Spectral and Durational Unstressed Vowel Reduction

An acoustic study of monolingual and bilingual speakers of Bulgarian and Turkish

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Abstract

This thesis is an extensive acoustic study of a range of phonetic and phonological phenomena traditionally referred to as unstressed vowel reduction. Five geographically contiguous varieties of two typologically distinct and genealogically unrelated languages, Bulgarian and Turkish, are investigated: two standard varieties, West Bulgarian and Istanbul Turkish, and three varieties from northeast Bulgaria: the Bulgarian and Turkish of a bilingual community, and monolingual East Bulgarian.

Vowels are modelled as three-dimensional objects defined by duration, F_1 and F_2 frequencies. Unstressed Vowel Shift or the systematic differences between stressed and unstressed realisations, categorical target split and contrast neutralisation are implicationally related yet distinct aspects of traditional vowel reduction which are addressed separately. It is demonstrated that Unstressed Vowel Shift may, but does not have to, result in the phonologisation of a separate unstressed target, which in turn may, but again does not have to, merge with the target of another vowel.

East Bulgarian exhibits the highest degree of overall reduction: Unstressed Vowel Shift is strong and categorical, and results in the unstressed merger of all open–close vowel pairs. Istanbul Turkish lies at the opposite end of a reduction continuum, with only gradient Unstressed Vowel Shift under temporal pressure. West Bulgarian shows different degrees of reduction across vowel pairs. The bilingual varieties reveal intricate patterns of interference: Bilingual Turkish is influenced by East Bulgarian and exhibits greater reduction than both Istanbul Turkish and Bilingual Bulgarian, the latter displaying little reduction as a result of substratal Turkish transfer.

In addition to providing an in-depth analysis of Unstressed Vowel Shift in multiple varieties, the thesis investigates claims of typological incompatibility between vowel harmony and reduction, Unstressed Vowel Shift in the context of language contact, the phonological status of Unstressed Vowel Shift, the nature of phonological rules, and emergent features, which prove useful for modelling processes at different stages of phonologisation, as well as hybrid structure that arises in language contact. A number of previous claims about Bulgarian and Turkish phonology are refuted.

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***** . . . . $0.01 < p \leq 0.05$

****** . . . . $0.001 < p \leq 0.01$

******* . . . . $p \leq 0.001$

∩ . . . . Intersection of sets

∪ . . . . Union of sets

§ . . . . Section

◌́ . . . . Stressed (e.g. ɔ́, V́, σ́, etc.)

◌̆ . . . . Unstressed (e.g. ɛ̆, V̆, σ̆, etc.)

◌̄ . . . . Mean value

◌̂ . . . . Estimated or predicted value

$_{1,2,3,4}$ . . . . . . A lower index number refers to the ordinal position of a syllable within a word, e.g. σ_2, V_2, u_2 (i.e. /u/ in a second syllable).

Δ . . . . Proportion of symmetric difference between PDEs; $\Delta = 1 - \eta$

η . . . . Proportion of overlap between PDEs; $\eta = \frac{\text{PDE}_a \cap \text{PDE}_b}{\text{PDE}_a \cup \text{PDE}_b}$

θ . . . . Threshold of negligibility (negligible if $< \theta$); $\theta(x) = \bar{x}/2$

Λ . . . . Pillai score

σ . . . . Syllable

ANOVA . . . . Analysis of variance

B. . . . . Bulgarian

BB . . . . Bilingual Bulgarian

BT . . . . Bilingual Turkish

C . . . . Consonant

dur . . . . Duration

EB . . . . East Bulgarian

F_1', F1′ . . . . . Normalised and rescaled first formant frequency

F_2', F2′ . . . . . Normalised and rescaled second formant frequency

IQR . . . . Interquartile range

IT . . . . Istanbul Turkish

M . . . . Mean (arithmetic)

MANOVA . . . Multivariate analysis of variance

Mdn . . . . Median

Mo . . . . Mode

N . . . . ① Number (of subjects, etc.); ② Nucleus (of a syllable)

n.s. . . . . Non-significant ($p > 0.05$)

o/c . . . . Open–close; open and close

PDE . . . . Probability density estimate

PDRC . . . . . . Parallel discriminant ratio coefficient

$\mathbf{Q_1, \ldots Q_3}$ . . . . First, ... third quartile

SB . . . . Standard Bulgarian (= West Bulgarian in terms of vowel reduction)

SC . . . . Structure coefficient

SD . . . . Standard deviation

SDFC . . . . . . Standardised discriminant function coefficient

sig. . . . . significance (level)

SPE . . . . *The Sound Pattern of English* (Chomsky and Halle 1968)

s/u . . . . Stressed–unstressed; stressed and unstressed

T. . . . . Turkish

UVS . . . . Unstressed Vowel Shift

V . . . . Vowel

$\mathbf{V}_c$ . . . . Close (high) vowel

$\mathbf{V}_o$ . . . . Open (low/non-high) vowel

$\boldsymbol{w}$ . . . . Adjusted PDRC

WB . . . . West Bulgarian

1
Introduction

Contents

'Unstressed vowel reduction' refers to a set of related phenomena that typically affect vowels in unstressed or weakly stressed syllables, such as shortening, raising, mid-centralisation, devoicing, elision, as well as decreased intensity and pitch prominence. The issue has been approached from different angles, both phonetic and phonological. The absence of stress at an abstract, phonological level may not itself be a direct cause of qualitative reduction, as it has been argued that spectral vowel reduction is in fact the result of shorter duration (Lindblom 1963; Flemming 2004; Barnes 2006). In addition, it has been demonstrated that unstressed vowel reduction is more substantial in languages where duration is a strong cue for stress (Barnes 2006): in unstressed syllables, there is often not enough time for the articulators to reach the target specified for a particular vowel, which in turn results in what is known as 'undershoot' (Lindblom 1963), unless extra effort is made to move the articulators more quickly. While phonetic vowel reduction is a gradient process, it results in an overall shrinkage of the vowel space, so that some vowel contrasts may be neutralised in unstressed position: it may be 'preferable' to maintain fewer contrasts rather than tolerate a greater number of less distinct ones (Flemming 2005). Such resulting contrast neutralisation is assumed to be not only a sufficient, but sometimes also a necessary condition for phonological reduction to be acknowledged: just as the presence of neutralisation is regarded as an indication of categorical reduction, lack of merger is often tacitly interpreted as evidence for absence of phonological reduction (e.g. Fourakis 1991; Barnes 2006). It seems natural to expect that phonetic (i.e. non-phonologised, gradient) reduction should display a certain universal tendency for target undershoot under temporal pressure. However, if the effects of undershoot become phonologised, the resulting patterns may differ substantially across languages and, as I shall argue, the relation between reduction and neutralisation is not as trivial as is often assumed.

1.1 Motivation

Bulgarian is frequently cited for its unstressed vowel reduction in the phonological literature. It is described as having an inventory of six contrastive stressed vowels, /i ɛ ə a u ɔ/, that neatly contracts into a three-vowel unstressed subsystem, /i ə u/, through the raising of non-high vowels and resultant height neutralisation (e.g. Trubetzkoy 1939; Scatton 1975; Crosswhite 2004; Harris 2005). However, traditional phonetic descriptions of Bulgarian disagree with this generalisation in two important respects (e.g. Tilkov et al. 1982; Ternes and Vladimirova-Buhtz 1999; Žobov 2004). First, it is maintained that in Standard Bulgarian only /ə–a/ and /u–ɔ/, but not /i–ɛ/, may merge in unstressed position (while in many eastern dialects height is neutralised in all three pairs). Secondly, the phonetic realisations of merged vowels are claimed to be of a height that is intermediate between the heights of the two corresponding stressed vowels. In other words, unstressed high vowels lower, as non-high vowels raise, to merge into some midway height.

The majority of phonetic accounts of Bulgarian unstressed vowel reduction are based on production studies from the 1970's, and both the linguistic situation and standard research methods are likely to have changed since. For example, more recent experimental work has confirmed raising in unstressed non-high vowels but has not found evidence for any lowering of high vowels (e.g. Andreeva et al. 2013; Sabev 2015; Sabev and Payne 2019; Dokovova et al. 2019). A thorough revised description of the Bulgarian vowel system therefore needs to be undertaken: not only because the vowel system may have changed in the past half century, but also in order to address issues that have become central to the understanding of phonetic and phonological processes, which earlier studies did not expressly address. To give an example, the traditional literature published in Bulgarian often does not explicitly distinguish between phonetics and phonology and no attempt is made to establish whether reduction is categorical or gradient (Tilkov et al. 1982, etc.; see § 2.1.2). Neutralisation is considered, but rather inconclusively: it is stated, for instance, that the vowel pair /ə–a/ is more likely to merge than /u–ɔ/, although this does not appear to be based on experimental evidence.

Standard Bulgarian as spoken in Sofia differs from eastern Bulgarian dialects in many ways, one of which is the extent of vowel reduction. Dialectological studies (Stojkov 1962; Stojkov et al. 1964–1981; Kočev et al. 2001) have reported considerably stronger reduction in eastern than in western dialects. It is therefore important to conduct a quantitative comparison of western and eastern varieties, as this is likely to reveal different routes or stages in the phonologisation of similar phonetic phenomena.

In contrast to Bulgarian, Turkish is not reported to have unstressed vowel reduction. This is not surprising, for it has been argued that Turkish is a pitch accent language (Levi 2005), that Turkish vowels do not show significant stress-dependent spectral variation (Konrot 1981), and that reduction cannot coexist with vowel harmony in a language, i.e. the two have been claimed to be typologically incompatible (Barnes 2006). A close phonetic examination of stress-mediated variation in vowels in Turkish can elucidate whether it is indeed possible for a language to exhibit no unstressed vowel reduction at all.

Given previous findings and typological assumptions, it is reasonable to expect East Bulgarian and Istanbul Turkish to lie at opposite ends of a reduction continuum, with East Bulgarian being an extensively reducing language, and Turkish a non-reducing or minimally reducing language. This presumed typological distinction raises an intriguing question about the nature and direction of prosodic transfer in bilingual speakers of Turkish and Bulgarian. Patterns of L1–L2 transfer would, as a rule, depend on individual circumstances, such as place of residence, biographical details, and speakers' attitudes to their own multilingualism. However, where a whole community is bilingual, the effects of prosodic transfer between two languages so typologically opposed, can be investigated without the filter of speaker-specific idiosyncrasy, and we find such a community in present-day eastern Bulgaria. While some work has been carried out on the Turkish spoken in Bulgaria in the framework of traditional dialectology (e.g. Mollova 1962, 1971; Boev 1976), the bilingual speakers' Bulgarian is severely understudied. The community is at present undergoing a fast-paced shift from dominant Turkish to dominant Bulgarian, and it is imperative that their speech be recorded as extensively as possible, as soon as possible. Of specific interest to this thesis is the question of whether the degree and nature of unstressed vowel reduction in the Bulgarian of these bilingual speakers differs from monolingual reduction, as a result of influence from their Turkish, or indeed whether there is evidence of reduction in their Turkish, which would indicate transfer from Bulgarian.

To address the diverse questions outlined above, I have undertaken an acoustic study of stressed and unstressed vowels in five geographically contiguous or overlapping varieties of two genetically unrelated and typologically distinct languages, Bulgarian and Turkish. The standard varieties are represented by monolingual speech from Sofia and Istanbul and will be referred to as West Bulgarian and Istanbul Turkish, respectively. Monolingual East Bulgarian, Bilingual Bulgarian and Bilingual Turkish all come from the town of Tărgovište in northeast Bulgaria and neighbouring villages.[1]

1.2 Objectives

The object of this thesis is to examine unstressed vowel reduction in the five selected linguistic varieties from a quantitative linguistic perspective. Three central questions will be addressed:

[1] A map of Bulgaria is shown in Figure 2.16 (p. 66).

(i) the degree of difference between stressed and unstressed realisations of a vowel;

(ii) whether reduction is gradient (phonetic) or categorical (phonological);

(iii) whether or not reduction leads to contrast neutralisation.

The first question can, to a large extent, be answered by applying quantitative methods that are already established in the field, although some additional new techniques will be introduced to gain further insights into the matter, and thus a more thorough understanding. Secondly, although a conceptual distinction between phonetic/gradient and phonological/categorical reduction is standardly upheld, there are no straightforward quantitative methods of discriminating between them. Phonological reduction is often equated with contrast neutralisation (e.g. Padgett and Tabain 2005; Barnes 2006). However, as will be argued, categorical reduction does not necessarily lead to merger: a vowel phoneme may have separate phonologised stressed and unstressed targets, whether the unstressed target overlaps with the that of another phoneme or not. I shall therefore approach (i), (ii) and (iii) above as separate research questions. A widespread current practice is to represent and measure merger as a proportion of overlap between phonetic distributions of vowels (e.g. Wassink 2006; Nycz and Hall-Lew 2014). However, there will always be some degree of overlap between the distributions of adjacent phonemes, even in their unreduced (i.e. stressed) realisations, so I shall propose a method of quantifying vowel merger in unstressed syllables that takes into account the overlap that is tolerated in stressed position.

My aim is, thus, to investigate the traditional notion of 'unstressed vowel reduction' by deconstructing it into three components, which are hinted at in questions (i–iii) above, but will be given a more formal consideration and definitions in Section § 1.4 and Chapter 3. More broadly, in seeking to answer these questions, I aim to address more general issues about the nature of vowel reduction, such as vowel reduction in the context of contact languages, the phonological status of reduction, degrees of contrast and neutralisation, the nature of phonological rules, and the emergence of phonological features (in the framework developed by Mielke 2008), which is a particularly helpful conceptual tool for modelling systems that are at different phonologisation stages, as well as hybrid structure that can arise in language contact.

A further objective of this study is to test the validity of established language-specific claims about unstressed vowel reduction. For Bulgarian, these include repeated assertions that:

(iv) unstressed vowel reduction is stronger in eastern than in western dialects;

(v) in Standard/West Bulgarian, unstressed /a–ə/ neutralise more readily than /ɔ–u/, while /ɛ–i/ do not neutralise at all;

(vi) in Standard/West Bulgarian, the phonetic qualities of merged realisations are intermediate between the heights of corresponding stressed vowels, i.e. [ɐ] for unstressed /a/ and /ə/, and [o] for unstressed /ɔ/ and /u/;

(vii) there are two distinct degrees of unstressed vowel reduction, more specifically that vowels in the syllable immediately preceding the stressed syllable (the 'pretonic') are less reduced than other unstressed vowels.

An important claim relating to Turkish which needs to be tested is one made by Barnes (2006), namely that:

(viii) vowel reduction and vowel harmony cannot coexist in a language.

Based on previous research and assumptions, one should expect any unstressed vowel reduction that may be present in Istanbul Turkish to be gradient, as would result from target undershoot under temporal pressure. Much stronger reduction is likely to be found in monolingual Bulgarian, probably more markedly categorical in the East than the West. It is difficult, if not impossible, to predict where exactly Bilingual Turkish and Bilingual Bulgarian will lie on a reduction scale, as little is known about these varieties. If we are to believe that vowel harmony and unstressed vowel reduction are typologically incompatible, there should be a definitive watershed point, with the two varieties logically lying on different sides. Alternatively, one of them—or indeed both—may have crossed that point as a result of L1–L2 transfer.

1.3 Acoustic parameters

Lexically stressed and unstressed vowels may exhibit differences in a number of acoustic parameters, most notably duration, formant frequencies, intensity and the fundamental frequency. This study focuses on vowel duration and the first two formant frequencies. Each vowel token, therefore, is modelled as a combination of three values: duration, F_1 frequency and F_2 frequency. A phrasing such as 'unstressed x' will refer either to the set of all three-dimensional tokens of phoneme x sourced from unstressed syllables in this study, or to a single point in the three-dimensional space defined by the mean values of each acoustic parameter. Context will make clear which of the two interpretations of 'vowel'—as a 'cloud' of tokens or as a mean point—is intended. Sometimes, especially in graphs, vowels will be reduced to only two (the formant frequencies), or even to one of their constituent parameters (as in probability density estimates). This will also be clear from the context.

The direction of qualitative vowel reduction has been a matter of some debate, and two main groups of findings have been reported. In one of them reduction manifests as mid-centralisation (e.g. Rietveld and Koopmans-van Beinum 1987; de Jong 1995; Palethorpe et al. 1999; Baltazani 2007), and in the other as raising (e.g. Wood and Pettersson 1988; Flemming 2005; Barnes 2006; Andreeva et al. 2013). In addition, some phonological models posit reduction patterns in which reduced vowels are 'attracted' towards the corner values [i, u, a] (e.g. Crosswhite 2001; Harris 2005). The spectral parameters selected for this study, i.e. the F_1 and F_2 frequencies, are sufficient to capture all of those types of potential qualitative variation.

1.4 Core concepts and metrics

As suggested in § 1.2 above, the notion of 'unstressed vowel reduction' will be broken down into three components in this work. First, **Unstressed Vowel Shift** will refer to a measurable difference between the stressed and unstressed realisations of a vowel phoneme. Secondly, Unstressed Vowel Shift may (but does not have to) be **phonologised**. In phonologised Unstressed Vowel Shift, stressed and unstressed realisations have distinct targets. Thirdly, a phonologised separate unstressed target may (but again does not have to) overlap with the target of another phoneme. If the overlap is substantially greater than the overlap tolerated in stressed position, then **contrast neutralisation** or **conditioned merger** is in place.

The vowel-as-cloud concept is central to defining Unstressed Vowel Shift and contrast. Both will be measured as the amount of non-overlapping space of two vowel clouds relative to the total space occupied by both clouds. In set-theoretic terms, the *overlapping space* of token sets A and B is their **intersection**, $A \cap B$, a two-dimensional view of which is diagrammed in Figure 1.1. The *total space* occupied by both token sets is their **union**, $A \cup B$ (Figure 1.2). The *non-overlapping space* of token sets A and B is

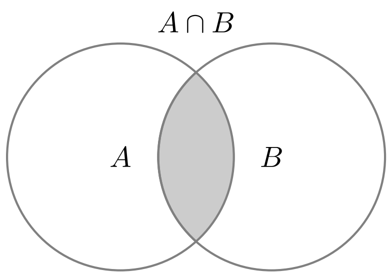

Figure 1.1: Intersection of sets A and B (shaded).

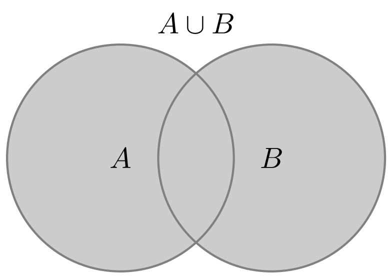

Figure 1.2: Union of sets A and B (shaded).

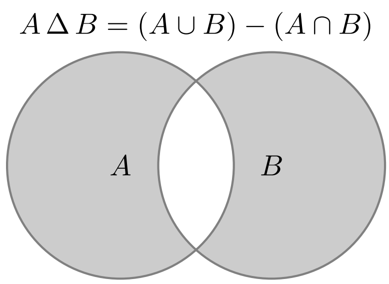

Figure 1.3: Symmetric difference of sets A and B (shaded).

their **symmetric difference**, $A \,\Delta\, B$, which equals their union less their intersection, $(A \cup B) - (A \cap B)$, as shown in Figure 1.3.

A definition of Unstressed Vowel Shift is given in (1.1): it is the ratio of the symmetric difference to the union of the stressed ($\acute{V}$) and unstressed ($\breve{V}$) realisations of a vowel phoneme.

$$\textbf{Unstressed Vowel Shift:} \quad \frac{\acute{V} \,\Delta\, \breve{V}}{\acute{V} \cup \breve{V}} \tag{1.1}$$

Height contrast (K) is defined in (1.2) as the ratio of the symmetric difference to the union of an open (V_o) and a corresponding close (V_c) vowel.

$$\textbf{Height contrast:} \quad K = \frac{V_o \,\Delta\, V_c}{V_o \cup V_c} \tag{1.2}$$

As can be seen from (1.1) and (1.2), both Unstressed Vowel Shift and contrast are defined as *Symmetric Difference*-to-*Union* ratios, $\Delta/\cup$. What differs is the token clouds that are being compared: for Unstressed Vowel Shift it is the stressed and unstressed realisations of a phoneme, while in the case of contrast it is the matching open and close vowel token sets, considered separately for stressed and unstressed syllables.

Vowel token sets modelled as three-dimensional $F_1 \times F_2 \times$ duration objects are compared through **multivariate analysis of variance** (MANOVA), using the **Pillai** statistic (Λ) from significant MANOVA tests to quantify both overall (3D) Unstressed Vowel Shift, $\Lambda(\acute{V},\breve{V})$, and overall contrast, $\Lambda(V_o,V_c)$. This quantification of *overall* shift and contrast is followed up by further analyses of each of the three acoustic parameters. Parameter-specific symmetric difference is calculated for **probability density estimates**, thus taking into account not only the size of non-overlapping intervals for each parameter, but also the estimated density of data points in those intervals. In addition, **discriminant function analysis** is performed to compute the relative contribution of each parameter in classifying tokens into categories (i.e. stressed vs unstressed, and open vs close). Unstressed Vowel Shift and contrast are thus assessed both from a global (three-dimensional) and from a local (parameter-specific) perspective.

A further test is applied to estimate whether Unstressed Vowel Shift is gradient or categorical. The **test of categoricality** adopted here consists in comparing each open vowel's *observed* mean unstressed $\bar{F}_1$ frequency with a corresponding *predicted* $\hat{F}_1$ frequency for gradient undershoot. An observed reduction in F_1 frequency that exceeds the reduction predicted for undershoot (for a given vowel phoneme in a given dialect) is interpreted as an indication of categorical Unstressed Vowel Shift.

I discuss these and other metrics in detail in Chapter 3.

One last concept needs to be defined in this section: that of **contrast neutralisation**. Let $\acute{K}$ denote height contrast in stressed position and $\breve{K}$ height contrast in unstressed position, for the same pair of open and close phonemes. Contrast neutralisation, as defined in (1.3), is then the amount of contrast that is lost in unstressed position, $\acute{K} - \breve{K}$, relative to the contrast that is maintained in stressed position, $\acute{K}$:

$$\textbf{Neutralisation:} \quad \frac{\acute{K} - \breve{K}}{\acute{K}} \tag{1.3}$$

Although many studies of vowel merger conceptualise and quantify merger as a Jaccard index, that is, as the ratio of the intersection to the union of two vowel distributions, $\frac{V_a \cap V_b}{V_a \cup V_b}$, I argue that definition (1.3) is superior, for it factors in the amount of overlap that is tolerated between realisations in more contrastive positions.[2,3]

The Pillai statistic and the neutralisation ratio derived from it are continuous output variables and as such are valuable in assessing differences and similarities between vowels within and across dialects. Later in the thesis (§ 9.4) I also discuss how these continuous variables can be categorised with the help of a machine learning algorithm.

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[2] A growing body of recent work on vowel mergers (including Hall-Lew 2010; Sloos 2013; Amengual and Chamorro 2015; Renwick and Olsen 2017; Diskin et al. 2019; Mairano et al. 2019; Sabev and Payne 2019) relies on the Pillai statistic to quantify merger (see § 3.2.3.1). The Pillai score is a measure of distinctness between multivariate distributions, or the proportion of their symmetric difference, and as such is an appropriate metric for contrast as defined in (1.2) above. Quantifying merger through the Pillai score (Λ) alone means (and some studies are more explicit about this than others) that merger is thought of as a proportion of overlap (i.e. intersection), which in turn is, at least conceptually, the complement of the Pillai score, $1 - \Lambda$.

[3] Wassink (2006) differs from the studies listed above in that she relativises overlap (intersection) not to the union (total space) of both distributions, but to the smaller of the two, i.e. Merger $= \frac{V_a \cap V_b}{\min(V_a, V_b)}$.

1.5 Thesis organisation

In Chapter 2, *Background*, I provide a detailed review of the literature on unstressed vowel reduction in Bulgarian (§ 2.1), an overview of relevant aspects of Turkish (§ 2.2) and East Bulgarian (§ 2.3.1) phonology, and an introduction to the bilingual varieties (2.3.2). Chapter 3, *Methodology*, discusses the experimental procedures and methods used in this study, and explains the structure of the five experimental chapters that follow. Chapters 4–8 report the results of the production experiments on each of the five varieties; each of these chapters concludes with a summary and discussion of findings. In Chapter 9, *Cross-varietal comparison*, I compare individual varieties and discuss the major similarities and differences between them. Chapter 10, *General discussion*, summarises the main findings of this work and addresses their wider phonological implications. The closing Chapter 11, *Conclusion*, assesses the contribution of this study towards the objectives set out in § 1.2 above, and suggests possible avenues for future research.

2

Background

Contents

In this chapter I review previous literature on unstressed vowel reduction in Standard Bulgarian (§ 2.1) and provide an overview of relevant aspects of Standard Turkish (§ 2.2) and East Bulgarian (§ 2.3.1) phonology. Although little has been published on the phonological structure of the bilingual varieties, there is some sociolinguistic research that is of interest, which is summarised in § 2.3.2.

2.1 The Bulgarian vowel system

After introducing the stressed vowel inventory in § 2.1.1, I turn to discussing a number of distinct strands of research on Bulgarian stressed and unstressed vowels. Traditional accounts (§ 2.1.2) maintain that height-contrasting pairs of vowels reduce to qualities of intermediate height, e.g. both /ɔ/ and /u/ are believed to change to [o] when unstressed. In § 2.1.3, I turn to a handful of empirical studies that have concluded that, in unstressed position, open vowels raise to the qualities of their close counterparts, whereas close vowels remain spectrally unchanged. In § 2.1.4, I consider a number phonological models of Bulgarian vowel reduction that have been proposed, before concluding the section on Standard Bulgarian with a brief summary in § 2.1.6.

2.1.1 The stressed vowel inventory

Contemporary Standard Bulgarian (SB) has six contrastive vowels in stressed position, as shown in Figure 2.1. The vowel /ə/ is typically somewhat closer and more retracted than 'mid central', and is therefore sometimes transcribed /ɤ/ (e.g. Ternes and Vladimirova-Buhtz 1999; Žobov 2004).

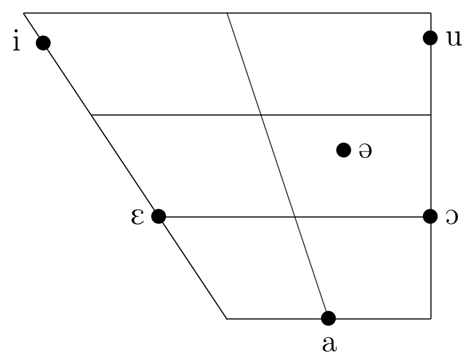


Figure 2.1: SB stressed vowels according to Ternes and Vladimirova-Buhtz (1999).

Phonetically, the Bulgarian vowels range from to close to open, which means that, in an *SPE*-type (Chomsky and Halle 1968) phonological analysis, they are assigned to three discrete and absolute heights on the basis of their canonical phonetic realisations, i.e. $\begin{bmatrix}\texttt{+high}\\ \texttt{-low}\end{bmatrix}$: /i u/, $\begin{bmatrix}\texttt{-high}\\ \texttt{-low}\end{bmatrix}$: /ɛ ə ɔ/, $\begin{bmatrix}\texttt{-high}\\ \texttt{+low}\end{bmatrix}$: /a/. Some of the phonological approaches reviewed later in this chapter explicitly apply this 2-feature/3-height analysis to Bulgarian vowels (Scatton 1975; Spahr 2014).

Prior to *SPE*, European Structuralists advocated a relative, rather than absolute and discrete, view of phonological oppositions, a view which is particularly pertinent to the study of the Bulgarian vowel inventory and phonological processes. Trubetzkoy (1939), for example, interprets the neutralisation patterns resulting from unstressed vowel reduction in Bulgarian as evidence that there are only two heights that enter into a phonological opposition:

> Der bulgarische unbestimmte Vokal weist ungefähr denselben Öffnungsgrad wie *o* und *e* auf, ist aber dabei weder gerundet noch palatal. Einen reinen Eigentongegensatz zwischen bulg. *ə* und *o* oder zwischen bulg. *ə* und *e* wird man wohl kaum annehmen dürfen. Wohl wird man aber die Proportionen $o : a = u : ə$, $e : a = i : ə$, und die aus ihnen abgeleitete Proportion $u : o = i : e = ə : a$ aufstellen dürfen. Daß diese Proportion einer Realität entspricht, beweisen die Verhältnisse in den unbetonten Silben (wenigstens in einem Teil der lokalen Aussprachetypen): in diesen werden nämlich keine *o*, *e*, *a*, sondern nur *u*, *i*, *ə* zugelassen, d. i. die Öffnungsgradgegensätze *u*-*o*, *i*-*e*, *ə*-*a* sind aufgehoben, aber der dreieckige Charakter des Vokalismus ist bewahrt.[1]
>
> (Trubetzkoy 1939: 105–106)

The Prague school (and Trubetzkoy in particular) viewed phonological oppositions as relations between phonemes and the dimensions of opposition as mere properties of phonemes with no autonomous status. Jakobson et al. (1952)[2] developed the Structuralist concept of phonological oppositions further, into a theory of twelve autonomous distinctive features, which combine simultaneously in the structure of phonemes. In contrast to the *SPE*'s phonetically invariant interpretation of distinctive features, and in keeping with the ideas of earlier Structuralists, Jakobson et al. (1952) emphasise that distinctive features are

[1] "The Bulgarian intermediate vowel has approximately the same degree of aperture as *o* and *e*, but it is neither rounded nor palatal. It would hardly be possible to assume a pure opposition of timbre between Bulgarian *ə* and *o*, or between Bulgarian *ə* and *e*. But the proportions $o : a = u : ə$, $e : a = i : ə$, and the proportion $u : o = i : e = ə : a$ deduced therefrom may well be established. The conditions in unstressed syllables (at least in a part of the local types of pronunciation) are proof that this proportion corresponds to a reality. For in these syllables *o*, *e*, and *a* are not permitted, only *u*, *i*, and *ə* are. In other words, the oppositions based on degree of aperture, *u*-*o*, *i*-*e*, and *ə*-*a* are neutralised, while the triangular character of the vowel system is preserved."

(Trubetzkoy 1969: 114)

[2] The version consulted and referred to here is Jakobson et al. (1963).

not endowed with phonetic but with *relational* invariance (p. 4ff). The Danish fortis–lenis opposition, for example, is realised phonetically as aspirated vs unaspirated stops in syllable onsets, but as unaspirated stops vs voiced fricatives in codas. Consequently, in Danish an unaspirated stop is lenis in relation to an aspirated stop, but also fortis in relation to a voiced fricative (ibid, pp. 5–6). Similar relational behaviour is illustrated with the feature `compact–diffuse` in the Romanian vowel system:

> [I]n Roumanian (and similar relations exist in many other languages) the open /a/ and the close /ɨ/ ... are opposed to one another as compact vs. diffuse. The corresponding mid vowel /ə/ is diffuse with respect to /a/ ... but at the same time compact in relation to /ɨ/ ...
>
> (Jakobson et al. 1952: 29)

Jakobson (1962) argues even more forcefully for the relative nature of distinctive features, providing numerous examples, including one relating to the Bulgarian vowel inventory:

> Every combination of distinctive features into simultaneous bundles results in a specific contextual variation. In view of incessant misunderstandings, it is necessary to emphasize that any distinctive feature exists only "as a term of relation". The definition of such a phonemic invariant cannot be made in absolute terms—it cannot refer to a metric resemblance but must be based solely on relational equivalence. For instance, in the Bulgarian or Goldic (Nanaian) vowel pattern, each of the three tonality classes—acute (front), grave flat (back rounded), and grave non-flat (back unrounded)—is represented by a pair compact (wider)–diffuse (narrower)—namely, /e/–/i/, /o/–/u/, /a/–/ə/. The physico-motor propinquity between /ə/ the diffuse phoneme of the last pair, and the compact phonemes of the other two pairs, /e/ and /o/, has no phonemic pertinence, for the same opposition underlies all three pairs: /a/ is to /ə/ as /e/ is to /i/ and as /o/ is to /u/. The wider articulation of /a/ and /ə/ as compared to both other pairs is a contextual variation associated with the concurrence of grave with non-flat (velarity with unroundedness), but the purely topological relations remain unchanged in all three pairs.
>
> (Jakobson 1962: 446)

Consistent with the Structuralist relational view of phonological oppositions, the literature in Bulgarian (reviewed in § 2.1.2 below) recognises two levels of distinctive vowel height, typically termed 'narrow' and 'wide':[3]

[3] For the purposes of the rest of the quotations in this section, /ɤ/ = /ə/. I explain my notational choices in the next section.

> The degree of tongue height in the oral cavity, i.e. the tongue's movement in the vertical direction, is the articulatory basis for the feature **open–closed** (wide–narrow). The feature **open** (wide) is shared by the vowel phonemes /a, ɔ, ɛ/, and the feature **closed** (narrow) by the vowels /ɤ, u, i/. In acoustic terms, the feature open corresponds to **compactness**, and the feature closed to **diffuseness**. ... The features compact and diffuse are identified within the vowel pairs /i–ɛ/, /ɤ–a/, /u–ɔ/: the vowel /i/ is diffuse in relation to the vowel /ɛ/, the vowel /ɤ/ in relation to /a/, and the vowel /u/ in relation to /ɔ/.[4]
>
> (Tilkov et al. 1982: 108–109)

Tilkov et al. (1982) suggest that systemic factors determine the phonological status of mid vowels, and also that Bulgarian vowels are divided into two *or* three heights according to different articulatory criteria—tongue-to-palate distance and tongue height, respectively—but no supporting data or further explanation is provided for the latter claim:

> The degree of tongue height in the oral cavity defines a vowel as **wide** or **narrow** (open or closed). The higher the tongue, the narrower (more closed) the vowel and vice versa: the lower its position, the wider (more open) the vowel. According to this criterion, the narrowest vowels are /i/ and /u/, and the widest is /a/. The remaining vowels are intermediate and their degree of closure and openness is determined by the sound system of the language.
>
> In Bulgarian, according to the **width of the passage** between the body of the tongue and the palate, there are, in general terms, two classes of vowel: **narrow**, /i/, /u/, /ɤ/, and **wide**, /ɛ/, /ɔ/, /a/.
>
> In regard to the degree of tongue height in the oral cavity, the vowels are divided into three classes: **high**, /i/, /u/, /ɤ/, **mid**, /ɛ/, /ɔ/, and **low**, /a/.
>
> Within these classes, vowels are not identical in terms of the above-mentioned properties. For instance, within the class of narrow vowels, the vowel /ɤ/ has a wider passage than the vowels /i/ and /u/, while in the class of wide vowels, the vowels /ɛ/ and /ɔ/ are narrower than the vowel /a/. At the same time, within the class of high vowels, the position of the tongue in articulating the vowel /ɤ/ is lower than it is for the vowels /i/ and /u/.
>
> (Tilkov et al. 1982: 31)

From this description, it unfortunately remains unclear what justifies classifying the 'narrow' vowel /ɤ/ (/ə/) as 'high' rather than 'mid'.

[4] All quotations from work published in Bulgarian are in my translation.

Despite some expository deficiencies in the earlier in-depth treatments of the Bulgarian vowel system, I shall retain the assumption of a two-way relational height contrast for both Bulgarian and Turkish vowels. The appositeness of a two-height phonological opposition to Bulgarian is clear from the argument presented by Trubetzkoy (1939) as quoted above. Justification for applying a two-way classification to Turkish as well will be given in relevant sections. However, the choice of relational versus absolute height classes is an important theoretical issue, to which I return—in the light of my findings—in Chapter 9 (§ 9.5).

I shall refer to the two contrastive heights as 'close' and 'open', in order to avoid referring to *low* F_1 frequencies in the context of 'high' vowels and vice versa, which could be inconvenient and potentially confusing. I shall also substitute 'close' and 'open' for 'narrow' and 'wide', respectively, in my translations from Bulgarian.

The phonological contrasts among the six Bulgarian stressed vowels, taking into account the assumptions relating to the height contrast stated above, are summarised in Figure 2.2. Bulgarian /a/ is phonetically central, whereas /ə/ may be somewhat more retracted.

	FRONT	NON-FRONT/BACK	
	(UNROUNDED)	UNROUNDED	ROUNDED
CLOSE	i	ə	u
OPEN	ɛ	a	ɔ

Figure 2.2: Bulgarian vowels categorised by binary height, backness and rounding.

2.1.2 Reduction (1): the traditional view

What may be termed the 'traditional view' of unstressed vowel reduction in Standard Bulgarian was laid down in Tilkov et al. (1982). This is the first volume of the standard university-level reference grammar of Standard Bulgarian, often dubbed 'the Academy Grammar'. Even though there has not been a second, revised edition to date, it remains very influential and serves as the standard textbook for university courses in Bulgarian phonetics and phonology in the country. An earlier book-length work by the same authors, Tilkov and Boyadžiev (1977), is the first publication in Bulgarian that incorporates an acoustic description of Bulgarian speech sounds. Although it has been published in numerous 'editions' (the latest one, at the time of writing, being from 2013), the only mention of a revision is the importation of a chapter on phoneme alternations from the Academy Grammar. The acoustic data in Tilkov and Boyadžiev (1977) and the Academy Grammar are from Dimitar Tilkov's doctoral thesis (Bistra Andreeva, personal communication), which was published as a monograph in French (Tilkov 1970). A number of later textbooks and reference works either replicate or provide abridged versions of the content set out in the Academy Grammar and Tilkov and Boyadžiev (1977). These include Scatton (1984), Boyadžiev and Tilkov (1997), Boyadžiev et al. (1998), Ternes and Vladimirova-Buhtz (1999) and Žobov (2004). The traditional view of Bulgarian unstressed vowel reduction may be summarised as follows.

