devoiced and voiceless members of a given pair may differ across repetitions, responses for each word pair were calculated separately based on the repetition it was taken from. Responses for each repetition are not reported here, though, as investigation of each repetition showed that the pattern of responses for a given repetition was similar to that across repetitions.

As in Experiment I, the overall percent correct identification for devoiced members (56%) was higher than for voiceless members (40%). In Figure 4.9, percent correct identification for each subject is plotted. Again, as in Experiment I, devoiced members were generally identified more accurately than voiceless members.

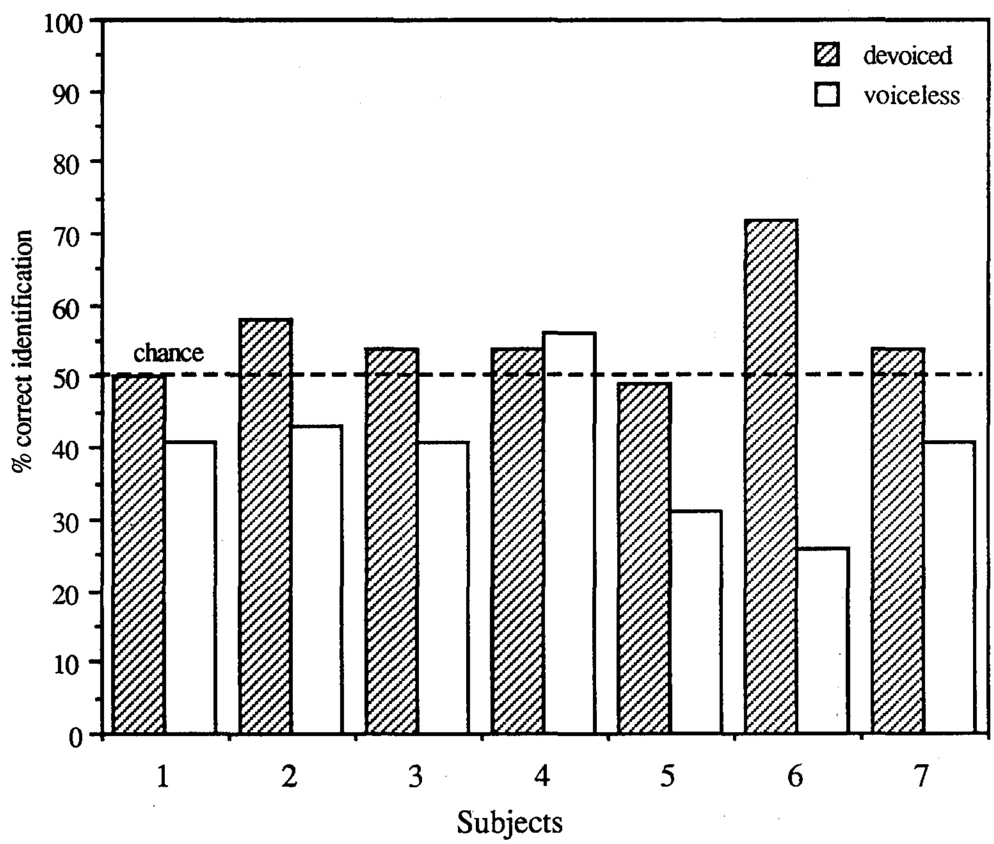

Figure 4.9. Percent correct identification of devoiced and voiceless pairs for each subject.

When each pair was analyzed separately (summing across subjects), the pattern was similar to that of Experiment I. Again, as seen in Figure 4.10, identification was generally better on devoiced tokens than voiceless ones. For pairs in which there was a bias towards the devoiced member, the devoiced member was generally more common than the voiceless one (except for *mekteb/istep* and *tombig/tatbik*). However, in this experiment, there were no pairs in which both members were identified better than chance, indicating that inclusion of the following word *'istiyorum'* did not provide additional cues as to the voicing of the final stop.

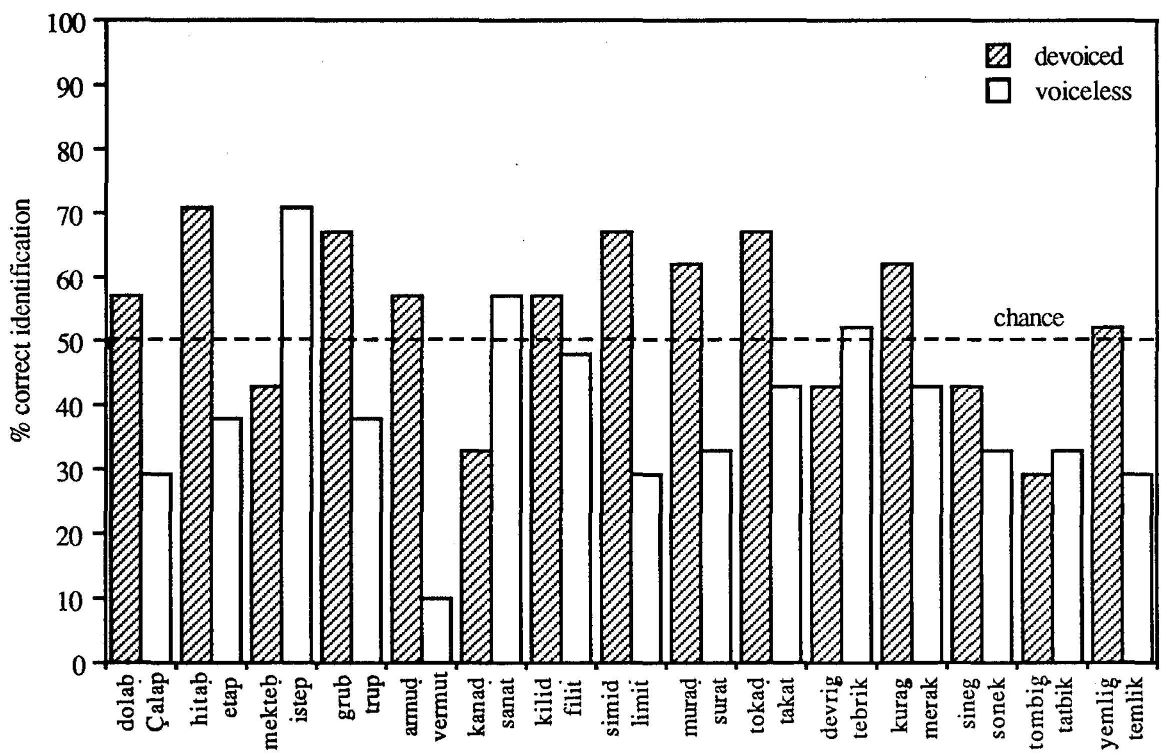

Figure 4.10. Percent correct identification for each word pair (across subjects).

The findings of Experiment II, as in Experiment I, suggest that Turkish listeners cannot distinguish the underlying voicing contrast of devoiced and voiceless stops better than chance within this experimental paradigm.

4.2.3 Perceptual Experiment III: Discrimination Test

Although Turkish listeners are apparently not able to label devoiced and voiceless stops as signalling different lexical items, it is still possible that differences between devoiced and voiceless stops might be discriminable. In the identification tests, listeners were presented with individual stimuli and were asked to identify the original word. In the discrimination experiment, stimuli were paired, and the members of a pair were presented successively. By hearing the pair members next to each other, listeners might be sensitive to differences that they would not label as different.

The purpose of this experiment was to determine whether differences between Turkish devoiced and voiceless stops are discriminable by Turkish listeners.

4.2.3.1 Method

Subjects: The 7 subjects who participated in the first two perceptual experiments served as subjects for this experiment.

Stimuli: The same 15 pairs used in the previous experiments were taken from the same second and third repetitions of words embedded in the carrier sentence. The speaker in this experiment was also the one used in the other two experiments.

The stimuli used in this experiment were those used in Experiment II except that the stimuli consisted of only the second syllables without the '*istiyorum*' context (as in Experiment I). The stimuli were excised from the original sentences in the same manner described in 4.2.1.1.

Procedure: The test sequence consisted of 16 occurrences of the 15 word pairs in each repetition. There was a total of 240 trials (15 word pairs x 8 occurrences of each pair x 2 randomizations) for each subject. The stimuli excised from the two repetitions were kept separate. A 1-second pause was inserted between the members of pairs and a 2-second pause after each pair.

Each trial involved sequential presentation of the members of a minimal pair (e.g., the *-lap* of *dolap* and the *-lap* of *Çalap*), with the order of pair members counterbalanced across trials. Subjects were told that they would hear a pair of syllables excised from two different words. Listeners were provided with score sheets containing one member of the pair followed by the numbers 1 and 2 (e.g., dolap 1 2). Which member of the pair appeared on the score sheet was also counterbalanced across trials.

The stimuli were presented on-line as in the previous experiments. Experiment III was given after Experiments I and Experiment II in the same testing session, and required approximately 15 minutes.

4.2.3.2 Results

Results for the group indicate that discrimination of devoiced and voiceless stops is at chance level (51%). As in Experiments I and II, there was some variation in performance level across subjects. Percent correct discrimination is shown in Figure 4.11 for each subject. (Subjects are assigned the same subject numbers as in Experiments I and II).

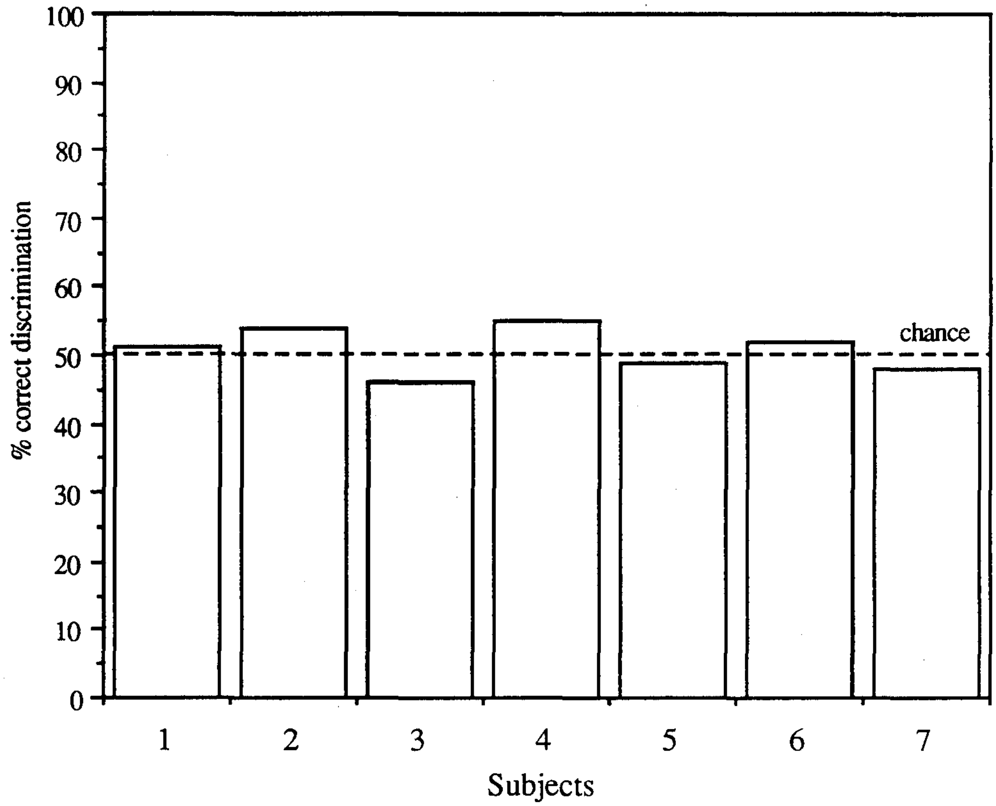

Figure 4.11. Percent correct discrimination of devoiced and voiceless pairs according to subject.

As in Experiments I and II, Subject 4 again performed the most accurately (55 %). In this experiment, Subject 3 has the lowest percent correct discrimination (46 %).

Percent correct discrimination for each pair is plotted in Figure 4.12.