(i) Of the three pairs /i–ɛ/, /ɤ–a/, /u–ɔ/,[5] *the second and the third neutralise height distinctions* in unstressed positions in Standard and, in general, western Bulgarian. The front pair is neutralised in eastern dialects only.

(ii) *Neutralised realisations are intermediate* between the heights of the two canonical stressed realisations, i.e. /ɤ–a/ neutralise to [ə] and /u–ɔ/ neutralise to [o].

[5] Tilkov et al. (1982) transcribe vowels with the corresponding letters of the Cyrillic alphabet and enclose all transcriptions in square brackets: [и, е, а, ъ, о, у]. Here I replace such transcriptions with IPA symbols; I also substitute phonemic slants where appropriate (though not in quotations): /i, ɛ, a, ɤ, ɔ, u/, respectively. In § 2.1.2 and § 2.1.3, I use /ɤ/ for the stressed close non-front unrounded vowel whenever the original notation distinguishes between its stressed and unstressed realisations. However, where the assumption is that there is little or no qualitative difference, I shall use /ə/.

(iii) The precise height of the merged realisation depends on the vowel's syntagmatic distance from the stressed syllable. *Two degrees of reduction* are recognised: the *first* is in a syllable immediately preceding the stressed one ('first pretonic') and is a more open realisation ([ɐ, o̞]), while the *second* degree is closer and occurs in all other unstressed positions ([ə, o]).

2.1.2.1 Tilkov's acoustic investigation and related work

The Academy Grammar (Tilkov et al. 1982) offers some formant frequency and duration values for different vowel allophones (stressed, first pretonic, other unstressed), at various places in the text (pp. 30–60). These are summarised in Table 2.1. Some of the frequencies are explicitly referred to as mean values; some are identified as male productions. The F_2 frequency for /ɤ/ is reported to be 1887 Hz on p. 59, which is probably an error.

The reported frequencies are, in all likelihood, based on data collected from three subjects for an acoustic study of Bulgarian vowels reported in Tilkov (1970). The subjects were the author himself, another male speaker, and a female speaker (ibid., 151–152). The vowels were produced in isolated open syllables with varied onset consonants, real words in isolation, and a few sentences. Figure 2.3 is a logarithmically scaled diagram of mean F_1 and F_2 frequencies across all conditions (including unstressed) calculated for the author (solid line) and the female speaker (broken line).

	Stressed			First pretonic (for /ɛ/: any pretonic)			Elsewhere (for /ɛ/: post-tonic)		
	F_1 (Hz)	F_2 (Hz)	Dur. (ms)	F_1 (Hz)	F_2 (Hz)	Dur. (ms)	F_1 (Hz)	F_2 (Hz)	Dur. (ms)
/a/	600–700, 750	1100–1200, 1300	110–120	600	1100	70–90	500–520		60
/ɤ/	413, 450–500	1200–1300 (1887?)							
/ɔ/	400, 478	800, 894	130	405	855	90	305–325	755–775	
/u/	250, 300	700, 850	150	(as stressed)			380	900	100
/ɛ/	400, 433	1600, 1917	110	358	1983	70	500	1693	
/i/	250	2000							

Table 2.1: SB S/U vowel formant frequencies and durations according to Tilkov et al. (1982: 32–59).

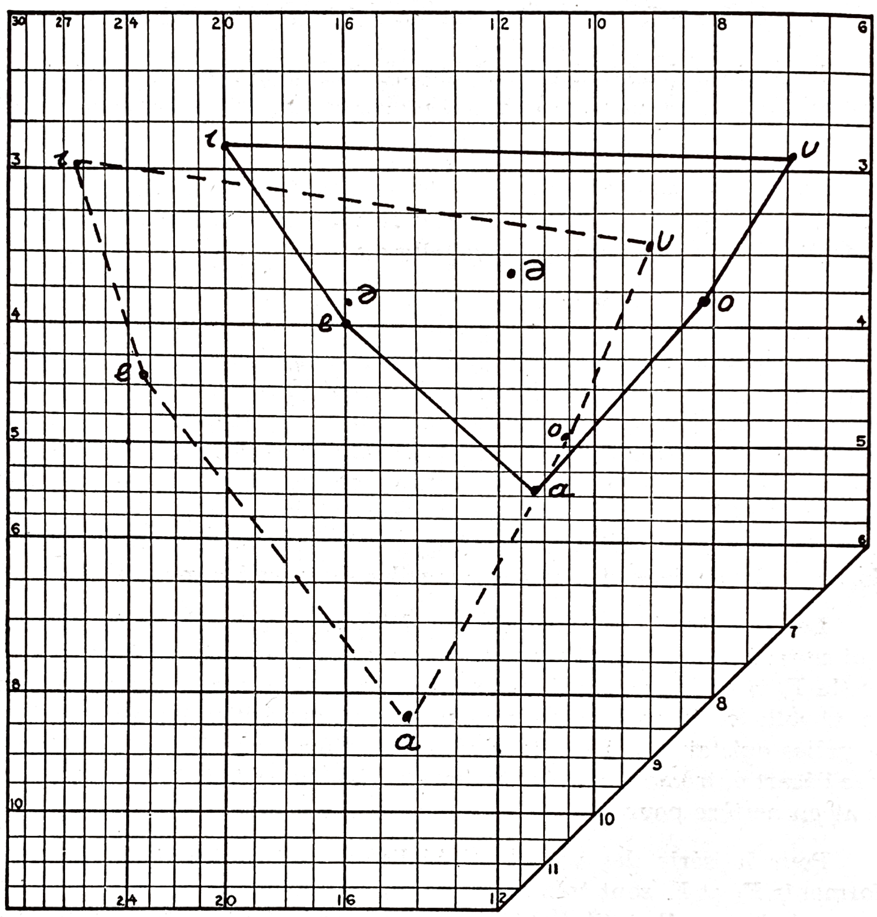


Fig. n° 28. — **Echelle logarithmique sur laquelle sont disposées les six voyelles bulgares émises par le sujet n° 1 (homme) et par le sujet n° 3 (femme). Les dimensions de la figure dépendent de la valeur des résonances du F_1 et du F_2 qui varient d'un sujet à l'autre. Ce qui reste stable, c'est la disposition des voyelles et le rapport qui s'établit entre elles.**

Figure 2.3: Mean F_1 and F_2 frequencies of Bulgarian vowels for a male (solid line) and a female (broken line) speaker reported by Tilkov (1970: 174).

Caption: *Logarithmic scale onto which the six Bulgarian vowels are plotted, as produced by Subject 1 (male) and Subject 3 (female). Plot sizes depend on the values of F_1 and F_2 resonances, which vary from one subject to another. What remains stable is the arrangement of the vowels and the relations between them.* (my translation)

Apart from the position of a vowel relative to the stressed syllable, Tilkov et al. (1982: 46–58) mention a number of other factors that may affect the degree of unstressed vowel reduction:

(i) Style: 'Reduction is stronger in colloquial speech, while in more refined speech, which is marked by careful articulation, it is less pronounced'.

(ii) Sociolinguistic factors also come into play in the form of a claim that realisations of open unstressed vowels that are closer than those described in the text are not acceptable in Standard Bulgarian (which implies that they exist).

(iii) Word-final boundaries: unstressed /u/ is said to have a more open realisation word-finally).

(iv) Morphological structure is argued to play a role in that there is less or no reduction of /ɔ/ when it is a vocative ending.

(v) Coarticulatory effects of adjacent consonants: /ɔ/ is claimed to reduce more in the environment of bilabials and velars than elsewhere.

Tilkov et al. (1982) further maintain that unstressed neutralisation is greatest between the unstressed central vowels /ɤ–a/, smaller for the back rounded vowels /u–ɔ/ and negligible in the front pair /i–ɛ/ (45). Unstressed /ɛ/ is described as undergoing only slight raising pretonically and some retraction (i.e. centralisation) in post-tonic position. It is repeatedly emphasised that the unstressed open vowels in Standard Bulgarian are not qualitatively identical to the stressed realisations of close vowels (ibid., 44–60). However, since the unstressed close vowels /ɤ/ and /u/ are claimed to undergo varying degrees of opening, this treatment does allow for positional neutralisation resulting from the overlap of the unstressed allophones of close and open vowels, even though those allophones are held to be distinct from the stressed realisations of both close and open vowels (ibid., 47, 51). Unstressed /u/ is said to undergo less lowering than unstressed /ɤ/ (ibid., 57).

There are a number of other factors that may affect the quality of unstressed vowels which, however, are not addressed in Tilkov's work, such as vowel duration, speech rate, vowel-to-vowel coarticulation, absence of onsets in word-initial syllables, word-final open syllables, prosodic boundaries, phrase-level prominence and word frequency.

2.1.2.2 Žobov (2004)

Žobov (2004) is a brief overview of Bulgarian speech sounds, with a section devoted to vowel reduction (pp. 43–48), which ought not to be left out of a review of the subject. Žobov starts by declaring that his own analysis of acoustic data for Standard Bulgarian corroborates the unstressed vowel reduction patterns described earlier in the Academy Grammar (Tilkov et al. 1982), if with some qualification concerning the front vowels. He endorses the received view of unstressed vowel reduction in which close vowels are lowered alongside open vowels' more pronounced raising. Table 2.2 shows the F_1 and F_2 frequencies he reports for Standard Bulgarian /a/ and /ɔ/. With regard to unstressed

		Stressed		First pretonic		Second pretonic	
		F_1 (Hz)	F_2 (Hz)	F_1 (Hz)	F_2 (Hz)	F_1 (Hz)	F_2 (Hz)
/a/	/kataˈrama/	600	1330	450	1360	410	1530
/ɔ/	/kɔlɔˈvɔz/	410	860	390	750	370	860

Table 2.2: F_1 and F_2 frequencies of SB s/u /a/ and /ɔ/ according to Žobov (2004: 44).

/ɛ/, he writes that a realisation which is both closer and centralised (retracted) tends to be generalised to all unstressed environments. Unstressed /i/ also shows a small decrease in F_2 frequency (by 100 Hz) compared to its value under stress. The formant frequencies reported for the front vowels are shown in Table 2.3. While the results confirm my personal impression that /ɛ/ is indeed slightly centralised in all unstressed positions, whether pre- or post-tonic, the drop in F_1 frequency to a level typical for /i/ is somewhat surprising, and is likely to be an error in the text.

		Stressed			Unstressed		
		F_1 (Hz)	F_2 (Hz)	F_3 (Hz)	F_1 (Hz)	F_2 (Hz)	F_3 (Hz)
/ɛ/	/ˈdɛsɛt/	410	1700	2670	350	1570	2480
/i/	/priˈbiramɛ/	340	2000	2500	350	1900	2400

Table 2.3: F_1 and F_2 frequencies of SB s/u front vowels according to Žobov (2004: 44).

		Stressed /a/		First pretonic /a/		Second pretonic or post-tonic /a/	
		F_1 (Hz)	F_2 (Hz)	F_1 (Hz)	F_2 (Hz)	F_1 (Hz)	F_2 (Hz)
East-central	/zaˈpalka/	670	1100	470	1310	450	1760
Northwest	/dɔkaˈramɔ/	600	1200	500	1230		
Golo Brdo	/za paˈsaliʃtɛ/	670	1390	560	1300	470	1500

Table 2.4: Formant frequencies of stressed and unstressed /a/ across Bulgarian dialects according to Žobov (2004: 45–46).

Žobov next turns to patterns of unstressed vowel reduction observed in four non-standard dialects of Bulgarian, two eastern and two western, pointing out that reduction-free dialects are very unlikely to exist; rather, 'there are gradual differences within what is a common Bulgarian phenomenon' (ibid., 45). He looks at dialects from southeast, east-central, and northwest parts of the country, as well as the dialect of a Bulgarian-speaking minority in the Golo Brdo region of Albania, probably the westernmost variety of Bulgarian.

Žobov's mean values for /a/ and /ɔ/ in the non-standard dialects are shown in Tables 2.4 and 2.5, respectively. For the most part, the formant frequencies reported from these dialects support an established view that, geographically, Bulgarian unstressed vowel reduction intensifies progressively on from West to East. Žobov further suggests that reduction may be less pronounced in final syllables, especially if those also happen to

		Stressed /ɔ/			Unstressed /ɔ/		
		F_1 (Hz)	F_2 (Hz)	Dur. (ms)	F_1 (Hz)	F_2 (Hz)	Dur. (ms)
East-central	/ɔˈpɔpia/	500	1100	100	350	880	60
Southeast	/ˈgɔtɔv/	500	1060		410	990	
	/kɔˈkɔʃka/	410	820	100	370	800	45
Northwest	/kɔlˈkɔ/	470	970		370	880	
	/pɔˈsɔli/	450	1010		410	800	
	/stɔˈlɔvɛ/			75			65
Golo Brdo	/ˈkɔkɔʃka/	430	780		390	930	
	/pɔ ˈpɔlnɔt͡ʃ/	450	800		390	750	
	/ɔt ˈkɔkɔʃka/			70			65

Table 2.5: Formant frequencies and durations of S/U /ɔ/ across Bulgarian dialects according to (Žobov 2004: 46–47).

be inflectional endings (ibid., 45–46). Very importantly, he also expressly links vowel reduction to the reduced duration of unstressed syllables:

> Differences in the degree of qualitative reduction between eastern and western dialects are coupled with differences in the degree of quantitative reduction, which seems to be under-acknowledged. In the eastern dialects, a stressed vowel may be more than twice as long as an unstressed one.
>
> (Žobov 2004: 47)

The data in Tables 2.4 and 2.5 reveal a few cases where F_1 frequency reduction in the West is in fact as strong as or even stronger than in the East. At times the text is at variance with the quantitative data reported: it is said, for example, that in the northwestern dialect there is less reduction of /ɔ/ in /kɔlˈkɔ/ than in the East, and also than is found in a position after a labial, but the figures tell a different story. One also notes a rather unexpected rise in F_2 frequency for post-tonic /a/ in the east-central dialect—a spectral profile thus defined would be more congruent with a realisation of /ɛ/.

Žobov then reaffirms the East–West divide drawn by unstressed front vowels:

> With front vowels, in the western dialects there is either no reduction or it is as insignificant as in standard pronunciation. In the eastern dialects reduced /ɛ/ crosses the category boundary and is replaced either by /i/ (or, more precisely, its more open allophone [ɪ]), or by a central vowel, with the preceding consonant palatalised.
>
> (Žobov 2004: 47)

It is indeed interesting to look at more recent spectral measurements. At the same time, it is unfortunate that there is no information about how those data were obtained: no experiments are described or referred to. The text makes clear that the values are derived from single lexical items, which are included in the tables above, but no information is provided as to whether those are measurements of single tokens or mean values for multiple repetitions. Moreover, where dialects are compared, the words themselves are not the same, nor are the vowels described in the same segmental environments. Stressed and unstressed vowel duration is also presented on the basis of single words (perhaps single tokens). However, Žobov also acknowledges, ‘While these examples are not the only ones, I am aware that a more substantial statistical study is needed in order to reach more convincing conclusions' (ibid., 47).

2.1.2.3 The IPA illustration of Bulgarian

The *Handbook of the International Phonetic Association* includes an illustration of Standard Bulgarian (Ternes and Vladimirova-Buhtz 1999). The vowel diagram, reproduced in Figure 2.4, displays *eight* vowel qualities.

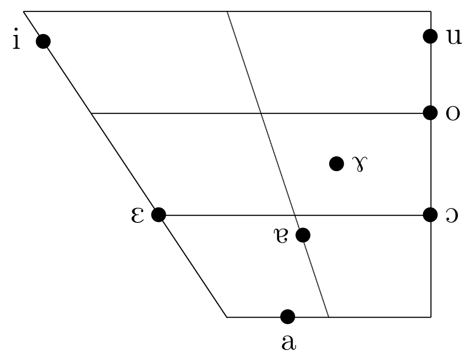


Figure 2.4: IPA illustration of SB vowels (Ternes and Vladimirova-Buhtz 1999: 56).

In the table of examples, however, [o] and [ɐ] are shown in square brackets and labelled 'unstressed only'. It is then explained that '[o] is a neutralization of /u/ and /ɔ/, [ɐ] is a neutralization of /a/ and /ɤ/, both in unstressed syllables', and then that '[o, ɐ] may be somewhat more closed than shown in the figure in unstressed syllables after stress' (56).

Clearly, the authors subscribe to the view that, in unstressed syllables, the pairs /ɤ–a/ and /u–ɔ/ neutralise by merging into qualities of intermediate height. The idea of two distinct degrees of reduction is also acknowledged as a possibility, if in a somewhat simplified form.

2.1.3 Reduction (2): dissenting views

A number of experimental studies have found no evidence for the lowering of unstressed close vowels and have argued instead that only unstressed open vowels raise in Bulgarian.

2.1.3.1 Wood and Pettersson (1988)

Wood and Pettersson (1988) is perhaps one of the first papers to argue that it is only open unstressed vowels that raise in Bulgarian, while close vowels undergo no qualitative change. The authors propose an articulatory explanation for this reduction pattern, in which unstressed vowels are the product of reduced mandibular opening. The study is based on recordings of two speakers from villages near Sofia (i.e. of western dialects), who were recorded reading words from a list, as well as in carrier phrases. The paper reports that, for one of the speakers, in isolated words, unstressed /a/ and /ɤ/ have overlapping but clearly distinct distributions, while unstressed /ɔ/ and /u/ overlap for both speakers, but many realisations of unstressed /ɔ/ fall outside the spectral distribution of /u/. For /ɛ/ and /i/, there is very little overlap for both speakers in both tasks. In general, more reduction is found in words in carrier phrases than in words in isolation. The following summarises Wood and Pettersson's main conclusions.

> The two informants were typical of the reported tendency in their dialect not to reduce unstressed /ɛ/ as much as /a, ɔ/. One informant tended to be more formal when reading isolated words. ... Reduction was gradual rather than discrete, suggesting that an underlying articulatory plan for a complete rendering is executed with varying degrees of attention, depending on which components are neutralized and how far.
>
> (Wood and Pettersson 1988: 258–259)

Wood and Pettersson's (1988) conclusion that reduction is 'gradual', however, rests on a line of reasoning that is less than compelling. They criticise an earlier study, Lehiste and Popov (1970), for reporting mean formant frequencies rather than uncollated absolute values: 'Lehiste and Popov summarize the vowel spectra as means, which gives the impression that vowel reduction in Bulgarian is discrete. But the raw data recorded in Figs 1–4 indicate that reduction is gradual' (251). Wood and Pettersson do not offer any statistical analysis that clearly shows whether unstressed /a–ɤ/ and /ɔ–u/ have single or separate distributions. They do apply linear regression, which however, as Andreeva et al. (2013: 347) point out, is 'less than convincing, since a regression calculated across categories separated along one dimension (here F1) will inevitably emerge as significant'.

2.1.3.2 Andreeva et al. (2013)

Andreeva et al. (2013) is the first large-scale study of a spoken corpus that reports mean values for F_1 and F_2 frequencies and duration of SB vowels. The paper is based on the analysis of 5,537 stressed and unstressed vowel tokens; the results are shown in Table 2.6.

Vowel	Tokens	F_1 (Hz)		F_2 (Hz)		Dur. (ms) *Male*		Dur. (ms) *Female*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
/i/ [+*str*]	368	393	68	2233	327	66.48	17.87	88.7	24.22
/i/ [−*str*]	657	384	64	2170	351	55.67	19.84	66.05	24.98
Mean difference		*9 Hz*		*63 Hz*		*10.81 ms (0.84)*		*22.65 ms (0.75)*	
/ɛ/ [+*str*]	411	615	97	1862	251	85.2	18.01	111.49	28.34
/ɛ/ [−*str*]	860	500	101	1843	276	52.98	18.8	62.02	19.73
Mean difference		*115 Hz*		*19 Hz*		*32.22 ms (0.62)*		*49.47 ms (0.56)*	
/a/ [+*str*]	553	773	116	1447	188	94.2	22.37	122.85	27.57
/a/ [−*str*]	1205	564	107	1520	254	58.59	16.63	64.1	23.45
Mean difference		*209 Hz*		*–73 Hz*		*35.61 ms (0.62)*		*58.75 ms (0.52)*	
/ə/ [+*str*]	158	579	100	1472	197	64.05	15.83	89.84	28.1
/ə/ [−*str*]	202	545	101	1504	234	55.78	16.53	62.52	19.64
Mean difference		*34 Hz*		*–32 Hz*		*8.27 ms (0.87)*		*27.32 ms (0.70)*	
/ɔ/ [+*str*]	343	688	99	1090	176	88.95	18.26	114.74	24.67
/ɔ/ [−*str*]	631	461	81	1077	213	53.55	16.43	62.7	21.69
Mean difference		*227 Hz*		*13 Hz*		*35.4 ms (0.60)*		*52.04 ms (0.55)*	
/u/ [+*str*]	108	446	77	1069	168	57.68	16.28	85.13	23.58
/u/ [−*str*]	41	434	73	1099	216	59.54	17.13	65.23	22.39
Mean difference		*12 Hz*		*–30 Hz*		*–1.86 ms (1.03)*		*19.9 ms (0.77)*	

Table 2.6: Mean F_1, F_2 frequencies and durations of SB stressed and unstressed vowels reported by Andreeva et al. (2013). [+*str*] = stressed; [−*str*] = unstressed; SD = standard deviation. Differences and ratios added; numbers in brackets indicate unstressed/stressed duration ratios.

The paper finds that while unstressed /ɛ/ and /i/ do not neutralise in Standard Bulgarian, both /a–ə/ and /ɔ–u/ do. Andreeva et al. argue that the phonetic process that leads to the neutralisation is the undershoot of the open vowel in each pair, /a/ and /ɔ/, yielding reduced F_1 frequencies that overlap with those for the close vowels, /ə/ and /u/, respectively. Very importantly, there is no significant difference in F_1 frequency between stressed and unstressed *close* vowels. The pattern is clearly visible in the group average $F_1 \times F_2$ frequency plot reproduced in Figure 2.5. Based on their analysis and findings, Andreeva et al. reach the following conclusions.

> There are no indications that high vowels are lowered to merge with raised low vowels in an intermediate vowel quality. ... The general pattern is one of low and mid vowel raising. ... This results in the neutralization of the low central with the mid-central vowel and of the mid back with the close back vowel. Articulatory undershoot of the mid-central vowel means that its unstressed counterpart remains numerically but not perceptually distinct from the raised unstressed /a/. ... [O]ur results show that the reduction process applies to the back vowels as strongly as it does to the central vowel group.
>
> (Andreeva et al. 2013: 347)

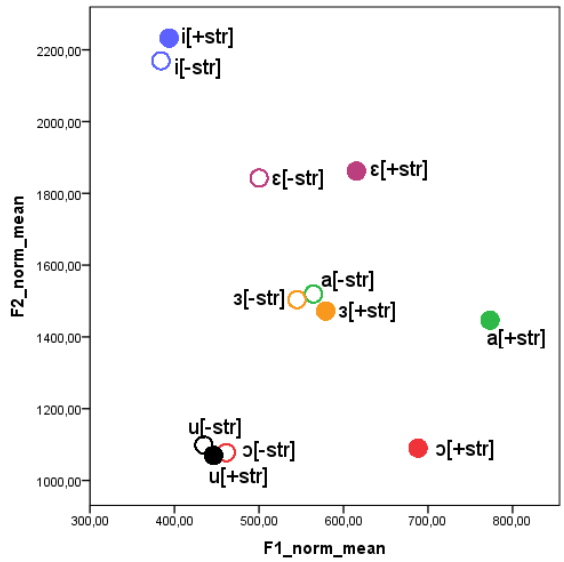


Figure 2.5: Andreeva et al.'s (2013: 347) group average $F_1 \times F_2$ vowel plot. 'ɜ' = my /ə/.

The following scales summarise the findings. From this it appears that unstressed /ə/ is raised, unstressed /a/ is not only raised but also fronted, and unstressed /ɔ/ is only raised (Andreeva et al. 2013: 346):

F_1: $\text{ə}_{[-str]} < \text{ə}_{[+str]} = \text{a}_{[-str]} < \text{a}_{[+str]}$

F_2: $\text{a}_{[+str]} < \text{ə}_{[+str]} = \text{ə}_{[-str]} = \text{a}_{[-str]}$

F_1: $(\text{u}_{[-str]} = \text{u}_{[+str]})$ & $(\text{u}_{[+str]} = \text{ɔ}_{[-str]}) < \text{ɔ}_{[+str]}$

F_2: $\text{u}_{[+str]} = \text{ɔ}_{[-str]} = \text{u}_{[-str]} = \text{ɔ}_{[+str]}$

Andreeva et al. also measure duration–F_1 correlations within stressed and unstressed allophones and report significant positive correlations for the open vowels and /ə/, albeit with small ($0.3 > r \geq 0.1$) to medium ($0.5 > r \geq 0.3$) effect sizes (Cohen 1988: 79–80).

Andreeva et al. (2013) directly challenge the traditional view of SB vowel reduction, according to which neutralised close and open vowels merge or overlap at an intermediate height. The data also demonstrate that /ɔ/ is no less affected by reduction than /a/, contrary to what Tilkov et al. (1982) maintain. A question that the paper does not address, however, is whether first pretonic realisations are in any way significantly different from reduced qualities in other unstressed syllables.

2.1.3.3 Sabev (2014, 2015)

In an Experimental Phonetics project that was part of my Master's course (Sabev 2014, revised and abridged in Sabev 2015), I examined the reduction and neutralisation of unstressed non-front SB vowels from an acoustic and a perceptual perspective.

In a production experiment eight female speakers of SB were recorded as they read out a list of words containing five repetitions of stressed and (pretonic) unstressed central and back vowels. 40 tokens of each of the 8 allophones were obtained. The mean F_1 and F_2 frequencies and durations are reproduced in Table 2.7.

Statistical analysis of the acoustic data revealed a less orderly pattern of the pairwise spectral convergence than reported by Andreeva et al. (2013). First, my data confirmed a high degree of acoustic overlap only for the unstressed back vowels, /ɔ–u/, whereas the difference in F_1 frequency for the unstressed central vowels, /a–ə/, was statistically significant ($p < 0.001$). Secondly, /ə/ showed an increase in F_1 and F_2 frequencies in unstressed contexts (i.e. mid-centralisation from a somewhat closer and more retracted stressed articulation). Table 2.8 summarises the statistically significant F_1 and F_2 differences across stress-dependent allophones.

Vowel	F_1 (Hz)		F_2 (Hz)		Dur. (ms)	
	Mean	SD	Mean	SD	Mean	SD
á	792	120	1416	86	163.66	19.28
ă	590	72	1407	111	81.04	24.53
Difference	*202 Hz*		*9 Hz*		*82.62 ms*	*(.495)*
ə́	522	29	1327	122	114.55	17.53
ə̆	549	52	1451	124	77.12	23.47
Difference	*–27 Hz*		*–124 Hz*		*37.43 ms*	*(.673)*
ɔ́	559	35	1157	95	130.67	17.92
ɔ̆	442	33	1244	135	58.96	11.84
Difference	*117 Hz*		*–87 Hz*		*71.71 ms*	*(.451)*
ú	430	25	1080	127	100.55	16.11
ŭ	435	26	1245	119	56.68	14.22
Difference	*–5 Hz*		*–165 Hz*		*43.87 ms*	*(.564)*

Table 2.7: Mean F_1, F_2 frequencies and durations (female) of SB stressed and unstressed /a, ə, ɔ, u/ (Sabev 2014). **V́** stressed vowel; **V̆** unstressed vowel; **SD** standard deviation. Differences and ratios added; numbers in brackets indicate unstressed/stressed duration ratios.

A significant effect of stress on duration was found for all phonemes. Given that stressed vowels are, on average, twice as long as their unstressed counterparts (Table 2.7), duration appears to be a salient and categorical cue for stress in Bulgarian. In addition, significant correlations between vowel duration and F_1 frequency were not found for any stress-dependent allophones except unstressed /a/ ($p = 0.025$, $r = 0.353$) and stressed /ə/ ($p = 0.038$, $r = -0.347$).

The perception experiment consisted of two tasks: identification and discrimination. It aimed to test the extent to which the observed formant frequency differences in unstressed vowels were perceptually significant. Thirteen speakers of Standard Bulgarian were first asked to listen to recordings of the eight target words from the production experiment. The words with a stressed target vowel were used as a control sample. Each stimulus was played ten times. Participants were given a forced choice between images of the

	á	**ă**	**ə́**
ă	F_1, —		
ə́	F_1, F_2	F_1, F_2	
ə̆	F_1, —	F_1, F_2	F_1, F_2

	ɔ́	**ɔ̆**	**ú**
ɔ̆	F_1, F_2		
ú	F_1, F_2	$(F_1)^\dagger$, F_2	
ŭ	F_1, F_2	—, —	—, F_2

Table 2.8: Statistically significant differences in F_1 and F_2 frequencies across SB S/U allophones, where present (Sabev 2014). $^\dagger p = 0.049$ for F_1 between [ú] and [ɔ̆].

concepts in a minimal or homophone pair. In the discrimination task sixteen pairs of either identical or different words from each minimal/homophone pair were played. Each stimulus pair was played five times and the participants were given a forced choice to identify the two words as ‘same’ or ‘different’.

F_1 frequency differences of 38 Hz and 48 Hz did not prove to be perceptually significant in unstressed vowels: neither the identification nor the discrimination task yielded a correct response rate that was significantly higher than chance. Thus, while my acoustic data confirmed complete neutralisation only for the pair /ɔ–u/, both /ɔ–u/ and /a–ə/ proved to be perceptually indistinguishable. Table 2.9 summarises the neutralisation status of the three pairs of SB vowels.

Vowel pair		Neutralisation	
		Acoustic	Perceptual
Front	/ɛ–i/	−	−
Central	/a–ə/	−	+
Back	/ɔ–u/	+	+

Table 2.9: Acoustic and perceptual neutralisation of SB O/C unstressed vowels (Sabev 2014).

These experimental results cannot be easily reconciled with any of the views outlined above. In line with Andreeva et al. (2013), my data contradict the traditional claim that central vowels are more strongly affected by unstressed vowel reduction than back vowels. On the other hand, the lowering (and fronting) of /ə/ I reported is in keeping with the traditional view while at odds with Andreeva et al. (2013). It should be pointed out, however, that while my data were derived from read word lists, the values Andreeva et al. (2013) report are based on read texts (namely the Bulgarian corpus for the BABEL project, Roach et al. 1996). It is not unlikely that the spectral differences I found between Bulgarian unstressed /a/ and /ə/ are not as a rule maintained in more natural or casual speech.

Since I did find significant F_1 frequency differences between categorically different conditions (stressed/unstressed), and F_1 frequency did not clearly prove to be a linear function of duration within the conditions, I concluded that ‘unstressed realisations implement separate, phonologised targets. While these unstressed targets are merged for the two back vowels, which are therefore categorically neutralised, the neutralisation of the central vowels is incomplete as their unstressed realisations remain acoustically (though not perceptually) distinct' (Sabev 2015: 4).

2.1.4 Reduction (3): phonological models

While all studies outlined in Sections § 2.1.2 and § 2.1.3 make some phonological assumptions (e.g. by dealing with contrastive sounds), none of them specifically focuses on how the phonological grammar deals with unstressed vowel reduction in Bulgarian. I now turn to phonological models of vowel reduction that discuss Bulgarian at some length. Most of the work examined in this section assumes that Bulgarian unstressed vowel reduction leads to complete neutralisation, and most authors also assume (or claim) that *all* three pairs of Bulgarian height-contrasting vowels neutralise in unstressed position. Both of these assumptions, however, are problematic, as is clear from the data and findings discussed above.

2.1.4.1 Scatton (1975): an SPE-based description

Scatton (1975) is an in-depth, SPE-style account of morphophonemic alternations in Standard Bulgarian. In the Introduction, Scatton states that he does 'not intend to deal explicitly with "low-level" phonetic facts', and that his 'goal is not to describe the phonetic system of SB *per se*, although there is no denying that this information belongs in the phonology' (Scatton 1975: vii). It is not surprising, then, that unstressed vowel reduction is addressed in a single sentence, in the Introduction:

> In all but the most formal styles of SB unstressed non-high vowels are raised towards their higher counterparts:
>
> [e] → [i]
> [a] → [ə]
> [o] → [u] (Scatton 1975: viii)[6]

Although neither neutralisation nor loss of contrast is explicitly mentioned, it is implied in the processes quoted above. Scatton uses SPE features (ibid., ix), so one can restate the raising rules using feature matrices as follows.[7]

6 Throughout § 2.1.4, I retain the authors' original transcriptions, as the work reviewed here is not concerned with phonetic realisation in any particular detail. In most phonological accounts of Bulgarian, the non-high front and back vowels are transcribed as /e, o/ rather than /ɛ, ɔ/. The mid central vowel often (though not always) appears as /ə/.

7 I have omitted the specifications for `[+syllabic]`, `[+sonorant]`, `[-consonantal]` and `[+continuant]`, which are shared by all SB vowels.

$$\underset{e}{\begin{bmatrix}\textit{-high}\\ \texttt{-low}\\ \texttt{-back}\\ \texttt{-round}\end{bmatrix}} \rightarrow \underset{i}{\begin{bmatrix}\textit{+high}\\ \texttt{-low}\\ \texttt{-back}\\ \texttt{-round}\end{bmatrix}} \quad \underset{a}{\begin{bmatrix}\texttt{-high}\\ \textit{+low}\\ \texttt{+back}\\ \texttt{-round}\end{bmatrix}} \rightarrow \underset{ə}{\begin{bmatrix}\texttt{-high}\\ \textit{-low}\\ \texttt{+back}\\ \texttt{-round}\end{bmatrix}} \quad \underset{o}{\begin{bmatrix}\textit{-high}\\ \texttt{-low}\\ \texttt{+back}\\ \texttt{+round}\end{bmatrix}} \rightarrow \underset{u}{\begin{bmatrix}\textit{+high}\\ \texttt{-low}\\ \texttt{+back}\\ \texttt{+round}\end{bmatrix}}$$

Based on these representations, no unitary process of unstressed vowel reduction can be posited: unstressed /a/ changes `[+low]` to `[-low]`, while unstressed /e/ and /o/ replace `[-high]` with `[+high]`, but even the latter partial generalisation is not faithful to fact, as the Standard Bulgarian front non-close vowel does not raise to neutralise with /i/.

2.1.4.2 Crosswhite (2001): reduction as prominence alignment

Crosswhite (2001) advances a general theory of phonological, neutralising vowel reduction in the framework of Optimality Theory. Vowel reduction is maintained to be a 'bipartite phenomenon resulting from two different formal mechanisms' Crosswhite (2001: 21), which have 'separate teleologies' and are termed 'prominence reduction' and 'contrast enhancement'. The former involves the avoidance of high-sonority (i.e. open) vowels in unstressed syllables, while the latter is a licensing constraint against non-corner ('nonperipheral', in her terminology) vowels occurring in unstressed position. This is illustrated and further qualified in the quotation below.

> With respect to prominence-reducing vowel reduction, unstressed /a/ is disfavored, being a highly sonorous vowel . . . In [contrast-enhancing] vowel reduction, unstressed /a/ is favored, since /a/ is one of the three corner vowels /i,u,a/ . . . [T]he two constraint families . . . only identify the vowels to be eliminated by vowel reduction and the contexts in which they are to be eliminated . . . [L]anguages will vary in the exact neutralizations used to meet the demands of these constraints.
>
> (Crosswhite 2001: 21–22)

Contrast-enhancing reduction

The constraint is stated as follows:

> Lic-Nonperiph/Stress:
> Nonperipheral vowels are licensed only in stressed positions.
>
> (Crosswhite 2001: 24)

Front and back mid vowels are claimed to be perceptually challenging and are therefore banned from unstressed syllables by contrast-enhancing constraints. The corner vowels, [i, u, a], on the other hand, are perceptually robust and are allowed in both stressed and unstressed position. [i, u, a] are special in that they are the three most common vowels across languages, they are the smallest attested complete vowel inventory and are the first vowels to be produced by children. Crosswhite refers to work by Lindblom, Stevens and Schwartz et al., among others, to identify three properties that explain the special status of corner vowels: dispersion, quantal characteristics and focalisation. [i, u, a] are thus individually 'good' vowel qualities that also constitute a particularly desirable vowel inventory, especially in contexts where correct vowel perception is at risk. The less 'privileged', non-corner vowels, on the other hand, are only licensed in contexts where exposure to them would be long enough to ensure correct identification, i.e. in stressed syllables. Crosswhite then points out that the Lic-Nonperiph/Stress constraint 'appears to be active only in those languages where stress is correlated with increased duration'. An example of this type of neutralisation system is found in Belarusian, where /e, o/ reduce to [a], and the five-vowel inventory /i, e, a, o, u/ shrinks to [i, a, u] in unstressed position (ibid., 22–27).