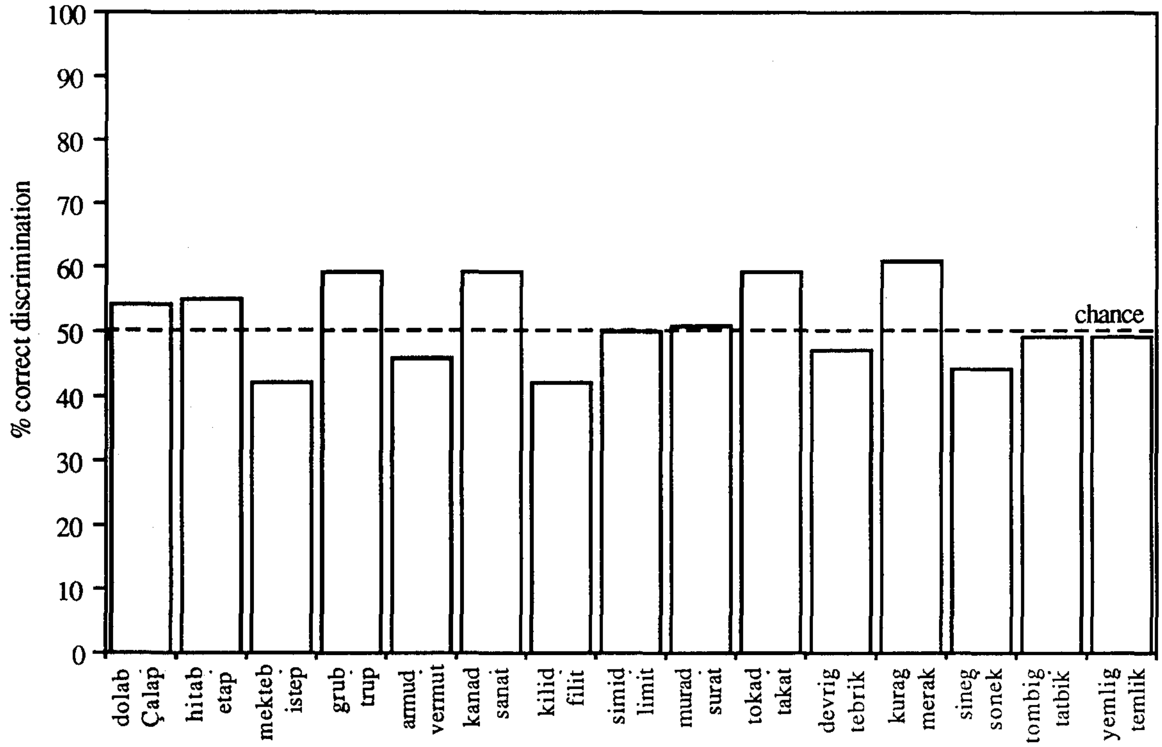

Figure 4.12. Percent correct discrimination for each word pair (across subjects).

Correct discrimination was above chance for 6 pairs, but discrimination accuracy did not exceed 61% (*kurag/merak*). Discrimination was at chance level for three pairs, and below chance for the remaining five pairs. The most poorly discriminated pair was *mekteb/istep* (42%).

The results for each repetition of each test pair (for each subject) were calculated separately, and are shown in Figure 4.13.

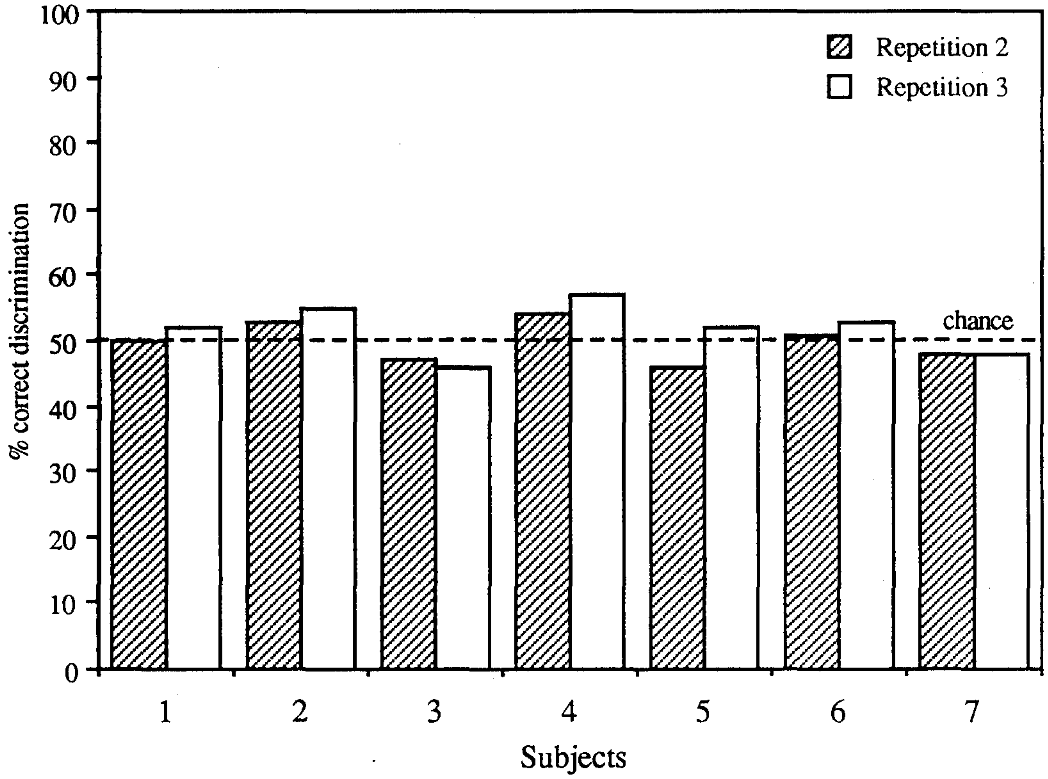

Figure 4.13. Percent correct discrimination for each repetition according to subject.

Subjects' performance, in general, was higher for Repetition 3 than for Repetition 2. This may be evidence of a weak practice effect, as stimuli excised from Repetition 3 were presented after those from Repetition 2. This suggestion, however, is not strongly borne out by data for individual word pairs, shown in Figure 4.14. Although responses differed as a function of the repetition the word pair was taken from, discrimination was not consistently better for pairs taken from Repetition 3.

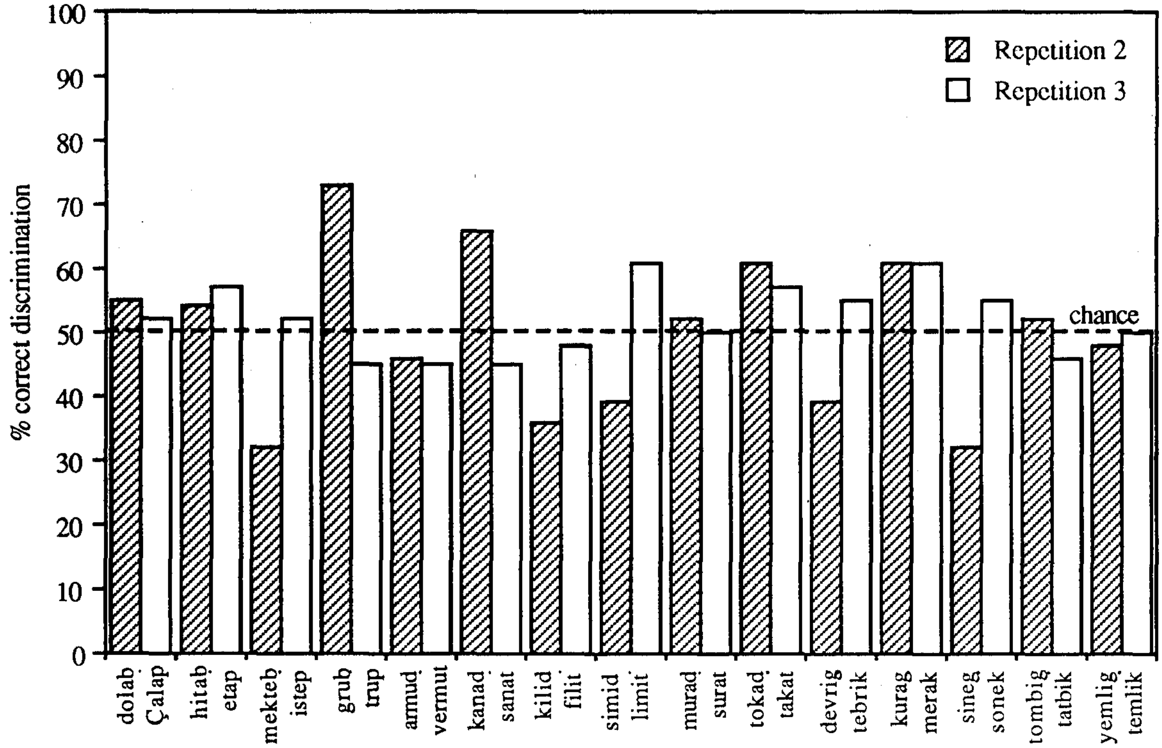

Figure 4.14. Percent correct discrimination for each repetition according to word pair.

Comparison of discrimination results with acoustic measures showed no direct correlation between temporal differences for a given pair and percent correct discrimination of the pair. Given the acoustic measures for the pair *mekteb/istep* in Repetition 2, for example, discrimination might be expected to be above chance. For this pair, although the temporal differences for the four parameters were in the expected direction (the size of the differences being 6 ms for vowel duration and closure duration, 13 ms for voicing into closure, and 11 ms for aspiration duration), discrimination accuracy was only 32% (see Figure 4.14). The pair *kanad/sanat*, on the other hand, was discriminated better than chance (66%) in Repetition 2, despite the almost equivalent durations for the four parameters (see Appendix J).

The results of this experiment indicate that Turkish listeners did not discriminate devoiced and voiceless members of pairs when the second syllables of disyllabic words were excised and presented as a pair. Accuracy for this experiment is slightly better than that of Experiments I and II. However, the overall performances of each subject, and for each word pair are still generally at chance level.

4.2.2 Summary and Discussion

The overall results for all three experiments were at chance level (Experiment I: 49%; Experiment II: 48%; Experiment III: 51%). In both versions of the identification test (Experiments I and II), there was a bias in favor of the devoiced member of the pair, at least in certain pairs. However, for the pairs which showed this bias, the devoiced member was the more commonly used lexical item. This suggests that the response bias towards the devoiced member was in part the result of the frequency of that lexical item.

Identification was better than chance for both pair members in only two pairs in Experiment I and in no pairs in Experiment II. In general, then, Turkish listeners were not, in the studies reported here, able to identify devoiced and voiceless stops as different.

Although the results of the discrimination test suggest that comparative presentation of devoiced and voiceless members as a pair somewhat facilitated Turkish listeners' ability to detect differences between devoiced and voiceless members, overall performance was still poor.

The findings of all three perceptual experiments indicate that the underlying voicing of devoiced and voiceless stops in Turkish was not perceived by Turkish listeners in this experimental paradigm. While it is possible that a more sensitive paradigm would have elicited different responses to devoiced and voiceless stops, the present data provide no evidence that the underlying voicing distinction in Turkish final stops is maintained through acoustic parameters other than the four temporal ones reported in this chapter.

4.3 GENERAL DISCUSSION AND CONCLUSION

The results of these acoustic and perceptual investigations of final devoicing in Turkish are consistent with the claim that the underlying voicing contrast in non-continuants in Turkish is completely neutralized in syllable-final position. Acoustically, no significant temporal differences between devoiced and voiceless stops were found. Perceptually, Turkish listeners were unable to differentiate devoiced and voiceless stops in identification and discrimination tests, suggesting that devoiced and voiceless non-continuants may not be perceptually distinct.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Including the current study, the phonetic realization of devoiced and voiceless final obstruents has been investigated in 5 languages, German, Polish, Russian, Catalan, and Turkish. In terms of orthographic representation, these five languages can be divided into two basic classes: languages which reflect final devoicing in the orthography (Catalan and Turkish), and languages which do not reflect final devoicing in the orthography (German, Polish, and Russian). The two languages which reflect final devoicing in the orthography show comparable phonetic results. In all three studies of Catalan (Dinnsen and Charles-Luce, 1984; Charles-Luce and Dinnsen, 1987; Charles-Luce, 1987), as in the Turkish data reported here, the overall acoustic differences between devoiced and voiceless obstruents were not significant (except that a 1 ms difference was found to be significant for one parameter in one of the Catalan studies)[1]. In the perceptual experiments, overall performance was at chance level. Thus, the Catalan and Turkish data suggest that final devoicing is neutralizing in these two languages.

Large acoustic differences between devoiced and voiceless obstruents have been reported only for the languages which maintain a final orthographic voicing distinction. However, the phonetic studies of these languages can be subdivided into two groups based on their experimental design: studies which controlled for an orthographic influence, and studies which did not. This subdivision is necessary in reevaluating the findings for these

[1] Charles-Luce (1987) found that vowel duration was significantly longer before devoiced than before voiceless obstruents in two assimilatory environments in one of the semantic contexts. This significant difference in vowel duration is not included in the discussion here, as this finding held for regressive voicing assimilation, rather than final devoicing.

languages as the claims of the two groups are substantially different. In general, temporal differences between devoiced and voiceless obstruents have been reported for studies which did not eliminate the orthographic influence. Such findings have led to the criticism that the differences were an artifact of the orthography. Some support for this criticism is provided by studies which failed to find temporal differences between devoiced and voiceless obstruents when the experimental paradigm controlled for the possible orthographic influence (e.g., Fourakis and Iverson, 1984; Jassem and Richter, 1989).

The claim that the temporal differences are an artifact of the orthography predicts that phonetic differences between devoiced and voiceless obstruents should be found only when the experimental paradigm introduces orthographic distinctions. It is the case that all acoustic studies of German, Polish, and Russian (except for Fourakis and Iverson, 1984) in which subjects were presented with the written forms of the test words showed significant devoiced-voiceless differences, at least in certain contexts (Mitleb, 1981; Port and O'Dell, 1985; Charles-Luce, 1985; Port and Crawford, 1989; Piroth *et al.*, 1991; Slowiaczek and Dinnsen, 1985; Jassem and Richter, 1989; Pye, 1986). However, it is not the case that temporal differences between devoiced and voiceless obstruents were found *only* in such studies. The clearest counterexample to attributing all temporal differences to an orthographic artifact is the study by Port and Crawford (1989), who found significant differences between devoiced and voiceless obstruents in German even when subjects were not presented with the written forms of the test words. In addition, Jassem and Richter (1989), who also eliminated an orthographic influence, found that the underlying voicing contrast was maintained when test words were elicited in dialogues which contained metalinguistic prompts. Thus, eliminating orthography from the experimental paradigm may reduce, but does not necessarily eliminate, temporal differences. Conversely, introducing orthography may increase temporal differences, but not necessarily to the point of significance (Fourakis and Iverson, 1984).

Not all of the acoustic data, then, can be explained by the claim that the differences between devoiced and voiceless obstruents are exclusively due to an orthographic artifact. This is true not only for data involving within-language comparisons of measures from different experimental conditions, but also true for cross-language comparisons. For example, similar experimental conditions in German (Charles-Luce, 1985; Piroth et al., 1991) and Catalan (Charles-Luce, 1987) have yielded devoiced-voiceless differences in German but not in Catalan. An account which encompasses all of the acoustic data cannot attribute all findings to an orthographic artifact. A possible alternative explanation is that speakers of languages which maintain an orthographic distinction are able to control the degree of neutralization. The notion of variability in degree of neutralization was introduced by Port and Crawford (1989) for German. This notion is extended here to generally apply to languages which maintain an orthographic distinction, such as Polish and Russian. But it is proposed that this variability does not extend to languages which reflect final devoicing in the orthography, such as Turkish and Catalan.

What are the phonological implications of these two types of languages? That comparable manipulations in the two language types have yielded different phonetic results suggest that the input to the phonetic component is different for the two types. One way to capture this difference would be to postulate that devoiced obstruents in languages which do not maintain an orthographic contrast (such as Turkish and Catalan) would be [-voice] at the output of the phonological component, as the underlying voicing contrast between devoiced and voiceless obstruents is phonetically neutralized. In contrast, in languages which maintain an orthographic distinction (such as German, Polish, and Russian) devoiced obstruents would be unspecified for voicing (i.e., [Øvoice]) at the output of the phonological component. The phonetic realization of these underspecified obstruents, as suggested by German and Polish studies, would depend in part on semantic or pragmatic conditions.

It has been argued here that there are at least two types of languages with respect to the neutralizing status of final devoicing, fully neutralizing languages such as Turkish and Catalan and not fully neutralizing languges such as German, Polish, and Russian. Dinnsen (1985) formulated four possible types of languages in terms of the phonetic realization of the neutralizing process. Type A languages show no acoustic and perceptual differences, Type B languages show acoustic differences but not perceptual differences, and Type C languages show both acoustic and perceptual differences. (Type D is classified as impossible, as there could presumably be no language in which two phonetically identical segments were perceived as distinct.) Based on phonetic data available at that time, Dinnsen (1985) argued that there were no Type A languages, and classified German as a Type C language. (Dinnsen argued that there were acoustic differences in Catalan, but as there were no perceptual experiments of Catalan final devoicing at the time, he did not include Catalan as an example of Type C.)

Current data, however, suggest that Dinnsen's (1985) classification has to be revised. First, Catalan and Turkish appear to be Type A languages. (Alternatively, it is possible that there may be acoustic, but non-perceptible, differences for Turkish and Catalan not measured in studies-to-date. If such differences are found, then these languages would be classified as Type B.) Second, in German and Polish, final devoicing appears to be neutralizing under certain conditions. Such variation in degree of neutralization is not accounted for in Dinnsen's A-D classification.

In conclusion, based on studies of five languages, it is argued here that there is a relation between orthography and the neutralizing status of final devoicing. Phonetic neutralization would be expected in languages which reflect final devoicing in the orthography, but not necessarily in languages which maintain an orthographic voicing contrast. However, this conclusion is based on limited language data, with two languages exemplifying one type and three languages exemplifying the other. Phonetic investigation of final devoicing in other languages is needed to determine whether the proposed relation between orthography and the neutralizing status of final devoicing is upheld in other languages. Phonetic studies of putative phonological neutralization processes other than final devoicing are also necessary to determine the generality of this proposed relation between orthography and the status of neutralization.

APPENDICES

APPENDIX A

Word pairs used in the acoustic analysis of intervocalic stops
OR: Orthographic Representation, **PR:** Phonetic Representation

OR	PR	Gloss	OR	PR	Gloss
soba	[soba]	stove	sopa	[sopa]	stick
kabı	[kabɯ]	container, acc	kapı	[kapɯ]	door
taba	[taba]	tobac	tapa	[tapa]	stopper
yaban	[jaban]	wild	yapan	[japan]	makes, agentive
tabu	[tabu]	taboo	tapu	[tapu]	title deed
çaba	[tʃaba]	effort	çapa	[tʃapa]	hoe
kabak	[kabak]	squash	kapak	[kapak]	lid, cover
habis	[habis]	malignant	hapis	[hapis]	imprisonment
kaban	[kaban]	coat, jacket	kapan	[kapan]	trap
saban	[saban]	plow	sapan	[sapan]	slingshot
kadı	[kadɯ]	judge	katı	[katɯ]	hard, solid
kadın	[kadɯn]	woman	katın	[katɯn]	add, 2nd prs.pl. imper.
kadar	[kadař̥]	until	katar	[katař̥]	train (of wagons)
model	[model]	model	motel	[motel]	motel
madem	[madem]	since	matem	[matem]	mourning
keder	[kedeř̥]	sorrow	keten	[keten]	linen
hatim	[hadim]	maid	hatim	[hatim]	reading of the Koran cover to cover
kuduz	[kuduz]	rabies	kutup	[kutup]	pole (e.g., geographic)
sadır	[sadɯř̥]	chest	satır	[satɯř̥]	meat cleaver
ladin	[ladin]	spruce	Latin	[latin]	Latin
pagan	[pagan]	pagan	takan	[takan]	attach, agentive
bagaj	[bagaj]	trunk	bakan	[bakan]	minister (in politics)
lagar	[lagař̥]	lean	lakoz	[lakoz]	a large gray mullet
fagot	[fagot]	bassoon	takoz	[takoz]	wedge
figür	[figyř̥]	figure	fikir	[fikiř̥]	idea
logos	[logos]	term	lokal	[lokal]	local
vagon	[vagon]	wagon	vakum	[vakum]	vacuum

APPENDIX B

Results of the statistical analysis (Mixed Model Analysis of Variance) of the voiced / voiceless distinction in intervocalic position (all factors and interactions are included)

vce: voicing, **param:** temporal parameter, **place:** place of articulation

SUBJECT 1

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	53.620	2.584	
CONSTANT	47.272	1.087	0.000
vce	0.447	0.278	0.108
param	20.816	1.813	0.000
param	-6.534	1.813	0.000
param	20.473	1.813	0.000
place	-0.659	1.489	0.658
place	0.266	1.489	0.858
vce*param	-8.339	0.465	0.000
vce*param	-14.395	0.465	0.000
vce*param	12.192	0.465	0.000
vce*place	0.470	0.381	0.217
vce*place	-0.980	0.381	0.010
param*place	-4.799	2.483	0.053
param*place	1.962	2.483	0.430
param*place	4.685	2.483	0.059
param*place	4.466	2.483	0.072
param*place	-1.473	2.483	0.553
param*place	-4.290	2.483	0.084
vce*param*place	-2.728	0.636	0.000
vce*param*place	0.638	0.636	0.316
vce*param*place	3.780	0.636	0.000
vce*param*place	1.532	0.636	0.016
vce*param*place	-0.662	0.636	0.298
vce*param*place	-3.060	0.636	0.000
word(place)	2.121	9.600	
word(place)*param	107.524	18.124	
word(place)*vce	0.275	1.255	
word(place)*param*vce	4.380	2.434	

SUBJECT 2

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	72.860	3.514	
CONSTANT	46.850	1.222	0.000
vce	0.586	0.369	0.113
param	13.591	1.733	0.000
param	-10.903	1.730	0.000
param	19.413	1.730	0.000
place	-2.623	1.673	0.117
place	0.801	1.673	0.632
vce*param	-10.796	0.644	0.000
vce*param	-16.712	0.638	0.000
vce*param	12.290	0.638	0.000
vce*place	0.032	0.505	0.950
vce*place	-0.082	0.508	0.872
param*place	-3.169	2.371	0.181
param*place	4.505	2.369	0.057
param*place	4.379	2.369	0.065
param*place	3.002	2.376	0.206
param*place	-0.508	2.370	0.830
param*place	-2.894	2.370	0.222
vce*param*place	-2.411	0.878	0.006
vce*param*place	1.644	0.873	0.060
vce*param*place	2.832	0.873	0.001
vce*param*place	2.308	0.893	0.010
vce*param*place	-1.092	0.875	0.212
vce*param*place	-2.164	0.875	0.013
word(place)	12.963	11.432	
word(place)*param	90.537	16.595	
word(place)*vce	0.000	0.000	
word(place)*param*vce	13.872	3.952	

SUBJECT 3

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	62.319	2.998	
CONSTANT	42.740	0.971	0.000
vce	-0.434	0.368	0.239
param	18.730	1.435	0.000
param	-10.396	1.435	0.000
param	16.770	1.435	0.000
place	-1.890	1.330	0.155
place	-0.477	1.330	0.720
vce*param	-7.796	0.590	0.000
vce*param	-16.320	0.590	0.000
vce*param	10.846	0.590	0.000
vce*place	1.624	0.504	0.001
vce*place	-0.379	0.504	0.452
param*place	0.860	1.965	0.662
param*place	0.236	1.965	0.904
param*place	2.710	1.965	0.168
param*place	0.077	1.965	0.969
param*place	-0.696	1.965	0.723
param*place	-2.662	1.965	0.176
vce*param*place	-2.794	0.808	0.001
vce*param*place	1.960	0.808	0.015
vce*param*place	4.434	0.808	0.000
vce*param*place	1.819	0.808	0.024
vce*param*place	-1.558	0.808	0.054
vce*param*place	-3.524	0.808	0.000
word(place)	6.217	7.387	
word(place)*param	59.910	11.490	
word(place)*vce	1.016	2.159	
word(place)*param*vce	11.910	3.877	