Prominence-reducing reduction

Prominence-reducing vowel reduction is driven by 'the desire to avoid particularly loud and lengthy vowel qualities in unstressed positions' (ibid., 34). This is in fact a group of constraints arranged on a scale, derived from the mechanism of Prominence Alignment introduced by Prince and Smolensky (1993) to account for syllabicity. The general idea is that prosodically prominent positions, such as syllable nuclei and stressed syllables, are 'aligned' with prominent segments, and vice versa. Segmental prominence is equated with the somewhat vague concept of intrinsic or phonological sonority. While Crosswhite acknowledges that 'sonority' has not been shown to have any clearly definable phonetic correlate, after a brief overview of the problem, she suggests that 'it seems at least reasonably plausible that sonority should not be equated with general amplitude, but with low-frequency amplitude' (ibid., 37).

Prominence-reducing vowel reduction is formalised as the application of Prominence Reducing constraints to vowels in unstressed positions, with the following sonority-based ranking held to be found in several languages, including 'Bulgarian'.

> *Unstressed/a ≫ *Unstressed/ɛ,ɔ ≫ *Unstressed/e,o ≫ *Unstressed/i,u ≫ *Unstressed/ə
>
> (Crosswhite 2001: 39)

This hierarchy seems to mirror more or less straightforwardly jaw opening (or tongue height, or F_1 frequency), with one notable exception: that of [ə]. Since [ə] is typically a mid vowel, one would expect it to have medium sonority as well. However, Crosswhite follows Kenstowicz (1994) in treating it as the least sonorous of all vowels, and refers to the fact that 'in certain languages, this vowel has the special property of repelling stress' (ibid., 38) and that in some languages it is significantly shorter than other vowels.

Bulgarian is one of the examples that Crosswhite gives for a Prominence-Reducing language. Although she first acknowledges that it is in the eastern dialects that the 6-vowel inventory /i, u, e, o, ə, a/ reduces to a 3-vowel subinventory, [i, u, ə], she then continues referring to this pattern as simply 'Bulgarian'. She points out that, because of its 'stepwise nature', Bulgarian unstressed vowel reduction is difficult to treat as a unified phenomenon in classical generative phonology, and puts forward the following solution.

> [T]he reduction process cannot be analyzed as the elimination of the non-high vowels, since the reduction of unstressed /a/ produces the non-high vowel [ə]. However, under the Prominence Reduction approach, this conundrum is easily solved: /e,o,a/ are defined as a group not according to distinctive features, but according to sonority. Under the same logic, the vowels /i,u,ə/ group together as a class of low-sonority vowels. Thus, Bulgarian vowel reduction can be formally modeled using the *Unstressed/X constraint family, along with faithfulness constraints for the features [round], [front], and [high].
>
> (Crosswhite 2001: 40)

As is clear from this quotation, Crosswhite adopts a feature-based approach to faithfulness. The tableaux reproduced in Table 2.10 show the constraint ranking used to derive

/rogát/ ‘horned’		Max [rnd]	Max [front]	*Unstr/ a	*Unstr/ e,o	*Unstr/ i,u	*Unstr/ ə	Max [-hi]
☞	[rugát]					*		*
	[rogát]				*!			
	[rəgát]	*!					*	*
	[ragát]	*!		*				

/selá/ ‘villages’		Max [rnd]	Max [front]	*Unstr/ a	*Unstr/ e,o	*Unstr/ i,u	*Unstr/ ə	Max [-hi]
☞	[silá]					*		*
	[selá]				*!			
	[səlá]		*!				*	*
	[salá]		*!	*				

/gradéts/ ‘town’		Max [rnd]	Max [front]	*Unstr/ a	*Unstr/ e,o	*Unstr/ i,u	*Unstr/ ə	Max [-hi]
☞	[grədéts]						*	*
	[grudéts]					*!		*
	[grodéts]				*!			
	[gradéts]			*!				

Table 2.10: Reduction of Bulgarian /e, o, a/ according to Crosswhite (2001: 41).

the reduction of unstressed /e, o, a/.[8] All Dep constraints are assumed to be crucially dominated and are not included for brevity. The next two tableaux (Table 2.11) show that unstressed /i, u/ do not reduce to [ə] (or any other quality).[9]

In order to account for what actually happens in Standard Bulgarian (rather than in East Bulgarian), some adjustments need to be made to the hierarchy Crosswhite proposes for ‘Bulgarian’. Since SB /e/ does not reduce to [i], the *Unstr/e,o constraint will have to be split into two, so that *Unstr/e is ranked lower than *Unstr/i,u. Next, in order to prevent unstressed /i/ from ‘reducing’ to [e], a new faithfulness constraint will have to operate at some point before *Unstr/i,u. In this way, however, the statement that

[8] Constraints that are ranked with respect to each other are separated by solid lines; those that are not ranked—by broken lines. Shaded cells are irrelevant for determining the optimal output. In Crosswhite's model [ə] is not specified for any features, so it will violate the constraint Max[-hi] whenever the input vowel is non-high. The last candidate in the second tableau, [salá], has asterisks for *Unstr/i,u and Max[-hi] in the original text; I have deleted those here, as they appear to be errors. It seems that ‘[rnd]’ and ‘[front]’ were intended as privative feature specifications; it may have been clearer to label the top-ranking faithfulness constraints using positive binary features instead, viz. ‘Max[+rnd]’ and ‘Max[+front]’, just as in the case of the low-ranking ‘Max[-high]’.

[9] I have replaced Crosswhite's original example /imená/ ‘names’ with the disyllabic /pismó/ ‘letter’.

/pismó/ ‘letter’	Max [rnd]	Max [front]	*Unstr/ a	*Unstr/ e,o	*Unstr/ i,u	*Unstr/ ə	Max [-hi]
☞ [pismó]					*		
[pesmó]				*!			
[pəsmó]		*!				*	

/bukvár/ ‘primer’	Max [rnd]	Max [front]	*Unstr/ a	*Unstr/ e,o	*Unstr/ i,u	*Unstr/ ə	Max [-hi]
☞ [bukvár]					*		
[bokvár]				*!			
[bəkvár]	*!					*	

Table 2.11: Non-reduction of Bulgarian /i, u/ according to Crosswhite (2001: 42). /imená/ ‘names’ replaced with /pismó/ ‘letter’.

‘/e,o,a/ are defined as a group . . . according to sonority’ will no longer hold true, as the sonority of /e/ will now appear to be lower than that of /i, u/.

It has been claimed in Optimality Theory that different consonant lenition processes are part of a single scenario in which constraints favouring the preservation of contrasts are outranked by constraints penalising the expenditure of articulatory effort; effort-based constraints are also claimed to drive target undershoot in speech production (Kirchner 1998, 2001; Flemming 1995, 2001, cited in Harris 2005: 5). Such an account, however, cannot be directly extended to all types of vowel reduction, because of the apparently conflicting articulatory trajectories followed by different unstressed vowel reduction processes. Crosswhite’s (2001) response to this is to posit two formally distinct types of phonological vowel reduction, only one of which is related to target undershoot.

However, it is often difficult or even impossible to tell which of the two ostensibly distinct types of reduction is in operation. A reductive change of front and back mid vowels to high vowels may result from either of Crosswhite’s constraint families. Thus, it appears that reduction to [ə] rather than ‘[a]’ is the only test available in distinguishing between the two teleologies. However, Flemming’s (2005) general model of unstressed vowel reduction shows that the lowest vowel of an unstressed inventory will be as a rule raised compared to the lowest stressed vowel, and might more accurately be transcribed [ɐ] or [ɜ]. If this prediction is borne out, there seems to be little left that helps differentiate between Crosswhite's two types, except perhaps cases like Russian, where unstressed /a, o/ both surface as [ɐ] or [ə] (depending on context). A change from [ɔ] or [o] to [ɐ / ə] is clearly not a decrease in sonority, but nor does it result in a true corner vowel.

The case of the reduction of Russian /o/ to [ɐ / ə] is particularly interesting because the contrast that seems to be neutralised is one of rounding, while it has been demonstrated—both empirically (Barnes 2006) and through simulations (Flemming 2005)—that unstressed vowel reduction primarily eliminates height contrasts. The history of the allophony of Russian /o/, however, is rather complex. While one hypothesis is that the contrast between /a/ and /o/ was lost in unstressed position, another holds that the contrast never emerged outside stressed syllables. Stressed East Slavonic /a/ and /o/ are the reflexes of Common Slavonic long /aː/ and short /a/, respectively. Contrastive length was lost across the board, and it may well be that long unstressed /aː/ shortened and merged with unstressed /a/ in a single [ɐ]-like quality before the quantitative contrast of stressed /aː–a/ was rephonologised as qualitative, /a–o/ (Shevelov 1964, cited in Barnes 2006: 36–37).

2.1.4.3 Harris (2005): reduction as information loss

Harris (2005) proposes a model of vowel reduction as information loss. He distinguishes between a 'centrifugal' pattern that results in corner vowels, [a, i, u], and a 'centripetal' pattern yielding centralised realisations. Unlike Crosswhite (2001), Harris treats his two patterns as a unitary phenomenon. He asserts that both the corner vowels and schwa have acoustic spectra that are simpler than those of mid peripheral vowels, and that spectral complexity can be taken as a measure of the amount of phonetic information present in a speech signal at a given time. On this basis, centripetal and centrifugal reduction are both construed as resulting in a loss of phonetic information.

Whereas Harris's centrifugal pattern, which 'attracts' unstressed vowels to the corner values [a, i, u], directly corresponds to Crosswhite's Contrast Enhancing reduction, centripetal reduction is different from Crosswhite's Prominence Reduction: it involves mid-centralisation but not raising (unless from [a]). Harris does not treat the two patterns as resulting from conflicting pressures on vowels: he allows them to combine freely and maintains that 'it is unusual for an entire vowel system to be centripetally contracted', and that 'it is common to find this pattern co-occurring with centrifugal reduction' (Harris 2005: 3).

Harris's schema of unstressed vowel reduction and neutralisation in 'Bulgarian' is reproduced in Figure 2.7. For reasons not understood, he describes an inventory of only *five* stressed vowels, [ə] appearing only as the reduced form of [a]. Like Crosswhite, he assumes that front vowels neutralise as well.

Strong	*i*	*e*	*a*	*o*	*u*
Weak	*i*		*ə*	*u*	

Figure 2.7: Bulgarian unstressed vowel reduction according to Harris (2005: 3).

Harris views speech as a 'carrier signal' modulated by acoustic events that convey linguistic information:

> In the unmarked case, the carrier is a periodic waveform lacking spectral peaks—the acoustic effect produced by a neutrally open vocal tract shape . . . Linguistically significant information—that part of the speech signal traditionally referred to as phonetic quality—resides in modulations that deviate from the carrier baseline along a number of parameters involving spectral shape, amplitude, periodicity and fundamental frequency. In the case of vowel quality, the modulations take the form of spectral peaks created by convergences between pairs of formants.
>
> (Harris 2005: 7)

Thus, the carrier signal is a sound filtered through 'a neutrally open vocal tract', i.e. schwa, whose spectrum displays more or less evenly spaced, rather than converged, formant frequencies.

> The magnitude of a modulation carrying vocalic information can be measured in terms of the extent to which its spectral characteristics deviate from the neutral baseline defined by the carrier signal . . . : the larger the modulation, the more phonetic information it bears . . . Centralising any of the corner qualities to schwa involves the suppression of energy peaks, thereby merging the vowel spectrum with the background defined by the carrier signal . . . The corner vowels can be construed as simplex in the sense that each projects a unitary spectral pattern onto the acoustic signal . . . On the other hand, mid

> peripheral vowels are spectrally more complex in that they can viewed [*sic*] as amalgamations of these simple patterns.
>
> (Harris 2005: 7–8)

Harris assigns the three corner vowels [a, i, u] schematic spectral shapes and mnemonic names (‘m**A**ss’, ‘d**I**p’, ‘r**U**mp’) as shown in Figure 2.8.

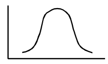
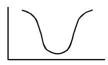
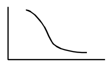
		Spectral shape	Schematic filter response
(a)	*a*	‘Mass’: mass of energy located in the centre of the vowel spectrum, with troughs at top and bottom.	
(b)	*i*	‘Dip’: energy distributed to the top and bottom of the vowel spectrum, with a trough in between.	
(c)	*u*	‘Rump’: marked skewing of energy to the lower half of the vowel spectrum.	

Figure 2.8: Simplex spectral shapes and schematic filter response curves of the corner vowels [a, i, u] (Harris 2005: 8).

The profiles of peripheral mid vowels, as shown in Figure 2.9, are deemed complex:

> *e* shares with *i* a clear energy gap between F1 and F2. However, F1 and F2 are closer together in *e* than in *i*; that is, as with *a*, energy is concentrated in a central region, with troughs at top and bottom of the vowel spectrum . . . [T]his configuration can be viewed as a combination of *a*’s mass pattern and *i*’s dip. *o* shares with *u* a marked skewing of energy towards the lower end of the vowel spectrum. However, in *o* the peak energy is located far enough away from the bottom of the vowel spectrum for a trough to be identifiable below it . . . [T]his configuration can be viewed as a combination of *a*’s mass pattern and *u*’s rump.
>
> (Harris 2005: 8–9)

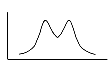
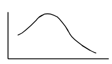
		Spectral shape	Schematic filter response
(a)	*e*	Dip and mass	
(b)	*o*	Rump and mass	

Figure 2.9: Complex spectral shapes and filter response curves of the mid peripheral vowels [e] and [o] (Harris 2005: 9).

To summarise, Harris maintains that the corner vowels have simplex spectral shapes and treats them as the basic components of phonetic information contained in vocalic speech signals. What the corner vowels and schwa share in common is their low degree of 'spectral complexity'. Both centrifugal and centripetal reduction are thus thought of as diminishing the amount of phonetic information borne by a vowel.

Harris's framework descends from the school of Dependency Phonology, where underlying representations of sounds are not composed of SPE-style distinctive features, but of primes variously labelled 'elements', 'components' or 'particles'. Any vowel is made up of one or a combination of three possible vocalic elements: `[A]`, `[I]`, `[U]`. The three basic spectral shapes—the mass, the dip and the rump—are the acoustic signatures of the vowel components `[A]`, `[I]` and `[U]`, respectively. Harris's arguments for a component-based representation are summarised as follows.

> If phonological features are to express informational asymmetries in any direct way, they have to be defined in auditory–acoustic terms ... What is required ... is a feature system that codes the gross spectral characteristics of vowel quality, in the spirit of Jakobson, Fant & Halle (1952). A system of vowel features exclusively dedicated to the representation of linguistically significant information will code the spectral prominences that modulate the carrier wave in vocalic speech signals.
>
> (Harris 2005: 11)

The model thus claims to be capable of expressing vowel reduction as suppressing information not only in the speech signal but also directly in the phonology, as spectral complexity is a projection of the component complexity of vowel representations.

The Bulgarian vowel reduction pattern shown earlier in Figure 2.7 is used again as an illustration, now with the phonological vowel components specified (Figure 2.10).

	i	*e*	*a*	*o*	*u*
Strong	[I]	[I,A]	[A]	[U,A]	[U]
Weak	[I] *i*		[ ] *ə*	[U] *u*	

Figure 2.10: Bulgarian vowel reduction with vowel components specified (Harris 2005: 9).

As can be seen, the component `[A]` is supported only in stressed syllables. The suppression of `[A]` in unstressed position produces reduction by raising, which can be either centrifugal (*e, o* → *i, u*) or centripetal (*a* → *ə*). Schwa maps to the spectral baseline associated with the carrier signal and is representationally null.

A final important point that Harris makes concerns vowel reduction as a mechanism that balances attention in the flow of speech:

> Talkers direct listeners' attention to prominent positions by selectively increasing and the amount of attention they devote to production. That is, in prominent positions, 'hyperarticulation' (Lindblom 1990) works in tandem with 'hyperperception' (see Cole *et al.* 1978). Meanwhile talkers 'hypoarticulate' (Lindblom 1990) in non-prominent positions, selectively decreasing attention to production. The overall communicative effect is to modulate attention across speech signals (cf. de Jong 2002): the occurrence of hypoarticulated weak positions enhances the prominence of intervening strong positions. Positionally sensitive vowel reduction, like consonantal lenition, can be understood as accentuating the syntagmatic contrast between information-heavy prominent syllables and information-light weak syllables. On this view, reduction is part of planned speech behaviour rather than an accidental by-product of vocal-organ inertia.
>
> (Harris 2005: 13-44)

While the idealised spectral shapes Harris draws for vowels are far from being the only perceptually significant cues there are in the speech signal, it seems conceivable that categorical perception could operate with such gross acoustic templates. The appeal of the model lies mainly in its representational simplicity and the claim that phonological primes are directly phonetically interpretable.

Harris's diagram of unstressed vowel reduction in Bulgarian (Figure 2.10) needs to be amended if it is to reflect reality at least in the eastern dialects. Figure 2.11 below is a corrected version.[10]

[10] Backley (2011: 34–35), who does not omit /ə/ from the Bulgarian stressed inventory, represents it as an empty vowel in the strong inventory as well.

Strong	*i* [I]	*e* [I,A]	*a* [A]	*ə* [ ]	*o* [U,A]	*u* [U]
Weak	[I] *i*		[ ] *ə*		[U] *u*	

Figure 2.11: Modified version of Harris's (2005: 9) model of Bulgarian vowel reduction.

2.1.4.4 Barnes (2006): reduction as phonologised undershoot

Barnes (2006) investigates cross-linguistic regularities and patterns in the positional neutralisation of contrasts in vowel inventories. He defines positional neutralisation as 'any instance of an asymmetrical capacity of two positions (or sets of positions) in the representation to license phonological contrasts, such that one set of structural positions licenses a larger array of contrasts than another' (Barnes 2006: 1). The former set of positions are termed 'strong', the latter 'weak'. Positional neutralisation can arise either from the loss of contrasts through mergers in weak positions, or the emergence of contrasts in strong positions.

A modular phonetics–phonology interface is argued for, with a gradient phonetics and an abstract categorical phonology. Phonetics can affect phonology only through language change, more specifically through the reinterpretative mechanism of phonologisation, which involves the discretisation of gradient phonetic patterns (Nevins 2007), as 'naturally arising language-specific phonetic patterns are divorced from their phonetic origins and made phonological' (Barnes 2006: 2). The link between phonetics and phonology is then broken and the phonology no longer has access to phonetic information. The phonetics, however, must have access to phonological representations in order to implement them in speech.

Barnes adopts Keating's (1996) theory of phonetic target windows of varying widths to model the realisation patterns created by the phonetic component. In this model, that a vowel /a/ is realised as [a] when stressed but [ə] when unstressed may be the result of (at least) three implementation scenarios. First, there may be a single wide target window for both contexts. Vowel height will then be a linear function of duration alone, it will be gradient, and will be linked to stress only inasmuch as (in a language with duration-cued stress) unstressed vowels are shorter than stressed ones. Stress-independent reductions of duration, e.g. at increased speech rates, will also cause raising. Secondly, there may be a narrow-window target for stressed realisations, but a wide window in unstressed position. In this case there will be little variation in the stressed realisations, no matter how fast the tempo. In unstressed position, however, F_1 frequency will have a gradient distribution, correlated with duration, and may even be very similar to stressed F_1 frequency at slow rates, provided that the two windows overlap. Finally, there may two separate narrow windows for stressed and unstressed realisations, in which case both allophones will show little contextual variation (Barnes 2006: 11–14).

As regards the phonological status of the stressed and unstressed realisations, in the first scenario, where a single target handles both realisations, obviously there is no difference in feature specifications. Where there are two targets (second and third scenarios), however, category boundaries may shift whether or not contrast neutralisation is involved.[11] Where there are two separate targets but nothing for the reduced realisation to merge with, however, rephonologisation is a justified analysis only if separate feature specifications are demonstrably relevant to some other process (ibid., 14).

Barnes maintains the common distinction between 'phonological reduction', which involves rephonologisation and often contrast neutralisation in unstressed syllables, and 'phonetic reduction', a less dramatic process resulting from articulatory undershoot. He further argues that many unstressed vowel reduction patterns commonly identified as phonological are in fact phonetic, and that it is these phonetic patterns that make most categorical patterns appear to be phonetically motivated synchronically, a possibility that the adopted model of the phonetics–phonology interface expressly rules out (ibid., 19).

Like Flemming (2005), Barnes asserts that the vast majority of unstressed vowel reduction patterns eliminate vowel height contrasts from unstressed syllables. Nasalisation and quantity contrasts may also be lost, but unstressed vowel reduction systems based on the elimination of other contrasts, such as front/back (his 'palatality'), rounding, ATR, RTR or pharyngealisation seem not to be attested. This is because 'except in the most

[11] Barnes defines neutralisation as the absence of a statistically significant difference between the distributions of two phonemes in a weak position (ibid., 13).

extreme cases of durational contraction of unstressed syllables, these contrasts are not threatened phonetically to the extent that height contrasts are'. Barnes acknowledges that neutralisation of front/back contrasts is possible for *low* vowels, because of the small articulatory distance between them, and suggests that '[f]or further reductions of front/back contrasts to occur, it is necessary for the unstressed inventory to fall below three vowels' (Barnes 2006: 19–23; cf. Flemming 2005).

Barnes regards the cross-linguistic prevalence of [i, ə, u] in unstressed syllables as evidence that maximal dispersion plays as important a part in the construction of reduced inventories as it does in stressed ones, but he also points out that 'while stressed and unstressed inventories are remarkably steady across unstressed vowel reduction systems, the mapping relationships between the vowels of the two inventories vary wildly from language to language' (Barnes 2006: 21–22) and that language-specific unstressed realisation patterns play a crucial role in determining which vowels will ultimately undergo categorical merger.

Barnes emphasises that unstressed vowel reduction is found predominantly in languages in which duration is a primary correlate of lexical stress, with unstressed syllables undergoing significant durational contraction. Since more open vowels are intrinsically more time-consuming, it is precisely non-high unstressed vowels that are affected by undershoot, which is evidenced in raising. This results in a more crowded vowels space, with greater overlaps between contrastive vowels, along with a listener who has considerably shorter time to identify them. 'This situation sets the stage for routine misperceptions, which can ultimately result in the loss of the contrasts in question. This reinterpretation is the phonologization process which produces systems of unstressed vowel reduction' (ibid., 30). The cross-linguistic variation found in patterns of unstressed vowel mergers, however, is held not to be entirely arbitrary, but rather to result from 'plausible groupings of vowels according to perceptual proximity' (ibid.). Thus, even though phonologised synchronic patterns of positional neutralisation are independent of phonetic factors, in order to understand their organisation it is necessary to consider unstressed realisations immediately prior to phonologisation (ibid., 240).

In his case study of unstressed vowel reduction in Bulgarian, Barnes acknowledges that there is not a single uniform pattern that holds across western and eastern dialects and assumes that the varieties in question reflect different stages of the same diachronic process:

> Bulgarian is an especially valuable example of unstressed vowel reduction in that the continuum of its dialects from west to east illustrates eloquently the way in which gradient phonetic patterns over time become phonologized, yielding categorical patterns of neutralization. Some of the westernmost dialects of Bulgarian lack qualitative vowel reduction more or less completely. Unstressed non-high vowels are realized with qualities not overly different from those of stressed non-high vowels. Other western dialects, such as that of the Sofia region, have varying degrees of phonetic raising of non-high vowels, without, however, neutralizing the relevant contrasts (at least in the case of the mid and high vowels). Further east, the phonetic raising pattern has undergone phonologization, such that Eastern Bulgarian has a fully developed system of categorical unstressed vowel reduction.
>
> (Barnes 2006: 32)

Relying on Pettersson and Wood (1987) and Wood and Pettersson (1988) as his main sources of empirical evidence for Bulgarian, Barnes concludes that 'vowel reduction in Bulgarian, except in its eastern dialects . . . , is not neutralizing. It is gradient and apparently rate-dependent', and he also affirms that 'from a dialectological perspective . . . the different Bulgarian dialects do represent a single whole with respect to unstressed vowel reduction: They preserve a number of stages along a possible progression of phonologizations of gradient phonetic patterns' (Barnes 2006: 35).

This analysis, however, is problematic. While it is indeed very interesting and potentially rewarding to be able to observe different stages of a language change process, regional variation can hardly be claimed, with any certainty, to directly show different degrees of completeness of a single process. As Barnes points out himself, speakers of different dialects must have different grammars, and even though a typical grammar of a speaker from Sofia *might* be in the process of categorically merging certain unstressed vowels, this is by no means necessarily the case: the process may just as well have been interrupted so that no further contrast neutralisation takes place in the future.

Overall, Barnes's view of unstressed vowel reduction is clear and well-reasoned. Unlike many other approaches, it is capable of capturing both categorical and gradient reduction: in fact, Barnes assigns a central role to non-phonological processes of gradient undershoot. Rather than deriving unstressed vowel reduction patterns from the makeup of underlying representations alone, he regards categorical change as resulting from the reanalysis of non-canonical realisations in unstressed position. The model advocates a clear 'division of labour' between phonetics and phonology, and assumes little (if any) phonetic content in the phonology:

> [W]hile the influence of phonology on phonetics takes place in the synchronic interpretation of categorical phonological representations implemented as sets of phonetic targets, in the approach assumed here the influence of phonetics on phonology is diachronic in nature. The vehicle of its influence is the process of phonologization, which alters phonological representations as a consequence of the reinterpretation of existing phonetic regularities.
>
> (Barnes 2006: 2)

This dissociation of the two components is an important aspect of the model as it helps to account for the existence of 'unnatural' or 'unexpected' unstressed vowel reduction patterns by suggesting that they may have resulted from changes other than the reanalysis of unstressed vowel realisations (ibid., 23).

2.1.4.5 Spahr (2014): reduction as underspecification

Spahr's (2014) approach to positional neutralisation builds on Dresher's (2009) Contrastive Hierarchy (CH) model, which organises contrastive features into language-specific, binary-branching trees. Spahr defines positional neutralisation as 'the systematic and categorical inability of segments in a phonologically defined environment to realize a particular contrast'. This is achieved by deleting both sister values in a terminal node in the CH, rather than having sounds in a neutralising position assume only the positive or the negative value of the feature. In other words, contrast neutralisation results in underspecification, rather than a ban on one of two otherwise contrastive feature specifications. Essentially, Spahr argues that non-terminal nodes are phonetically interpretable and that they define archiphonemes, which are members of the inventory in their own right, different from both of the non-neutralised phonemes. Positional neutralisation is held to affect the

CH in a bottom-up manner: 'Non-terminal oppositions cannot be neutralized without terminal nodes being affected first'.

Spahr further claims that 'neutralized segments often show intermediate phonetic realisations relative to their corresponding non-neutralized segments, which is expected if the contrastive feature defining the boundary between segments is deleted'. The specifics of phonetic realisation are assumed to be handled by post-lexical phonetic rules, and Spahr contends that 'phonetic realization cannot be used as a diagnostic for phonemic identity'. While a neutralised realisation may or may not overlap with that of one of the phonemes in a non-neutralised pair, a neutralised sound—an archiphoneme—cannot be represented as the same segment as any of its dependent contrastive segments, as that would imply the presence of a contrast in a position where it has been eliminated. Positional neutralisation is evidenced in alternations, so assuming phonemic identity between a neutralised sound and any of the phonemes that feed into that neutralisation would preclude the alternation in question from being visible. Representations that imply identity of neutralised and non-neutralised phonemes are deemed incapable of capturing the fact that neutralisation has occurred. A neutralised inventory is therefore not a 'literal subset' of a full, non-neutralised inventory, but rather an inventory of phonemes defined by non-terminal nodes where terminal contrasts have been suspended.

Spahr adopts Hall's (2007) Contrastivist Hypothesis:

> The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another.
>
> (Spahr 2014: 559)

Phonetic realisations are allowed to be acoustically enhanced, however, by non-contrastive features, such as rounding added to `[+back]` or backness to `[+round]` and different types of enhancement occur in terminal and non-terminal nodes.

Spahr applies his model of positional neutralisation to vowel reduction in Bulgarian and Russian, as well as to consonant palatalisation and voicing neutralisation in Bulgarian. His data come from Scatton (1984), a reference grammar of Bulgarian, which adopts the traditional view of Bulgarian reduction discussed in § 2.1.2. Spahr summarises Bulgarian vowel reduction and proposes an implicational hierarchy of vowel pair neutralisations as follows.

> First, virtually all dialects and registers will neutralize unstressed /â/[12] and /a/, typically realizing them as [ə]. Some dialects will further neutralize /u/ and /o/, whose merger is realized as [ʊ]. Finally, some "non-literary" varieties will neutralize unstressed /i/ and /e/, the result of which is realized as [ɪ]. This is schematized as the implicational hierarchy [below]; any variety which neutralizes /i/ – /e/ must also neutralize /u/ – /o/ and /â/ – /a/, but a variety which neutralizes /u/ – /o/ does not necessarily neutralize /i/ – /e/, and one which neutralizes /â/ – /a/ does not necessarily neutralize anything else.
>
> Implicational hierarchy of Bulgarian vowel pair neutralizations
>
> | | | | | |
> |---|---|---|---|---|
> | /i/ – /e/ | > | /u/ – /o/ | > | /â/ – /a/ |
> | (eastern dialects) | | (informal registers) | | (all dialects/registers) |
>
> (Spahr 2014: 562)

Given that in Spahr's model neutralisation deletes terminal nodes in the hierarchical inventory, he argues that 'the organization of the inventory can be determined by the patterns in which oppositions neutralize'. Bulgarian vowel neutralisation affects vowel height, and the contrastive features assigned to terminal nodes in his analysis are the standard SPE `[±low]` for /â–a/ and `[±high]` for /u–o/ and /i–e/. The hierarchy of contrastive features proposed for Bulgarian is shown in Figure 2.12. The neutralised unstressed vowels are described as being unable to show contrast between nodes 3–4, 7–8 and 9–10: they are heightless vowels, endowed with phonemic status, that have unique feature specifications and their own phonetic realisations (e.g. node 6, the neutralisation of /a/ – /â/, is uniquely `[-front, -round]` and unspecified for `[±low]`, realised as [ə]). Spahr suggests that '[t]he specifics of varying phonetic realization are handled by post-lexical phonetic rules': despite the lack of any height features, the `[+front]` (node 1) and `[-front, +round]` (node 5) archiphonemes are realised as 'somewhat high', as a

[12] 'â' is Scatton's (1984) ad hoc symbol for the phoneme /ə/. —MS

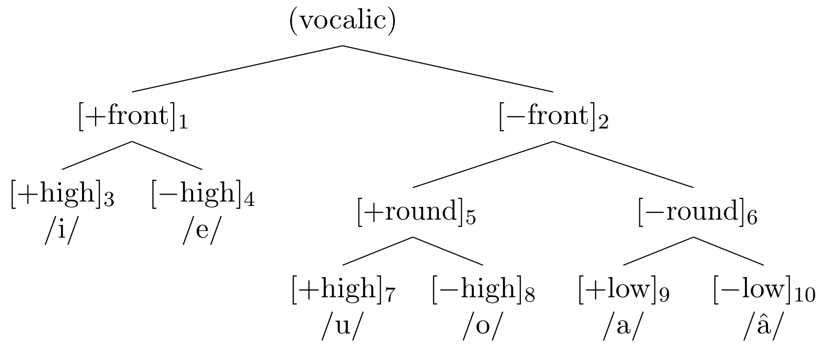


Figure 2.12: Spahr's (2014) contrastive hierarchy for Bulgarian.

result of contrast enhancement: both frontness and roundness are enhanced if articulated at the top of the vowel space.

Spahr then returns to his proposed implicational hierarchy and suggests that it may in fact be explained by his Contrastive Hierarchy for Bulgarian:

> [T]he two terminal nodes dominated by only negatively valued features are the first the neutralize [*sic*] (/a/ and /â/, dominated by [−front] and [−round]). These are followed by those dominated by a negatively dominated feature and a positively valued feature (/u/ and /o/, dominated by [−front] and [+round]). The final terminal nodes to neutralize are dominated by a single positively valued feature (/i/ and /e/, dominated by [+front]). This means that, at least for Bulgarian vowel reduction, neutralization to a node with a smaller number of negatively valued features implicates neutralization of those with a greater number of negatively valued features . . .
>
> (Spahr 2014: 565)

Spahr's model of positional neutralisation is interesting in many ways. The specifics of its application to Bulgarian vowel reduction, however, are not borne out by recent findings. First, Andreeva et al. (2013) and Sabev (2015) have shown that close vowels do not lower in unstressed position; only open vowels raise, and they raise as high as the close vowels they otherwise contrast with. This is not a serious issue, as one can still derive close realisations for unstressed /i–e/ and /u–o/ through the proposed post-lexical enhancement of `[+front]` and `[+round]`, respectively.

Another aspect of the traditional view of Bulgarian vowel reduction which Spahr has embraced and which has been challenged is that central (or back unrounded) vowels reduce more and neutralise earlier than back rounded vowels. According to Andreeva et al. (2013) /u–o/ neutralise as readily as /ə–a/, while in Sabev (2015) I found that back rounded vowels undergo *complete* neutralisation in careful speech, while central vowels do not. In other words, if an implicational hierarchy is to be postulated it should be either (*a*) '/i–e/ > /ə–a/, /u–o/', or (*b*) '/i–e/ > /ə–a/ > /u–o/', but not '/i–e/ > /u–o/ > /ə–a/'. This means that Spahr's speculation that 'neutralization to a node with a smaller number of negatively valued features implicates neutralization of those with a greater number of negatively valued features' is not empirically justified for Bulgarian. Implicational hierarchy (*a*), based on Andreeva et al.'s (2013) findings and conclusions could be referenced to Spahr's contrastive hierarchy for Bulgarian by stating that *neutralisation to a node with a smaller number of specified features implicates neutralisation of those with a greater number of specified features.* Implicational hierarchy (*b*), on the other hand, cannot be deduced from the contrastive hierarchy as it stands. However, if the feature `[±front]` were to be replaced with `[±back]`, *mutatis mutandis*, as shown in Figure 2.13, one could claim that *neutralisation to a node with a smaller number of* positively *valued features implicates neutralisation of those with a greater number of* positively *valued features.*

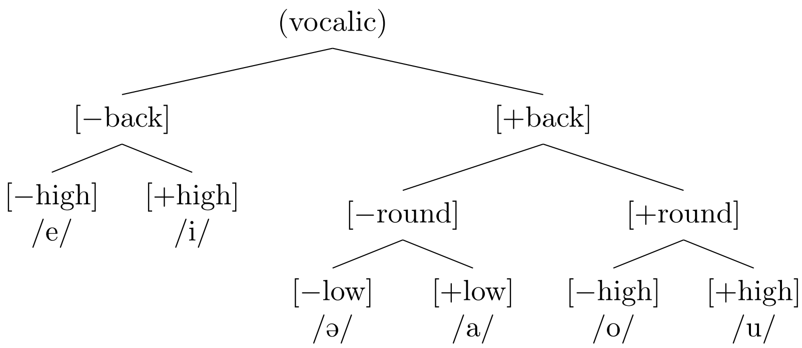


Figure 2.13: Adapted version of Spahr's (2014) contrastive hierarchy for Bulgarian.

2.1.5 Incomplete neutralisation

The phonological accounts reviewed in the preceding section assume that Bulgarian unstressed vowel reduction results in categorical merger, either by an unstressed open vowel changing into its close counterpart, or by the open and the close vowels both changing into a third phonological category. At the same time, many experimental studies of mergers in various languages have discovered states of **near-merger**, in which 'speakers consistently report that two classes of sounds are the same, yet consistently differentiate them in production at a better than chance level' (Yu 2011: 305). Near-mergers that are phonologically conditioned, i.e. restricted to specific structural positions or environments, are often referred to as cases of **incomplete neutralisation**.

Much of the work on incomplete neutralisation has focused on the loss of the voicing contrast in obstruents, e.g. Bishop et al. (2019) for Bulgarian; Burton and Robblee (1997); Dmitrieva et al. (2010); Shrager (2012); Kharlamov (2014) for Russian; Port and O'Dell (1985); Port and Crawford (1989) for German; Warner et al. (2004) for Dutch; Fox and Terbeek (1977); Braver (2014) for American English /t/- and /d/-tapping. Most research on the incomplete suppression of vowel contrasts is concerned with unconditioned near-mergers. The following vowel pairs, for example, have been demonstrated to be near-merged in various dialects of English: SOURCE–SAUCE in New York City, COT–CAUGHT in Pennsylvania (Labov 1994); TOO–TOE and BEER–BEAR in Norwich (Trudgill 1974); MEAT–MATE in Belfast (Milroy and Harris 1980); PIECE–PIERCE is Western Sydney (Bundgaard-Nielsen et al. 2008); FOOL–FULL in Salt Lake City and Albuquerque (Di Paolo 1988; Labov 1994); the last is in fact an instance of conditioned near-merger, or incomplete neutralisation of the tense–lax contrast in /u–ʊ/ before coda /l/. Incomplete neutralisation of vowels in unstressed position has been reported for Russian (Padgett and Tabain 2005), and in Sabev (2015) I demonstrate that West Bulgarian /ə–a/ are acoustically but not perceptually distinct.

Two dominant theoretical views of incomplete neutralisation can be contrasted. The first explains unexpected phonetic realisations in neutralising positions as **analogical levelling** (Steriade 2000; Yu 2007). For instance, utterance-final obstruents that are partially cued as `[+voice]` in Russian or German are accounted for as generalisation of a voiced segment from morphologically related forms in which that segment occurs in a non-neutralising position, e.g. intervocalically. Note that this view is compatible with an assumption of complete neutralisation: in neutralising environments categories are merged and paradigm levelling operates post-merger. In other words, recognising incomplete neutralisation is not a theoretical necessity under this interpretation.