SUBJECT 4

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	57.121	2.761	
CONSTANT	45.095	0.875	0.000
vce	1.474	0.344	0.000
param	17.877	1.516	0.000
param	-12.484	1.516	0.000
param	18.871	1.516	0.000
place	-1.112	1.198	0.353
place	2.079	1.199	0.083
vce*param	-9.487	0.596	0.000
vce*param	-16.069	0.596	0.000
vce*param	15.107	0.596	0.000
vce*place	1.639	0.471	0.000
vce*place	-1.230	0.471	0.009
param*place	-6.149	2.076	0.003
param*place	5.061	2.076	0.015
param*place	6.417	2.076	0.002
param*place	-1.355	2.076	0.514
param*place	-1.954	2.076	0.347
param*place	1.406	2.076	0.498
vce*param*place	-0.895	0.815	0.272
vce*param*place	1.017	0.815	0.212
vce*param*place	2.551	0.815	0.002
vce*param*place	1.639	0.816	0.045
vce*param*place	-1.998	0.816	0.014
vce*param*place	1.540	0.816	0.059
word(place)	0.000	0.000	
word(place)*param	68.018	11.077	
word(place)*vce	0.000	0.000	
word(place)*param*vce	13.324	3.427	

APPENDIX C

Mean values (in ms) of intervocalic voiced and voiceless stops and pairwise test results for each place of articulation

-vce: voiceless **+vce:** voiced

significant if p> |1.96|

VOWEL DURATION

	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=
bilabial	52	73	11.0208	42	67	11.9333	51	70	12.3856	48	63	9.1024
dental	65	80	7.9697	56	72	7.1457	54	68	8.9466	55	71	9.4315
velar	62	75	5.6194	52	72	7.9755	54	71	9.3703	60	78	9.5471

VOICING INTO CLOSURE

	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=
bilabial	29	55	12.6280	23	52	11.2056	18	44	9.2619	25	49	8.6804
dental	24	55	15.3326	19	54	13.4157	12	50	13.1438	15	51	12.9165
velar	27	54	11.0379	17	50	10.7888	17	54	10.8263	15	43	8.5165

CLOSURE DURATION

	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=
bilabial	89	55	-19.3354	84	52	-15.1261	77	44	-13.2425	90	49	-17.1725
dental	72	55	-9.8451	75	54	-10.2154	63	50	-5.2354	85	51	-13.9264
velar	80	55	-11.9040	79	54	-9.8851	70	54	-5.5546	67	43	-8.3112

ASPIRATION DURATION

	SUBJECT 1			SUBJECT 2			SUBJECT 3			SUBJECT 4		
	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=	-vce (ms)	+vce (ms)	p=
bilabial	20	0	-14.9420	30	3	-10.2004	23	1	-10.6174	25	4	-12.1508
dental	26	2	-18.6853	43	9	-12.3486	36	5	-15.3689	34	15	-10.5704
velar	24	3	-13.8166	49	15	-10.5184	32	9	-9.7572	39	8	-14.2636

APPENDIX D

For each word pair, mean values (in ms) for four temporal parameters of voiced and voiceless intervocalic stops

-vce: voiceless **+vce:** voiced

	Subject 1		Subject 2		Subject 3		Subject 4	
	-vce	+vce	-vce	+vce	-vce	+vce	-vce	+vce
kapak/kabak								
vowel duration	46	65	34	55	60	65	47	59
voicing into closure	30	60	22	47	22	33	22	41
closure duration	86	60	69	47	67	33	90	41
aspiration duration	15	0	7	3	21	1	19	2
kapı/kabı								
vowel duration	47	74	34	74	43	66	51	68
voicing into closure	32	57	21	53	20	55	30	57
closure duration	89	57	92	53	96	55	95	57
aspiration duration	17	1	30	1	25	3	23	5
sapan/saban								
vowel duration	50	73	38	63	54	71	46	54
voicing into closure	27	50	23	46	15	39	21	50
closure duration	89	50	85	46	69	39	89	50
aspiration duration	23	1	20	3	19	2	26	4
tapu/tabu								
vowel duration	53	77	43	72	51	72	53	70
voicing into closure	26	59	29	63	16	48	28	43
closure duration	99	59	82	63	74	48	81	43
aspiration duration	28	1	50	0	29	0	41	5
yapan/yaban								
vowel duration	42	54	54	68	54	69	46	61
voicing into closure	30	56	22	55	15	45	12	55
closure duration	91	56	86	55	72	45	100	55
aspiration duration	20	0	33	13	30	0	22	8
kapan/kaban								
vowel duration	48	76	39	62	47	70	47	60
voicing into closure	29	50	25	49	13	36	24	38
closure duration	77	50	77	49	75	36	93	38
aspiration duration	22	0	38	4	18	3	24	6

	Subject 1		Subject 2		Subject 3		Subject 4	
	-vce	+vce	-vce	+vce	-vce	+vce	-vce	+vce
tapa/taba								
vowel duration	59	75	44	70	59	76	52	70
voicing into closure	31	62	23	57	21	44	25	47
closure duration	86	62	89	57	67	44	88	47
aspiration duration	19	0	29	2	26	2	26	3
çapa/çaba								
vowel duration	67	85	46	71	55	74	56	71
voicing into closure	26	45	24	48	17	46	24	40
closure duration	80	45	83	48	86	46	85	40
aspiration duration	20	0	24	0	22	0	27	1
sopa/soba								
vowel duration	58	76	44	68	54	75	49	65
voicing into closure	27	60	22	43	16	47	29	50
closure duration	99	60	90	43	85	47	79	50
aspiration duration	18	0	30	0	23	0	24	1
hapis/habis								
vowel duration	54	75	45	69	44	60	37	51
voicing into closure	34	51	21	62	20	46	31	64
closure duration	90	51	83	62	77	46	100	64
aspiration duration	16	0	20	1	16	0	21	0
katı/kadı								
vowel duration	55	60	46	64	52	63	51	71
voicing into closure	25	59	17	58	12	68	15	46
closure duration	82	59	76	58	69	68	84	46
aspiration duration	26	1	48	11	41	4	38	20
katın/kadın								
vowel duration	49	62	42	50	45	57	43	61
voicing into closure	26	52	15	48	12	41	18	54
closure duration	71	52	74	48	63	41	94	54
aspiration duration	31	0	46	14	37	5	39	22
katar/kadar								
vowel duration	55	65	39	62	45	58	48	69
voicing into closure	26	54	13	50	10	41	21	40
closure duration	72	54	74	50	63	41	84	40
aspiration duration	23	2	34	3	27	0	31	13
motel/model								
vowel duration	82	100	66	74	70	91	62	69
voicing into closure	31	49	19	47	78	32	10	51
closure duration	71	49	71	47	61	32	83	51
aspiration duration	23	1	42	3	36	2	32	13

	Subject 1		Subject 2		Subject 3		Subject 4	
	-vce	+vce	-vce	+vce	-vce	+vce	-vce	+vce
matem/madem								
vowel duration	146	172	133	162	115	130	118	138
voicing into closure	31	56	38	48	11	48	85	45
closure duration	68	56	72	48	58	48	82	45
aspiration duration	32	0	39	8	47	7	39	11
keten/keder								
vowel duration	59	66	50	75	41	47	51	71
voicing into closure	26	49	16	44	47	54	18	40
closure duration	61	49	63	44	58	54	77	40
aspiration duration	23	6	38	2	29	5	34	15
hatim/hadim								
vowel duration	56	69	55	--	56	65	47	61
voicing into closure	20	63	20	73	26	48	12	62
closure duration	74	63	91	73	60	48	98	62
aspiration duration	29	5	53	16	46	5	33	12
kutup/kuduz								
vowel duration	27	47	20	28	21	38	24	37
voicing into closure	17	54	15	53	38	45	17	52
closure duration	73	54	72	53	62	45	74	52
aspiration duration	20	2	26	14	23	10	25	15
satır/sadır								
vowel duration	54	75	43	56	38	54	51	63
voicing into closure	22	61	19	58	20	57	20	50
closure duration	82	61	80	58	64	57	45	50
aspiration duration	27	1	44	10	32	5	41	23
latin/ladin								
vowel duration	71	87	68	79	59	76	66	74
voicing into closure	16	55	17	57	12	64	13	65
closure duration	70	55	73	57	72	64	94	65
aspiration duration	28	2	57	12	43	5	32	9
takan/pagan								
vowel duration	58	75	52	64	54	69	59	94
voicing into closure	25	54	17	40	10	51	11	37
closure duration	76	54	75	51	64	51	58	37
aspiration duration	22	3	40	15	30	7	40	4
bakan/bagaj								
vowel duration	76	82	64	80	62	79	67	84
voicing into closure	17	48	19	47	7	52	20	36
closure duration	69	48	75	53	66	52	55	40
aspiration duration	25	1	49	13	36	3	41	8

	Subject 1		Subject 2		Subject 3		Subject 4	
	-vce	+vce	-vce	+vce	-vce	+vce	-vce	+vce
lakoz/lagor								
vowel duration	68	88	57	88	66	77	70	85
voicing into closure	34	62	18	49	20	55	14	38
closure duration	80	62	87	49	76	55	83	38
aspiration duration	22	0	47	22	31	14	32	15
takoz/fagot								
vowel duration	62	67	47	65	51	67	60	72
voicing into closure	21	56	17	60	17	60	16	42
closure duration	75	58	74	60	67	60	70	42
aspiration duration	22	0	48	0	30	14	33	3
fikir/figür								
vowel duration	35	49	29	47	35	55	36	53
voicing into closure	30	57	15	49	28	47	16	51
closure duration	90	57	75	55	83	47	67	51
aspiration duration	19	1	50	22	28	4	49	17
lokal/logos								
vowel duration	71	75	57	75	57	64	66	80
voicing into closure	30	48	12	53	13	58	12	50
closure duration	81	55	84	56	68	58	69	50
aspiration duration	32	7	54	13	32	8	32	6
vakum/vagon								
vowel duration	67	90	60	88	59	79	65	84
voicing into closure	32	53	22	54	22	52	12	43
closure duration	90	53	83	57	67	52	69	43
aspiration duration	30	0	53	18	40	12	44	2

APPENDIX E

Word pairs used in the acoustic analysis of final stops

UR: Underlying Representation, **PR**: Phonetic Representation,
OR: Orthographic Representation,
IFO: Inflected form; Orthographic [Phonetic] Representation

UR	PR	OR	IFO	Gloss
talib	[talip]	talip	talibi [talibi]	applicant, nom/acc.
polip	[polip]	polip	polipi [polipi]	polyp, nom/acc.
gurub	[guɾup]	grup	grubu [guɾubu]	group, nom/acc.
turup	[tuɾup]	trup	trupu [tuɾupu]	toupe, nom/acc.
mekteb	[mektep]	mektep	mektebi [mektebi]	school, nom/acc.
istep	[istep]	istep	istepi [istepi]	steppe, nom/acc.
dolab	[dolap]	dolap	dolabı [dolabɯ]	closet, nom/acc.
tʃalap	[tʃalap]	Çalap	Çalabı [tʃalabɯ]	God, nom/acc.
hitab	[hitap]	hitap	hitabı [hitabɯ]	direct address, nom/acc.
etap	[etap]	etap	etapı[etabɯ]	lap, nom/acc.
istob	[istop]	istop	istobum [istobum]	kind of game, stem/1 pers. sing.
tortop	[tortop]	tortop	tortopum [tortopum]	round (emph), stem/1 pers. sing.
kab	[kap]	kap	kabı [kabɯ]	container, nom/acc.
tap	[tap]	tap	tapıyor [tapɯjoɾ̥̌]	worship, stem/pres.
dib	[dip]	dip	dibi [dibi]	bottom, nom/acc.
dʒip	[dʒip]	cip	cipi [dʒipi]	jeep, nom/acc.

řob	[řop]	rop	robu [řobu]	robe, nom/acc.
lop	[lop]	lop	lopum [lopum]	soft stem/1 pers. sing.
aɾgɯd	[aɾgɯt]	argıt	argıdı [aɾgɯdɯ]	mountain pass, nom/acc.
aɾgɯt	[aɾgɯt]	argıt	argıtı [aɾgɯtɯ]	tool, nom/acc.
tokad	[tokat]	tokat	tokadı [tokadɯ]	smack, nom/acc.
takat	[takat]	takat	takatı [takatɯ]	strength, nom/acc.
kilid	[kilit]	kilit	kilidi [kilidi]	lock, nom/acc.
filit	[filit]	flit	fliti [filiti]	spray insecticide, nom/acc.
simid	[simit]	simit	simidi [simidi]	kind of food, nom/acc.
limit	[limit]	limit	limiti [limiti]	limit, nom/acc.
aɾmud	[armut]	armut	armudu [aɾmudu]	pear, nom/acc.
veɾmut	[vermut]	vermut	vermutu [veɾmutu]	vermouth, nom/acc.
kanad	[kanat]	kanat	kanadı [kanadɯ]	wing, nom/acc.
sanat	[sanat]	sanat	sanatı [sanadɯ]	arts, nom/acc.
sened	[senet]	senet	senedi [senedi]	voucher, nom/acc.
lanet	[lanet]	lanet	laneti [laneti]	curse, nom/acc.
muɾad	[muɾat]	murat	muradı [muɾa:dɯ]	wish,nom/acc.
suɾat	[suɾat]	surat	suratı [suɾatɯ]	face, nom/acc.
tad	[tat]	tat	tadı [tadɯ]	taste, nom/acc.
kat	[kat]	kat	katı [katɯ]	layer, nom/acc.
bud	[but]	but	budu [budu]	thigh, nom/acc.
dut	[dut]	dut	dutu [dutu]	berry, nom/acc.

med	[met]	met	meddi [med:i]	high tide, nom/acc.
net	[net]	net	neti [neti]	net, nom/acc.
tombig	[tombik]	tombik	tombiğim[tombiim]	cute, stem/1 pers. sing poss.
tatbik	[tatbik]	tatbik	tatbiki [tatbi:ki]	application, nom/acc.
aylag	[aylak]	aylak	aylağı [aylaɯ]	idle, nom/acc.
ahlak	[ahlak]	ahlak	ahlakı [ahla:kɯ]	morals, nom/acc.
yemlig	[jemlik]	yemlik	yemliği [yemlii]	manger, nom/acc.
temlik	[temlik]	temlik	temliki [temliki]	alienation,nom/acc.
sineg	[sinek]	sinek	sineği [sineii]	fly, nom/acc.
sonek	[sonek]	sonek	soneki [soneki]	suffix, nom/acc.
devřig	[devřik]	devrik	devriği [devřii]	tilted, nom/acc.
tebřik	[tebřik]	tebrik	tebriki [tebřiki]	congratulation, nom/acc.
boʃlug	[boʃluk]	boşluk	boşluğu [boʃluu]	emptiness, nom/acc.
mahluk	[mahluk]	mahluk	mahluku [mahluku]	creature, nom/acc.
kuɾag	[kuɾak]	kurak	kurağı [kuɾaɯ]	drought, nom/acc.
meɾak	[meɾak]	merak	merakı [meɾakɯ]	curiosity, nom/acc.
gœg	[gœk]	gök	göğü [gœy]	sky, nom/acc.
dœk	[dœk]	dök	döküyor [dœkyjoř̥]	pour, stem/present
tʃog	[tʃok]	çok	çoğu [tʃou]	many, nom/acc.
tok	[tok]	tok	tokum [tokum]	full, stem/1 pers. sing.
jog	[jok]	yok	yoğu [jou]	nonexistent,nom/acc.
dok	[dok]	dok	doku [doku]	dock, nom/acc.

APPENDIX F

CONJUGATION TASK

Aşağıdaki boşlukları parantez içindeki kelimeleri cümlenin anlamına uygun şekilde çekimleyerek doldurunuz.

[Fill in the blanks with the correct forms of the words in parentheses.]

Örnek:

[Example:] (Sample sentences with the correct responses)

Şişenin ____ (kapak) iyice kapat.

Şişenin **kapağını** iyice kapat.

Pınar özel ders ____ (almak).

Pınar özel ders **alıyor**.

Ali Ayşe'nin ____ (hayat) yönünü değiştirdi.

Ali Ayşe'nin **hayatının** yönünü değiştirdi.

1. Halk ____ (paye) kraldan alacak.
2. _____ (arşiv) kaldırılan belgelerin önemi çok büyük.
3. _____ (kar) beyazlığı ne kadar iç açıcı.
4. Varını _____ (yok) Çocuk Esirgemeye bağışladı.
5. Ali____ (dolap) açınca herşey yerlere döküldü.
6. O _____ (kubbe) yapan Mimar Sinan'dır.
7. Kümesteki tüm tavuklar _____ (yemlik) doğru koştular.
8. Kasabanın _____ (ümran) belediyenin sorumluluğundadır.
9. Her dernek için gazete gibi bir duyurma _____ (organ) gereklidir.
10. Çocuğu için _____ (Çalap) yalvardı.
11. Tavuğun _____ (but) en lezzetli yeridir.
12. O _____ (filit) çocuklara yaklaştırma.
13. Kadın çocuğa "_____ (hele) bir gel" diye bağırdı.
14. Gemi _____ (dok) doğru yaklaşıyor.
15. Yaramaz çocuk kuşun _____ (kanat) kırdı.
16. Atatürk'ün gençliğe _____ (hitap) okudunuz mu?
17. Işimin manevi _____ (tatmin) her şeyden önce gelir.
18. Evin _____ (senet) vaktinde ödemeliyiz.
19. Şu anda ben çöpü ____ (dökmek).
20. Şu ____ (sinek) öldür!
21. Denizin _____ (met) kumsalda değişikliğe neden oldu.
22. Öğretmenin _____ (tokat) öğrencinin yüzünü bereledi.
23. _____ (argıt) geçince düzlüğe ulaştık.
24. Ailesinin _____ (kadir) hiç bilemedi.
25. Annesinin üzerine geçirdiği _____ (temlik) noterden aldı.
26. Onun kafası çok _____ (fos).
27. Onun _____ (surat) sinirden mosmor oldu.

28. Askerler _____ (cip) hareket ettirmeye çalışıyor.

29. _____ (kaşif) kaşif yapan yeniye olan ilgisidir.

30. Bu incinin _____ (sedef) bozulmuş.

31. Bu yaz üç _____ (zayıf) kurtarabilmek için çok çalıştı.

32. Bisikletin _____(sele) oldukça eskimiş.

33. Denizin _____ (dip) balık dolu.

34. O _____ (grup) katılmak istemiyorum.

35. Bugün ağzımın _____ (tat) hiç yok.

36. _____ (yarga) büyük piliç olduğunu biliyor muydun?

37. Bu filimdeki ____ (dev) daha önce hiç görmemiştim.

38. Ilk insanlar cisimlere ______ (tapmak).

39. Ayşe'nin _____ (kemer) çok güzel.

40. _____ (karga) sesini hiç sevmem.

41. O cümlenin _____ (devrik) kurabilir misin?

42. _____ (sanat) sanat için yapmayın.

43. Bizim ______ (trup) ilde oyun verirken gördüm.

44. _____ (şimdi) çocuklar çok bilmiş.

45. Uzay _____ (mefhum) hala sır halinde.

46. Öyle bir yaşta ki sürekli soru _____ (sormak).

47. Yakaladığı _____ (horoz) elinden kaçırdı.

48. Ali şu anda öğretmenin _____ (gözde).

49. Bu yaz ayının _____ (kurak) bitkileri çok etkiledi.

50. Ahmet bu köyün en _____ (aylak).

51. Kömürün _____ (ton) 15 bin oldu.

52. _____ (vermut) o güzel kokusunu özledim.

53. Öyle şişmanım ki küre gibi _____ (tortop).

54. Bu toprağın _____ (istep) bitki yetişmesine olanak vermiyor.

55. Arzu _____ (merak) yenemeyip Ali'nin odasına gizlice girdi.

56. Cem'in kedisi _____ (minnoş) yolda gördüm.

57. Basit yapılı bir hayvan olan _____ (polip) laboratuvarda incelediler.

58. Benim artık merdivenlerden çıkmaya _____ (takat) kalmadı.

59. O garip _____ (mahluk) görünce tüylerim diken diken oldu.

60. Ayakkabının _____ (taban) tekrar yaptırmanın zamanı geldi.

61. Bir birim olan ____ (jul) bir türlü öğrenemedim.

62. ____ (han) kapıları korkunç bir gürültüyle açıldı.

63. Nemrut ____ (dağ) güneşin doğuşunu izlemelisin.

64. Yumurtanın ____ (lop) severim.

65. _____ (gök) maviliği havanın açık olacağına işaret.

66. Karşıdan karşıya geçerken hem sağınıza hem ____ (sol) bakınız.

67. Onun _____ (lanet) üzerimde olsun istemem.

68. Şu çocukların oynadıgı _____ (istop) bende çocukken çok oynardım.

69. Her annenin _____ (murat) çocuklarının mutlu olmasıdır.

70. Her ______ (kumaş) kalitesi fiyatı ile ölçülemez.

71. Can _____(kalem) kaybedince çok ağladı.

72. Sıcak _____ (simit) peynirle çok severim.

73. Romandaki kızın ____ (talip) onu üzeceğe benzer.

74. ____ (limon) kabuğu ile yemek sağlığa çok yararlı.

75. Süt _____ (kap) masanın üzerinden alır mısın?

76. _____ (kan) son damlasına kadar ülkesi için savaştı.

77. Taşınırken kitaplarının _____ (çok) posta ile yolladı.

78. Dün bir an _____ (yön) şaşırdık.

79. ____ (batı) doğru gittikçe iklim değişti.

80. Kapının _____ (kilit) kırdım.

81. Kardeşimden _____ (milföy) tarifini bulmasını istedim.

82. Yeğenim kedisi _____ (tombik) kaybetti.

83. Arkadaşları Ali'nin _____ (ahlak) bozmaya uğraşıyorlar.

84. Ilk ____ (gaye) doktorasınıbitirmek.

85. Alev ____ (rop) üzerine alarak balkona çıktı.

86. Maddi _____ (limit) aşması nedeniyle proje durduruldu.

87. O ____ (aygıt) çalıştırman çok zor.

88. ____ (rağmen) anlamını bilmeyen küçük öğrenci tümceyi kavrayamadı.

89. Bu karakter ona ____(has) bir şeydir.

90. Her zaman işin _____(kolay) kaçar.

91. ____ (kayser) eski Roma, Bizans ve Alman Imparatorluğu'na verilen sandır.

92. Bu konuda ben çok _____ (müthiş) ; üzerime kimse yok.

93. Evin _____ (plan) kendim çizdim.

94. Otel şehir _____ (merkez) oldukça uzak.

95. 3 yaşında olmasına rağmen 10'a kadar _____ (saymak).

96. Maaşının _____ (net) söylemek istemedi.

97. ____ (dut) dalından yemeği çok severim.

98. Hafta sonunu yeni tuttuğu ____ (ev) temizlemeye ayırdı.

99. Uçak hava ____ (boşluk) gelince sarsıldı.

100.Bu planın ____ (tatbik) bir hayli zor olacak.

101.____ (toz) dumana katarak gitti.

102.Yüzücünün son _____ (kulaç) yarışmayı kazanmasını sağladı.

103.Damla her gün bize _____(gelmek).

104.Kumara olan düşkünlüğü ____ (iflas) neden oldu.

105.Eskisi olmayanın ____ (acar) olmaz.

106.Ayşe'nin ____ (henüz) okula giremediğini bilmiyorlar.

107.O sözcüğün ____ (sonek) doğru yazmamışsın.

108.____ (vakum) ona ne etkisi olduğunu anlayamadık.

109.____ (hedef) Akdeniz!

110.Bana karşı olan haksız davranışı yüzünden ona çok ____ (kırgın).

111.Buranın _____ (ortam) beni çok rahatsız ediyor.

112.____ (melal) avutmak için bin türlü eğlence icat ettik.

113.Hayır, bunları yiyemem. Ben çok ____ (tok).

114.Bu evin üçüncü ____ (kat) oturuyorum.

115.At beşinci ____ (etap) geçemedi.

116.O çocuk karşıdaki _____ (mektep) gidiyor.

117.____(armut) iyisini ayılar yer derler.

118.Sana yeni yıl ____ (tebrik) yollayamadım.

119.Bu açının ____ (sinüs) 0.5'den küçük.

120.Bir peynir türü olan ____ (lor) hiç sevmem.

APPENDIX G

Results of the Mixed Model Analysis of Variance (different models)
of word-final stops

alt: underlying voicing, **param**: temporal parameter,
cont: context, **place**: place of articulation, **fam**: familiar pairs

Due to lack of sufficient memory size, not all factors and interactions among these factors could be included in one analysis. Therefore, different models were designed to eliminate non-significant interactions from subsequent analyses. There were 4 models, all of which are presented here. In Model 1, 4 factors and interactions among these factors were tested.