Alternatively, incomplete neutralisation may be thought of as the suppression of contrast to perceptually undetectable levels. The perception of many phonological contrasts relies on multiple parallel acoustic cues, such as consonant voicing, voice onset time, consonant duration and amplitude acting as parallel cues to voice in obstruents, for example. In word-final position these phonetic cues are suppressed to varying degrees in different languages, though some residual contrast often remains (Steriade 1999, cited in Yu 2011). Contrast suppression in phonologically weak positions may result in **covert contrast**, which, even though maintained and detectable in the acoustic signal, is not perceptually significant. A weakened contrast may be lost altogether (complete neutralisation), be suppressed to covert level (incomplete neutralisation), or be transphonologised, if a secondary phonetic cue is retained and reinforced while a primary one is suppressed completely, as in tonogenesis, where consonantal voicing-induced pitch perturbations on neighbouring vowels are phonologised as lexical tone, while the original voicing contrast is lost (Hyman 1976, cited in Yu 2011).

Only the latter of the two views of incomplete neutralisation outlined above would be compatible with any cases of near-merger that might come to light from comparing the results of this or similar studies to those of a parallel perceptual investigation, for the target items used here are nonsense words (§ 3.1.1) and as such do not enter into paradigmatic alternations with any other forms. Moreover, incomplete neutralisation has been reported even for non-alternating morphemes (Iverson and Salmons 2011).

There are, however, further factors that may contribute to subtle acoustic differences in speech production experiments. Kharlamov (2014) investigated the effects of a number of linguistic and methodological variables on acoustic cues to voicing in Russian underlyingly voiced obstruents in neutralising positions. The methodological variables examined were (i) elicitation through reading vs picture naming or word guessing, and (ii) presence vs absence of voicing-based minimal pairs among the test items. Both availability of orthographic representation and encountering minimal pairs during the experiment had a strengthening effect on one of the acoustic cues, glottal pulsing: underlyingly voiced and voiceless word-final obstruents were significantly different only where stimuli were elicited through reading, or where minimal pairs were present. Other cues were not affected: various measures of consonantal duration showed significant `[±voice]` differences regardless of elicitation method and exposure to minimal pairs, while at the same no difference was found with respect to preceding vowel duration in any of the experimental conditions.

The production experiments presented in Chapters 4–8 are based on recordings of nonsense words in carrier sentences elicited through reading, which means that some of the reported contrast values may be somewhat higher than would have been obtained from non-read speech. As regards the second of Kharlamov's methodological factors, presence of minimal pairs among the test items, the participants in my experiments were exposed to nonsense forms differing only in the phonemes under investigation. However, it is unclear whether the minimal pair effect extends to minimally different pairs of non-words. In addition, my test items do not form minimal pairs per se, for they contain multiple instances of the same vowel.

Since this study does not include a perceptual component, it is beyond its scope to identify cases of near-merger as defined above, i.e. contrasts that are acoustically but not perceptually detectable. Nonetheless, different vowel pairs can be expected to exhibit different degrees of neutralisation within and across the linguistic varieties examined here, and it should be borne in mind that some of the statistically significant acoustic differences that will be reported in later chapters would probably not be sufficient for perceptual contrast to be maintained. I address a related issue in Chapter 9, where I discuss a machine learning experiment that was designed to assess whether various significant acoustic differences detected in my data are sufficient to reliably classify novel observations (§ 9.4).

2.1.6 Summary

The work described in § 2.1.2 has been the very influential to the present day, even though the research that it is based on was carried out in the 1970's. The more recent empirical studies addressed in § 2.1.3 have directly challenged some of the traditional claims, e.g. that unstressed open and close non-front vowels neutralise in qualities that are intermediate between those of the two stressed realisations, or that central vowels neutralise more readily than back vowels. It is not easy to explain what this disagreement stems from, but—among other things—it could be attributable to historical change or to differences in experimental methodology. Yet to be verified is the traditional claim that there are two distinct degrees of vowel reduction in Standard Bulgarian, resulting in more open realisations in pretonic syllables but closer allophones in other unstressed positions.

In § 2.1.4, a number of phonological models of Bulgarian unstressed vowel reduction were discussed. All except Barnes (2006) and Spahr (2014) either ignore or overlook the fact that unstressed /ɛ/ and /i/ do not neutralise in Standard Bulgarian and assume symmetrical pairwise height neutralisation across the board. Thus, what they actually model under the name of 'Bulgarian' is at best East Bulgarian. Barnes (2006) does acknowledge different neutralisation patterns in western and eastern dialects, though he does not address this variation from a theoretical perspective. All of the studies in § 2.1.4 also assume that Bulgarian reduction leads to *complete* neutralisation of the height contrast in unstressed syllables. This is a questionable assumption, and unless it can be demonstrated that significant acoustic differences cannot be found, incomplete neutralisation should not be ruled out.

None of the work on Bulgarian vowel reduction reviewed in this chapter addresses the matter from a sociolinguistic perspective, while it is very likely that the factors involved in blocking the neutralisation of Standard Bulgarian unstressed /i–ɛ/ are not simply systemic but at least partly sociolinguistic. Two major characteristics of East Bulgarian pronunciation have to do with the front vowels: their merger in unstressed syllables (typically realised as [i]) and the palatalisation they induce in preceding consonants (Stojkov 2002). Both of these processes are strongly stigmatised in Standard Bulgarian.

2.2 The Turkish vowel system

This section is an outline of the vowel system of Standard Turkish. In § 2.2.1, I describe the full vowel inventory and its contrastive features, before addressing the suppression of contrast in non-initial syllables, or vowel harmony, in § 2.2.2. Finally, I summarise the little work that has been published on the acoustic correlates of lexical stress in Turkish (§ 2.2.3).

2.2.1 The full vowel inventory

Standard Modern Turkish has eight contrastive vowels, which will be transcribed /i, y, ɛ, œ, ɯ, u, ɑ, ɔ/ here. Phonological accounts treat height, backness and rounding dichotomously, so that the vowels are symmetrically divided across the following classes: front /i, y, ɛ, œ/ vs back /ɯ, u, ɑ, ɔ/; close (high) /i, y, ɯ, u/ vs open (low) /ɛ, œ, ɑ, ɔ/; unrounded /i, ɛ, ɯ, ɑ/ vs rounded /y, œ, u, ɔ/[13] (e.g. Gussmann 2002; Polgárdi 1999; Lotz 1975); this classification is shown in Figure 2.14.[14]

	FRONT		BACK	
	UNROUNDED	ROUNDED	UNROUNDED	ROUNDED
CLOSE	i	y	ɯ	u
OPEN	ɛ	œ	ɑ	ɔ

Figure 2.14: Turkish vowels categorised by binary height, backness and rounding.

The vowel diagram of the IPA illustration of Turkish (Zimmer and Orgun 1999) is reproduced in Figure 2.15. It corroborates a classification based on three binary contrasts, even though their ‘a’ is conspicuously more open and advanced than ‘o’. In the phonological categorisation of phonemes, however, it is not unusual to give priority to system symmetry

[13] Symbols and class labels vary in the literature. Other symbols used in transcription include **ü** for /y/; **e** for /ɛ/; **ø**, **ö** for /œ/; **a** for /ɑ/; **o** for /ɔ/; **ɨ**, **ï**, **ı** for /ɯ/.

[14] Descriptions of Modern *Literary* Turkish additionally include three long vowels: /iː, uː, ɑː/, orthographically ⟨î, û, â⟩. Both the lengthened pronunciation and the circumflex diacritic, however, are obsolete (or obsolescent) in present-day Standard Turkish. These historically long vowels are found in Arabic and Persian loans, and a small number of them would be in length-based minimal pairs, had the traditional long pronunciation survived, e.g. *azim* /ɑˈzim/ ‘determination’ vs *azîm* /ɑˈziːm/ (now rare) ‘grand’, *mahsus* /mɑhˈsus/ ‘intentional(ly)’ vs *mahsûs* /mɑhˈsuːs/ ‘peculiar’, *alem* /ɑˈlɛm/ ‘flag’ vs *âlem* /ɑːˈlɛm/ ‘universe’ (Kononov 1956).
Lengthened vowel realisations are possible in Standard Modern Turkish as a result of compensatory lengthening triggered by the deletion of an approximant or /h/, especially in informal speech, e.g. *seyret* /sɛjˈrɛt/ → [seːˈrɛt] ‘watch [imper.]’, *övmek* /œvˈmɛk/ → [œʊˈmɛc] → [œːˈmɛc] ‘to praise’, *dağ* /dɑɰ/ → [dɑː] ‘mountain’, *kahve* /kɑhˈvɛ/ → [kɑːˈvɛ] ‘coffee’ (Sezer 1986).

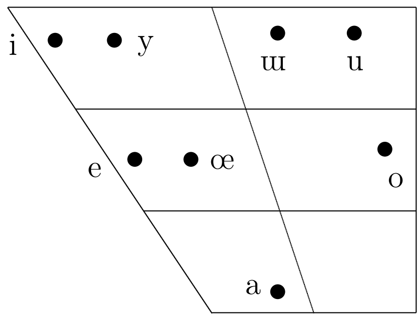


Figure 2.15: Modern Turkish vowels according to Zimmer and Orgun (1999).

over phonetic detail, and since no vowel of intermediate height intervenes between /ɯ/ and /ɑ/ (‘a’), it seems justified to assume a two-height phonological system: close vs open/non-close. Further, while all unrounded vowels in the IPA diagram appear to be more advanced than their rounded counterparts, ‘a’ is conspicuously fronter than ‘o’: it is plotted to the left of the ‘central’ line of the vowel space. Nonetheless, there are good phonological reasons to treat the phoneme as back. It patterns with other back vowels in harmonic processes: for example, the substantival plural suffix surfaces as *-ler* /lɛɾ/ after a syllable containing /i, y, ɛ, œ/, e.g. *ipler* ‘ropes’, *yüzler* ‘faces’, *eller* ‘hands’, *köyler* ‘villages’, but as *-lar* /lɑɾ/ after a syllable with /ɯ, u, ɑ, ɔ/, e.g. *kızlar* ‘girls’, *pullar* ‘stamps’, *çanlar* ‘bells’, *sonlar* ‘end(ing)s’ (examples from Halle and Clements 1983). Furthermore, three consonant phonemes, /k, ɡ, l/, are sensitive to the backness of neighbouring vowels: in the environment of /i, y, ɛ, œ/, they are realised as palatal(ised) [c, ɟ, lʲ], while with /ɯ, u, ɑ, ɔ/ they are velar(ised), [k, ɡ, ɫ] (Clements 1980; Waterson 1959), thus *çekmek* [tʃɛcˈmɛc] ‘to pull’ but *çakmak* [tʃɑkˈmɑk] ‘lighter [n.]’.

Surprisingly little acoustic research has been devoted to Turkish vowels, which is discussed in § 2.2.3.

2.2.2 Vowel harmony

Within a non-compound Turkish word, the vowel phonemes described in § 2.2.1 are fully contrastive only in word-initial syllables. Exceptions aside, all vowels in non-initial syllables display vowel harmony, a regular process in which a vowel agrees with the vowel in the immediately preceding syllable in either backness and rounding or only backness (Kabak

2011). Two types of vowel harmony operate in Turkish: palatal and labial.[15] Palatal harmony affects both close and open target vowels: if the preceding vowel (the trigger vowel) is back, the vowels that may occur after it are /ɯ/ and /u/ if close, and /ɑ/ if open. Conversely, if the preceding vowel is front, the next will be /i/ or /y/ if close, and /ɛ/ if open. Only close vowels exhibit labial harmony: /y/ and /u/ occur after rounded vowels, /i/ and /ɯ/ after unrounded ones. Thus, low rounded vowels, /œ/ and /ɔ/, are disallowed outside initial syllables. All possible harmonic sequences are shown in Table 2.12.

TRIGGER VOWEL				CLOSE TARGET VOWEL				OPEN TARGET VOWEL			
close	front	unrounded	/i/	close	**front**	**unrounded**	/i/	open	**front**	unrounded	/ɛ/
open	front	unrounded	/ɛ/	close	**front**	**unrounded**	/i/	open	**front**	unrounded	/ɛ/
close	front	rounded	/y/	close	**front**	**rounded**	/y/	open	**front**	unrounded	/ɛ/
open	front	rounded	/œ/	close	**front**	**rounded**	/y/	open	**front**	unrounded	/ɛ/
close	back	unrounded	/ɯ/	close	**back**	**unrounded**	/ɯ/	open	**back**	unrounded	/ɑ/
open	back	unrounded	/ɑ/	close	**back**	**unrounded**	/ɯ/	open	**back**	unrounded	/ɑ/
close	back	rounded	/u/	close	**back**	**rounded**	/u/	open	**back**	unrounded	/ɑ/
open	back	rounded	/ɔ/	close	**back**	**rounded**	/u/	open	**back**	unrounded	/ɑ/

Table 2.12: Turkish vowel harmony trigger vowels and corresponding target vowels. Harmonising properties shown in bold.

Thus, the vowel in the initial syllable may be any of the eight contrastive vowels (and therefore may be of any height, backness and rounding) and serves as a vowel harmony trigger for the vowel in the second syllable. A vowel in a non-initial syllable will be a vowel harmony target for the preceding vowel, as well as a trigger for the following vowel, if there is one. Two subsets of the full inventory may occur as targets: (*a*) all close vowels, /i, y, ɯ, u/, and (*b*) the open unrounded vowels, /ɛ, ɑ/. Examples are given in Table 2.13.

The mechanisms of vowel harmony have been approached from numerous theoretical angles. Phonological accounts have variously conceptualised harmony as vowel co-occurrence restrictions (Bloomfield 1933), positional neutralisation to archiphonemes (Trubetzkoy 1939), whole-word features or prosodies (Waterson 1959; Lightner 1965; Gussmann 2002), linear vowel-to-vowel assimilation (Lees 1961; Kardestuncer 1982; van der Hulst and van de Weijer 1991), and non-linear feature spreading (Clements 1976; Clements and Sezer

[15] Palatal harmony is also known as front–back, backness or frontness harmony; labial harmony is alternatively called rounding or roundness harmony.

	NOM SG (base)	GEN SG +{-In}	NOM PL +{-lEr}	GEN PL +{-lEr} +{-In}	GLOSS
(a)	ip	ipin	iplɛr	iplɛrin	rope
(b)	kɯz	kɯzɯn	kɯzlɑr	kɯzlɑrɯn	girl
(c)	jyz	jyzyn	jyzlɛr	jyzlɛrin	face
(d)	pul	pulun	pullɑr	pullɑrɯn	stamp
(e)	ɛl	ɛlin	ɛllɛr	ɛllɛrin	hand
(f)	tʃɑn	tʃɑnɯn	tʃɑnlɑr	tʃɑnlɑrɯn	bell
(g)	kœj	kœjyn	kœjlɛr	kœjlɛrin	village
(h)	sɔn	sɔnun	sɔnlɑr	sɔnlɑrɯn	end

Table 2.13: Examples of Turkish vowel harmony (Halle and Clements 1983, transcription adapted). High target vowels are illustrated with the genitive suffix /-In/, and non-high ones with the plural suffix /-lEr/. /I/ and /E/ denote a high and a non-high vowel, respectively, that is not specified for any other features.

1982; Lahiri 2000). Since Turkish vowel harmony is not the focus of this study, the great many interesting theoretical approaches to it will have to be left out of the discussion.

2.2.3 Word stress

2.2.3.1 Stress placement

Regular lexical stress is fixed on the final syllable of the word. This applies to both simplex and complex polysyllabic words, i.e. word-final suffixes attract stress (Lees 1961; Kabak and Vogel 2001); this can be seen in the examples in (2.1) (from Kabak and Vogel 2001, transcription added).

ki**táp**	/kiˈtɑp/	'book'	
kitap**lík**	/kitɑpˈlɯk/	'bookcase	
kitaplık**lár**	/kitɑplɯkˈlɑɾ/	'bookcases'	(2.1)
kitaplıkla**rím**	/kitɑplɯklɑˈɾɯm/	'my bookcases'	
kitaplıkları**míz**	/kitɑplɯklɑɾɯˈmɯz/	'our bookcases'	
kitaplıklarımız**dán**	/kitɑplɯklɑɾɯmɯzˈdɑn/	'from our bookcases'	

A small number of bound word-final morphemes do not receive stress. Although traditionally also termed suffixes, they are now usually considered to be clitics, precisely because of their unstressability (Erdal 2000). Two other groups of exceptions to the final stress rule are simplex adverbs with early stress (e.g. /ˈʃimdi/ 'now', /ˈbɛlki/ 'maybe', /ˈɑndʒɑk/ 'hardly, however'), and a large number of place names and foreign personal names. The last group—that of proper nouns—follow the so-called Sezer Stress Rule:

> If the antepenultimate syllable is heavy and the penultimate syllable is light, stress the antepenultimate syllable; otherwise stress the penultimate syllable.
>
> (Kabak and Vogel 2001: 317)

E.g. *Ánkara, Bárbara; Orégon, Adána, İstánbul, Edírne,* etc.

2.2.3.2 Acoustic correlates of stress in Turkish

Konrot (1981) is the first comprehensive instrumental study of how 'linguistic stress' correlates with vowel duration, formant frequencies, amplitude and the fundamental frequency. It is based on recordings of two groups of target words: (*a*) 5 disyllabic finally stressed word-forms of the shape /CɛˈCɛ/; (*b*) 3 disyllabic minimal pairs with contrastive initial and final stress. Konrot does not find significant differences between stressed and unstressed vowels with regard to duration or formant structure. However, the measure he uses for formant structure is the $F_2 - F_1$ frequency difference and no separate formant frequencies are reported. This seems unfortunate, because a change in F_1 frequency could thus have been masked by a simultaneous equivalent change in F_2 frequency (or vice versa). Amplitude, on the other hand, does interact with stress, if not in a very straightforward manner: initial stressed syllables have a higher amplitude than final unstressed syllables within the same word, whereas in finally stressed words there is no significant difference between the two syllables. Konrot concludes that the two different amplitude profiles serve as perceptual cues for word stress location: if amplitude falls from first to second syllable, the first syllable is perceived as stressed; if it does not change, the word has final stress.

Two measurements of fundamental frequency are taken: (*a*) the mean of f_0 at vowel onset and f_0 at vowel offset, $\frac{f_0^{\mathrm{on}} + f_0^{\mathrm{off}}}{2}$; this is used to compare the average fundamental frequencies of stressed and unstressed syllables; (*b*) the difference between f_0 at vowel onset and f_0 at vowel offset: if significant, $f_0^{\mathrm{on}} - f_0^{\mathrm{off}}$ is calculated to identify pitch contours within syllables, with a positive value indicating a falling tone, and a negative one a rising tone. Initially stressed syllables show a significantly higher mean f_0 than the final syllable. There is no significant difference in mean f_0 between the two syllables of words with final stress. As regards local pitch movement, words with final stress show steady f_0 (level tones), whereas in initially stressed words there are statistically significant falling contours in the second, unstressed syllable, with first syllables tending to bear a slight, though not significant, rise. Although Konrot does not point this out, amplitude and mean f_0 frequency appear to follow the same pattern: with initial stress, both mean f_0 and amplitude fall from stressed to unstressed syllables, while words with final stress exhibit plateaux, i.e. little change, throughout the word.

Overall, Konrot's (1981) experiments appear to have been designed and performed to a very high standard as Levi's (2005) later and, understandably, more sophisticated study clearly confirms his results: she finds that f_0 is the most robust cue for lexical stress in Turkish, followed by intensity and then duration; she does not look at formant frequencies. Although Levi's data reveal statistically significant durational differences between stressed and unstressed syllables, she refers to studies of duration discrimination to argue that the differences she finds, of 4 ms on average, could not be in the range of perceptibility for vowels whose mean duration is about 100 ms. Further, Levi's discriminant function analysis shows that duration does not significantly contribute to the classification of stress location. With regard to fundamental frequency, Levi's findings are that finally stressed words show a slight rise or a plateau in f_0, whereas words with non-final stress show a drop in f_0 after the stressed syllable. This confirms Konrot's (1981) observations; Levi further analyses both patterns as a H*L pitch accent where the H is associated with the prominent syllable as well as the preceding syllables, while the L is associated with syllables that follow, *if present*. Based on her findings and comparison with earlier research on other languages, Levi states that 'Turkish bears a great similarity with other [pitch-accent] languages such as Japanese, Basque, and Serbo-Croatian', and concludes that Turkish, too, is a pitch-accent language.

2.2.4 Summary

Turkish has attracted a good deal of scholarly interest, much of which has focused on segmental alternations like those resulting from vowel harmony or obstruent voicing assimilation. Very little acoustic work is available on Turkish vowels, and in this section I discussed two papers that investigate the relative importance of the fundamental frequency, amplitude/intensity and vowel duration as correlates of lexical stress—Konrot (1981) and Levi (2005)—the former of which also uses a combined $F_1 - F_2$ frequency measure in comparing stressed and unstressed vowels. Apart from that, to the best of my knowledge, there is no literature on spectral and durational differences between vowels in stressed and unstressed position. This is hardly surprising, for Turkish is not known for unstressed vowel reduction; this is to be expected for a pitch accent language, which Levi (2005) argues it is. In addition, it has been claimed that vowel reduction cannot coexist with vowel harmony in a single language (Barnes 2006).

2.3 The non-standard varieties

It is often the case that we know more about official standard varieties of languages than about non-standard regional dialects, because codification requires detailed description, which in turn requires research. Bulgarian is a language of considerable regional diversity and a good deal of work has been done in the framework of traditional dialectology. Naturally, the methods and results of such research do not always conform with modern procedures and standards. However, the traditional primary division of Bulgarian dialects into eastern and western varieties (Stojkov 1962/2002: 93–96) has been validated in a recent quantitative classification of Bulgarian dialects (Houtzagers et al. 2010) based on historical data from the 1950's, which earlier classifications also relied upon, at least in part.[16] I summarise the most conspicuous properties of eastern Bulgarian dialects in § 2.3.1.

The bilingual varieties of Bulgarian and Turkish, which are spoken by a significant minority of Bulgaria's population, have been severely neglected in linguistic work, mostly because of ideological barriers that were in place in the past. An overview of the little that has been published on the languages of the bilingual community is given in § 2.3.2.

2.3.1 East Bulgarian

The most prominent isogloss in Modern Bulgarian is the so-called '*yat* border', shown in Figure 2.16, which divides the country into eastern and western dialect groups. *Yat* is the name of an obsolete Cyrillic letter, ⟨Ѣ ѣ⟩, which in Old Bulgarian Cyrillic orthography stood for a front (near-)open vowel phoneme, /æ/. It was later raised to [ɛ] in unstressed syllables, as well as in stressed position when followed by a front vowel, /i/ or /ɛ/, in the next syllable. In other contexts /æ/ retracted somewhat, but left a trace of its original frontness in the form of palatalisation of preceding consonants. This historical development, known as *Yat* Umlaut, resulted in phoneme alternations within lexical stems, e.g. /bʲ**a**l/ 'white [masc sg]', /ˈb**ɛ**li/ 'white [pl]' (before a front vowel), /b**ɛ**lɔˈta/ 'whiteness' (unstressed). The alternations were subsequently levelled in most non-standard varieties, but different

[16] Houtzagers et al. (2010): 'The data set used in this paper consists of phonetic transcriptions of 156 words collected from 197 sites all over Bulgaria . . . The main source of the data was the *Archive of the Ideographic Dialect Dictionary of Bulgarian* of the University of Sofia that was initiated during the 1950s by Professor Stojko Stojkov, at that time the leading expert in the field of Bulgarian dialectology.'

Figure 2.16: Bulgarian dialects: the dashed line (A- - -B) represents the *yat* isogloss, dividing Bulgarian dialects into western and eastern (Adapted from Radkova 2009: 29, based on Stojkov 1962/1968).

dialects favoured different alternants, which eventually resulted in the *yat* isogloss: varieties to the west selected [ɛ], while most eastern varieties generalised the palatalisation+[a] pattern (Mirčev 1978: 118–122, Stojkov 1962/2002: 83–87). This is illustrated in (2.2).

Standard Bulgarian	Non-standard eastern dialects	Non-standard western dialects	Gloss	
/bʲal/	/bʲal/	/bɛl/	white [masc sg]	(2.2)
/ˈbɛli/	/ˈbʲali/	/ˈbɛli/	white [pl]	
/bɛlɔˈta/	?/bʲalɔˈta/	/bɛlɔˈta/	whiteness	

Apart from this historically important demarcation line, there are a number of other properties that distinguish eastern varieties from both non-standard western dialects and Standard Bulgarian. Naturally, the isoglosses for these other differences do not coincide with the *yat* border, but are nonetheless located close enough to justify a general east–west dialect partition of the country. Important phonological defining properties of eastern varieties are summarised below, based on Stojkov (1962/2002: 97–100).

(1) Consonants are palatalised before front vowels, e.g. East Bulgarian [pʲɛt] 'five' vs West Bulgarian [pɛt]; East Bulgarian [dʲiˈtʲɛ][17] 'child' vs West Bulgarian [dɛˈtɛ] or

[17] Palatalised dental plosives, [tʲ dʲ], are often affricated in the East, and may also be retracted, thus frequently [d͡zʲiˈt͡sʲɛ] or [d̠͡ʑiˈt̠͡ɕɛ].

[dˠɛˈtˠɛ].

(2) Unstressed vowel reduction is, on the whole, stronger in the East; some dialects are described as exhibiting 'complete' reduction, which means that open vowels merge with corresponding close vowels in unstressed position, e.g. East Bulgarian [bəˈʃta] 'father' vs West Bulgarian [bɐˈʃta] (according to the received view, § 2.1.2); East Bulgarian [zʲiˈlʲɛnu] 'green [neut sg]' vs West Bulgarian [zɛˈlɛno].

(3) In many eastern varieties when unstressed /ɛ/ follows a sonorant consonant, instead of [i], it reduces to [ə], while leaving the preceding sonorant palatalised: East Bulgarian [ˈbɔlʲən] 'ill [masc sg]' vs West Bulgarian [ˈbɔlɛn]; East Bulgarian [ˈdʲɛnʲəm] 'in the daytime' vs West Bulgarian [ˈdɛnɛm].

These are common *realisational* characteristics of eastern dialects which are highly pertinent to this study. (2) and (3) make explicit claims about unstressed vowel reduction, while (1), palatalisation before front vowels, may be one reason why unstressed /ɛ/ raises to [i] in eastern, but not in western Bulgarian. A good deal of dialectological work focusing on small linguistic areas, often individual villages, has been undertaken since the publication of Stojkov's (1962) seminal *Bulgarian Dialectology* and a lot of this research served as a basis for the *Bulgarian Dialect Atlas* (Stojkov et al. 1964–1981) and a separately published 'recapitulatory' volume (Kočev et al. 2001). Maps in the atlas confirm that all three eastern features listed above should be expected to be in place in the monolingual variety spoken in the northeastern town of Tărgovište, which is examined in Chapter 5.

Stojkov's (1962) characterisation of eastern Bulgarian dialects includes a further three phonological features, summarised in (4–6). These other eastern traits, however, have to do with the lexical distribution of certain phonemes and are of little relevance here, as they are the consequence of patterns long phonologised, and do not engender any large-scale contrast neutralisation, while features (1–3) allegedly or potentially do.

(4) In some eastern dialects a small subset words has /a/ where western dialects have /ə/, e.g. eastern /daʒd/ 'rain', /san/ 'sleep, dream' vs West Bulgarian /dəʒd, sən/.

However, the /ə–a/ contrast is not affected. Similarly, a few lexical items have /ə/ in the East but /ɛ/ in the West, e.g. eastern /ˈʃəpa/ 'a handful', /mə/ 'me [acc.]', /tə/ 'you [acc.]', /sə/ '-self [acc.]' (reflexive clitic) vs West Bulgarian /ˈʃɛpa, mɛ, tɛ, sɛ/.

(5) Eastern dialects that maintain unlevelled reflexes of *yat* umlaut, which surface as alternating /ɛ/ and palatalisation+[a], have generalised this to instances of Modern Bulgarian palatalisation+[a] that have arisen from sources other than the Old Bulgarian *yat*-vowel, e.g. eastern /pɔˈl^{j}ana/ 'meadow [sg]' – /pɔˈlɛni/ ([puˈl^{j}ɛn^{j}i]) [pl] vs SB /pɔˈl^{j}ana/ – /pɔˈl^{j}ani/.

(6) While in Standard Bulgarian phonologically palatalised consonants are restricted to positions before non-front vowels, as in /b^{j}al/ 'white [masc sg]', in some eastern varieties historical palatalised consonants have also been preserved in word-final position, e.g. eastern /pət^j/ 'road', /sɔl^j/ 'salt' (vs SB /pət/, /sɔl/).

2.3.2 The bilingual community and their languages

The largest ethnic minority in Bulgaria is a Turkish community that makes up about 9 per cent of the country's total population, estimated to be approximately 7 million in 2019 (World Population Review 2019). Turks have lived in Bulgaria since the late 14th century, i.e. the very beginning of Ottoman rule in Bulgaria, which lasted until the late 19th century. It was not until post-Ottoman times that knowledge of Bulgarian, and thus bilingualism, began to spread amongst Bulgarian Turks (Rudin and Eminov 1990; Rudin 2019). The following brief outline of the community's history and language use patterns is based on Rudin (2019) and, to a lesser extent, Rudin and Eminov (1990).[18]

The earliest Turkish colonists settled in Bulgaria soon after the Ottoman conquest in the late 14th century, and many of their descendants remained in the country after it was re-established as a sovereign state in 1878. Prior to Bulgarian independence Turkish was the language of the Empire and consequently the prestige language used by the ruling classes. Bulgarians who lived near Turkish communities would often learn Turkish, while

[18] Yalămov (2005) and Eminov (1997) are in-depth histories of the Turkish community in Bulgaria. Social and political aspects of language use are addressed by Eminov (2019); Rudin and Eminov (1993); Yusufoff (2013). The a bilingual varieties are discussed from a sociolinguistic perspective in Rudin and Eminov (1990, 1993) and Rudin (2019), with a linguistic focus on syntax, morphology and vocabulary.

the Turks remained monolingual. In Ottoman times schools were run by each ethnic community, so there were separate Bulgarian and Turkish schools. Only boys would be sent to school, so the majority of women remained illiterate.

During the early post-Ottoman period—in the first half of the 20th century—Turkish lost its prestige status and became a minority language. However, the Turkish communities that remained in the country inhabited isolated, often mountainous, regions and had little contact with Bulgarians, so their day-to-day language use and education patterns were largely unchanged in that period.

In the 1950's a policy of compulsory education in Bulgarian for all children started to be enforced increasingly strictly, which gave rise to the spread of bilingualism, though many, especially women, remained monolingual, as they often attended only primary school. With collectivisation in the 1960's, entire Turkish villages moved to join collectives in the plains. While many of the communities stayed together, resettlement led to intensified exposure to and use of Bulgarian, as some people had to communicate with Bulgarian co-workers and children spent longer years at school.

Language policy towards Turkish saw many changes under the communist regime (1944–1989), becoming increasingly hostile. In the early years minority mother-tongue education was encouraged; later it was made optional and finally discontinued. Policy towards the Turkish community and their language reached very severe levels of repression in the mid-1980's when the government declared that 'there are no Turks in Bulgaria', forced them to change their names to Bulgarian ones, and outlawed Turkish cultural practices, as well as the use of Turkish. This led to the exodus of over 300,000 Bulgarian Turks to Turkey in 1989, many of whom returned after the fall of communism. Families and friends were separated, some having moved to Turkey and others having stayed or returned to Bulgaria, which in turn led to more intense exposure to Standard Turkish through visits, as well as newly free access to foreign media. 'In short, the communist era overall was a time of expanded exposure both to Bulgarian and to standard Turkish' (Rudin 2019).

After the collapse of the communist regime, people could once again speak Turkish freely and most Turks reclaimed their Turkish names. Exposure to Standard Turkish has now intensified through the media and the internet. Contact with Bulgarians and schooling in Bulgarian have also increased. The majority of young people are now natively fluent in both languages, although often literate only in Bulgarian, as Turkish language tuition is not offered in state schools. However, some young speakers, especially those who now live in bigger towns and cities, have fewer and more restricted occasions to use Turkish and as a result feel more confident speaking Bulgarian.

Rudin (2019) describes the patterns of language use she observed in four generations of her husband Ali's family and their friends. **Generation 1**, that of Ali's parents, were born the 1910's, shortly after Bulgarian independence and grew up before the communist period.

> They lived most of their lives in an isolated village in the eastern Rhodopes, accessible only on foot, and a long day's walk from the nearest town. The surrounding villages were uniformly Turkish. With no ethnic diversity came lack of linguistic diversity: the only language in daily use was the local dialect of Turkish. Men, who were more likely to have been to school and who made occasional trips to town, might know a few words of Bulgarian and might be literate. . . . My mother-in-law never did learn Bulgarian beyond a few memorized words. During the period when speaking Turkish in public was illegal, she was not able to shop or communicate with anyone outside the house.
>
> (Rudin 2019: 3–4)

Generation 2 is that of Ali and his siblings, who were born in the 1940's and 1950's. They spent most of their childhood in the family's original home village in the Rhodope mountains before moving to a cooperative farm village in east-central Bulgaria in the 1960's. Several of them later moved to a nearby larger town.

> Unlike the previous generation, they all had some education, even the girls. Primary school in the mountain village was taught in Turkish, with Bulgarian as a school subject, so they learned to read and write both Turkish and Bulgarian. . . . Some of the siblings also attended high school . . . In addition to exposure to Bulgarian through schooling, members of this generation ended up as adults using Bulgarian in public situations like stores and restaurants, and in some cases having Bulgarian co-workers. Their Bulgarian is fluent but clearly non-native, with typical grammatical errors . . .
>
> (ibid., 4)

Generation 3, that of Ali's nephews and nieces, were born in the 1970's. They were raised in the family's new village, which is predominantly Turkish speaking; Turkish is the language they used at home growing up, and their monolingual grandparents were involved in their upbringing. At the same time, people of this generation may not be able to write well in Turkish, since they have not had any formal education in it. Instead, they received both primary and secondary education entirely in Bulgarian, in which they are also very fluent as result.

> This generation were children or teenagers during the anti-Turkish campaign of the 1980s, and their language attitudes were inevitably shaped by that traumatic time. For them as young people speaking Turkish was a political act; listening to Turkish radio or cassettes was a potentially dangerous rebellion. The official repression of Turkish identity backfired: it actually strengthened their sense of Turkishness, encouraged some to become literate in Turkish, and probably slowed the linguistic assimilation to Bulgarian that had been in progress before the 1980s. This generation is also the first to be significantly impacted by the post-communist opening of borders. As young adults they were suddenly able to travel to Turkey or to Western Europe . . .
>
> (ibid., 6)

Generation 4 are currently in their teens or twenties: this is the generation of Ali's great-nieces and great-nephews, who were born in the 1990's and 2000's. They have been bilingual since early childhood, as their parents and grandparents are bilingual, they went to Bulgarian-speaking primary and secondary school, and many of them were also sent to Bulgarian nursery school.

> They have Bulgarian friends. . . . This generation continues their parents' trajectory toward greater Bulgarian fluency and a broader range of other languages besides Turkish, but apparently without much of the ethno-political baggage; they speak Turkish, but they aren't militant about it. Another trend they continue is that of diminishing literacy in Turkish. Some do read and write Turkish, but they tend to be more comfortable reading and writing in Bulgarian, and their Turkish spelling may be idiosyncratic.
>
> (ibid., 7)

This completes my summary of Rudin's (2019) observations that are most relevant to the present study. The bilingual speakers whose speech I recorded for the experiments reported in Chapters 7 and 8 were predominantly in their 20's, with a couple of participants aged 18 and 19. Their age places them in the bracket of Rudin's Generation 4. Their self-reported language use habits, however, varied considerably. Most of those who lived in the town of Tărgovište said they spoke Turkish primarily to their grandparents and older people, and only sporadically to their peers. At the other extreme were participants who lived in nearby villages, most of whom reported a much more extensive everyday use of Turkish, including as a main language at home. One participant commented, 'we mix so much that no [monolingual] Turk or Bulgarian would ever understand us; we've invented a language of our own'. While the last suggestion, that they speak a language that is different from both Turkish and Bulgarian, is almost certainly an overstatement from a linguistic point of view, the claim that their speech would be incomprehensible for monolinguals is highly likely to be true: the statement seems to reflect an introspective awareness of extensive code-switching.

The dialects of Turkish nowadays spoken in Bulgaria, Greece, Romania, North Macedonia and Kosovo are known as Balkan or Rumelian Turkish dialects. They are divided into two major groups, Eastern and Western Rumelian, and a bundle of isoglosses that separates them roughly follows the Bulgarian *yat* border. The isoglosses represent West Rumelian innovations against the backdrop of the more conservative East Rumelian dialects, including a merger of all close vowels, /i, y, ɯ, u/ into [i] in word-final position; loss of vowel harmony in open vowels and in certain close-vowel suffixes; retraction of /y, œ/ to [u, ɔ] in many words and raising of /œ/ to /y/ in some words (Friedman 1982). Since the Turkish-speaking communities in Bulgaria are concentrated in the southeast and northeast of the country, their dialects belong to the Eastern Rumelian group and as such do not exhibit these innovative features. Some dialectological work on Bulgarian Turkish varieties, primarily southeastern, was done in the 1960's and 1970's, notably by Mollova (1962; 1967; 1970; 1971) and Boev (1976). Boev's (1961) *Programme for data collection for a little atlas of Turkish dialects in Bulgaria*, regrettably, was not carried through and no such atlas was published. While Turkish dialects in Bulgaria as a rule have the same full vowel inventory as Standard Turkish (§ 2.2.1), descriptions based on auditory impression suggest that open vowels may undergo moderate to substantial raising in unstressed position

(Boev 1976; Akif et al. 2006). There is no clear indication of how systematic this could be, since claims to that effect are based on individual words.

While the Turkish spoken in Bulgaria has received some attention from dialectologists, the bilinguals' Bulgarian has not—to the best of my knowledge—been studied at all.

2.3.3 Summary

The primary division of the Bulgarian dialect continuum is between east and west. Eastern dialects are defined by two major processes that are synchronically active at present: palatalisation before front vowels and considerable unstressed vowel reduction. Much of what is known about non-standard dialects of Bulgarian comes from traditional dialectological research; there are practically no acoustic and statistical data available.

The present-day varieties of Turkish and Bulgarian spoken by Bulgarian Turks are largely understudied. In a matter of four generations, from being monolingual in Turkish, the community has shifted to being fully bilingual. There are now indications that, for some speakers, Bulgarian has become the dominant language.

3
Methodology

Contents

3.1 Procedure

The experiments reported in this thesis were reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.

3.1.1 Target words

In order to assess the repeated claim that Bulgarian vowels reduce to a lesser extent in immediately pretonic than in other unstressed syllables, four-syllable words with penultimate stress were required for the experiments. To ensure uniform word length and segmental context in examining all vowel phonemes, nonsense words were used as the primary test items for all five varieties. The basic nonsense words for Bulgarian had the shape /pV.pV.ˈpV.pVp/, keeping vowel phonemes constant throughout the word.

Turkish, as a rule, has word-final stress and, in order to elicit comparable penultimately stressed items, a common enclitic (*-le*/*-la* 'with') was attached to a trisyllabic nonsense 'stem',[1] thus forming target words like /pV.pV.ˈpVp.lɛ/ and /pV.pV.ˈpVp.lɑ/ for front and back vowels, respectively. Only the vowels of the nonsense stem, i.e. those in the first three syllables, have been analysed for Turkish.

In the two earliest experiments, on West Bulgarian and Istanbul Turkish, the following variations on the basic word-type were also included.

- No word-initial onset (and word-final coda): **B.** /V.pV.ˈpV.pV/, **T.** /V.pV.ˈpVp.lV/.
- Different consonant voicing: **B.** /bV.bV.ˈbV.bVb/, **T.** /bV.bV.ˈbVb.lV/.
- Different consonant manner of articulation: **B.** /fV.fV.ˈfV.fVf/, **T.** /fV.fV.ˈfVf.lV/.
- Different consonant place of articulation:

  a. coronal: **B.** /tV.tV.ˈtV.tVt/, **T.** /tV.tV.ˈtVt.lV/;

  b. dorsal: **B.** /kV.kV.ˈkV.kVk/, **T.** /kV.kV.ˈkVk.lV/.

Replacing the plosives with fricatives did not affect adjacent vowels, whereas the changes in voicing and place of articulation had predictable effects in both languages: vowel duration was longer before voiced consonants, front vowels had lower F_2' in a dorsal environment, while back rounded vowels tended to have higher F_2' in coronal contexts than elsewhere. Only target words with /p/ were retained for the subsequent experiments (East Bulgarian, Bilingual Bulgarian, Bilingual Turkish), without variation in consonant voice, place, manner or onset/coda presence. The total numbers of vowel tokens elicited and analysed for each variety are shown in the following section (§ 3.1.2).

All Bulgarian nonsense words conform to Bulgarian phonotactics. Stress was indicated with a grave accent on the stressed vowel, as well as the stressed syllable appearing in bold typeface.[2] All Turkish nonsense words are phonotactically well-formed, except for

[1] Turkish enclitics are sometimes referred to as 'unstressed suffixes'.

[2] Lexical stress is free in Bulgarian but is not usually indicated in texts aimed for native speakers, except in dictionaries, school primers, and in certain homographs that are distinguished by stress location. Where it is indicated, the grave rather than the acute accent is used.

those containing /œ/ or /ɔ/, since the open rounded vowels do not typically occur in non-initial syllables. However, such violations are not infrequent in loan words, including some common well-assimilated borrowings, such as *pilot* /piˈlɔt/ 'pilot', *motör* /mɔˈtœr/ 'engine, motor' (both of which also happen to violate Turkish Vowel Harmony).

In the experiments on Istanbul Turkish, East Bulgarian, Bilingual Bulgarian and Bilingual Turkish, real Bulgarian or Turkish words were also included in the target items, in order to verify that the nonsense words were reliable indicators for speakers' natural linguistic behaviour. Comparisons of real- and nonsense-word vowels revealed mostly non-significant differences in F_1' frequency. Real words were not included for West Bulgarian—an unfortunate oversight in the design of the earliest of the five experiments.

The target words used, as well as the t-test results for comparisons of real and nonsense words, can be found in Appendix A.

Target words were embedded in carrier sentence (3.1) for Bulgarian and (3.2) for Turkish.

Казах	<target word>	*пак.*	(3.1)
/ˈkazax		ˈpak/	
say-1SG.AOR		again	
'I said <target word> again.'			

Ahmet	<target word>	*dedi.*	(3.2)
/ɑhˈmɛt		dɛˈdi/	
Ahmet		say-PAST	
'Ahmet said <target word>.'			

3.1.2 Participants and recording

Native speakers of each variety, aged 18–27, were recorded in return for nominal payment. The bilingual speakers' Bulgarian and Turkish recordings were made on separate days. The utterances were displayed on a computer screen, one at a time, in quasi-random order, and the participants were asked to read out each one twice. This aimed to elicit more fluent production the second time, and only the second rendition was included in the analysis. In the Istanbul Turkish experiment nonsense words from the basic set (/pV. . . /) appeared twice in each recording session, and those from the subsidiary sets were shown once. In the West Bulgarian design basic words appeared four times, subsidiary ones twice. In the sessions for East Bulgarian, Bilingual Bulgarian and Bilingual Turkish, basic words were elicited six times each. Table 3.1 summarises the numbers of speakers and vowels tokens analysed for each variety.

Variety	**Speakers**			**Basic**		**Subsidiary**		**Vowels per word**	**Vowel tokens**
	F	*M*	*Total*	*N*	×	*N*	×		
West B.	8	4	12	6	4	30	2	4	4032
East B.	5	3	8	6	6	0		4	1152
Istanbul T.	8	6	14	8	2	40	1	3	2352
Bilingual B.	9	5	14	6	6	0		4	2016
Bilingual T.	9	5	14	8	6	0		3	2016
Total	39	23	62						11,568

Table 3.1: Number of participants and vowel tokens in each experiment.
N number of basic/subsidiary nonsense words; × number of elicitations per word analysed.

The recordings were made on a MacBook with an iRig Mic HD external microphone, digitised at a sampling rate of 44,100 Hz and a 16-bit resolution, stored as PCM-encoded single-channel .wav files.

3.1.3 Segmentation and measurements

Vowels were manually segmented in Praat, version 6.0 (Boersma and Weenink 2015), on the basis of the synchronised wideband spectrogram,[3] waveform and audio signal. Vowel boundaries were determined by the presence of visible glottal pulses, clear formant structure[4] and sharp changes in intensity.

A Praat script, *Semi-Auto Formant Extractor* (McCloy and McGrath 2012, modified), was used to measure and extract F_1 and F_2 frequencies at vowel mid-points, as well as duration, for each vowel that allowed reliable spectral analysis. The script allows visual inspection and manual correction of formant frequency measurements: it cycles through a directory of .TextGrid and associated sound files, opens them one at a time,

[3] Gaussian window shape, 0.004 s window length, 0.001 s time step.
[4] To facilitate visual inspection, a formant tracker was used on occasion, set to detect 5 formants, with a maximum frequency of 5 500 Hz for female and 5 000 Hz for male talkers, and a dynamic range of 20 dB from the strongest peak.

displays the waveform, spectrogram and annotation for a segment, along with a table of formant frequencies at user-specified time points. The user is offered three options: (*a*) to accept the formant measurements, (*b*) to adjust the formant settings and recalculate, or (*c*) to skip the segment and mark it as unmeasurable, as well as to add notes—before continuing on to the next segment or file.

The following default settings proved, on the whole, effective in estimating formant frequencies: number of formants = 5; maximum formant frequency = 5 500 Hz (female) or 5 000 Hz (male); window length = 0.025 s; time step = 0.01 s; dynamic range = 20 dB. Manual adjustments to the formant settings were occasionally deemed necessary—in cases of improbable values resulting from undetected formants—and usually involved slightly altering the maximum frequency or, for some male voices, setting the number of formants to 4, with a maximum frequency of 4 500 Hz.

A small change was made to the original script, in order to append automatically measured segment durations to each row of the output file.

3.2 Statistical analysis

The remainder of this chapter aims to describe the statistical procedures used for the analysis of acoustic data, as well as to explain how the experimental chapters (4–8) are organised. All statistical analyses were performed in R, versions 3.3.3–3.5.2 (R Core Team 2018); associated graphics were created using the R package ggplot2, version 3.2.0 (Wickham 2016).

3.2.1 Normalisation, outliers and missing data

Formant frequencies were normalised using Nearey's (1978) speaker-intrinsic, vowel-extrinsic, formant-intrinsic log-mean method, and subsequently rescaled to Hertz-like values. A speaker-intrinsic procedure was chosen as the number of speakers representing each variety is not large. Vowel-extrinsic methods are best suited for studies of entire vowel inventories like the present one, and they perform better than vowel-intrinsic methods in factoring out physiologically conditioned variation in acoustic representations of vowels

(Adank et al. 2004). Nearey (1978: 147) assesses the formant-extrinsic and formant-intrinsic versions of his method and concludes that the latter outperforms the former, which is also corroborated by Adank et al. (2004). Finally, Disner (1980) compares four normalisation methods and finds that Nearey is the most effective in scatter reduction, and that '[a] log-mean normalization appears to be the best technique in general'.

A Nearey-normalised value F^* is the difference of the natural logarithm ($\log_e$) of the frequency of formant n for a particular token r of vowel V for speaker s, and the mean of the log-transformed frequencies of all tokens of all vowels, for that formant (n) for that speaker (s), as shown in (3.3) (Nearey 1978: 138; notation adapted).

$$F^*_{nV_rs} = \log_e(F_{nV_rs}) - \overline{\log_e(F_{ns})} \tag{3.3}$$

Normalisation was performed with the R package vowels (Kendall and Thomas 2010). The normalised values were then rescaled to the intervals $[200, 850]$ for F_1 and $[400, 2500]$ for F_2, applying Equations (3.4) and (3.5) to derive the rescaled values F_1' and F_2', respectively, with minimum and maximum values determined speaker-extrinsically.

$$F_1' = 200 + 650\,\frac{F_1^* - F^*_{1\,\text{min}}}{F^*_{1\,\text{max}} - F^*_{1\,\text{min}}} \tag{3.4}$$

$$F_2' = 400 + 2100\,\frac{F_2^* - F^*_{2\,\text{min}}}{F^*_{2\,\text{max}} - F^*_{2\,\text{min}}} \tag{3.5}$$

Duration, F_1' and F_2' values for vowels marked as 'unmeasurable' during segmentation and/or formant extraction (e.g. devoiced vowels), as well as outliers, defined as values beyond the interquartile range by 1.5 times the interquartile range, were removed. The resulting missing values were replaced with mean values for syllable-specific allophones, calculated after the removal, and did not exceed 0.5 per cent of all vowel tokens for any of the three parameters. The reason why missing data had to be imputed is that some of the statistical procedures used—repeated measures ANOVA, paired t-tests, correlations—require complete data sets.

3.2.2 Mean comparisons and correlations

According to the model I adopted in § 1.3, a vowel token is a unique point in a three-dimensional acoustic space defined by the parameters duration, F_1' frequency and F_2' frequency. The first part of each of the five experimental chapters that follow (4–8) examines the three parameters (or dependent variables) separately, by calculating and comparing mean values for all tokens of each phoneme in each *syllable* analysed. Thus, the independent variable is 'syllable' and it has four groups for Bulgarian ($\sigma_1, \sigma_2, \acute{\sigma}_3, \sigma_4$) and three groups for Turkish ($\sigma_1, \sigma_2, \acute{\sigma}_3$). The token sets, as well as their central tendencies, can be referred to as 'syllable-specific allophones' (such as [i_1, ɔ_3], etc.) and are of interest in assessing differences between unstressed vowels in initial, pretonic and final position.

3.2.2.1 Means and distributions

A table of syllable-specific means and standard deviations for each parameter of each phoneme is given at the beginning of every chapter. This is followed by a brief summary and a series of box plots like those in Figure 3.1, showing the distribution of tokens in each of the three dimensions. The significance levels drawn between syllable-specific distributions were obtained in the dependent t-tests described below. The box spans from the first to the third quartile, the horizontal line in the box is at the median, and whiskers extend to maximum

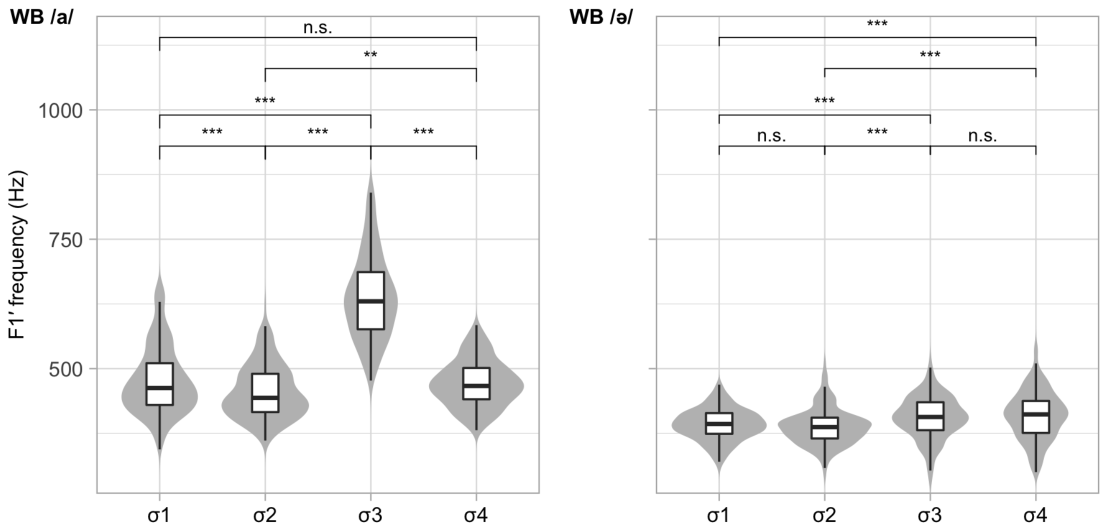


Figure 3.1: Boxplots and density estimates (F_1' frequencies of West Bulgarian /a/ and /ə/).

and minimum values but no further than 1.5 times the interquartile range from each end of the box. The shaded violin plots around the boxes show aligned probability densities, redundantly mirrored, estimated at 1024 equally spaced points using Gaussian kernels. The procedure used to find optimal kernel bandwidths is described in § 3.2.3.3 below.

3.2.2.2 Analysis of variance and post hoc *t*-tests

A repeated-measures ANOVA was run for each vowel phoneme, with 'speaker' as case identifier, 'syllable' as independent variable and each of the parameters (duration, F_1' and F_2' frequency) as dependent variables. Wherever the assumption of sphericity was violated (i.e. Mauchly's test was significant), Greenhouse-Geisser correction ($\hat{\varepsilon}$) was used to adjust the degrees of freedom and p-values. The results are listed in a table in each chapter and accompanied by a summary of the main effects.

The duration, F_1' and F_2' frequencies of the syllable-specific allophones of each phoneme were further examined in order to establish which comparisons are likely to have produced significant main effects in the ANOVAs. Dependent t-tests with Bonferroni correction for multiple testing were used ($\alpha = 0.05/4 = 0.0125$ for Bulgarian and $\alpha = 0.05/3 \approx 0.0167$ for Turkish). Occasionally the t-tests yielded significant results where the corresponding ANOVAs were non-significant; such cases are explicitly marked in the tables reporting t-test results.

It should be borne in mind that some acoustic differences, even though statistically significant, may be too small to be perceptually relevant. There is experimental evidence that the Just Noticeable Difference in formant frequency is between 10 and 15 Hz in the F_1 frequency range, and 1.5%–2% of the formant frequency in the F_2 range (Sinnott and Kreiter 1991; Hawks 1994; Kewley-Port and Watson 1994). Similarly, listeners' sensitivity to durational differences depends on the duration of the stimulus, T. For stimuli shorter than about 100 ms, the Just Noticeable Difference, ΔT, is approximately $\sqrt{T}$, whereas for stimuli in the range 100–500 ms, $\Delta T \approx T/10$, or approximately 10% of the stimulus duration (Creelman 1962; Stevens 1998: 228–229).

3.2.2.3 Correlations

Pearson product-moment correlations were computed between duration and each formant frequency within syllable-specific allophones. A predominance of significant positive correlations of duration and F_1' frequency in open vowels is interpreted as an indication of prevalent **gradient undershoot** within syllable-specific realisations. Open vowels have lower mean F_1' frequency values in unstressed position in all varieties, which may be the effect of gradient undershoot or a categorical target switch, but also a combination of both applying at once, as the two phenomena are not mutually exclusive: there may be separate targets that are reached to different extents under temporal pressure. In § 3.2.3.4 I propose a method to estimate whether distinct stressed and unstressed vowel targets are likely to be in place for a vowel phoneme.

Correlations of duration with the F_2' frequency will be considered on a case-by-case basis, as the sign of the correlation coefficient has different implications for front and back vowels with regard to potential centralisation.

3.2.3 Stress effects

In the second part of each experimental chapter, I move away from syllable-specific means and turn to stress-dependent allophones and their distributions, rather than means. I examine two types of difference, which are addressed in separate sections in each chapter:

(i) the difference between the stressed and unstressed allophones of each phoneme, or the amount of **Unstressed Vowel Shift**, and

(ii) the difference between the vowels in each height-contrasting pair, that is, the amount of contrastiveness, or **contrast** for short, in both stressed and unstressed position.

The procedures described below were used in assessing both Unstressed Vowel Shift and contrast, so the sections devoted to each for the most part follow a parallel structure. The only difference is that in the sections on contrast I apply an additional procedure to quantify neutralisation in unstressed position.

3.2.3.1 MANOVA and the Pillai score

Despite the fact that Euclidean distances between means or medians have often been used to measure differences or similarities between vowels, I shall avoid this technique as it cannot quantify the overlap—or its complement, the symmetric difference—between two sets of tokens. Instead, I use multivariate analysis of variance (MANOVA) to compare vowel token sets as trivariate objects, and further propose a method of quantifying divergences within individual parameters as weighted symmetric differences between their probability density estimates. MANOVA is used, as a rule, in investigating independent variable effects on *two or more* dependent variables, in order to reduce the risk of Type I error that would otherwise ensue from conducting only separate univariate tests for each dependent variable (Warne 2014).

Hay et al. (2006) were the first to quantify vowel merger using Pillai's trace, a common MANOVA statistic which has since been employed to compare vowel distributions in a growing body of work (Hall-Lew 2010; Sloos 2013; Amengual and Chamorro 2015; Renwick and Olsen 2017; Diskin et al. 2019; Mairano et al. 2019; Sabev and Payne 2019, to list but a few). Pillai's trace (Λ), also known as the Pillai–Bartlett trace, is the trace of the matrix defined by the ratio of between-group variance B to total variance T, given by (3.6),

$$\Lambda = \text{trace}\left(\frac{B}{T}\right) = \sum_{i=1}^{p} \frac{\lambda_i}{1+\lambda_i} \tag{3.6}$$

where $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$ are the eigenvalues of B/W in which W is the within-group variance (Manly and Alberto 2017: 66–69; Indira et al. 2015). Olson (1976) compares four common MANOVA statistics—Roy's largest root, Hotelling–Lawley trace, Wilks' lambda and Pillai's trace—and concludes that Pillai's trace is to be recommended for general use, as it is highly robust to many violations of MANOVA assumptions.

Pillai's trace has, as a rule, been referred to as the 'Pillai *score*' in the linguistic literature and I shall adopt this label as well; I also substitute the symbol Λ for the more usual V, since I regularly use V for 'vowel'. Λ can range from 0 to 1 and a high value means a high amount of separation between the token sets, since the between-group variance is large compared to the total variance. In other words, $\Lambda = 1$ would indicate that there is no overlap between the token clusters being compared, whereas $\Lambda = 0$, which normally will be coupled with a non-significant p-value, would mean that there is not a significant difference. I interpret the Pillai score from a MANOVA comparing the *stressed and unstressed* token sets of a vowel phoneme as a direct measure of Unstressed Vowel Shift:

$$\textbf{Unstressed Vowel Shift} = \Lambda\left(\begin{bmatrix} +\texttt{syllabic} \\ \alpha\,\texttt{high} \\ \beta\,\texttt{back} \\ \gamma\,\texttt{round} \\ +\texttt{stress} \end{bmatrix}, \begin{bmatrix} +\texttt{syllabic} \\ \alpha\,\texttt{high} \\ \beta\,\texttt{back} \\ \gamma\,\texttt{round} \\ -\texttt{stress} \end{bmatrix}\right) \tag{3.7}$$

Similarly, a Pillai score obtained by comparing the stressed or unstressed tokens of *open and close* vowels in a height-contrasting pair is taken as a straightforward quantification of contrast:

$$\textbf{Contrast} = \Lambda\left(\begin{bmatrix} +\texttt{syllabic} \\ +\texttt{high} \\ \alpha\,\texttt{back} \\ \beta\,\texttt{round} \\ \gamma\,\texttt{stress} \end{bmatrix}, \begin{bmatrix} +\texttt{syllabic} \\ -\texttt{high} \\ \alpha\,\texttt{back} \\ \beta\,\texttt{round} \\ \gamma\,\texttt{stress} \end{bmatrix}\right) \tag{3.8}$$

In current phonetic research, for instance in the work listed above but not only, lower Pillai scores are generally equated with higher degrees of overlap between vowels, or with more advanced merger. In Sabev and Payne (2019) we took a step further and used the *complement* to the Pillai score for contrast between open and close unstressed vowels, $1 - \Lambda(\check{V}_o, \check{V}_c)$, as a direct measure of contrast *neutralisation*, or merger, in unstressed position. However, there are at least two reasons why a raw Pillai score, or its complement, may in fact not be an optimal index of merger. First of all, a significant MANOVA means that the null hypothesis—that the token sets being compared are identical—should be rejected, and a higher Pillai score is then indeed indicative of greater separation. A non-significant MANOVA, on the other hand, which will always have a very low Pillai score, only shows that the null hypothesis cannot be rejected; it does not prove that we are dealing with completely overlapping clusters. Secondly, and more importantly from a linguistic point of view, any two clouds of vowel tokens in the acoustic space that represent distinct but adjacent phonemes are bound to exhibit some degree of overlap. How much overlap is tolerated of course depends on many factors, such as the size and shape of the inventory, speech rate, prosodic prominence, perceptual factors, and perhaps functional load and the potential for lexical ambiguity.

For these reasons a modified quantitative definition of neutralisation has been adopted here, which is the ratio of the difference of the contrast in stressed and unstressed position, to the contrast in stressed position:

$$\textbf{Neutralisation} = \frac{\Lambda(\acute{V}_o,\acute{V}_c) - \Lambda(\breve{V}_o,\breve{V}_c)}{\Lambda(\acute{V}_o,\acute{V}_c)} \tag{3.9}$$

To take an example, the contrast between East Bulgarian /ɛ/ and /i/ is $\Lambda = 0.85$ in stressed and 0.04 in unstressed position. I quantify the neutralisation in unstressed position as $(0.85 - 0.04)/0.85 = 0.81/0.85 \approx 0.95$. For East Bulgarian /ɔ, u/ the contrast is $\Lambda = 0.48$ when stressed and 0.15 when unstressed, so the amount of neutralisation is $(0.48 - 0.15)/0.48 = 0.33/0.48 \approx 0.69$. In other words, the observed *loss of contrast* is 95 per cent for /ɛ, i/ and 69 per cent for /ɔ, u/.

The Pillai statistic and the neutralisation ratios derived from it are continuous output variables that I employ extensively to compare vowels and vowel pairs within individual dialects in the experimental chapters that follow (4–8), as well as for cross-varietal comparisons in much of Chapter 9. In § 9.4, on the other hand, I propose a method of grouping Pillai scores and neutralisation ratios into linguistically meaningful categories, without comparative reference to other vowels. This is done by mapping the continuous output values onto categorical output variables estimated from the same inputs (duration, F_1' and F_2' frequency) using the ***k*-nearest-neighbours** algorithm.

3.2.3.2 Discriminant function analysis

Of all 68 MANOVAs that were performed, 66 produced significant results. Discriminant function analysis (DFA) was then applied as a post hoc test in order to determine the contribution of each acoustic parameter in distinguishing between stressed and unstressed or open and close vowels. The roles of MANOVA variables are reversed in DFA: we are now interested how duration, F_1' and F_2' values as *independent* variables affect group membership (stressed/unstressed or open/close), the *dependent* variable. DFA creates a set of uncorrelated prediction equations based on the independent variables and combines them into a new latent variable, or discriminant function, that is used to classify individual data points (tokens) into groups. Two types of coefficient are computed: a Standardised

Discriminant Function Coefficient (SDFC) and a Structure Coefficient (SC). The SDFC of a variable is its weight in the discriminant function, while its SC is its correlation with the discriminant function. Neither coefficient on its own, however, indicates which parameter is more 'important' for distinguishing between the groups. To obtain a measure of relative importance the two coefficients must be multiplied with each other to produce a statistic known as a Parallel Discriminant Ratio Coefficient (PDRC) (Thomas 1992; Warne 2014).

The PDRCs for individual variables always sum to one and are, on most occasions, straightforward indicators of relative importance, or contribution. However, PDRCs may, albeit rarely, have negative values, which cannot be interpreted in any meaningful way. Thomas (1992) proposes an indicator of 'lack of importance', defined as a PDRC less than half the mean of all absolute PDRC values.[5] Notice that this threshold will be different from $\mathbf{0.1\dot{6}}$ only if there is a negative PDRC. I adopt this recommendation and apply a threshold of negligibility θ, such that

$$\theta = 0.5\,\overline{|\,\text{PDRC}\,|} \tag{3.10}$$

When reporting DFA results, I give the SDFC, SC and PDRC for each parameter, as well as an adjusted PDRC, obtained by levelling any negligible PDRCs ($< \theta$) down to zero, and adjusting any remaining non-negligible PDRCs ($\geq \theta$) so that they sum to one while keeping the original ratio between them unchanged. I interpret the adjusted PDRC, w, as the relative importance, or **weight**, of the acoustic parameter in discriminating between two token sets (stressed vs unstressed or open vs close).

Table 3.2 gives examples of MANOVA and DFA results for Unstressed Vowel Shift. The amount of Unstressed Vowel Shift in West Bulgarian /a/, $\Lambda = 0.6411$, is considerably greater than in /ə/, $\Lambda = 0.1377$. The adjusted PDRCs indicate that the little difference there is between stressed and unstressed /ə/ is wholly attributable to duration, whereas for /a/ duration and F_1' contribute 1/3 and 2/3 of the difference, respectively, while F_2' plays no role.

[5] Thomas (1992) further warns against applying this concept of importance if a negative PDRC has a non-negligible absolute value, but none of my DFAs yielded such PDRCs.

	MANOVA			Discriminant function analysis				
	p	Λ		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
ə́, ə̆	0.000	0.1377	*Duration*	-0.93	-0.90	0.84	0.17	1
			F_1'	-0.17	-0.26	0.05		
			F_2'	-0.45	-0.26	0.12		
á, ă	0.000	0.6411	*Duration*	0.43	0.73	0.32	0.17	0.33
			F_1'	0.74	0.88	0.65		0.67
			F_2'	0.14	0.23	0.03		

Table 3.2: MANOVA and DFA results for West Bulgarian S/U /ə/ and /a/.

3.2.3.3 Probability densities

Having established the global (multivariate) differences between token sets and the relative importance of each acoustic parameter, I next undertake a closer inspection of differences between individual parameters by comparing their probability density functions.

Probability densities were estimated at 1024 equally spaced points using Gaussian kernels. The kernel bandwidth, or smoothing parameter, h was selected by applying Silverman's (1998: 47–48) 'rule of thumb' given in (3.11), which is the product of (a) a constant factor 0.9, (b) whichever is smaller of (b') the standard deviation, SD, and (b'') the interquartile range, IQR, divided by 1.34, and (c) the sample size n to the negative one-fifth power.

$$h = 0.9 \min\left(\text{SD}, \frac{\text{IQR}}{1.34}\right) n^{-\frac{1}{5}} \tag{3.11}$$

This optimal bandwidth estimator is designed to cope with both unimodal and 'moderately bimodal' densities (Silverman 1998: 47).

The probability density estimates (PDEs) for token sets under comparison were plotted against each other and supplemented with a number of associated statistics. Figure 3.2 illustrates the graphic digests that were compiled to summarise Unstressed Vowel Shift for each phoneme. This type of diagram is also used for contrast and neutralisation. The summary statistics at the top of PDEs for duration, F_1' and F_2' frequencies are the relative weight w of the acoustic parameter in distinguishing the two token sets; this is followed by the symmetric difference Δ between the two PDEs, which is explained below, and allophone-specific central tendencies: mean, median and mode. The mode

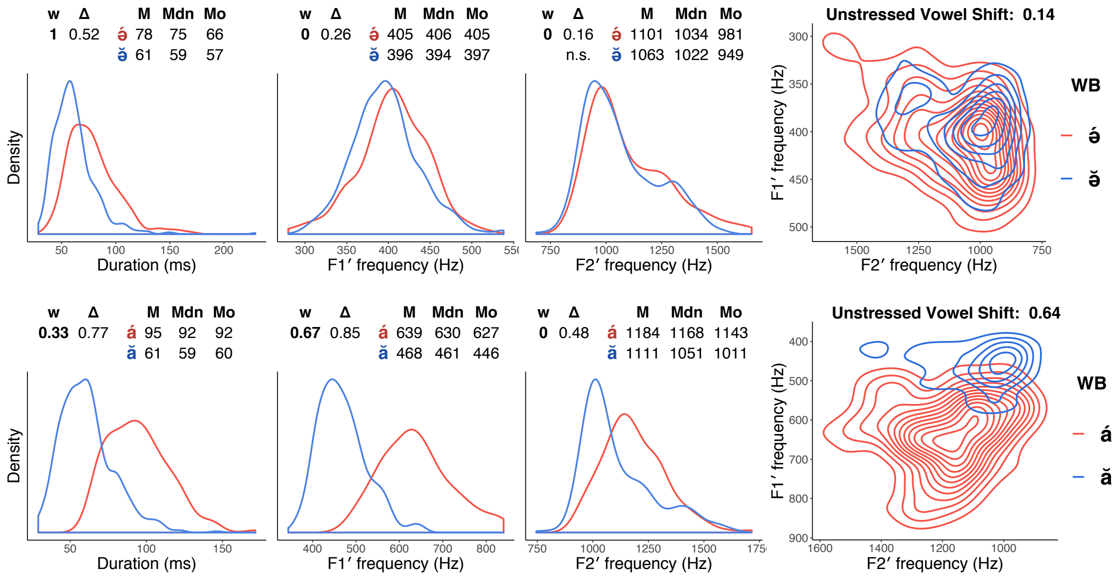


Figure 3.2: Probability density estimates (West Bulgarian /ə, a/). ***w*Δ** weighted symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **Unstressed Vowel Shift** = Pillai score.

value represents the abscissa point at which the highest density was estimated in the corresponding PDE. The two-dimensional contour maps of $F_1' \times F_2'$ estimates were plotted using 100 grid points in each direction. The Unstressed Vowel Shift index for each vowel is the Pillai score of a comparison of the stressed and unstressed token sets based on duration, F_1' and F_2' frequencies, as explained above.

While such plots of overlapping PDEs provide a good basis for visual assessment, it would be beneficial to quantify differences between estimates. I applied two distinct quantitative techniques. First, I adopted Bowman and Azzalini's (1997: 107–111) test of equal densities, which computes an empirical p-value through a permutation test. An integrated squared error statistic is used to compare two PDEs, $\hat{f}$ and $\hat{g}$:

$$\int \{\hat{f}(y) - \hat{g}(y)\}^2 dy \tag{3.12}$$

The integral is approximated numerically, 'using density estimates which are evaluated over a finely spaced grid along the horizontal axis' (ibid., 108). Rather than selecting individual optimal bandwidths, the geometric mean of the two is used in the construction of both PDEs, in order to ensure that the contrast of the PDEs, $\hat{f} - \hat{g}$, will have mean 0 under the null hypothesis, $H_0 : f(y) = g(y)$, for all y. The permutation procedure applied to obtain an empirical p-value for the difference between two PDEs is described as follows.

> The distributional properties of the test statistic are difficult to establish when the null hypothesis is of such a broad form, with no particular shape specified for the common underlying density. A similar situation holds with a more familiar form of nonparametric testing, when ranks are used as the basis of analysis. In a two-sample problem the distribution of the sum of the ranks of one set of observations within the joint sample can be calculated easily. A similar approach in the present setting is to condition on the observed data and to permute the labels which identify each observation with a particular group. Under the null hypothesis, the allocation of group labels is entirely random, since both groups of data are generated from the same underlying density function. The distribution of statistic (3.12) under the null hypothesis can therefore be constructed easily by evaluating the statistic on data produced by random permutation of the group labels. The empirical significance of the statistic calculated from the original data is then simply the proportion of simulated values which lie above it.
>
> (Bowman and Azzalini 1997: 109)

Bowman and Azzalini (1997) was published with a companion library for S-Plus—sm (**s**moothing **m**ethods)—which has since been ported to an R package of the same name (Bowman and Azzalini 2018). I computed *p*-values for significance of differences between PDE pairs using the sm package for R, based on a simulation size of 1000 and estimates calculated at 1024 equally spaced points. The *p*-values thus obtained are reported in the PDE summary tables in Appendix B. Non-significant differences are also indicated as 'n.s.' in the second line of the Δ column in PDE diagrams like Figure 3.2, as in the case of F_2' frequency for West Bulgarian stressed and unstressed /ə/, for example.

Each global significance test also generates a graphical display, in which the PDEs are shown along with a superimposed 'reference band which is centred at the average of the two curves and whose width at the point y is two standard errors' (Bowman and Azzalini 1997: 110). For any significant test of equal densities, at least one of the PDE curves will lie outside the reference band at some point. Figure 3.3 shows PDEs with associated reference bands that correspond to the PDEs in Figure 3.2 above. I provide all reference band plots in Appendix B, as they can be useful in locating specific PDE regions that give rise to significant differences. Slight dissimilarities in curve shape may sometimes be observed across the two types of PDE plot as a result of the different

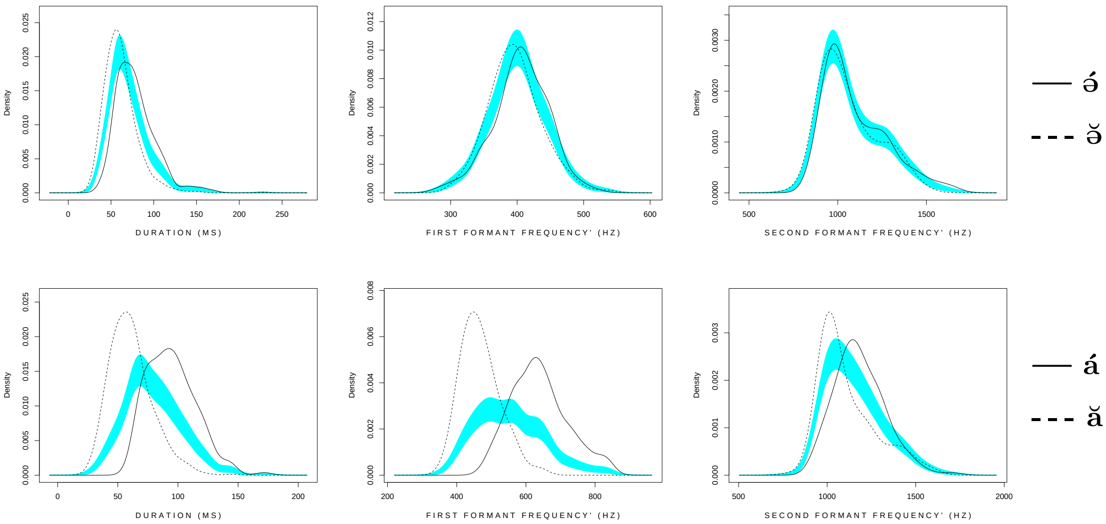


Figure 3.3: Comparative PDEs with reference bands.

smoothing bandwidths used: as pointed out earlier, Bowman and Azzalini's estimates are constructed with averaged, instead of individual, kernel bandwidths.