MODEL 1 **SUBJECT 1**

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	289.381	14.146	
CONSTANT	62.022	1.322	0.000
alt	-0.544	0.550	0.322
param	-16.745	2.225	0.000
param	25.348	2.224	0.000
param	-40.893	2.223	0.000
cont	-14.010	0.550	0.000
alt*param	0.089	0.954	0.926
alt*param	0.423	0.953	0.657
alt*param	0.290	0.952	0.760
alt*cont	0.628	0.550	0.254
param*cont	-2.551	0.955	0.008
param*cont	-0.036	0.953	0.970
param*cont	11.147	0.952	0.000
alt*param*cont	-1.255	0.955	0.189
alt*param*cont	0.835	0.953	0.381
alt*param*cont	-0.224	0.952	0.814
word	2.999	15.419	
word*param	161.502	29.540	

SUBJECT 2

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	280.417	14.055	
CONSTANT	53.026	1.237	0.000
alt	-0.929	0.555	0.094
param	-17.245	2.006	0.000
param	28.584	2.006	0.000
param	-32.024	2.006	0.000
cont	-7.271	0.557	0.000
alt*param	-2.110	0.961	0.028
alt*param	2.703	0.961	0.005
alt*param	0.271	0.961	0.778
alt*cont	0.409	0.555	0.461
param*cont	-3.801	0.964	0.000
param*cont	-4.855	0.964	0.000
param*cont	9.094	0.964	0.000
alt*param*cont	0.972	0.961	0.312
alt*param*cont	-0.132	0.961	0.891
alt*param*cont	-0.408	0.961	0.671
word	5.704	13.276	
word*param	123.712	24.030	

SUBJECT 3

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	161.234	7.953	
CONSTANT	61.957	1.377	0.000
alt	-0.462	0.414	0.265
param	-35.437	2.386	0.000
param	44.798	2.385	0.000
param	-39.211	2.385	0.000
cont	-0.182	0.414	0.660
alt*param	-0.078	0.721	0.914
alt*param	1.069	0.717	0.136
alt*param	-0.331	0.717	0.644
alt*cont	0.937	0.414	0.024
param*cont	-1.130	0.721	0.117
param*cont	-0.389	0.717	0.587
param*cont	-0.072	0.717	0.920
alt*param*cont	0.228	0.721	0.752
alt*param*cont	-0.294	0.717	0.682
alt*param*cont	0.014	0.717	0.984
word	0.000	0.000	
word*param	206.988	29.396	

SUBJECT 4

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	241.957	11.979	
CONSTANT	69.135	1.643	0.000
alt	-0.394	0.509	0.439
param	-21.485	2.848	0.000
param	31.076	2.849	0.000
param	-49.706	2.842	0.000
cont	-12.214	0.512	0.000
alt*param	-0.843	0.889	0.343
alt*param	3.209	0.892	0.000
alt*param	-0.477	0.874	0.585
alt*cont	-0.127	0.509	0.803
param*cont	-4.486	0.894	0.000
param*cont	-3.797	0.900	0.000
param*cont	13.510	0.875	0.000
alt*param*cont	0.497	0.889	0.576
alt*param*cont	-0.605	0.892	0.498
alt*param*cont	0.489	0.874	0.575
word	0.000	0.000	
word*param	292.337	41.811	

SUBJECT 5

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	240.119	11.888	
CONSTANT	63.151	1.149	0.000
alt	0.036	0.507	0.943
param	6.661	1.992	0.001
param	14.312	1.989	0.000
param	-46.779	1.989	0.000
cont	-15.569	0.508	0.000
alt*param	-0.501	0.883	0.571
alt*param	2.210	0.877	0.012
alt*param	-0.993	0.877	0.258
alt*cont	-0.081	0.507	0.874
param*cont	-1.468	0.884	0.097
param*cont	-8.493	0.878	0.000
param*cont	17.325	0.878	0.000
alt*param*cont	1.699	0.883	0.054
alt*param*cont	-0.215	0.877	0.806
alt*param*cont	-0.776	0.877	0.376
word	0.000	0.000	
word*param	127.470	20.499	

MODEL 2

The interactions which were not significant in Model 1 (*alt*cont, alt*param*cont*) were not included in Model 2. The three-way interaction between *alt*word*param* which was not in Model 1 was added to Model 2.

SUBJECT 1

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	287.250	15.170	
CONSTANT	62.025	1.322	0.000
alt	-0.542	0.570	0.342
param	-16.749	2.225	0.000
param	25.357	2.225	0.000
param	-40.896	2.224	0.000
cont	-14.010	0.548	0.000
alt*param	0.084	0.989	0.932
alt*param	0.432	0.987	0.662
alt*param	0.288	0.986	0.770
param*cont	-2.541	0.951	0.008
param*cont	-0.046	0.950	0.961
param*cont	11.148	0.948	0.000
word	2.953	15.417	
word*param	158.957	29.930	
alt*word	0.000	0.000	
alt*word*param	5.860	10.753	

SUBJECT 2

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	278.085	15.110	
CONSTANT	53.027	1.237	0.000
alt	-0.912	0.571	0.110
param	-17.739	2.005	0.000
param	28.589	2.005	0.000
param	-32.028	2.005	0.000
cont	-7.273	0.555	0.000
alt*param	-2.061	0.989	0.037
alt*param	2.703	0.989	0.006
alt*param	0.251	0.989	0.799
param*cont	-3.807	0.960	0.000
param*cont	-4.860	0.960	0.000
param*cont	9.099	0.960	0.000
word	5.714	13.271	
word*param	121.350	24.467	
alt*word	0.000	0.000	
alt*word*param	5.097	10.788	

SUBJECT 3

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	159.803	8.528	
CONSTANT	61.945	1.386	0.000
alt	-0.441	0.460	0.337
param	-35.458	2.382	0.000
param	44.800	2.381	0.000
param	-39.199	2.381	0.000
cont	-0.170	0.413	0.680
alt*param	-0.061	0.738	0.934
alt*param	1.061	0.735	0.148
alt*param	-0.332	0.735	0.651
param*cont	-1.109	0.717	0.122
param*cont	-0.392	0.714	0.583
param*cont	-0.084	0.714	0.906
word	0.000	0.000	
word*param	205.196	29.543	
alt*word	1.884	3.629	
alt*word*param	2.400	6.786	

SUBJECT 4

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	242.252	11.993	
CONSTANT	69.136	1.643	0.000
alt	-0.400	0.509	0.432
param	-21.488	2.848	0.000
param	31.080	2.850	0.000
param	-49.706	2.842	0.000
cont	-12.215	0.512	0.000
alt*param	-0.818	0.889	0.358
alt*param	3.172	0.891	0.000
alt*param	-0.471	0.874	0.590
param*cont	-4.482	0.895	0.000
param*cont	-3.801	0.901	0.000
param*cont	13.511	0.876	0.000
word	0.000	0.000	
word*param	292.357	41.818	
alt*word	0.000	0.000	
alt*word*param	0.000	0.000	

SUBJECT 5

FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	241.273	11.945	
CONSTANT	63.155	1.149	0.000
alt	0.030	0.508	0.953
param	6.682	1.992	0.001
param	14.306	1.989	0.000
param	-46.787	1.989	0.000
cont	-15.566	0.509	0.000
alt*param	-0.564	0.885	0.524
alt*param	2.223	0.879	0.011
alt*param	-0.967	0.879	0.271
param*cont	-1.448	0.886	0.102
param*cont	-8.498	0.880	0.000
param*cont	17.317	0.880	0.000
word	0.000	0.000	
word*param	127.317	20.499	
alt*word	0.000	0.000	
alt*word*param	0.000	0.000	

MODEL 3: addition of place of articulation as a 5th factor

SUBJECT 1 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	279.241	14.747	
CONSTANT	62.155	1.254	0.000
alt	-0.512	0.550	0.352
param	-17.246	2.070	0.000
param	25.713	2.070	0.000
param	-40.733	2.069	0.000
cont	-14.035	0.542	0.000
place	3.157	1.819	0.083
place	-0.389	1.729	0.822
alt*param	0.030	0.954	0.975
alt*param	0.516	0.953	0.589
alt*param	0.275	0.951	0.772
param*cont	-2.455	0.941	0.009
param*cont	-0.196	0.940	0.835
param*cont	11.251	0.938	0.000
alt*place	0.324	0.799	0.685
alt*place	-0.217	0.759	0.775
param*place	-9.914	3.003	0.001
param*place	7.556	3.003	0.012
param*place	3.782	3.001	0.208
param*place	4.793	2.856	0.093
param*place	-2.218	2.854	0.437
param*place	-1.465	2.854	0.608
cont*place	-1.263	0.787	0.109
cont*place	-0.773	0.748	0.301
alt*param*place	0.366	1.386	0.792
alt*param*place	1.337	1.385	0.334
alt*param*place	0.413	1.380	0.765
alt*param*place	1.807	1.317	0.170
alt*param*place	-0.253	1.314	0.847
alt*param*place	0.431	1.312	0.743
alt*cont*place	-0.791	0.785	0.314
alt*cont*place	0.692	0.746	0.354
param*cont*place	0.712	1.367	0.603
param*cont*place	-2.282	1.366	0.095
param*cont*place	2.797	1.361	0.040
param*cont*place	-1.379	1.299	0.288
param*cont*place	1.174	1.295	0.365
param*cont*place	-0.034	1.294	0.979
alt*param*cont*place	1.018	1.363	0.455
alt*param*cont*place	-1.697	1.362	0.213
alt*param*cont*place	1.163	1.357	0.392
alt*param*cont*place	0.454	1.296	0.726
alt*param*cont*place	1.100	1.292	0.394
alt*param*cont*place	-0.660	1.291	0.609
word(place)	4.304	13.654	
word(place)*param	134.083	25.783	
word(place)*param*alt	2.019	10.011	

SUBJECT 2 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	264.593	14.276	
CONSTANT	53.215	1.208	0.000
alt	-0.830	0.559	0.137
param	-17.817	1.766	0.000
param	29.004	1.766	0.000
param	-31.756	1.766	0.000
cont	-7.415	0.544	0.000
place	2.380	1.756	0.175
place	-1.651	1.667	0.331
alt*param	-1.921	0.967	0.047
alt*param	2.720	0.967	0.005
alt*param	0.130	0.967	0.893
param*cont	-3.750	0.942	0.000
param*cont	-5.293	0.942	0.000
param*cont	9.314	0.942	0.000
alt*place	0.627	0.817	0.442
alt*place	-0.820	0.774	0.289
param*place	-10.942	2.569	0.000
param*place	7.498	2.569	0.004
param*place	6.206	2.569	0.016
param*place	7.290	2.438	0.003
param*place	-2.606	2.438	0.285
param*place	-3.298	2.438	0.176
cont*place	-1.867	0.797	0.019
cont*place	0.759	0.752	0.313
alt*param*place	2.211	1.414	0.118
alt*param*place	-0.338	1.414	0.811
alt*param*place	-1.171	1.414	0.408
alt*param*place	-0.127	1.340	0.925
alt*param*place	-0.161	1.340	0.904
alt*param*place	1.406	1.340	0.294
alt*cont*place	-0.648	0.788	0.411
alt*cont*place	-0.330	0.748	0.659
param*cont*place	0.808	1.379	0.558
param*cont*place	-5.467	1.379	0.000
param*cont*place	3.256	1.379	0.018
param*cont*place	-1.797	1.301	0.167
param*cont*place	5.161	1.301	0.000
param*cont*place	-1.881	1.301	0.148
alt*param*cont*place	-3.006	1.364	0.028
alt*param*cont*place	0.280	1.364	0.837
alt*param*cont*place	1.663	1.364	0.223
alt*param*cont*place	1.427	1.295	0.270
alt*param*cont*place	-0.575	1.295	0.657
alt*param*cont*place	-0.198	1.295	0.879
word(place)	12.507	12.122	
word(place)*param	86.397	19.038	
word(place)*param*alt	4.656	10.240	