My final test relating to PDEs aims to quantify the difference between overlapping density estimates of individual parameters (duration, F_1', F_2' frequency), such as those diagrammed in the three left-hand panels of Figure 3.2. I compute the proportion of symmetric difference between two PDEs, that is, the proportion of the total area that belongs to either of the PDEs but not to both. If the overlap of two PDEs η is defined as the proportion of the area that belongs to *both*, then the symmetric difference Δ is its complement: $\Delta = 1 - \eta$. I used the overlapping index $\boldsymbol{\eta}$ as defined by Pastore and Calcagní (2019):[6]

> [L]et us assume two real probability density functions $f_A(x)$ and $f_B(x)$. The overlapping index $\eta : \mathbb{R}^n \times \mathbb{R}^n \rightarrow [0, 1]$ is defined as follows:
>
> $$\eta(A, B) = \int_{\mathbb{R}^n} \min\left[f_A(x), f_B(x)\right] dx \tag{3.13}$$
>
> where the integral can be replaced by summation in the discrete case. As for any measure of association, $\eta(A, B)$ is normalized to one, with $\eta(A, B) = 0$ indicating that $f_A(x)$ and $f_B(x)$ are distinct (i.e., the support of the distributions of A and B does not present interior points in common). ... [T]he following alternative definition sheds light on how overlapping can work as a

[6] $\delta = \Delta$

dissimilarity measure:

$$\eta(A,B) = 1 - \delta(A,B) \\ = 1 - \left(\frac{1}{2}\int_{\mathbb{R}^n} |f_A(x) - f_B(x)|dx\right) \tag{3.14}$$

(Pastore and Calcagní 2019)

Pastore and Calcagní (2019) propose that η be computed through distribution-free approximation, in order to provide an assumption-free index that can serve as an alternative to classical effect size indices that require distributional assumptions such as symmetry of the distributions or unimodality to be met. The approximation is computed as follows.

> Let $\mathbf{x} = (x_1, \ldots, x_i, \ldots, x_n)$ and $\mathbf{y} = (y_1, \ldots, y_i, \ldots, y_n)$ be realizations of X and Y. Then the unknown densities f_X and f_Y can be estimated via Kernel density estimators:
>
> $$\hat{f}_X(x) = n^{-1}\sum_{i=1}^{n}\mathcal{K}\left(\frac{x - x_i}{\beta}\right) \tag{3.15}$$
>
> $$\hat{f}_Y(y) = n^{-1}\sum_{i=1}^{n}\mathcal{K}\left(\frac{y - y_i}{\beta}\right) \tag{3.16}$$
>
> where $\mathcal{K}$ is the Kernel function (e.g., gaussian, epanechnikov, biweight) and β is the usual bandwidth parameter. Substituting Equations 3.15–3.16 into Equation 3.13 yields the following approximation for the overlapping index:
>
> $$\hat{\eta}(X,Y) = \int_{\mathbb{R}^n} \min\left[\hat{f}_X(z), \hat{f}_Y(z)\right] dz \tag{3.17}$$
>
> where the integral $\int_{\mathbb{R}} f(z)dz$ can be computed numerically (e.g., trapezoidal rule, numerical quadrature) or using the average operator on a discretization of the integration support.
>
> (ibid.)

Overlapping indices were computed with the R package overlapping (Pastore 2018, 2019), in which 'the indefinite integral in the formula is approximated with a sum of definite integrals on all the subintervals/classes defined on z. The definite integrals are finally computed using the well-known trapezoidal rule' (Pastore and Calcagní 2019). Probability densities were estimated at 1024 equally spaced points, using Gaussian kernels with bandwidths determined by Silverman's (1998) estimator given in (3.11) above. I took the complement to each η-value to obtain the symmetric differences Δ reported in the following chapters (i.e., $\Delta = 1 - \eta$).

Numbers in the Δ-columns of PDE diagrams indicate symmetric differences between the PDEs calculated in this way. The results for the vowels I used in the example in Figure 3.2 are repeated below:

West Bulgarian /ə/: $\Delta_{dur} = 0.52$ $\Delta_{F_1'} = 0.26$ $\Delta_{F_2'} = 0.16$

West Bulgarian /a/: $\Delta_{dur} = 0.77$ $\Delta_{F_1'} = 0.85$ $\Delta_{F_2'} = 0.48$

Notice that there is a fair amount of symmetric difference between the F_2' estimates for stressed and unstressed /a/, $\Delta = 0.48$. However, discriminant function analysis has shown that this difference plays a negligible role in distinguishing between this vowel's stress-dependent allophones, i.e. $w = 0$. Each symmetric difference Δ and p-value from a corresponding test of equal densities is calculated for two density estimates without any reference to the rest of the acoustic parameters and their contribution as discriminants. PDE comparisons should not, therefore, be considered in isolation, but in conjunction with the relative weight w of the variable in question.

3.2.3.4 Stressed and unstressed targets

Lindblom's (1963) influential study of vowel reduction establishes a direct relation between vowel duration and the amount of undershoot with respect to the first two formant frequencies. He proposes Equation (3.18) to describe the extent to which target formant frequencies are reached, as a function of vowel duration.

$$F_{n\mathbf{0}} = \kappa \cdot (F_{n\boldsymbol{i}} - F_{n\boldsymbol{t}}) \cdot e^{-\beta\tau} + F_{n\boldsymbol{t}} \tag{3.18}$$

where $F_{n\mathbf{0}}$ = nth formant frequency at vowel midpoint
$F_{n\boldsymbol{i}}$ = nth formant frequency at consonant release
$F_{n\boldsymbol{t}}$ = nth formant target frequency for the vowel
τ = vowel duration
κ, β = constants dependent on consonant place of articulation

Whereas the second formant frequency at the release of the consonant, $F_{2\boldsymbol{i}}$, varies with consonant (place of articulation) and vowel, the first formant frequency at consonant release is fixed at $F_{1\boldsymbol{i}} = 375\,\text{Hz}$, which is motivated as follows. 'The critical value of

375 cps refers to a frequency that, according to spectrographic measurements, the first formant comes close to almost instantaneously after the plosion during the transition from /b–/, /d–/, or /g–/ to a following vowel' (Lindblom 1963). This implies that the place of articulation of a plosive does not affect F_1' frequency at the onset of a following vowel, and predicts that any vowel with a target $F_{1\boldsymbol{t}}$ frequency higher than 375 Hz will undergo F_1' frequency reduction as an exponential function of temporal reduction. The constants κ and β are determined by fitting straight lines through data points on semi-log graphs, and are specific to each consonantal place of articulation. The rules that describe the behaviour of $F_{1\mathbf{0}}$ as a function of duration are summarised in (3.19).

$$\begin{array}{ll} a)\ \text{Labial context:} & F_{1\mathbf{0}} = 1.0\,(375 - F_{1\boldsymbol{t}}) \cdot e^{-0.01\tau} + F_{1\boldsymbol{t}} \\ b)\ \text{Coronal context:} & F_{1\mathbf{0}} = 2.0\,(375 - F_{1\boldsymbol{t}}) \cdot e^{-0.011\tau} + F_{1\boldsymbol{t}} \\ c)\ \text{Dorsal context:} & F_{1\mathbf{0}} = 1.5\,(375 - F_{1\boldsymbol{t}}) \cdot e^{-0.008\tau} + F_{1\boldsymbol{t}} \end{array} \tag{3.19}$$

Thus formulated, the rules would also predict that vowels with target $F_{1\boldsymbol{t}}$ frequencies lower than 375 Hz would undergo an increase in $F_{1\mathbf{0}}$ frequency at shorter durations, had Lindblom (1963) not explicitly ruled that out: 'If the $F_{1\boldsymbol{t}}$ value of a vowel is lower than approximately 375 cps, a reduction of its length (everything else being equal) will not bring about a shift in $F_{1\mathbf{0}}$ away from $F_{1\boldsymbol{t}}$ … If $F_{1\boldsymbol{t}} < 375$ cps, $F_{1\mathbf{0}} = F_{1\boldsymbol{t}}$ in all contexts.'

To estimate whether the stressed–unstressed shift each open vowel undergoes can be explained by gradient undershoot alone, I calculated a **predicted** unstressed frequency, $\hat{F}_1$, using Lindblom's rules in (3.19). My mean unstressed durations served as Lindblom's τ, and for target $F_{1\boldsymbol{t}}$ frequency I used my mean stressed F_1' frequencies for each vowel. As explained in § 3.1.1, the nonsense words in the East Bulgarian, Bilingual Bulgarian and Bilingual Turkish experiments contained bilabial consonants only, so Equation (3.19) (*a*) was applied. In West Bulgarian and Istanbul Turkish, the ratio of word elicitations containing labial : coronal : dorsal consonants was 5 : 1 : 1, so the context constants for these two varieties were calculated as weighted means: $\kappa = (5 + 2 + 1.5)/7 = 1.214286$; $\beta = (5 \times 0.01 + 0.011 + 0.008)/7 = 0.009857143$.

Where the reported mean unstressed F_1' frequency does not fall below the value thus predicted on the basis of the stressed frequency and unstressed duration, $\bar{F_1'} \geq \hat{F_1}$, Unstressed Vowel Shift can be accounted for by gradient undershoot. A decrease in F_1' frequency that exceeds the undershoot predicted for that vowel at that duration, on the other hand, would suggest that a separate unstressed target is likely to be present, as the shift cannot be wholly attributed to gradient undershoot. Three values are reported for each open vowel: the predicted unstressed $\hat{F_1}$ frequency, the observed mean unstressed $\bar{F_1'}$ frequency, and the residual value, $\bar{F_1'} - \hat{F_1}$. A negative residual indicates that the actual amount of F_1' frequency reduction is greater than the predicted effect of undershoot.

4
West Bulgarian

Contents

4.1 Mean comparisons and correlations

4.1.1 Means and distributions

Group means and standard deviations for the duration and normalised F_1 and F_2 frequencies of stressed and unstressed West Bulgarian vowels are listed in Table 4.1. Table 4.2 shows the same parameters for vowels in separate syllables: unstressed positions are broken down into initial (σ_1), pretonic (σ_2) and final (σ_4) syllables.[1]

[1] Subscript numbers indicate the ordinal positions of syllables within a word, e.g. σ_2, V_2, [u_2] (i.e. /u/ in the second syllable). Subscripts separated by a colon refer to differences or comparisons of vowels in the syllables indicated, e.g. [$ə_{2:4}$]: difference between [$ə_2$] and [$ə_4$].

Phoneme	Stress	n	Duration (ms) Mean	Duration (ms) SD	F_1' (Hz) Mean	F_1' (Hz) SD	F_2' (Hz) Mean	F_2' (Hz) SD
/i/	+	168	79.22	21.23	312	46	1983	204
	−	504	65.42	21.19	310	36	1973	195
/ɛ/	+	168	86.86	20.17	424	34	1615	192
	−	504	61.57	18.82	387	36	1528	192
/ə/	+	168	78.36	22.78	405	42	1101	179
	−	504	61.45	19.62	396	40	1063	162
/a/	+	168	94.74	20.16	639	82	1184	142
	−	504	60.93	17.34	468	56	1111	163
/u/	+	168	75.94	21.51	379	45	1079	541
	−	504	63.67	21.98	369	34	930	281
/ɔ/	+	168	88.96	19.70	462	43	878	95
	−	504	59.81	19.71	386	37	847	162

Table 4.1: Group means and standard deviations for West Bulgarian vowel duration, F_1' and F_2' by stress.

Phoneme	σ	n	Duration (ms) Mean	Duration (ms) SD	F_1' (Hz) Mean	F_1' (Hz) SD	F_2' (Hz) Mean	F_2' (Hz) SD
/i/	*1.*	168	63.70	18.29	311	39	2010	200
	2.	168	62.88	18.31	309	32	1983	177
	3.	168	79.22	21.23	312	46	1983	204
	4.	168	69.69	25.59	310	37	1925	198
/ɛ/	*1.*	168	61.50	17.95	384	27	1556	196
	2.	168	58.12	16.19	374	30	1538	191
	3.	168	86.86	20.17	424	34	1615	192
	4.	168	65.09	21.42	402	44	1489	182
/ə/	*1.*	168	57.43	17.56	392	31	1092	169
	2.	168	59.82	14.99	388	36	1015	151
	3.	168	78.36	22.78	405	42	1101	179
	4.	168	67.10	23.98	409	48	1082	156
/a/	*1.*	168	62.85	17.35	478	66	1155	170
	2.	168	57.96	17.58	456	52	1074	155
	3.	168	94.74	20.16	639	82	1184	142
	4.	168	61.97	16.80	472	45	1106	154
/u/	*1.*	168	61.92	21.39	372	27	966	333
	2.	168	60.55	18.43	365	33	984	291
	3.	168	75.94	21.51	379	45	1079	541
	4.	168	68.55	24.91	369	41	840	172
/ɔ/	*1.*	168	64.35	21.35	382	28	846	133
	2.	168	53.59	16.69	376	31	841	175
	3.	168	88.96	19.70	462	43	878	95
	4.	168	61.48	19.31	400	45	853	176

Table 4.2: Group means and standard deviations for West Bulgarian vowel duration, F_1' and F_2' by syllable. **σ** syllable: *1.* initial, *2.* pretonic, ***3.*** stressed, *4.* final.

4.1.1.1 Duration

Syllable-specific distributions of West Bulgarian vowel duration data points are shown in Figure 4.1. The shaded curves around box-plots ('violin plots') are (mirrored) probability density estimates (PDEs), greater width across the shape representing higher probability density. PDEs, discussed in § 3.2.3.3 above, can be thought of as smoothed histograms, and are predicted to match real-life continuous distributions more closely.

As expected, West Bulgarian vowels are invariably longer in stressed (σ_3) than in unstressed syllables. For the close vowels, /i, ə, u/, as well as /ɛ/, there is no (significant) difference between first- and second-syllable allophones, while V_4 is significantly longer than V_1 and V_2 for all vowels except /a, ɔ/, where there is no difference between V_4 and V_1, both being longer than V_2. West Bulgarian pretonic (σ_2) vowels, overall, have the shortest duration.

4.1.1.2 F_1' frequency

Figure 4.2 shows F_1' frequency distributions and PDEs by syllable. As predicted, F_1' frequency is higher in stressed than in unstressed syllables for the open vowels, /ɛ, a, ɔ/. Where significant differences are found between V_2 and other unstressed positions (/ɛ, a, ɔ/, [$ə_{2:4}$] and [$u_{1:2}$]), V_2 has lower F_1', which tallies with the shortest duration observed in the same syllable. Another parallel with duration is that F_1' values for V_4 tend to be significantly higher than in other unstressed syllables: this is the case with all open vowels and /ə/ (except for [$a_{1:4}$] showing no significant difference).

4.1.1.3 F_2' frequency

Figure 4.3 shows syllable-specific F_2' distributions and PDEs. All unstressed vowels except /ɔ/ exhibit some degree of retraction: F_2' frequency is lower in unstressed allophones of /ɛ/ and /a/ (especially [a_2]), as well as in [$ə_2$] and possibly [i_4, u_4].

The significance levels indicated in Figures 4.1, 4.2 and 4.3 are from the *t*-tests reported in § 4.1.3 below. Several *t*-tests yielded significant results, while the corresponding ANOVA outputs (§ 4.1.2) were non-significant; this is the case where significance levels are shown in brackets.

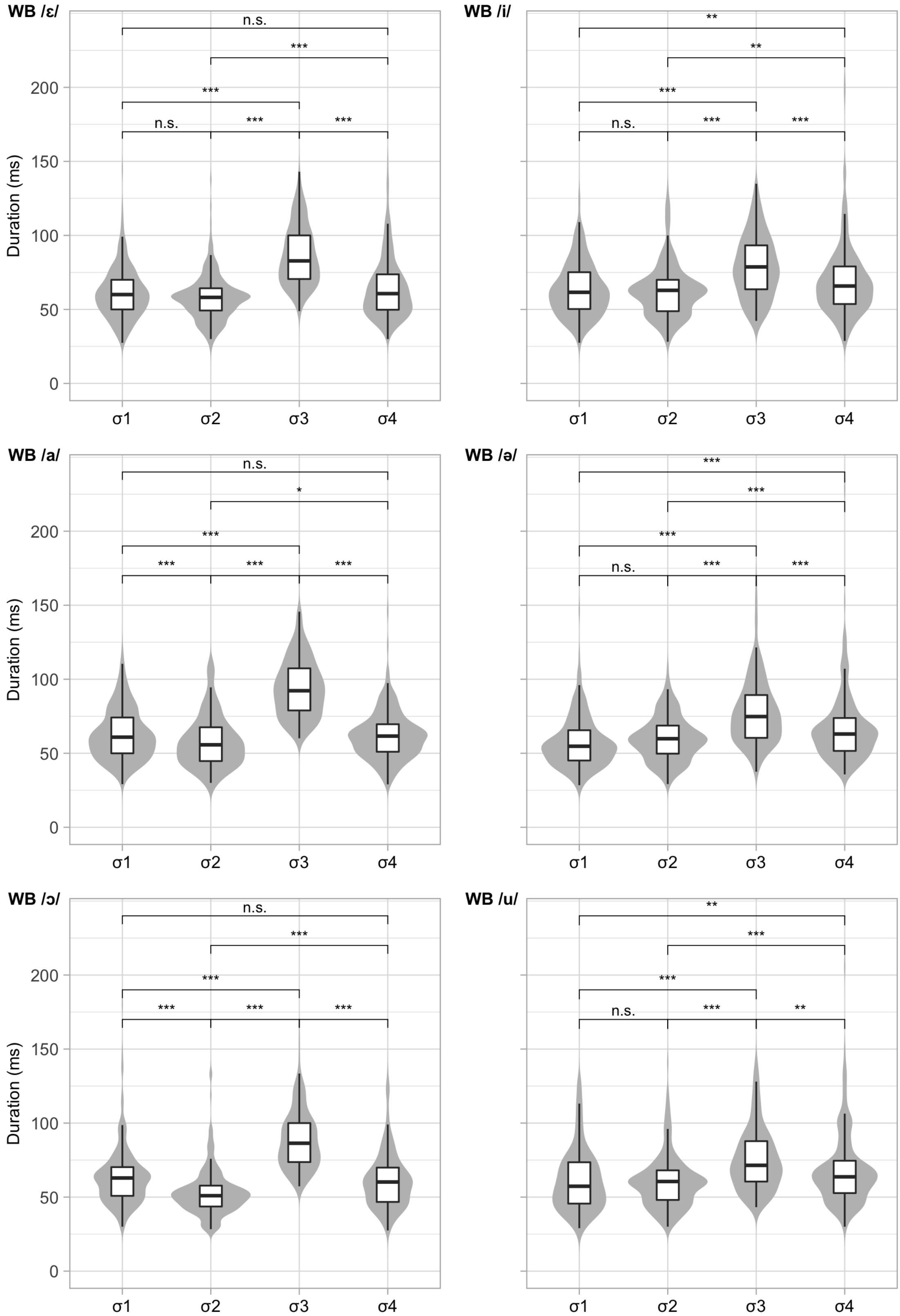


Figure 4.1: Distribution of duration in West Bulgarian (WB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 4.1.3.

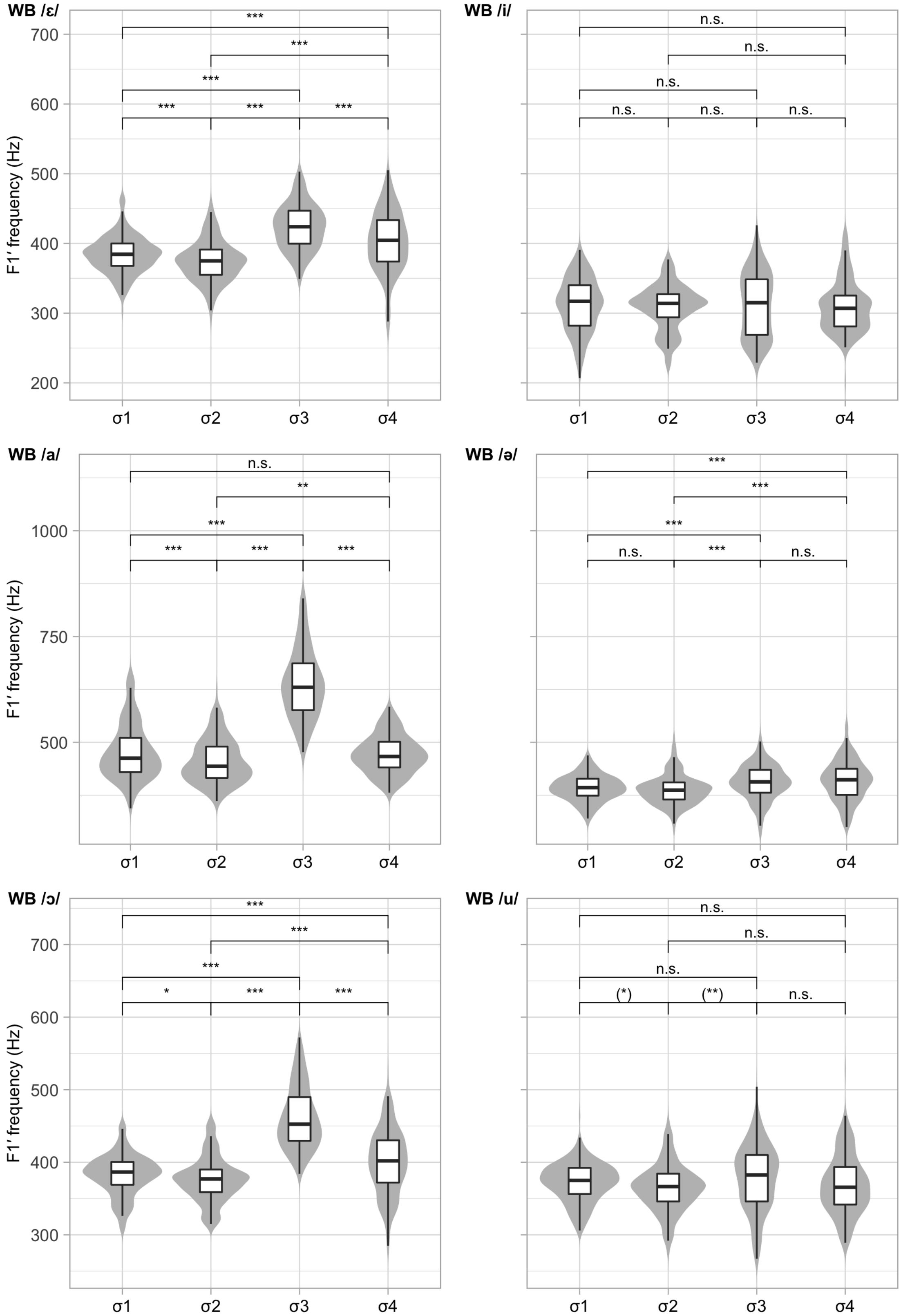


Figure 4.2: Distribution of F_1' frequency in West Bulgarian (WB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 4.1.3; where in brackets, ANOVA n.s. (§ 4.1.2).

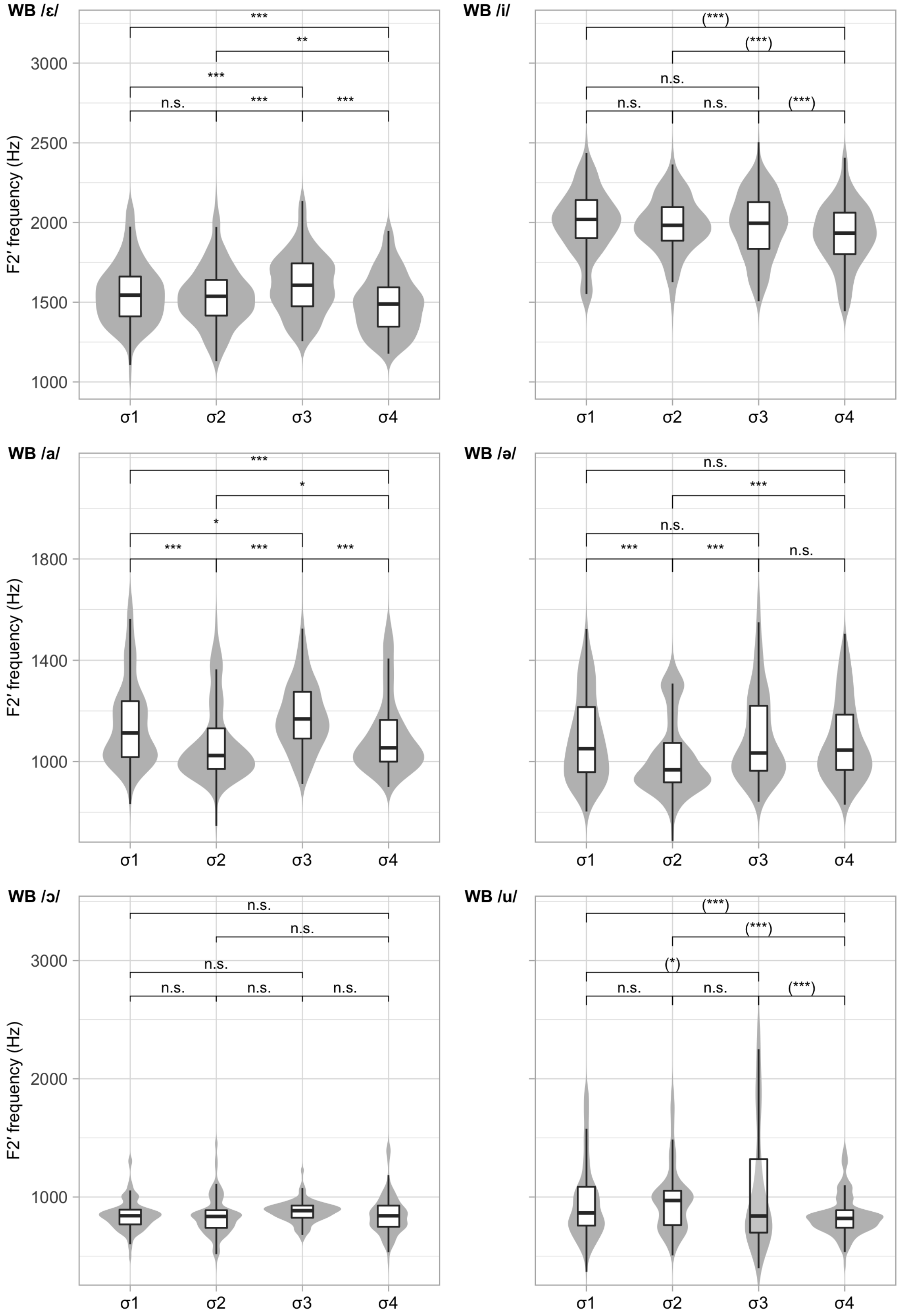


Figure 4.3: Distribution of F_2' frequency in West Bulgarian (WB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 4.1.3; where in brackets, ANOVA n.s. (§ 4.1.2).

4.1.2 Analysis of variance

A repeated-measures ANOVA was run for each vowel phoneme, with 'speaker' as case identifier, 'syllable' $(1, 2, 3, 4)$ as independent variable and each of the acoustic parameters (duration, F_1', F_2') as dependent variables. Wherever the assumption of sphericity was violated (i.e., Mauchly's test was significant), Greenhouse-Geisser correction ($\hat{\varepsilon}$) was used to adjust degrees of freedom and p-values. The results are listed in Table 4.3; the main effects can be summarised as follows. A highly significant effect on duration ($p \leq 0.001$) is found in all West Bulgarian vowel phonemes except /u/, where $p = 0.0021$ after Greenhouse-Geisser

***A.* Duration**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df$_1$	df$_2$	F	p	sig.	η^2
/i/	0.47	0.7381	n.s.		3	33	27.77	0.0000	***	0.26
/ɛ/	0.29	0.4753	n.s.		3	33	36.04	0.0000	***	0.61
/ə/	0.40	0.6421	n.s.		3	33	26.83	0.0000	***	0.46
/a/	0.44	0.6987	n.s.		3	33	67.22	0.0000	***	0.76
/u/	0.04	0.0375	*	0.55	1.66	18.30	15.24	0.0021	**	0.26
/ɔ/	0.23	0.3760	n.s.		3	33	53.86	0.0000	***	0.65

***B.* F_1' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df$_1$	df$_2$	F	p	sig.	η^2
/i/	0.57	0.8385	n.s.		3	33	0.11	0.9508	n.s.	0.00
/ɛ/	0.28	0.4623	n.s.		3	33	25.81	0.0000	***	0.57
/ə/	0.46	0.7206	n.s.		3	33	3.45	0.0438	*	0.16
/a/	0.01	0.0028	**	0.36	1.08	11.89	28.68	0.0022	**	0.79
/u/	0.49	0.7566	n.s.		3	33	1.53	0.2474	n.s.	0.08
/ɔ/	0.14	0.2169	n.s.		3	33	47.02	0.0000	***	0.72

***C.* F_2' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df$_1$	df$_2$	F	p	sig.	η^2
/i/	0.30	0.4922	n.s.		3	33	2.40	0.1082	n.s.	0.06
/ɛ/	0.15	0.2245	n.s.		3	33	8.02	0.0020	**	0.16
/ə/	0.22	0.3595	n.s.		3	33	7.06	0.0035	**	0.36
/a/	0.31	0.5136	n.s.		3	33	14.31	0.0001	***	0.40
/u/	0.04	0.0445	*	0.40	1.19	13.12	2.44	0.1703	n.s.	0.14
/ɔ/	0.72	0.9441	n.s.		3	33	2.19	0.1322	n.s.	0.09

Table 4.3: Repeated-measures ANOVAs for the effect of 'syllable' on vowel duration, F_1' and F_2', for each West Bulgarian phoneme, with 'speaker' as case identifier. **GG** Greenhouse-Geisser correction; **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

correction for sphericity violation. The effect on F_1' frequency is highly significant for /ɛ/ and /ɔ/; for the other open vowel, /a/, the Greenhouse-Geisser correction brought the p-value down from a highly significant level to 0.0022. There is not a significant main effect on F_1' for the close vowels /i/ and /u/, while for /ə/ the effect is just significant ($p = 0.0438$). There are significant effects on F_2' frequency for /ɛ, ə, a/.

4.1.3 Pairwise comparisons

The duration, F_1' and F_2' frequencies of the four syllable-specific allophones of each West Bulgarian phoneme were further examined in order to establish which between-syllable comparisons are likely to have produced significant main effects in the ANOVAs reported above. Dependent t-tests with Bonferroni correction for multiple testing ($\alpha =$

***A.* Duration**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.0000	***	0.0000	***	0.0000	***	1.0000	n.s.	0.0100	**	0.0019	**
/ɛ/	0.0000	***	0.0000	***	0.0000	***	0.1662	n.s.	0.2340	n.s.	0.0002	***
/ə/	0.0000	***	0.0000	***	0.0000	***	0.1463	n.s.	0.0000	***	0.0005	***
/a/	0.0000	***	0.0000	***	0.0000	***	0.0002	***	1.0000	n.s.	0.0326	*
/u/	0.0000	***	0.0000	***	0.0023	**	1.0000	n.s.	0.0029	**	0.0003	***
/ɔ/	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.1957	n.s.	0.0000	***

***B.* F_1' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.
/ɛ/	0.0000	***	0.0000	***	0.0000	***	0.0005	***	0.0000	***	0.0000	***
/ə/	0.0005	***	0.0001	***	1.0000	n.s.	1.0000	n.s.	0.0000	***	0.0000	***
/a/	0.0000	***	0.0000	***	0.0000	***	0.0000	***	1.0000	n.s.	0.0027	**
/u/†	0.3688	n.s.	0.0012	**	0.1393	n.s.	0.0109	*	1.0000	n.s.	1.0000	n.s.
/ɔ/	0.0000	***	0.0000	***	0.0000	***	0.0170	*	0.0000	***	0.0000	***

***C.* F_2' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/†	0.4844	n.s.	1.0000	n.s.	0.0002	***	0.4575	n.s.	0.0000	***	0.0003	***
/ɛ/	0.0008	***	0.0000	***	0.0000	***	0.8023	n.s.	0.0000	***	0.0027	**
/ə/	1.0000	n.s.	0.0000	***	1.0000	n.s.	0.0000	***	1.0000	n.s.	0.0000	***
/a/	0.0297	*	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0220	*
/u/†	0.0324	*	0.0954	n.s.	0.0000	***	1.0000	n.s.	0.0000	***	0.0000	***
/ɔ/	0.0783	n.s.	0.1106	n.s.	0.5044	n.s.	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.

Table 4.4: Pairwise comparisons of West Bulgarian syllable-specific allophones (dependent t-tests with Bonferroni correction). **σ** syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$. † ANOVA n.s. (§ 4.1.2).

0.05/4 = 0.0125) were used. The results are listed in Table 4.4 and the significance levels thus obtained are also shown in Figures 4.1, 4.2 and 4.3. In three cases, indicated with † in the table, the *t*-tests produced significant results, while the corresponding ANOVAs (§ 4.1.2) were non-significant.

4.1.4 Correlations

Pearson product-moment correlations between duration and the formant frequencies, calculated for West Bulgarian syllable-specific allophones, are listed in Table 4.5. Where significant, correlations with F_1' are all positive. There are predominantly significant duration–F_1' correlations in /ɛ/ and /a/, as well as in half of the /ɔ/ allophones, which

			Duration–F_1'				Duration–F_2'			
	σ	n	r	size	p	sig.	r	size	p	sig.
/i/	*1.*	168	0.01		0.9330	n.s.	-0.08		0.3070	n.s.
	2.	168	0.02		0.7630	n.s.	-0.02		0.8340	n.s.
	3.	168	-0.11		0.1560	n.s.	0.02		0.7750	n.s.
	4.	168	-0.01		0.8860	n.s.	0.10		0.1890	n.s.
/ɛ/	*1.*	168	0.25	S	0.0010	***	-0.06		0.4800	n.s.
	2.	168	0.33	M	0.0000	***	0.14		0.0790	n.s.
	3.	168	0.21	S	0.0080	**	0.08		0.3020	n.s.
	4.	168	0.32	M	0.0000	***	0.23	S	0.0030	**
/ə/	*1.*	168	0.20	S	0.0090	**	-0.25	S	0.0010	***
	2.	168	0.13		0.0980	n.s.	-0.10		0.1920	n.s.
	3.	168	0.25	S	0.0010	***	-0.29	S	0.0000	***
	4.	168	0.14		0.0810	n.s.	-0.07		0.3920	n.s.
/a/	*1.*	168	0.19	S	0.0160	*	-0.11		0.1540	n.s.
	2.	168	0.31	M	0.0000	***	-0.13		0.0990	n.s.
	3.	168	0.04		0.6110	n.s.	0.18	S	0.0190	*
	4.	168	0.26	S	0.0010	***	-0.03		0.7190	n.s.
/u/	*1.*	168	0.36	M	0.0000	***	-0.15		0.0590	n.s.
	2.	168	0.08		0.3030	n.s.	-0.25	S	0.0010	***
	3.	168	0.26	S	0.0010	***	-0.11		0.1420	n.s.
	4.	168	0.09		0.2470	n.s.	-0.13		0.0870	n.s.
/ɔ/	*1.*	168	0.19	S	0.0120	*	-0.13		0.1070	n.s.
	2.	168	0.02		0.7660	n.s.	-0.08		0.2990	n.s.
	3.	168	-0.13		0.0930	n.s.	-0.15	S	0.0460	*
	4.	168	0.20	S	0.0090	**	-0.11		0.1700	n.s.

Table 4.5: Pearson correlations of duration with F_1' and duration with F_2' in West Bulgarian. **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$; **σ** syllable (*1*, *2*, ***3***, *4*). Effect size (shown where $p \leq 0.05$): **L** large $r \geq 0.5$, **M** medium $r \geq 0.3$, **S** small $r \geq 0.1$ (Cohen 1988: 79–80).

is an indication of gradience within, but not necessarily across, syllables. I address the likelihood of single-target undershoot versus the presence of distinct stressed and unstressed targets in § 4.2.1.4.

Significant correlations with F_2' are only sporadic in West Bulgarian.

4.2 Stress effects

In § 4.1 I addressed each of the three dependent variables separately and measured correlations between duration and each of the formant frequencies. I considered the acoustic parameters in stressed (σ_3), unstressed word-initial (σ_1), pretonic (σ_2) and word-final (σ_4) syllables. The results reported so far suggest that there are considerably greater differences between stressed and unstressed vowels than between unstressed vowels in different syllables, which is not surprising. A differentiated analysis of the three unstressed positions, however, was necessary in order to test the repeated claim that there is a lesser degree of unstressed vowel reduction in pretonic syllables than elsewhere, which I discuss in § 4.3.

I now turn to a more global examination of similarities and differences between stressed and unstressed vowels. The main analytical tools I shall use for this purpose, described in detail in Chapter 3, are multivariate analysis of variance (MANOVA), post hoc discriminant function analysis and comparisons of probability density estimates.

4.2.1 Unstressed Vowel Shift

4.2.1.1 MANOVA (1)

MANOVAs were performed for each vowel phoneme to examine the effect of stress on the dependent variables (duration, F_1', F_2'). Highly significant effects ($p \leq 0.001$) were obtained for all West Bulgarian vowels. Results are shown in Table 4.6. The Pillai score (Λ) here is interpreted as a measure of distinctness between stressed and unstressed allophones, potentially ranging from 0 (no difference) to 1 (no similarity). As revealed by this index, stressed–unstressed differences are largest in /a/ and /ɔ/, smaller in /ɛ/, and considerably smaller in the close vowels, /i, ə, u/.

	df_1	df_2	F	p	sig.	**UVS** $= \Lambda$
í, ĭ	3	668	18.09	0.0000	***	0.0751
έ, ɛ̆	3	668	101.35	0.0000	***	0.3128
ə́, ə̆	3	668	35.55	0.0000	***	0.1377
á, ă	3	668	397.67	0.0000	***	0.6411
ú, ŭ	3	668	24.48	0.0000	***	0.0990
ɔ́, ɔ̆	3	668	237.06	0.0000	***	0.5157

Table 4.6: MANOVAs for effect of stress on $dur \times F_1' \times F_2'$ in each West Bulgarian vowel phoneme. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$; **UVS** Unstressed Vowel Shift; **Λ** Pillai score.

4.2.1.2 Discriminant function analysis (1)

The discriminant function analysis (DFA) of stress-dependent variation in West Bulgarian vowels produced only positive PDRC values (Table 4.7); as a result, the threshold of negligibility, θ, is $1.\dot{6}$ for all phonemes. The adjusted PDRCs, recalculated after removing negligible PDRCs, show that duration plays a role in distinguishing stressed from unstressed realisations for all vowels, and is the sole contributing acoustic parameter for the close vowels /i/ and /ə/. Both duration and F_1' frequency are important for open vowels: F_1' is roughly twice as important as duration in the case of /a/ and /ɔ/, while for /ɛ/ it is the other way around. The contribution of F_2' is negligible for all vowels but /u/.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
/i/	Duration	0.99	0.99	0.98	0.17	1
	F_1'	0.11	0.09	0.01		
	F_2'	0.07	0.08	0.01		
/ɛ/	Duration	0.65	0.86	0.55	0.17	0.61
	F_1'	0.49	0.71	0.35		0.39
	F_2'	0.29	0.33	0.10		
/ə/	Duration	-0.93	-0.90	0.84	0.17	1
	F_1'	-0.17	-0.26	0.05		
	F_2'	-0.45	-0.26	0.12		
/a/	Duration	0.43	0.73	0.32	0.17	0.33
	F_1'	0.74	0.88	0.65		0.67
	F_2'	0.14	0.23	0.03		
/u/	Duration	-0.79	-0.74	0.59	0.17	0.62
	F_1'	-0.17	-0.36	0.06		
	F_2'	-0.64	-0.55	0.35		0.38
/ɔ/	Duration	-0.53	-0.71	0.37	0.17	0.38
	F_1'	-0.73	-0.85	0.62		0.62
	F_2'	-0.09	-0.12	0.01		

Table 4.7: Discriminant function analysis of stress correlates in West Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

4.2.1.3 Probability densities (1)

Stress-conditioned differences in the probability density estimates (PDEs) of duration, F_1' and F_2' frequencies are summarised in Figure 4.4. The tests of equal densities indicate that all compared PDEs are significantly different, excepting two: F_2' of /i/ and F_2' of /ə/; p-values and PDE diagrams with reference bands showing whether differences between curves are significant can be found in Appendix B. Only non-significant differences are indicated Figure 4.4, as 'n.s.' appearing underneath the Δ score. There are noticeable symmetric differences, Δ, in the F_2' estimates of the open vowels. However, the DFA showed that F_2' plays a negligible part in distinguishing between those stressed and unstressed allophones, $w = 0$.

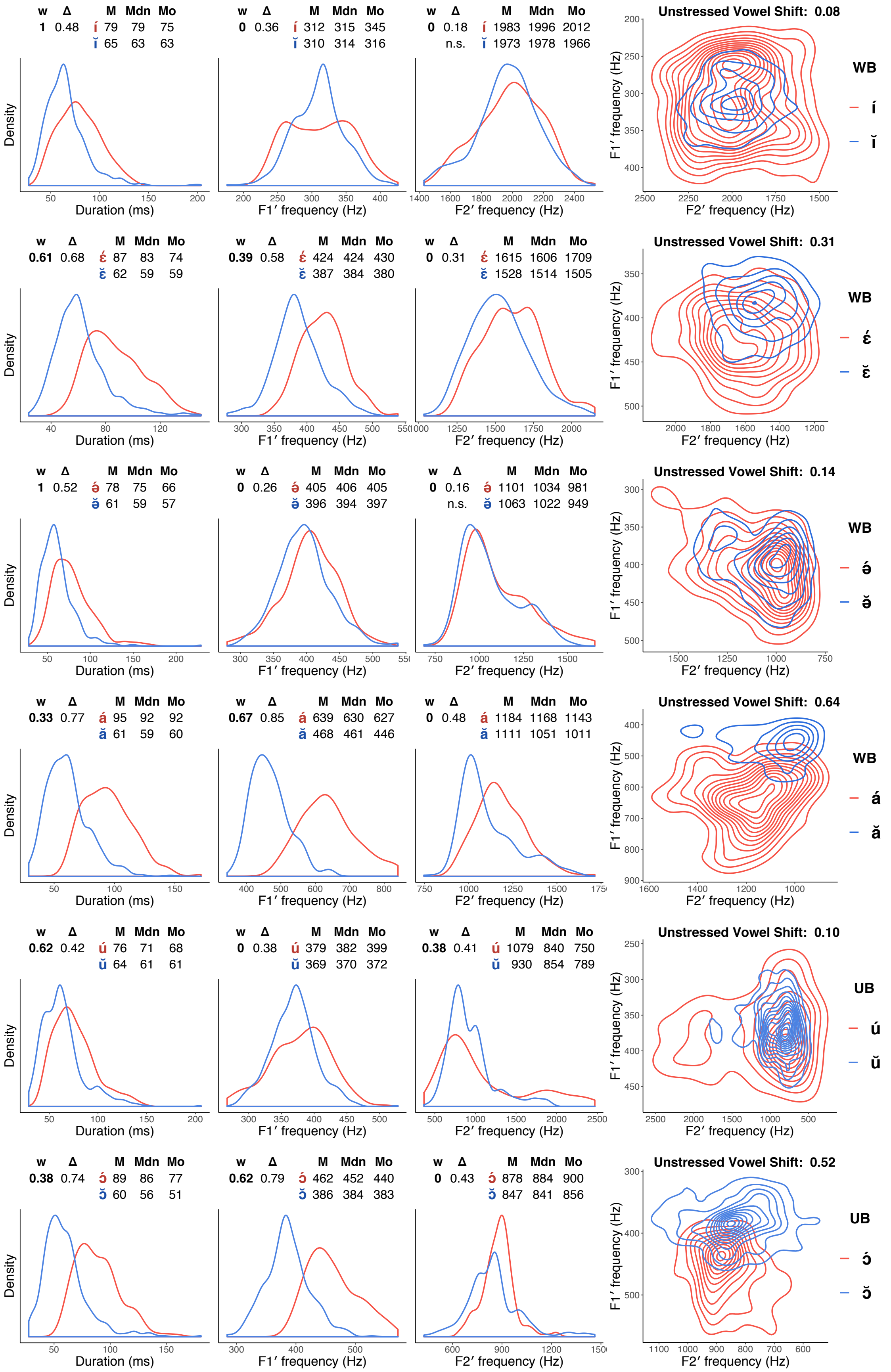


Figure 4.4: PDEs and summary statistics for West B. S/U vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

4.2.1.4 Stressed and unstressed targets

The correlation analysis in § 4.1.4 indicates that gradient undershoot is predominant for open vowels within syllable specific allophones. However, this does not mean that unstressed realisations result from undershoot alone. To verify whether separate stressed and unstressed targets may be in place for the open vowels, I calculated the unstressed $\hat{F}_1$ frequencies predicted from mean stressed F_1' frequencies and mean unstressed durations, using the method described in § 3.2.3.4 (p. 92). Table 4.8 lists the predicted unstressed ($\hat{F}_1$) and observed mean unstressed ($\bar{F}_1'$) frequencies, as well as the corresponding residual values ($\bar{F}_1' - \hat{F}_1$).

	Predicted unstressed $\hat{F}_1$ frequency (Hz)	Observed unstressed $\bar{F}_1'$ frequency (Hz)	Residual value $\bar{F}_1' - \hat{F}_1$
/ɛ/	391.67	386.94	-4.73
/a/	463.06	468.21	5.16
/ɔ/	403.38	386.19	-17.19

Table 4.8: Predicted and observed unstressed F_1' frequencies of West Bulgarian open vowels.

The results show that the highest Unstressed Vowel Shift score in this variety, that of /a/ ($\Lambda = 0.64$), can in fact be attributed to undershoot under temporal pressure, as the observed mean unstressed F_1' frequency is higher than the frequency predicted for the mean unstressed duration, given the canonical (stressed) realisation. At the same time, the Unstressed Shift of West Bulgarian /ɛ/, which has the lowest Pillai score amongst open vowels ($\Lambda = 0.31$), cannot be wholly explained by undershoot, because the observed F_1' frequency reduction exceeds the amount of predicted undershoot (hence the negative residual value). Observed reduction exceeds predicted undershoot in West Bulgarian /ɔ/ as well, by a considerably greater residual value.

It should, however, be noted that the deviations from the $\hat{F}_1$ baseline for /ɛ/ (-4.73) and /a/ ($+5.16$) are small, and speakers may in fact differ in terms of their underlying Unstressed Vowel Shift strategies. I therefore calculated the observed–predicted residuals ($\bar{F}_1' - \hat{F}_1$) for each speaker. For /ɛ/, five out of the twelve participants' mean unstressed F_1' frequency is within the bounds of predicted undershoot (hence positive residuals: 12.86,

$10.18, 7.14, 4.89, 1.57$). The remaining seven participants have negative residuals that are more clearly removed from the $\hat{F}_1$ baseline than the West Bulgarian average (-10.77, -11.24, -12.24, -13.06, -14.62, -15.07, -17.05). With respect to /a/, the speaker count is reversed: there are seven positive ($45.58, 42.09, 28.38, 26.15, 19.76, 16.61, 7.15$) and five negative residual values (-7.39, -8.76, -13.12, -44.95, -46.26). All twelve speaker-specific residual values for West Bulgarian /ɔ/ are negative.

4.2.2 Contrast and neutralisation

4.2.2.1 MANOVA (2)

The outcomes of MANOVAs computed to compare open and close vowels, in both stressed and unstressed positions, are given in Table 4.9. There is considerable unstressed vowel neutralisation, or contrast loss, in the non-front pairs: 50% in /ə–a/ and 78% in /u–ɔ/. West Bulgarian /i–ɛ/, on the other hand, are practically as contrastive in unstressed as in stressed position (only 2% loss).

	df_1	df_2	F	p	sig.	**Contrast** $= \Lambda$	**Loss**
í, ɛ́	3	332	298.18	0.0000	***	0.7293	
ĭ, ɛ̆	3	1004	831.21	0.0000	***	0.7130	0.02
ə́, á	3	332	382.87	0.0000	***	0.7758	
ə̆, ă	3	1004	213.27	0.0000	***	0.3892	0.50
ú, ɔ́	3	332	116.57	0.0000	***	0.5130	
ŭ, ɔ̆	3	1004	41.70	0.0000	***	0.1108	0.78

Table 4.9: MANOVAs for West Bulgarian O/C vowel pairs: effect of height on $dur \times F_1' \times F_2'$. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$; **Λ** Pillai score; **Loss** $= (\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 1 - \breve{\Lambda}/\acute{\Lambda}$.

4.2.2.2 Discriminant function analysis (2)

As can be seen from the discriminant analysis results in Table 4.10, vowels in height-contrasting pairs are primarily distinguished by F_1' frequency, while F_2' is also important for /i–ɛ/ and unstressed [u–ɔ]. Duration does not contribute to the contrast in any of the pairs.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
í, έ	Duration	0.11	0.19	0.02	0.17	
	F_1'	0.74	0.86	0.64		0.65
	F_2'	-0.47	-0.72	0.34		0.35
ĭ, ɛ̆	Duration	-0.13	-0.10	0.01	0.17	
	F_1'	0.62	0.77	0.47		0.48
	F_2'	-0.64	-0.80	0.51		0.52
ə́, á	Duration	-0.12	-0.39	0.05	0.17	
	F_1'	-0.94	-0.96	0.89		1
	F_2'	-0.22	-0.27	0.06		
ə̆, ă	Duration	0.21	0.02	0.00	0.17	
	F_1'	-0.99	-0.94	0.93		1
	F_2'	-0.28	-0.23	0.07		
ú, ɔ́	Duration	-0.20	-0.40	0.08	0.17	
	F_1'	-0.89	-0.92	0.83		1
	F_2'	0.28	0.34	0.09		
ŭ, ɔ̆	Duration	0.48	0.27	0.13	0.17	
	F_1'	-0.78	-0.70	0.55		0.63
	F_2'	0.60	0.53	0.32		0.37

Table 4.10: Discriminant function analysis of phonological vowel height in West Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

4.2.2.3 Probability densities (2)

Probability density diagrams for contrast are displayed in Figure 4.5. There is not a significant difference between the duration PDEs for unstressed [ə–a]; all other differences are significant. There is an appreciable symmetric difference, Δ, between the F_2' estimates for stressed /u–ɔ/, reflecting the wider range that /u/-tokens are spread over. Nonetheless, F_2' frequency does not play an important role as a discriminant between the two stressed vowels ($w = 0$).

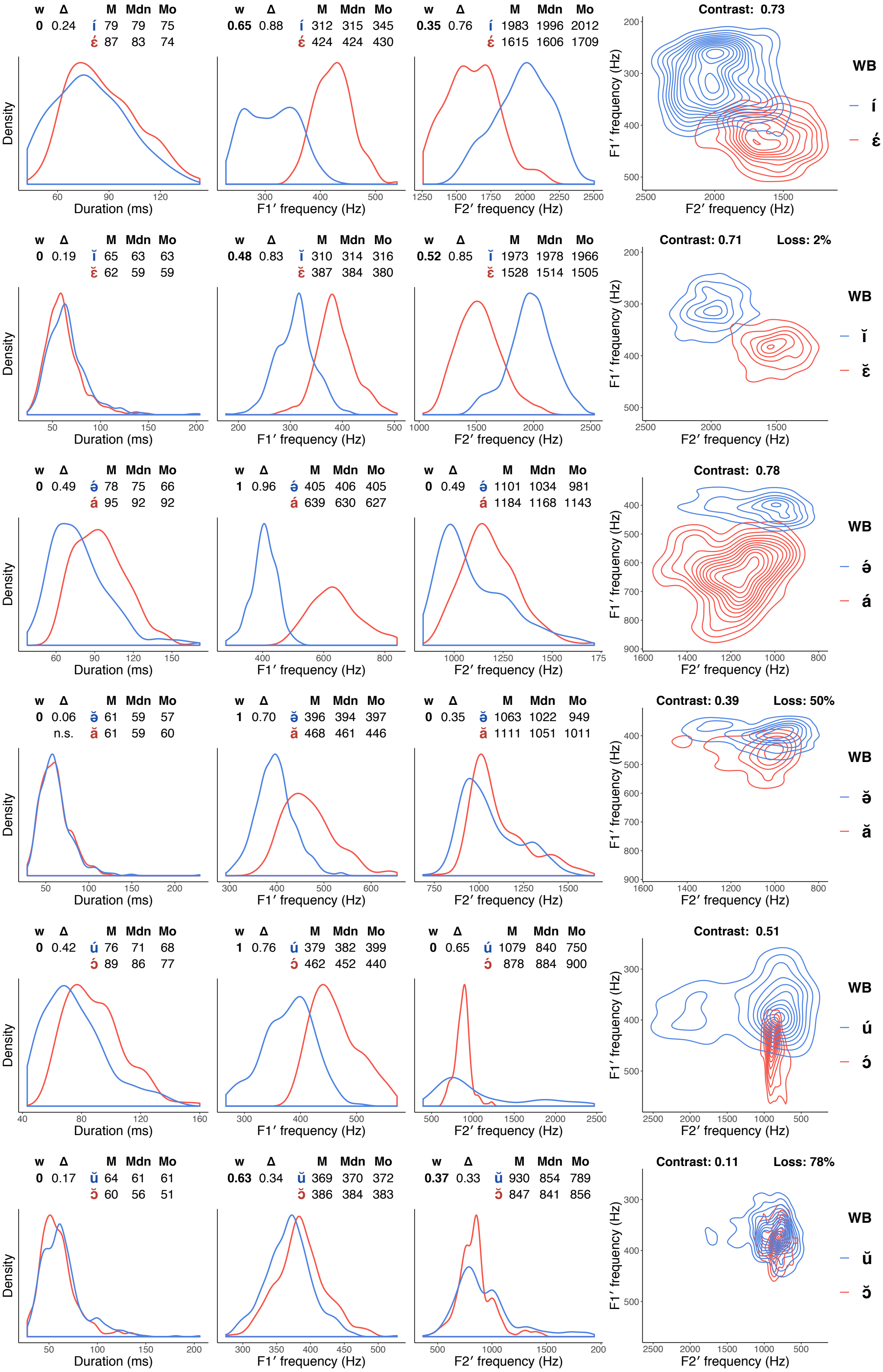


Figure 4.5: PDEs and summary statistics for West B. O/C vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

4.3 Discussion of findings

The results and analyses reported in this chapter evidence a predictable pattern of unstressed vowel shortening and raising in West Bulgarian: all unstressed vowels are significantly shorter, while the open vowels, /ɛ, a, ɔ/ in addition have significantly lower F_1' frequencies when unstressed. At the same time, /ɛ, ə, a/ are somewhat retracted, that is, their F_2' frequencies are significantly lower in unstressed syllables, which in the case of /ɛ/ constitutes centralisation. However, discriminant function analysis has shown that F_2' plays no important role in distinguishing stressed from unstressed allophones for any vowel but /u/, for which the stressed realisations are spread over a wider range of F_2' values

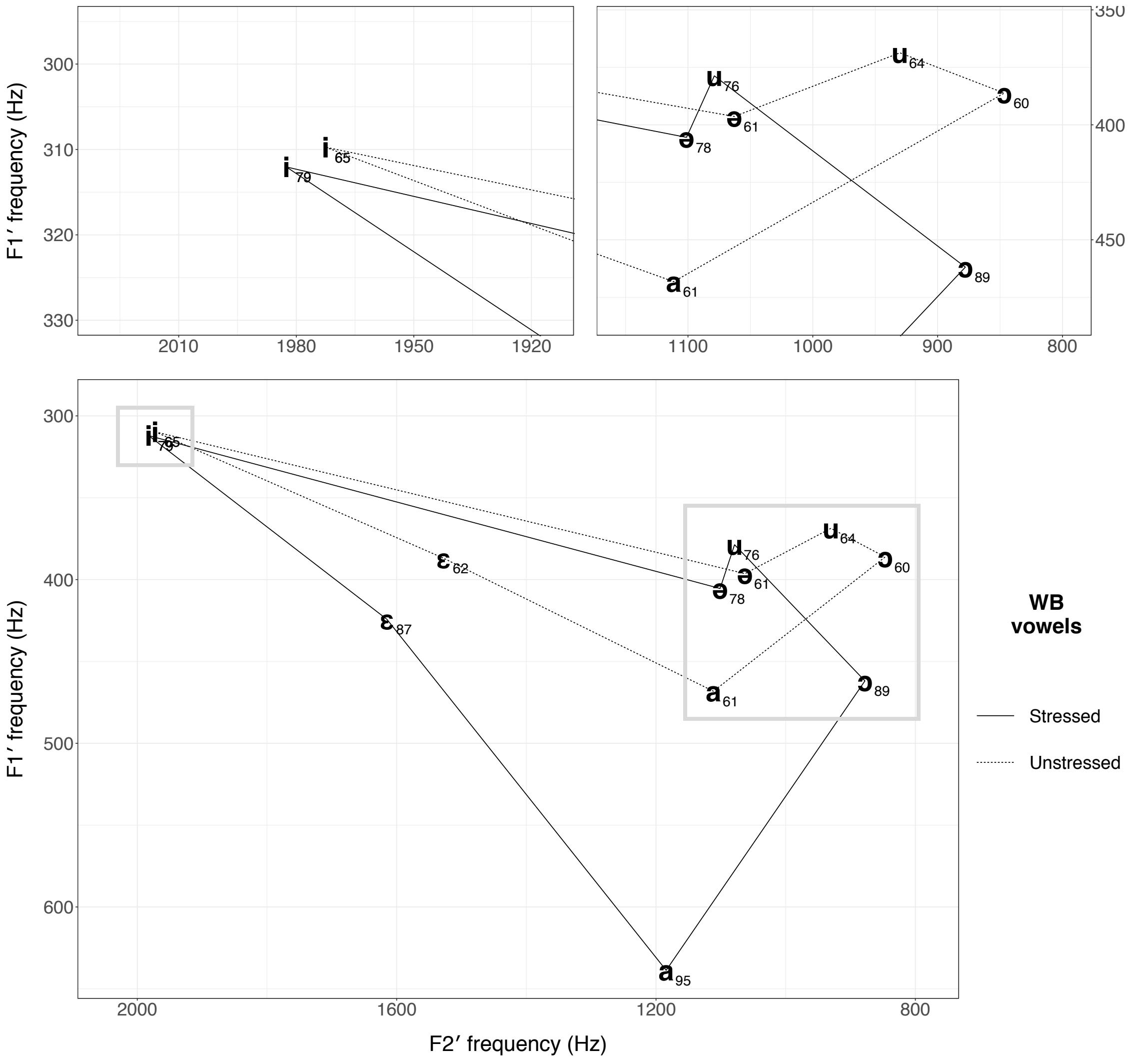


Figure 4.6: West Bulgarian S/U vowels in the $F_1' \times F_2'$ frequency space (means). Numbers next to vowels: mean durations (ms); top panels: enlarged views of grey frames in main chart.

than unstressed /u/. All differences are clearly seen in the $F_1' \times F_2'$ plot of mean values in Figure 4.6. The crowded close front and close back corners are expanded in the top panels.

The Unstressed Vowel Shift that open vowels undergo results in different degrees of neutralisation with their close counterparts. It is strongest with the back rounded vowels, /u–ɔ/, weaker but nonetheless considerable in /ə–a/,[2] and practically lacking in the front pair, /i–ɛ/. Although my findings are based on the investigation of three acoustic parameters—duration, F_1' and F_2' frequency—the two-dimensional contour display of F_1' and F_2' probability density estimates in Figure 4.7 captures the varying degrees of overlap quite accurately. I can therefore confirm the traditional observation that unstressed /i–ɛ/

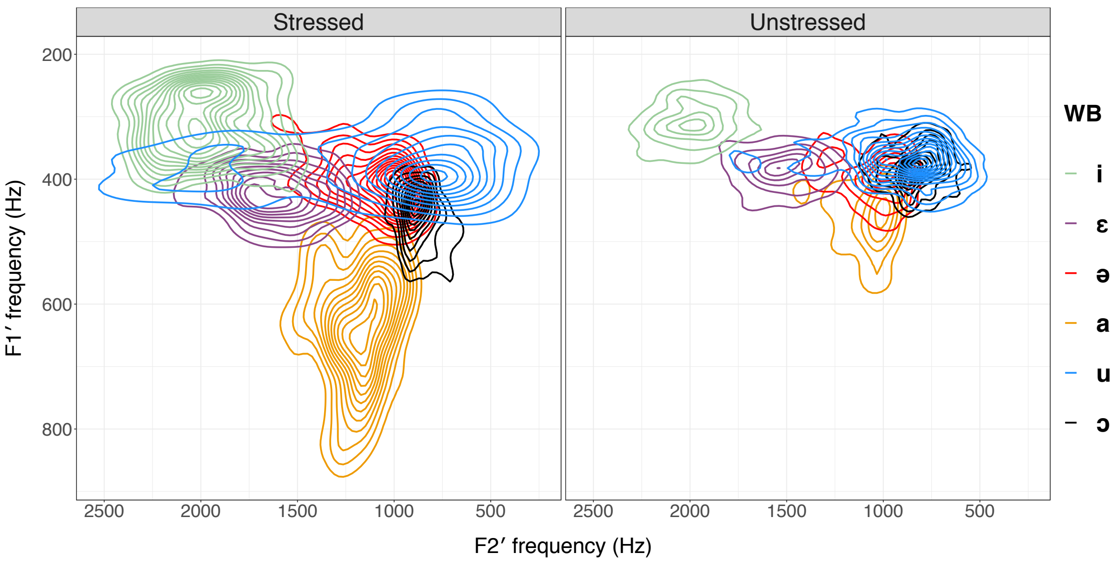


Figure 4.7: Probability density estimates of West Bulgarian S/U vowels in the $F_1' \times F_2'$ space.

do not neutralise in West Bulgarian, while at the same time my results disprove the claim that unstressed /ə–a/ merge to a greater extent than unstressed /ɔ–u/ (Tilkov et al. 1982): my data show the opposite and agree with the more recent findings of Andreeva et al. (2013) and Sabev (2015).

Significant positive duration–F_1' correlations predominate in open vowels, indicating that gradient undershoot is prevalent within syllable-specific allophones. The comparison

[2] In Sabev (2015) I found that the merger of West Bulgarian unstressed /ə–a/, while acoustically incomplete, was perceptually neutralising.

of unstressed F_1' frequencies predicted from stressed F_1' frequencies, on the one hand, and observed mean unstressed F_1' frequencies, on the other, has revealed that different open vowels probably implement different underlying Unstressed Vowel Shift mechanisms, with a good deal of inter-speaker variation. West Bulgarian unstressed /ɔ/ shows an amount of F_1' frequency reduction that is consistently greater than the predicted undershoot, a fact that justifies positing a separate unstressed target. Unstressed /a/, on the other hand, while scoring highest in Unstressed Vowel Shift, does not quite reach the predicted level of undershoot, suggesting that unstressed /a/ has the same target as the stressed allophone, which is substantially undershot in unstressed syllables. Speaker-by-speaker analysis of predicted and observed unstressed F_1' frequencies has pointed to a fragmented distribution in which a narrow majority's Unstressed Vowel Shift can indeed be accounted for by undershoot alone, while a separate unstressed target appears to be necessary to explain the stronger Unstressed Vowel Shift of the remaining speakers. Cross-speaker consistency is also lacking with regard to /ɛ/, but here the balance is reversed, favouring a categorical target switch over undershoot (again, by a small majority).

As we saw in Chapter 2, a widespread traditional view holds that neutralised unstressed realisations are intermediate between the two canonical stressed realisations with respect to openness (Tilkov et al. 1982; Boyadžiev and Tilkov 1997; Žobov 2004). In other words, the claim is that not only do open vowels raise but close vowels also lower in unstressed position. Recent research has repeatedly demonstrated that not to be the case (Andreeva et al. 2013; Sabev 2015; Dokovova et al. 2019) and my experiment provides further evidence that there is no lowering of unstressed close vowels: F_1' frequency differences are non-significant for /i/ and /u/, whereas the pseudo-close vowel /ə/ in fact has a slightly *lower* F_1' frequency in word-initial and pretonic unstressed syllables, even though this does not play a discriminating role.

A third received view that my results are at odds with is that Bulgarian unstressed vowels are less reduced in immediately pretonic than in other unstressed syllables. In fact, in many cases there is more spectral and durational reduction there: open vowels have the shortest durations and lowest F_1' frequencies in immediately pretonic syllables, while close vowels have equal durations in initial and pretonic position, where they are shorter than in final unstressed syllables.

5

East Bulgarian

Contents

5.1 Mean comparisons and correlations

5.1.1 Means and distributions

The group means and standard deviations for the duration and normalised F_1 and F_2 frequencies of stressed and unstressed East Bulgarian vowels are listed in Table 5.1. Table 5.2 shows the same parameters, with unstressed positions broken down into initial (σ_1), pretonic (σ_2) and final (σ_4) syllables.

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
Phoneme	Stress	n	Mean	SD	Mean	SD	Mean	SD
/i/	+	96	50.22	10.92	315	25	1758	186
	−	288	47.49	15.12	314	35	1739	179
/ɛ/	+	96	69.96	14.29	417	26	1674	159
	−	288	43.68	8.34	323	29	1715	177
/ə/	+	96	51.44	12.78	414	47	907	75
	−	288	49.43	14.10	426	45	934	100
/a/	+	96	77.76	16.04	640	91	1065	134
	−	288	49.24	19.92	432	57	940	103
/u/	+	96	49.25	20.04	406	46	910	341
	−	288	48.66	17.80	395	33	1010	404
/ɔ/	+	96	68.75	19.34	456	25	823	83
	−	288	47.48	15.33	414	35	860	275

Table 5.1: Group means and standard deviations for East Bulgarian vowel duration, F_1' and F_2' by stress.

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
	σ	n	Mean	SD	Mean	SD	Mean	SD
/i/	*1.*	96	45.28	14.04	303	17	1802	230
	2.	96	45.32	11.57	294	21	1729	123
	3.	96	50.22	10.92	315	25	1758	186
	4.	96	51.87	18.30	343	42	1685	151
/ɛ/	*1.*	96	44.33	9.58	314	21	1805	191
	2.	96	43.77	6.52	309	15	1697	122
	3.	96	69.96	14.29	417	26	1674	159
	4.	96	42.95	8.73	345	32	1642	173
/ə/	*1.*	96	46.78	16.39	411	44	972	134
	2.	96	47.82	9.61	429	45	908	61
	3.	96	51.44	12.78	414	47	907	75
	4.	96	53.68	14.67	437	42	923	83
/a/	*1.*	96	44.72	12.11	426	49	991	137
	2.	96	44.06	11.91	416	43	888	70
	3.	96	77.76	16.04	640	91	1065	134
	4.	96	58.93	27.84	454	69	940	56
/u/	*1.*	96	50.06	16.70	390	38	830	165
	2.	96	43.78	12.93	397	31	1154	425
	3.	96	49.25	20.04	406	46	910	341
	4.	96	52.13	21.89	399	30	1046	483
/ɔ/	*1.*	96	48.80	18.12	409	44	960	350
	2.	96	43.57	12.54	412	23	879	264
	3.	96	68.75	19.34	456	25	823	83
	4.	96	50.08	14.34	420	35	742	112

Table 5.2: Group means and standard deviations for East Bulgarian vowel duration, F_1' and F_2' by syllable. **σ** syllable: *1.* initial, *2.* pretonic, ***3.*** stressed, *4.* final.

5.1.1.1 Duration

East Bulgarian duration distributions and probability density estimates by syllable are shown in Figure 5.1. The open vowels, /ɛ, a, ɔ/, are significantly longer in stressed than in unstressed position. Stressed close vowels are not distinct in duration. V_4 is longer than V_2 in the close vowels and /a/. V_1 and V_2 are not differentiated.

5.1.1.2 F_1' frequency

Figure 5.2 shows syllable-specific F_1' distributions and PDEs. All open vowels have significantly higher F_1' frequencies in stressed position than elsewhere. In addition, F_1' is higher in [a_4] than in [a_2], and also in [ε_4] than in [ε_2] and [ε_1]. V_1 and V_2 are not significantly different. /i/ has significantly higher F_1' in the final syllable than elsewhere and [i_3] has higher F_1' than [i_2]. /ə/ also appears to have higher F_1' in σ_4 than in σ_3 and σ_1: this is significant according to the *t*-tests (§ 5.1.3), though not the ANOVA (§ 5.1.2). There are no statistically significant differences in F_1' frequency across syllables for /u/.

5.1.1.3 F_2' frequency

Syllable-specific F_2' distributions and PDEs for East Bulgarian are shown in Figure 5.3. While there are some statistically significant inter-syllabic differences, they do not seem to form any pattern. For /i/, F_2' is lower in the final syllable than in the third and the first; for /ɛ/, F_2' is highest in σ_1; for /ə/, it is higher in σ_1 than in σ_2; with /a/, it is highest in σ_3 and lowest in σ_2; /ɔ/ has lower F_2' in σ_4 than elsewhere; [u_2] and [u_4] are higher in F_2' than [u_1], while [u_2] is also higher than [u_3].

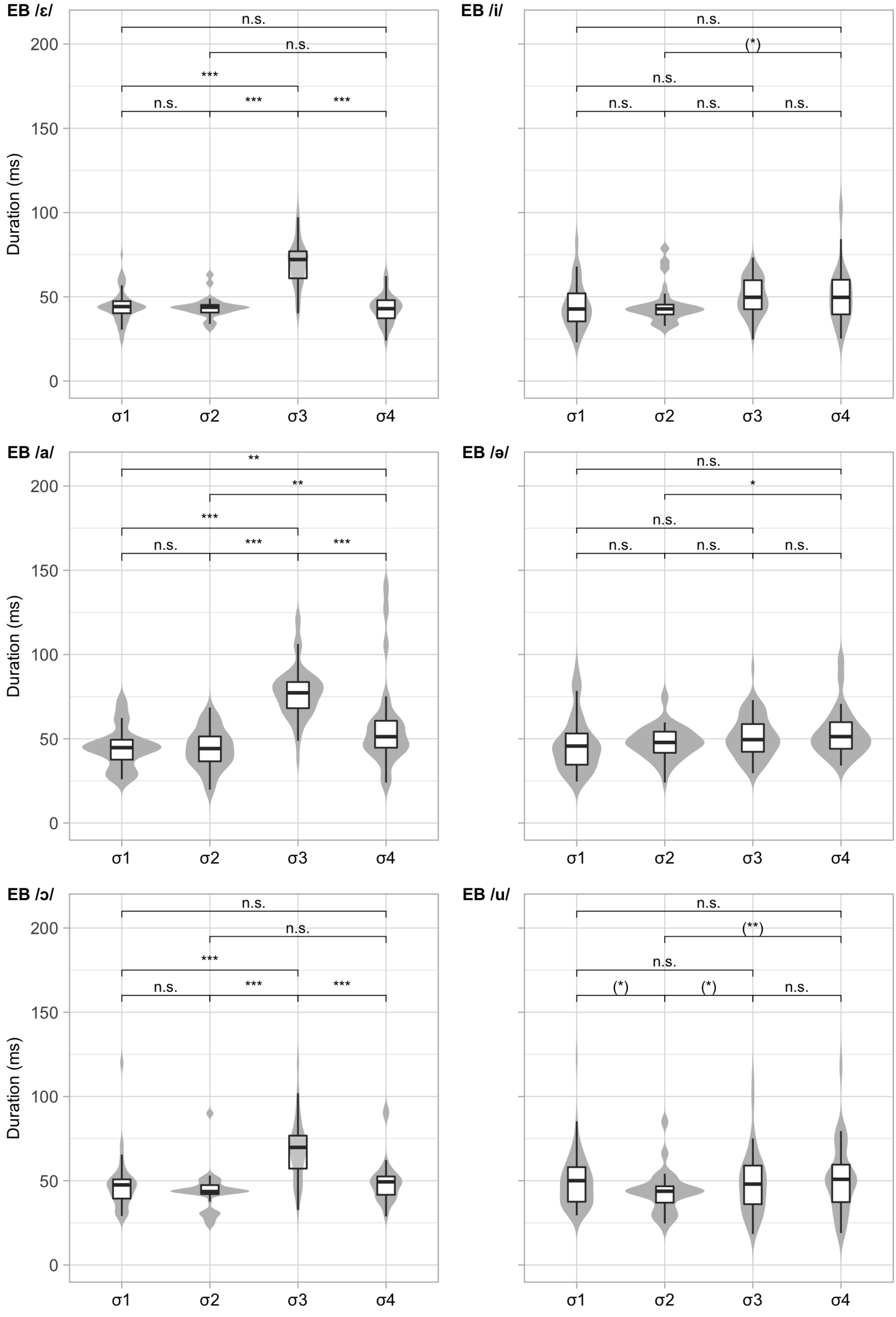


Figure 5.1: Distribution of duration in East Bulgarian (EB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 5.1.3; where in brackets, ANOVA n.s. (§ 5.1.2).