SUBJECT 3 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	155.293	8.287	
CONSTANT	62.057	1.244	0.000
alt	-0.413	0.427	0.333
param	-36.125	2.080	0.000
param	45.537	2.079	0.000
param	-39.137	2.079	0.000
cont	-0.159	0.408	0.697
place	2.393	1.805	0.185
place	-0.446	1.716	0.795
alt*param	-0.056	0.741	0.940
alt*param	1.069	0.739	0.148
alt*param	-0.36	0.739	0.649
param*cont	-1.053	0.710	0.138
param*cont	-0.523	0.707	0.460
param*cont	-0.037	0.707	0.958
alt*place	0.823	0.622	0.186
alt*place	-0.438	0.589	0.457
param*place	-11.804	3.018	0.000
param*place	15.407	3.018	0.000
param*place	0.593	3.018	0.844
param*place	9.036	2.871	0.002
param*place	-6.672	2.868	0.020
param*place	-1.545	2.868	0.590
cont*place	-0.187	0.595	0.754
cont*place	-1.037	0.563	0.066
alt*param*place	-0.237	1.077	0.826
alt*param*place	1.238	1.079	0.258
alt*param*place	-0.567	1.078	0.599
alt*param*place	-0.987	1.026	0.336
alt*param*place	0.621	1.018	0.542
alt*param*place	0.184	1.018	0.857
alt*cont*place	-0.105	0.593	0.859
alt*cont*place	0.214	0.562	0.703
param*cont*place	0.517	1.031	0.616
param*cont*place	-1.997	1.033	0.053
param*cont*place	0.866	1.032	0.401
param*cont*place	-2.000	0.982	0.042
param*cont*place	1.926	0.974	0.048
param*cont*place	-0.264	0.974	0.787
alt*param*cont*place	-1.387	1.028	0.178
alt*param*cont*place	-0.679	1.029	0.509
alt*param*cont*place	0.892	1.028	0.386
alt*param*cont*place	1.260	0.981	0.199
alt*param*cont*place	-0.358	0.972	0.713
alt*param*cont*place	-1.266	0.971	0.193
word(place)	3.154	13.513	
word(place)*param	150.110	25.755	
word(place)*param*alt	3.627	5.969	

SUBJECT 4 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	230.194	11.396	
CONSTANT	69.210	1.397	0.000
alt	-0.373	0.502	0.457
param	-22.595	2.424	0.000
param	32.263	2.428	0.000
param	-49.817	2.414	0.000
cont	-12.200	0.506	0.000
place	2.003	2.033	0.325
place	1.063	1.924	0.581
alt*param	-0.884	0.880	0.315
alt*param	3.344	0.885	0.000
alt*param	-0.406	0.857	0.636
param*cont	-4.376	0.887	0.000
param*cont	-3.995	0.897	0.000
param*cont	13.558	0.859	0.000
alt*place	0.046	0.743	0.951
alt*place	0.050	0.686	0.942
param*place	-16.435	3.532	0.000
param*place	18.191	3.543	0.000
param*place	-0.784	3.505	0.823
param*place	15.697	3.335	0.000
param*place	-13.684	3.338	0.000
param*place	1.249	3.328	0.708
cont*place	-0.137	0.752	0.855
cont*place	-1.868	0.688	0.007
alt*param*place	0.213	1.314	0.871
alt*param*place	1.060	1.326	0.424
alt*param*place	1.817	1.252	0.147
alt*param*place	1.196	1.195	0.317
alt*param*place	-1.509	1.199	0.208
alt*param*place	-0.929	1.179	0.430
alt*cont*place	-0.167	0.738	0.821
alt*cont*place	-0.319	0.683	0.640
param*cont*place	-1.358	1.332	0.308
param*cont*place	0.026	1.359	0.985
param*cont*place	0.446	1.257	0.723
param*cont*place	-3.499	1.200	0.004
param*cont*place	2.210	1.208	0.067
param*cont*place	0.306	1.180	0.796
alt*param*cont*place	0.516	1.303	0.692
alt*param*cont*place	-0.863	1.314	0.511
alt*param*cont*place	-0.339	1.247	0.786
alt*param*cont*place	-1.632	1.188	0.170
alt*param*cont*place	1.232	1.191	0.301
alt*param*cont*place	0.769	1.175	0.513
word(place)	0.000	0.000	
word(place)*param	202.177	29.979	
word(place)*param*alt	0.000	0.000	

SUBJECT 5 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	226.168	11.197	
CONSTANT	63.110	1.039	0.000
alt	0.070	0.493	0.888
param	6.053	1.775	0.001
param	14.819	1.772	0.000
param	-46.595	1.772	0.000
cont	-15.502	0.494	0.000
place	-0.082	1.506	0.957
place	0.870	1.434	0.544
alt*param	-0.486	0.859	0.571
alt*param	2.234	0.853	0.009
alt*param	-1.054	0.853	0.217
param*cont	-1.172	0.860	0.173
param*cont	-8.731	0.854	0.000
param*cont	17.332	0.854	0.000
alt*place	0.284	0.712	0.690
alt*place	-0.431	0.681	0.527
param*place	-9.996	2.573	0.000
param*place	8.902	2.567	0.001
param*place	2.901	2.567	0.259
param*place	10.516	2.449	0.000
param*place	-7.102	2.445	0.004
param*place	-2.861	2.445	0.242
cont*place	1.128	0.713	0.114
cont*place	-1.183	0.682	0.083
alt*param*place	0.992	1.243	0.425
alt*param*place	0.439	1.231	0.721
alt*param*place	-1.189	1.231	0.334
alt*param*place	-0.967	1.186	0.415
alt*param*place	0.125	1.178	0.916
alt*param*place	1.297	1.178	0.271
alt*cont*place	-0.338	0.711	0.635
alt*cont*place	-0.513	0.680	0.451
param*cont*place	0.520	1.243	0.676
param*cont*place	-2.089	1.232	0.000
param*cont*place	0.237	1.232	0.847
param*cont*place	-6.094	1.186	0.000
param*cont*place	4.296	1.179	0.000
param*cont*place	-0.214	1.179	0.856
alt*param*cont*place	-0.673	1.240	0.587
alt*param*cont*place	0.323	1.229	0.793
alt*param*cont*place	0.027	1.229	0.983
alt*param*cont*place	0.803	1.183	0.497
alt*param*cont*place	-2.797	1.176	0.017
alt*param*cont*place	0.799	1.176	0.497
word(place)	0.957	9.254	
word(place)*param	95.821	18.674	
word(place)*param*alt	0.000	0.000	

MODEL 4: addition of familiarity as a 6th factor

SUBJECT 1 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	279.856	13.680	
CONSTANT	62.172	1.252	0.000
alt	-0.502	0.541	0.316
param	-17.299	2.068	0.000
param	25.768	2.068	0.000
param	-40.418	2.067	0.000
cont	-14.081	0.543	0.000
place	3.674	2.108	0.081
place	-0.746	1.870	0.690
fam	-0.719	1.459	0.622
alt*fam	0.216	0.541	0.689
alt*param	0.048	0.939	0.959
alt*param	0.468	0.937	0.618
alt*param	0.288	0.936	0.758
param*cont	-2.476	0.943	0.009
param*cont	-0.177	0.942	0.851
param*cont	11.286	0.940	0.000
param*place	-10.354	3.482	0.003
param*place	8.446	3.482	0.015
param*place	3.825	3.481	0.272
param*place	5.065	3.089	0.101
param*place	-2.811	3.088	0.363
param*place	-1.485	3.088	0.631
cont*place	-2.132	0.915	0.020
cont*place	-0.191	0.811	0.814
param*cont*place	0.326	1.587	0.837
param*cont*place	-2.034	1.586	0.200
param*cont*place	3.468	1.583	0.028
param*cont*place	-1.132	1.407	0.421
param*cont*place	1.013	1.405	0.471
param*cont*place	-0.482	1.404	0.731
fam*param	0.570	2.409	0.813
fam*param	-1.215	2.409	0.614
fam*param	-0.042	2.409	0.986
fam*cont	1.209	0.632	0.056
fam*alt*param	-2.034	0.939	0.030
fam*alt*param	1.950	0.937	0.037
fam*alt*param	0.346	0.936	0.712
fam*alt*cont	0.309	0.541	0.568
fam*param*cont	0.587	1.096	0.592
fam*param*cont	-0.344	1.095	0.754
fam*param*cont	-0.939	1.095	0.391
fam*alt*cont*param	1.977	0.939	0.035
fam*alt*cont*param	-1.368	0.937	0.145
fam*alt*cont*param	-0.338	0.936	0.718
word(place)	4.237	13.585	
word(place)*param	134.303	25.312	

SUBJECT 2 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	268.237	13.449	
CONSTANT	53.225	1.203	0.000
alt	-0.907	0.543	0.094
param	-17.859	1.767	0.000
param	28.998	1.767	0.000
param	-31.742	1.767	0.000
cont	-7.425	0.548	0.000
place	2.272	1.754	0.195
place	-1.634	1.663	0.326
fam	-0.595	1.210	0.623
alt*fam	-0.073	0.543	0.893
alt*param	-2.158	0.940	0.022
alt*param	2.787	0.940	0.003
alt*param	0.256	0.940	0.786
param*cont	-3.707	0.948	0.000
param*cont	-5.287	0.948	0.000
param*cont	9.300	0.948	0.000
param*place	-11.075	2.577	0.000
param*place	7.509	2.577	0.004
param*place	6.226	2.577	0.016
param*place	7.365	2.442	0.003
param*place	-2.665	2.442	0.275
param*place	-3.382	2.442	0.166
cont*place	-1.751	0.805	0.030
cont*place	0.778	0.757	0.304
param*cont*place	1.030	1.393	0.460
param*cont*place	-5.602	1.393	0.000
param*cont*place	3.145	1.393	0.024
param*cont*place	-1.799	1.311	0.170
param*cont*place	5.119	1.311	0.000
param*cont*place	-1.870	1.311	0.154
fam*param	-0.025	1.777	0.989
fam*param	-0.407	1.777	0.819
fam*param	-0.367	1.777	0.836
fam*cont	0.674	0.550	0.220
fam*alt*param	1.671	0.940	0.076
fam*alt*param	-1.250	0.940	0.184
fam*alt*param	-0.351	0.940	0.709
fam*alt*cont	-0.639	0.543	0.239
fam*param*cont	0.840	0.952	0.378
fam*param*cont	-0.719	0.952	0.450
fam*param*cont	-0.458	0.952	0.630
fam*alt*cont*param	-1.250	0.940	0.184
fam*alt*cont*param	0.779	0.940	0.408
fam*alt*cont*param	0.122	0.940	0.897
word(place)	12.101	12.028	
word(place)*param	88.285	18.519	

SUBJECT 3 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	157.346	7.761	
CONSTANT	61.860	1.259	0.000
alt	-0.298	0.419	0.477
param	-35.538	2.067	0.000
param	45.528	2.065	0.000
param	-38.782	2.065	0.000
cont	-0.257	0.421	0.542
place	2.989	1.931	0.122
place	-0.371	1.704	0.828
fam	-1.092	1.416	0.441
alt*fam	0.796	0.419	0.058
alt*param	-0.063	0.730	0.932
alt*param	0.836	0.726	0.249
alt*param	-0.463	0.725	0.523
param*cont	-1.187	0.734	0.106
param*cont	-0.465	0.729	0.524
param*cont	-0.032	0.729	0.965
param*place	-13.399	3.168	0.000
param*place	15.627	3.167	0.000
param*place	-0.417	3.167	0.895
param*place	8.682	2.796	0.002
param*place	-6.664	2.794	0.017
param*place	-1.717	2.794	0.539
cont*place	0.042	0.644	0.948
cont*place	-0.961	0.569	0.091
param*cont*place	0.846	1.118	0.449
param*cont*place	-2.356	1.115	0.035
param*cont*place	0.872	1.114	0.434
param*cont*place	-1.878	0.991	0.058
param*cont*place	1.892	0.984	0.055
param*cont*place	-0.275	0.984	0.780
fam*param	3.150	2.325	0.175
fam*param	-0.290	2.322	0.901
fam*param	1.929	2.322	0.406
fam*cont	-0.496	0.472	0.293
fam*alt*param	0.022	0.731	0.975
fam*alt*param	-0.856	0.726	0.238
fam*alt*param	-0.732	0.725	0.313
fam*alt*cont	0.345	0.410	0.400
fam*param*cont	-0.713	0.822	0.386
fam*param*cont	0.559	0.816	0.494
fam*param*cont	0.007	0.816	0.994
fam*alt*cont*param	-0.360	0.713	0.613
fam*alt*cont*param	-0.110	0.709	0.876
fam*alt*cont*param	0.232	0.709	0.744
word(place)	4.675	13.131	
word(place)*param	141.875	24.163	

SUBJECT 4 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	231.969	11.484	
CONSTANT	68.683	1.430	0.000
alt	-0.524	0.522	0.316
param	-22.022	2.483	0.000
param	32.311	2.490	0.000
param	-49.261	2.469	0.000
cont	-11.903	0.535	0.000
place	2.661	2.072	0.199
place	1.415	1.906	0.458
fam	-1.921	1.546	0.214
alt*fam	-0.388	0.522	0.457
alt*param	-0.736	0.915	0.421
alt*param	2.938	0.920	0.001
alt*param	-0.193	0.890	0.829
param*cont	-4.391	0.942	0.000
param*cont	-3.941	0.960	0.000
param*cont	13.574	0.903	0.000
param*place	-17.304	3.598	0.000
param*place	17.986	3.606	0.000
param*place	-1.484	3.576	0.678
param*place	15.330	3.305	0.000
param*place	-13.701	3.310	0.000
param*place	0.878	3.296	0.790
cont*place	-0.467	0.775	0.546
cont*place	-2.071	0.701	0.003
param*cont*place	-1.284	1.366	0.347
param*cont*place	0.086	1.387	0.951
param*cont*place	0.329	1.307	0.801
param*cont*place	-3.494	1.224	0.004
param*cont*place	2.162	1.236	0.080
param*cont*place	0.305	1.198	0.799
fam*param	2.259	2.681	0.399
fam*param	0.338	2.685	0.900
fam*param	2.033	2.671	0.447
fam*cont	1.037	0.570	0.069
fam*alt*param	0.227	0.916	0.804
fam*alt*param	-0.650	0.920	0.480
fam*alt*param	0.968	0.890	0.277
fam*alt*cont	0.203	0.499	0.685
fam*param*cont	-0.117	0.998	0.906
fam*param*cont	0.053	1.009	0.958
fam*param*cont	0.167	0.972	0.864
fam*alt*cont*param	-0.244	0.872	0.779
fam*alt*cont*param	0.162	0.870	0.853
fam*alt*cont*param	-0.049	0.856	0.955
word(place)	0.000	0.000	
word(place)*param	193.116	28.841	

SUBJECT 5 FACTORS	Estimate	Standard Deviation	Two-Tail Probability
ERR. VAR.	220.925	10.937	
CONSTANT	63.477	0.920	0.000
alt	0.002	0.491	0.996
param	5.737	1.528	0.000
param	14.445	1.525	0.000
param	-47.04	1.525	0.000
cont	-15.669	0.494	0.000
place	-0.144	1.328	0.914
place	0.236	1.284	0.854
fam	-2.715	0.944	0.004
alt*fam	0.199	0.491	0.685
alt*param	-0.570	0.855	0.505
alt*param	2.256	0.849	0.008
alt*param	-1.053	0.849	0.215
param*cont	-1.181	0.860	0.170
param*cont	-8.250	0.854	0.000
param*cont	17.413	0.854	0.000
param*place	-9.915	2.190	0.000
param*place	8.940	2.184	0.000
param*place	3.005	2.184	0.169
param*place	11.017	2.116	0.000
param*place	-6.446	2.113	0.002
param*place	-2.033	2.113	0.336
cont*place	1.176	0.705	0.095
cont*place	-0.935	0.685	0.172
param*cont*place	0.539	1.228	0.661
param*cont*place	-2.228	1.218	0.067
param*cont*place	0.220	1.218	0.856
param*cont*place	-6.100	1.190	0.000
param*cont*place	3.540	1.184	0.003
param*cont*place	-0.359	1.184	0.762
fam*param	2.203	1.556	0.157
fam*param	3.006	1.553	0.053
fam*param	3.599	1.553	0.020
fam*cont	1.099	0.504	0.029
fam*alt*param	0.118	0.856	0.890
fam*alt*param	-0.027	0.850	0.795
fam*alt*param	0.572	0.850	0.501
fam*alt*cont	0.679	0.487	0.163
fam*param*cont	0.009	0.877	0.991
fam*param*cont	-3.104	0.872	0.000
fam*param*cont	-0.611	0.872	0.484
fam*alt*cont*param	-0.053	0.847	0.950
fam*alt*cont*param	-0.114	0.841	0.893
fam*alt*cont*param	-0.481	0.841	0.567
word(place)	2.438	7.294	
word(place)*param	62.063	13.556	

APPENDIX H

Mean values (in ms) of final stops and pairwise test results for each context

(From Model 1)

significant if p> |1.96|

SUBJECT 1	voiceless (ms)	devoiced (ms)	p=
vowel duration			
context	72	72	0.0483
isolation	114	120	1.6850
voicing into closure			
context	18	18	-0.0966
isolation	23	25	0.4239
closure duration			
context	75	72	-0.8640
isolation	100	103	1.0153
aspiration duration			
context	28	30	0.6939
isolation	62	62	-0.1098

SUBJECT 2	voiceless (ms)	devoiced (ms)	p=
vowel duration			
context	64	68	1.1884
isolation	80	83	1.1010
voicing into closure			
context	22	23	0.4307
isolation	18	20	0.4096
closure duration			
context	71	67	-1.3410
isolation	95	92	-0.9311
aspiration duration			
context	23	26	1.0848
isolation	43	52	2.7480

SUBJECT 3	voiceless (ms)	devoiced (ms)	p=
vowel duration			
context	93	93	0.1150
isolation	88	92	1.7943
voicing into closure			
context	23	22	-0.1366
isolation	21	25	1.4758
closure duration			
context	107	105	-1.0784
isolation	107	107	0.0293
aspiration duration			
context	26	25	-0.5392
isolation	26	29	1.4203

SUBJECT 4	voiceless (ms)	devoiced (ms)	p=
vowel duration			
context	89	95	1.9660
isolation	125	128	1.2500
voicing into closure			
context	20	21	0.3580
isolation	17	19	0.8686
closure duration			
context	86	82	-1.4672
isolation	117	110	-2.3541
aspiration duration			
context	30	32	0.6103
isolation	64	68	1.0744

SUBJECT 5	voiceless (ms)	devoiced (ms)	p=
vowel duration			
context	64	67	1.0150
isolation	112	112	-0.0766
voicing into closure			
context	16	20	1.2534
isolation	15	15	0.0707
closure duration			
context	56	52	-1.3477
isolation	104	99	-1.7968
aspiration duration			
context	54	52	-0.7814
isolation	85	89	1.4728

APPENDIX I

Mean values (in ms) of final stops for each context and place of articulation and pairwise test results

(from Model 3)

vowel: vowel duration, **voicing:** voicing into closure
closure: closure duration, **aspiration:** aspiration duration

significant if p> |1.96|

SUBJECT 1

	BILABIAL			ALVEOLAR			VELAR		
	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=
vowel									
context	68	74	1.7453	67	72	1.6059	80	69	-1.7117
isolation	118	125	0.7338	112	121	1.4320	114	114	0.4900
voicing									
context	28	26	-0.3457	16	16	-0.0037	12	14	0.6576
isolation	29	30	-0.0509	23	24	0.0232	19	21	0.3244
closure									
context	81	80	0.3272	74	69	-0.5690	69	68	0.2037
isolation	119	114	-1.6229	96	103	0.9693	88	94	0.7777
aspiration									
context	21	21	-0.1725	33	29	-0.9577	29	32	1.7072
isolation	56	55	0.0052	69	67	0.0164	60	62	0.5749

SUBJECT 2

	BILABIAL			ALVEOLAR			VELAR		
	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=
vowel									
context	64	67	0.5695	58	67	2.0490	72	70	-0.3501
isolation	78	83	0.8512	77	83	1.1200	83	83	0.1348
voicing									
context	33	34	0.0906	17	18	0.2796	18	21	0.5169
isolation	25	29	0.8497	16	15	-0.1682	16	17	0.1089
closure									
context	74	70	-0.7291	71	71	0.0001	69	61	-1.6219
isolation	114	110	-0.9680	87	83	-0.7446	89	86	-0.5495
aspiration									
context	12	17	1.4388	27	31	1.1378	28	30	0.8769
isolation	42	37	-1.4247	47	59	1.9848	39	56	3.0020

SUBJECT 3

	BILABIAL			ALVEOLAR			VELAR		
	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=
vowel									
context	93	90	-0.1947	91	91	0.4392	95	98	1.5805
isolation	85	91	0.9070	86	93	1.0903	93	94	-0.2305
voicing									
context	28	25	-0.1359	18	21	1.1777	23	22	0.2686
isolation	24	28	0.6512	22	23	-0.0226	20	24	0.5574
closure									
context	125	120	-1.0229	102	99	-0.3999	98	98	0.3615
isolation	131	127	-1.7823	100	100	-0.5578	93	99	1.3867
aspiration									
context	15	16	0.7247	31	30	0.2400	30	27	-0.2137
isolation	18	17	-0.8182	35	42	1.8299	25	26	-0.1897

SUBJECT 4

	BILABIAL			ALVEOLAR			VELAR		
	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=
vowel									
context	88	99	2.1679	87	91	0.8654	92	94	0.2313
isolation	122	133	2.6232	125	125	0.2126	127	128	0.3847
voicing									
context	23	21	-0.2526	21	22	0.5738	17	20	0.7783
isolation	20	18	-0.6959	20	24	1.0002	11	15	0.8302
closure									
context	107	103	-1.3191	75	71	-1.1401	80	75	1.5555
isolation	143	131	-1.8636	106	103	-0.2813	114	106	-1.4498
aspiration									
context	14	14	0.2817	40	43	0.9245	34	35	0.5249
isolation	50	55	0.5049	87	84	-0.9138	49	59	1.9762

SUBJECT 5

	BILABIAL			ALVEOLAR			VELAR		
	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=	voiceless (ms)	devoiced (ms)	p=
vowel									
context	65	68	0.2632	65	69	0.3869	61	65	0.1999
isolation	108	107	0.2508	110	113	1.0475	118	115	-0.4078
voicing									
context	19	26	0.9692	14	15	-0.0786	16	20	0.4096
isolation	16	17	0.6952	14	14	0.1933	14	14	0.4457
closure									
context	64	59	-1.3277	49	52	0.6135	54	44	-2.3173
isolation	115	109	-1.3403	98	87	-2.5349	100	103	0.6602
aspiration									
context	46	42	0.0647	57	57	0.7037	58	55	-0.1865
isolation	74	74	-0.8224	101	108	1.0038	76	81	0.4658

APPENDIX J

Mean values (in ms) for four temporal parameters of devoiced and voiceless members of test pairs used in the perceptual study

VD: Vowel duration **VIC**: Voicing into closure
CD: Closure Duration **AD**: Aspiration duration

	2nd REPETITION				3rd REPETITION			
	VD	**VIC**	**CD**	**AD**	**VD**	**VIC**	**CD**	**AD**
/dolab/	108	20	120	13	106	15	99	13
/tʃalap/	97	25	94	16	100	26	87	16
/hitab/	119	17	128	5	121	24	91	16
/etap/	102	19	119	10	119	21	113	8
/mekteb/	90	20	92	12	94	20	76	23
/istep/	84	13	98	23	102	36	102	0
/guɾub/	91	20	105	9	62	36	115	8
/tuɾup/	55	23	84	32	64	31	113	11
/aɾmud/	63	10	88	30	45	52	63	43
/veɾmut/	46	31	95	30	59	27	84	34
/kanad/	106	34	89	31	109	43	89	27
/sanat/	109	35	89	35	113	28	67	46
/kilid/	73	16	59	86	89	20	53	39
/filit/	77	9	62	50	77	20	60	46
/simid/	54	16	59	63	67	29	29	52
/limit/	42	16	80	43	66	23	80	59

/murad/	131	16	75	55	132	25	76	46
/surat/	97	13	95	16	138	33	70	28
/tokad/	101	15	84	27	96	16	77	45
/takat/	95	0	74	25	110	16	85	34
/devřig/	57	42	85	24	48	20	94	23
/tebřik/	59	11	66	28	58	34	74	30
/kurag/	134	12	77	37	131	12	70	17
/merak/	89	0	71	39	121	23	73	42
/sineg/	107	25	88	38	121	25	82	21
/sonek/	109	11	93	21	115	31	91	24
/tombig/	61	19	77	22	55	23	77	48
/tatbik/	45	11	84	37	41	32	81	53
/yemlig/	48	27	95	30	45	25	65	63
/temlik/	52	20	74	44	62	20	72	42

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