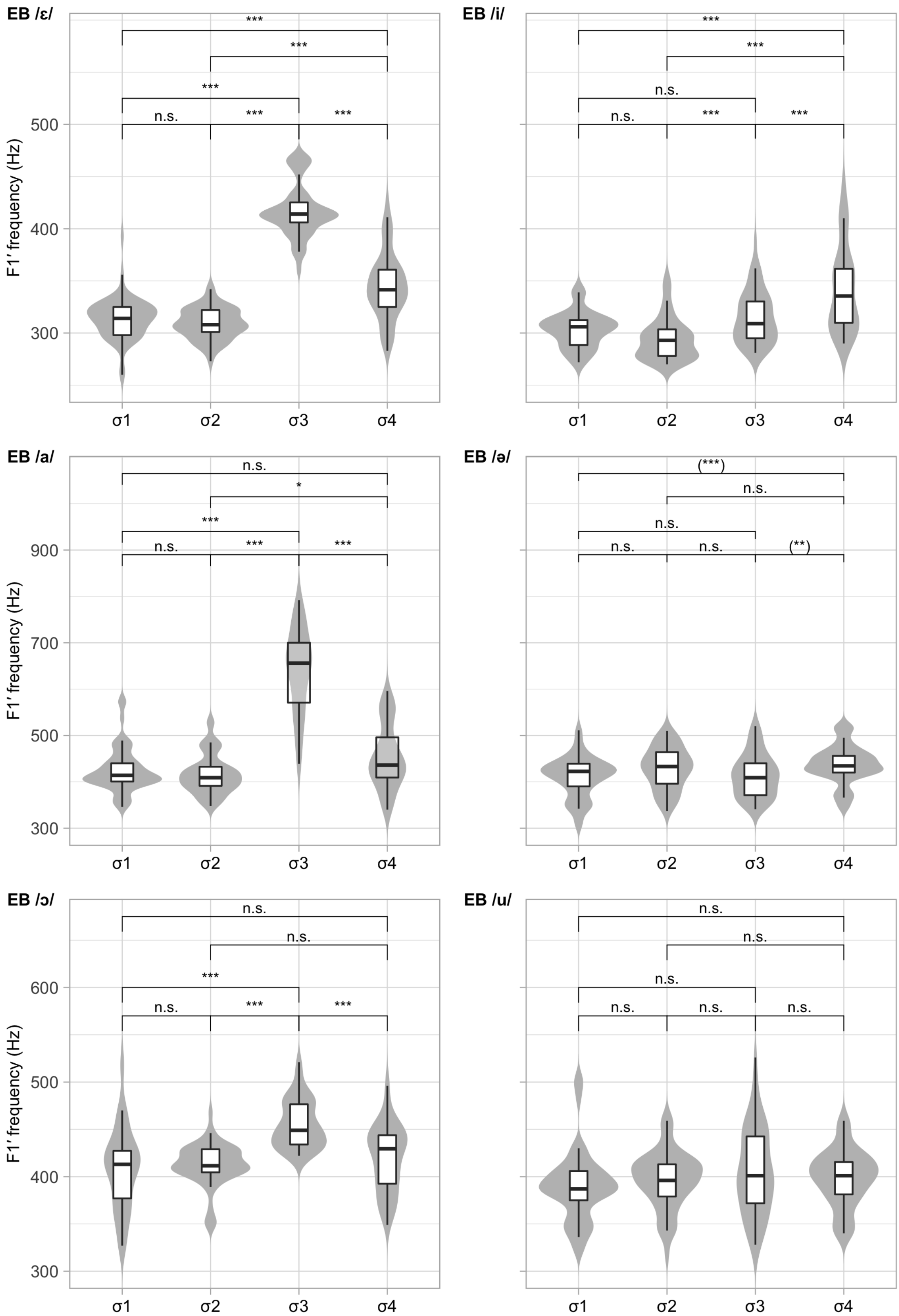


Figure 5.2: Distribution of F_1' frequency in East Bulgarian (EB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 5.1.3; where in brackets, ANOVA n.s. (§ 5.1.2).

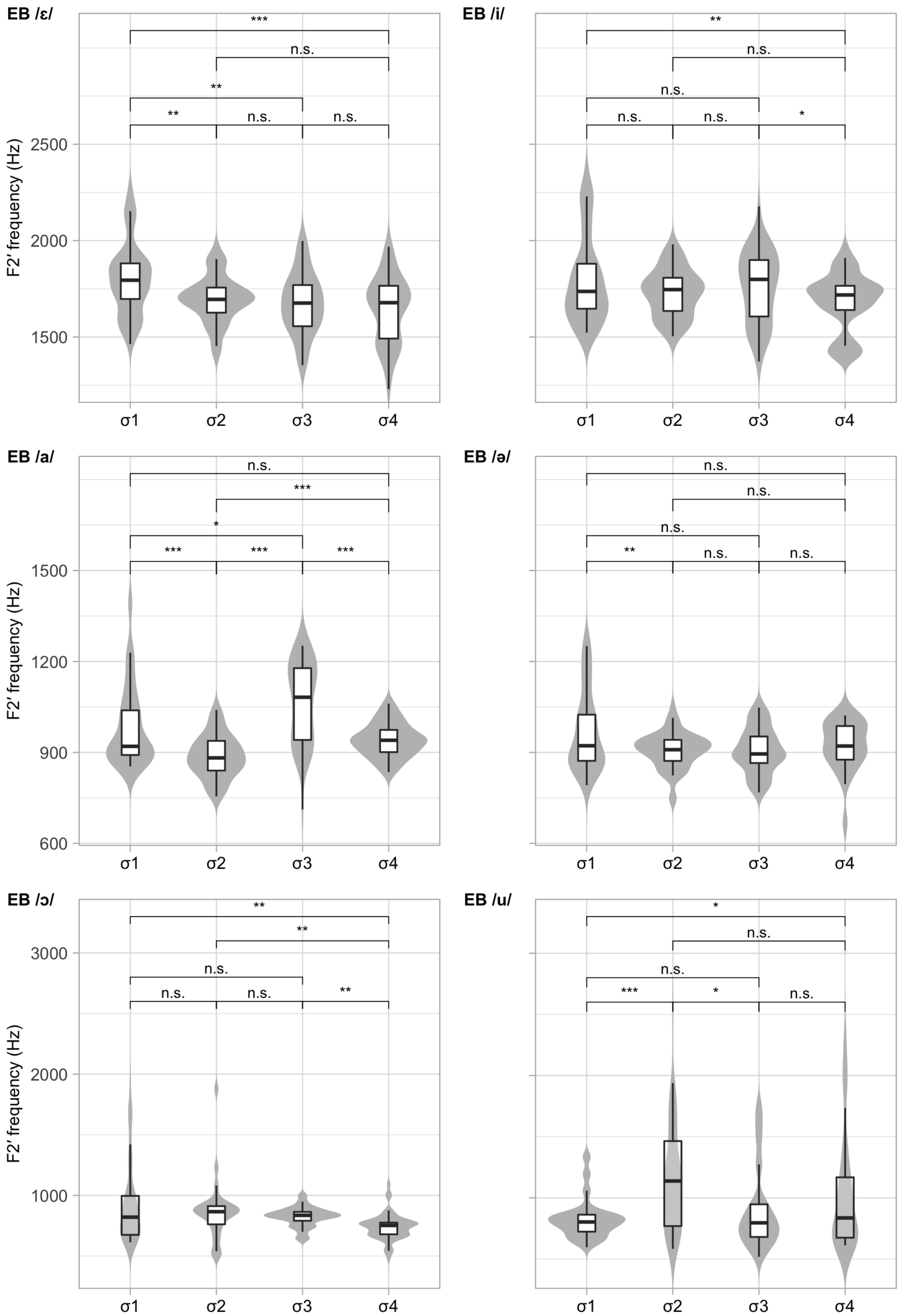


Figure 5.3: Distribution of F_2' frequency in East Bulgarian (EB). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 5.1.3.

5.1.2 Analysis of variance

The results obtained from repeated-measures ANOVAs for each East Bulgarian vowel phoneme with 'speaker' as case identifier, 'syllable' $(1, 2, 3, 4)$ as predictor variable, and each of the three parameters (duration, F_1' and F_2') as dependent variables are shown in Table 5.3. There is a highly significant effect on duration ($p \leq 0.001$) in the open vowels, /ɛ, a, ɔ/, as well as $p = 0.0364$ for /ə/. There is no significant effect for /i/ and /u/. For F_1' frequency, along with the expected significant effects for the open vowels, there is also a significant main effect for /i/, which appears to be closer in $σ_2$ and more open in $σ_4$

A. **Duration**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.08	0.0161	*	0.57	1.72	12.03	2.77	0.1078	n.s.	0.16
/ɛ/	0.03	0.0009	***	0.44	1.33	9.30	28.99	0.0002	***	0.73
/ə/	0.47	0.5126	n.s.		3	21	3.41	0.0364	*	0.11
/a/	0.20	0.1030	n.s.		3	21	20.60	0.0000	***	0.57
/u/	0.28	0.2106	n.s.		3	21	2.64	0.0760	n.s.	0.06
/ɔ/	0.38	0.3532	n.s.		3	21	15.60	0.0000	***	0.55

B. F_1' **frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.02	0.0003	***	0.43	1.28	8.95	11.92	0.0054	**	0.54
/ɛ/	0.14	0.0471	*	0.56	1.68	11.73	72.54	0.0000	***	0.86
/ə/	0.06	0.0065	**	0.51	1.52	10.64	4.20	0.0535	n.s.	0.09
/a/	0.03	0.0014	**	0.53	1.59	11.10	25.70	0.0001	***	0.77
/u/	0.04	0.0031	**	0.41	1.24	8.65	1.61	0.2447	n.s.	0.05
/ɔ/	0.15	0.0610	n.s.		3	21	9.75	0.0003	***	0.45

C. F_2' **frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.19	0.0953	n.s.		3	21	7.14	0.0017	**	0.11
/ɛ/	0.12	0.0380	*	0.50	1.51	10.55	8.49	0.0091	**	0.23
/ə/	0.15	0.0560	n.s.		3	21	4.18	0.0181	*	0.32
/a/	0.05	0.0040	**	0.41	1.24	8.70	19.01	0.0014	**	0.44
/u/	0.19	0.0951	n.s.		3	21	6.91	0.0020	**	0.28
/ɔ/	0.06	0.0063	**	0.42	1.25	8.78	4.95	0.0480	*	0.29

Table 5.3: Repeated-measures ANOVAs for the effect of 'syllable' on vowel duration, F_1' and F_2', for each East Bulgarian phoneme, with 'speaker' as case identifier. **GG** Greenhouse-Geisser correction; **df** degrees of freedom; **sig.** significance level: ***** $p \leq 0.001$, **** $p \leq 0.01$, *** $p \leq 0.05$, **n.s.** $p > 0.05$.

than in stressed (σ_3) position, as we saw in § 5.1.1. The ANOVAs with F_2' as dependent variable produce significant effects for all phonemes, although no consistent pattern of shift in backness is evident from the data in § 5.1.1 and § 5.1.3.

5.1.3 Pairwise comparisons

Dependent t-tests with Bonferroni correction ($\alpha = 0.05/4 = 0.0125$) were run for the three parameters across syllable pairs to establish which comparisons are likely to have produced significant main effects in the ANOVAs reported in the previous section. The results are given in Table 5.4 and are also the source of the significance levels indicated in the box plots in § 5.1.1. In three cases, indicated with † in the table below, the t-tests produced significant results, while the corresponding ANOVAs showed no significant main effects.

A. **Duration**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/†	0.2383	n.s.	0.2567	n.s.	1.0000	n.s.	1.0000	n.s.	0.1817	n.s.	0.0438	*
/ɛ/	0.0000	***	0.0000	***	0.0000	***	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.
/ə/	0.4924	n.s.	0.7054	n.s.	1.0000	n.s.	1.0000	n.s.	0.0764	n.s.	0.0268	*
/a/	0.0000	***	0.0000	***	0.0007	***	1.0000	n.s.	0.0062	**	0.0022	**
/u/†	1.0000	n.s.	0.0372	*	1.0000	n.s.	0.0325	*	1.0000	n.s.	0.0060	**
/ɔ/	0.0000	***	0.0000	***	0.0000	***	0.1061	n.s.	1.0000	n.s.	0.1066	n.s.

B. **F_1' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.0792	n.s.	0.0000	***	0.0003	***	0.1055	n.s.	0.0000	***	0.0000	***
/ɛ/	0.0000	***	0.0000	***	0.0000	***	0.4405	n.s.	0.0000	***	0.0000	***
/ə/†	1.0000	n.s.	0.0535	n.s.	0.0027	**	0.1098	n.s.	0.0003	***	1.0000	n.s.
/a/	0.0000	***	0.0000	***	0.0000	***	0.5904	n.s.	0.1522	n.s.	0.0113	*
/u/	0.3881	n.s.	0.7184	n.s.	1.0000	n.s.	1.0000	n.s.	0.5034	n.s.	1.0000	n.s.
/ɔ/	0.0000	***	0.0000	***	0.0000	***	1.0000	n.s.	0.6274	n.s.	0.5789	n.s.

C. **F_2' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.9970	n.s.	1.0000	n.s.	0.0149	*	0.0645	n.s.	0.0011	**	0.0543	n.s.
/ɛ/	0.0012	**	1.0000	n.s.	0.5887	n.s.	0.0021	**	0.0000	***	0.1255	n.s.
/ə/	0.0672	n.s.	1.0000	n.s.	1.0000	n.s.	0.0040	**	0.2400	n.s.	1.0000	n.s.
/a/	0.0201	*	0.0000	***	0.0000	***	0.0000	***	0.0601	n.s.	0.0000	***
/u/	0.8283	n.s.	0.0131	*	0.8636	n.s.	0.0000	***	0.0204	*	0.9560	n.s.
/ɔ/	0.0664	n.s.	0.9484	n.s.	0.0030	**	0.3356	n.s.	0.0013	**	0.0068	**

Table 5.4: Pairwise comparisons of East Bulgarian syllable-specific allophones (dependent t-tests with Bonferroni correction). **σ** syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$. † ANOVA n.s. (§ 5.1.2).

5.1.4 Correlations

Pearson product-moment correlations between duration and each formant frequency are listed in Table 5.5. Very few—two out of twenty-four—syllable-specific allophones positively correlate duration with F_1' frequency, which suggests that Unstressed Vowel Shift is clearly phonologised in East Bulgarian and is no longer the effect of gradient undershoot. The two positive significant correlations are in the stressed and the final allophones of /a/ and also have large and medium effect sizes. In other words, there is one notable exception to the overall non-gradience of East Bulgarian, and it happens to be in the longest and most open realisations of the most open vowel.

			Duration–F_1'				Duration–F_2'			
	σ	n	r	size	p	sig.	r	size	p	sig.
/i/	*1.*	48	0.03		0.8550	n.s.	0.22		0.1420	n.s.
	2.	48	0.00		0.9960	n.s.	0.21		0.1530	n.s.
	3.	48	-0.06		0.6850	n.s.	0.32	M	0.0280	*
	4.	48	-0.24		0.1050	n.s.	0.32	M	0.0270	*
/ɛ/	*1.*	48	-0.17		0.2540	n.s.	0.16		0.2860	n.s.
	2.	48	0.02		0.8920	n.s.	-0.04		0.8140	n.s.
	3.	48	-0.36	M	0.0120	*	0.61	L	0.0000	***
	4.	48	-0.17		0.2460	n.s.	0.10		0.4870	n.s.
/ə/	*1.*	48	0.14		0.3590	n.s.	0.62	L	0.0000	***
	2.	48	0.00		0.9840	n.s.	0.11		0.4390	n.s.
	3.	48	0.12		0.4340	n.s.	0.39	M	0.0060	**
	4.	48	0.26		0.0770	n.s.	-0.18		0.2180	n.s.
/a/	*1.*	48	0.20		0.1840	n.s.	0.41	M	0.0030	**
	2.	48	-0.02		0.8960	n.s.	0.07		0.6280	n.s.
	3.	48	0.55	L	0.0000	***	0.64	L	0.0000	***
	4.	48	0.31	M	0.0350	*	0.12		0.4280	n.s.
/u/	*1.*	48	-0.16		0.2720	n.s.	-0.01		0.9450	n.s.
	2.	48	-0.01		0.9520	n.s.	0.34	M	0.0180	*
	3.	48	-0.20		0.1760	n.s.	-0.08		0.6120	n.s.
	4.	48	-0.10		0.5060	n.s.	-0.40	M	0.0050	**
/ɔ/	*1.*	48	-0.17		0.2420	n.s.	0.08		0.6050	n.s.
	2.	48	-0.11		0.4600	n.s.	0.07		0.6190	n.s.
	3.	48	0.25		0.0940	n.s.	0.18		0.2150	n.s.
	4.	48	-0.11		0.4390	n.s.	-0.26		0.0700	n.s.

Table 5.5: Pearson correlations of duration with F_1' and duration with F_2' in East Bulgarian. **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$. **σ** syllable (*1*, *2*, ***3***, *4*). Effect size (shown where $p \leq 0.05$): **L** large $r \geq 0.5$, **M** medium $r \geq 0.3$, **S** small $r \geq 0.1$ (Cohen 1988: 79–80).

There are eight instances of significant positive correlation of F_2' with duration, [i$_{3,4}$, ɛ$_3$, ə$_{3,1}$, a$_{3,1}$, u$_2$], and one significant negative correlation, [u$_4$].

5.2 Stress effects

5.2.1 Unstressed Vowel Shift

5.2.1.1 MANOVA (1)

The results of MANOVAs measuring the effect of stress on the dependent variables (duration, F_1', F_2') for each East Bulgarian vowel are shown in Table 5.6. As expected, there are highly significant effects ($p \leq 0.001$) for all open vowels and the corresponding Pillai scores are also high. For close vowels, on the other hand, Pillai scores are very low, the effect is non-significant for /i/ and marginally significant for /ə/.

	df$_1$	df$_2$	F	p	sig.	**UVS** $= \Lambda$
í, ĭ	3	188	0.57	0.6322	n.s.	0.0091
ɛ́, ɛ̆	3	188	274.88	0.0000	***	0.8144
ə́, ə̆	3	188	2.65	0.0499	*	0.0406
á, ă	3	188	130.64	0.0000	***	0.6758
ú, ŭ	3	188	2.97	0.0333	*	0.0452
ɔ́, ɔ̆	3	188	42.70	0.0000	***	0.4052

Table 5.6: MANOVAs for effect of stress on $dur \times F_1' \times F_2'$ in each East Bulgarian vowel phoneme. **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$; **UVS** Unstressed Vowel Shift; **Λ** Pillai score.

5.2.1.2 Discriminant function analysis (1)

Both the comparisons of means and the MANOVA have shown that East Bulgarian stressed and unstressed close vowels differ very little in terms of duration and formant frequencies, while open vowels have significantly higher F_1' frequencies and durations in stressed position. As can be seen from the discriminant analysis results in Table 5.7, F_1' plays a more important discriminating role than duration for /ɛ/ and, more clearly so, for /a/, while in the case of /ɔ/, F_1' and duration contribute equally to the stressed–unstressed distinction. The role of F_2' is negligible in all open vowels.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
/i/	Duration	0.79	0.88	0.69	0.17	0.76
	F_1'	0.37	0.26	0.10		
	F_2'	0.43	0.50	0.21		0.24
/ɛ/	Duration	-0.58	-0.71	0.41	0.17	0.41
	F_1'	-0.77	-0.78	0.60		0.59
	F_2'	-0.12	0.09	-0.01		
/ə/	Duration	0.62	0.31	0.20	0.17	0.20
	F_1'	-0.62	-0.54	0.33		0.33
	F_2'	-0.77	-0.61	0.47		0.47
/a/	Duration	0.35	0.64	0.22	0.19	0.21
	F_1'	0.89	0.93	0.83		0.79
	F_2'	-0.11	0.51	-0.06		
/u/	Duration	0.07	0.07	0.00	0.17	
	F_1'	0.94	0.58	0.54		0.54
	F_2'	-0.88	-0.52	0.46		0.46
/ɔ/	Duration	-0.67	-0.72	0.49	0.17	0.50
	F_1'	-0.69	-0.71	0.49		0.50
	F_2'	0.20	0.10	0.02		

Table 5.7: Discriminant function analysis of stress correlates in East Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5\overline{|PDRC|}$).

5.2.1.3 Probability densities (1)

Figure 5.4 compares the probability density estimates of duration, F_1' and F_2' for stressed and unstressed vowels. Six tests of equal densities, primarily involving the close vowels, did not return significant differences. There is a sizeable symmetric difference between the stressed and unstressed estimates of F_2' for /a/, $\Delta = 0.64$, but this is paired with negligible discriminating power, $w = 0$.

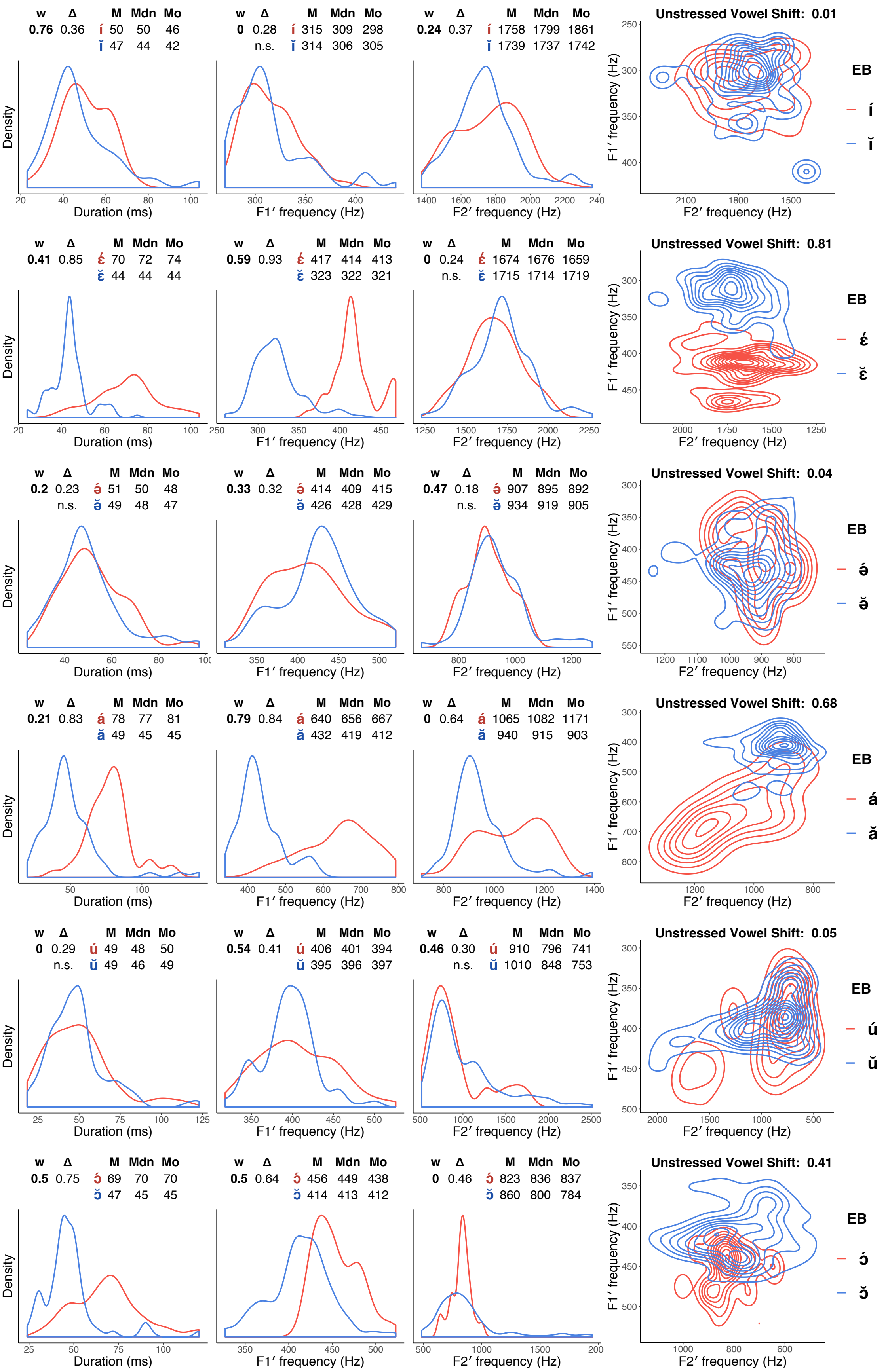


Figure 5.4: PDEs and summary statistics for East B. S/U vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

5.2.1.4 Stressed and unstressed targets

As we saw in § 5.1.4, East Bulgarian does not correlate F_1' frequency with duration. Unstressed Vowel Shift, therefore, must result from a categorical target alternation between stressed and unstressed open vowels. Table 5.8 shows what the predicted unstressed $\hat{F}_1$ frequencies of underlying open vowels would be if Unstressed Vowel Shift were the result of undershoot, along with the observed mean unstressed $\bar{F}_1'$ frequencies and corresponding residual values, $\bar{F}_1' - \hat{F}_1$.

	Predicted unstressed $\hat{F}_1$ frequency (Hz)	Observed unstressed $\bar{F}_1'$ frequency (Hz)	Residual value $\bar{F}_1' - \hat{F}_1$
/ɛ/	389.96	322.85	-67.11
/a/	477.92	432.06	-45.86
/ɔ/	405.48	413.51	8.02

Table 5.8: Predicted and observed unstressed F_1' frequencies of East Bulgarian open vowels.

Unstressed /ɛ/ and /a/ have large negative residual values, which is to be expected if the actual F_1' frequency reduction is greater than Unstressed Vowel Shift levels that could be subsumed under predicted undershoot. Somewhat surprisingly, this is not the case with East Bulgarian /ɔ/, where the observed reduction remains within the bounds of predicted undershoot (hence a positive residual). And indeed, East Bulgarian /ɔ/ has a markedly lower Unstressed Vowel Shift score ($\Lambda = 0.41$) than the other open vowels (0.81 for /ɛ/ and 0.68 for /a/). Nonetheless, it is unclear whether predicted and observed values can be compared in a meaningful way when correlation analysis offers no evidence of gradient undershoot. Moreover, we should recall that (uncorrelated) duration is as important in discriminating between stressed and unstressed /ɔ/ as F_1' frequency is.

5.2.2 Contrast and neutralisation

5.2.2.1 MANOVA (2)

MANOVAs comparing open and close East Bulgarian vowels, reported in Table 5.9, reveal very high levels of neutralisation in unstressed position. There is 95 and 99 per cent of contrast loss in unstressed /i–ɛ/ and /ə–a/, respectively, pointing to complete merger. The neutralisation index for unstressed /u–ɔ/ is also high, corresponding to 70% contrast loss, though not as high as in the other two pairs, partly because the contrast between the stressed allophones is not very strong itself, $\Lambda = 0.48$. In unstressed position it drops to $\Lambda = 0.15$ and this small residue seems to derive from the concentration of /ɔ/ at slightly higher F_1' frequencies, as well as from the wider F_2' range in /u/ against a more compact distribution of /ɔ/.

	df_1	df_2	F	p	sig.	**Contrast** $= \Lambda$	**Loss**
í, έ	3	92	185.74	0.0000	***	0.8583	
ĭ, ɛ̆	3	284	4.18	0.0064	**	0.0423	0.95
ə́, á	3	92	81.21	0.0000	***	0.7259	
ə̆, ă	3	284	0.41	0.7486	n.s.	0.0043	0.99
ú, ɔ́	3	92	28.59	0.0000	***	0.4824	
ŭ, ɔ̆	3	284	16.11	0.0000	***	0.1455	0.70

Table 5.9: MANOVAs for East Bulgarian O/C vowel pairs: effect of height on $dur \times F_1' \times F_2'$. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$ **Λ** Pillai score; **Loss** $= (\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 1 - \breve{\Lambda}/\acute{\Lambda}$.

5.2.2.2 Discriminant function analysis (2)

F_1' frequency is the major acoustic parameter distinguishing open and close stressed vowels, as shown by the discriminant function analysis in Table 5.10. Somewhat surprisingly, duration is also important, contributing a third of the contrast for [í–ɛ́] and [ú–ɔ́], and 0.2 for [ə́–á]. The role F_2' is negligible in all pairs except [ŭ–ɔ̆].

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
í, ɛ́	Duration	-0.55	-0.56	0.31	0.17	0.33
	F_1'	-0.78	-0.81	0.64		0.67
	F_2'	0.23	0.22	0.05		
ĭ, ɛ̆	Duration	0.72	0.75	0.54	0.17	0.53
	F_1'	-0.68	-0.70	0.47		0.47
	F_2'	-0.05	0.33	-0.02		
ə́, á	Duration	0.29	0.78	0.23	0.22	0.20
	F_1'	0.96	0.97	0.94		0.80
	F_2'	-0.24	0.69	-0.16		
ə̆, ă	Duration	-0.18	-0.08	0.02	0.17	
	F_1'	0.90	0.93	0.84		1
	F_2'	0.35	0.40	0.14		
ú, ɔ́	Duration	0.50	0.59	0.29	0.17	0.33
	F_1'	0.82	0.74	0.60		0.67
	F_2'	-0.44	-0.23	0.10		
ŭ, ɔ̆	Duration	-0.06	-0.09	0.01	0.17	
	F_1'	0.86	0.66	0.57		0.57
	F_2'	-0.79	-0.54	0.43		0.43

Table 5.10: Discriminant function analysis of phonological vowel height in East Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5\overline{|PDRC|}$).

5.2.2.3 Probability densities (2)

The PDE comparisons in Figure 5.5 show that there are no significant differences between the duration and F_2' estimates for [ə̆–ă] and between the F_2' estimates for [ĭ–ɛ̆]. The apparent symmetric differences in F_2' estimates for stressed open vowels have only negligible weight as height discriminants.

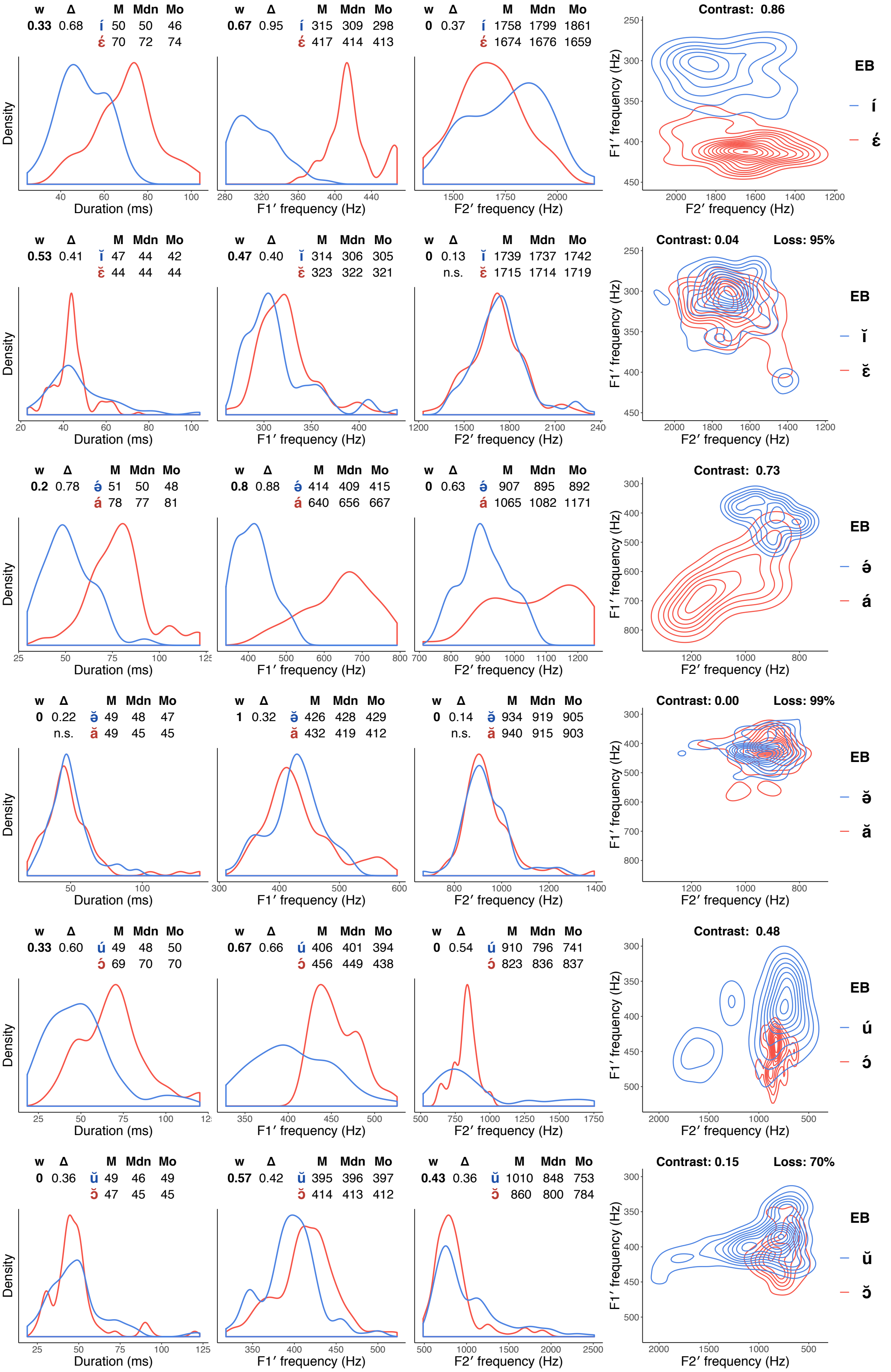


Figure 5.5: PDEs and summary statistics for East B. o/c vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

5.3 Discussion of findings

East Bulgarian open vowels have significantly higher durations and F_1' frequencies in stressed syllables; where differences between unstressed syllables are significant, final syllable allophones, V_4, have higher values than initial and pretonic unstressed vowels. Close vowels do not have higher F_1' frequencies in stressed position; in fact for /i/ and /ə/ the highest F_1' frequencies were measured in word-final unstressed syllables. While it is not surprising that close vowels do not undergo F_1' reduction when unstressed, interestingly there are also no significant stress-dependent differences in duration. Unstressed close vowels tend to be shortest in pretonic, and longest in word-final syllables. Mean values are

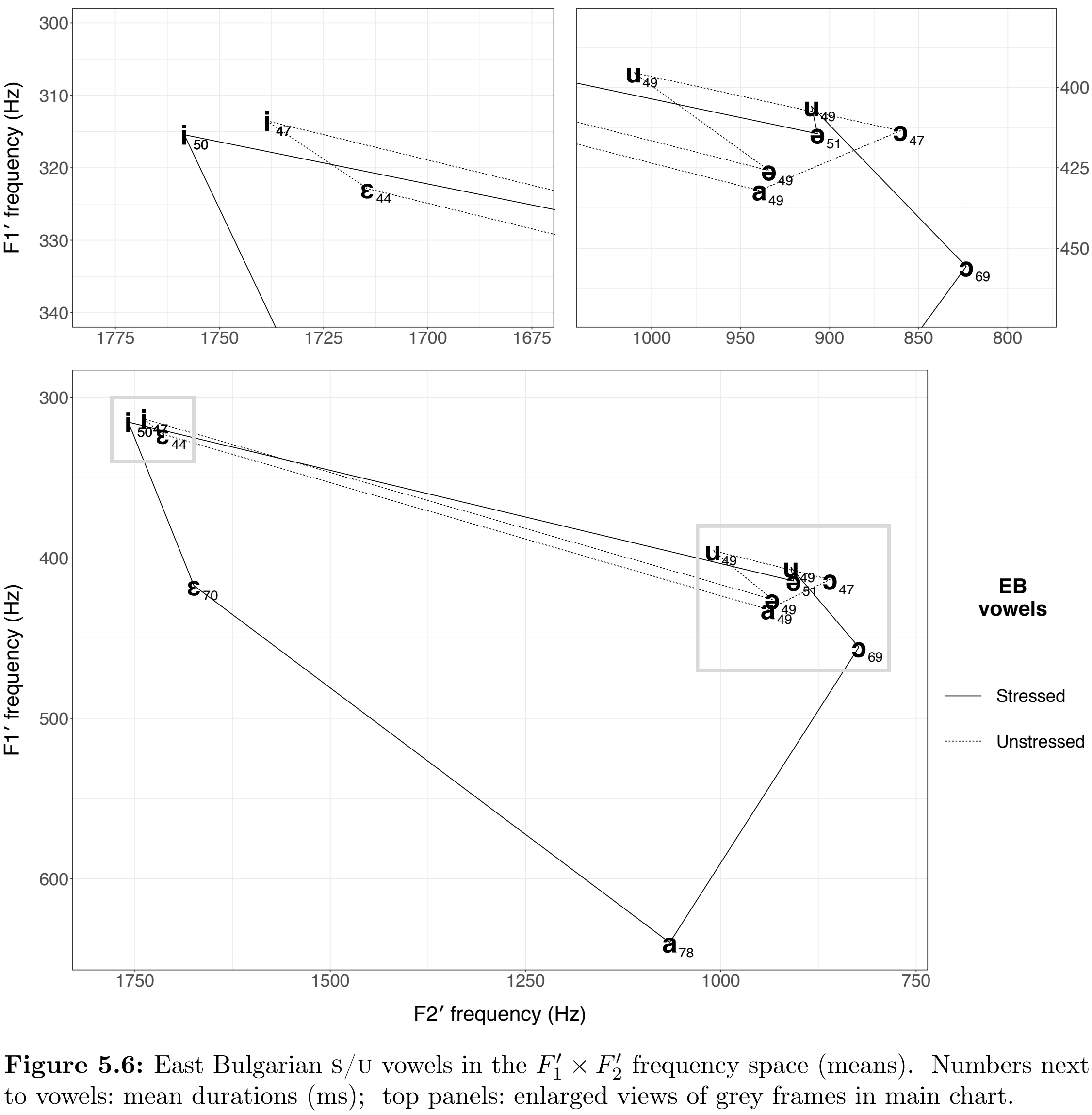


Figure 5.6: East Bulgarian S/U vowels in the $F_1' \times F_2'$ frequency space (means). Numbers next to vowels: mean durations (ms); top panels: enlarged views of grey frames in main chart.

mapped in Figure 5.6. These results, obtained from comparisons of means, are corroborated by the global measure of Unstressed Vowel Shift: open vowels have high Pillai scores, while close vowels show very little or no variation between stressed and unstressed syllables. F_1' frequency and duration have equal weight in discriminating between stressed and unstressed /ɔ/, whereas for /a/ and /ɛ/ F_1' frequency is more important. F_2' frequency, as a rule, plays no role as a stress discriminant.

Correlation analysis provides clear evidence that Unstressed Vowel Shift is categorical in East Bulgarian: there are no significant positive correlations of F_1' frequency and duration, except at the extreme end of duration and vocal tract aperture—in stressed and final-syllable /a/. Even though the degree of F_1' frequency reduction in unstressed East Bulgarian /ɔ/ does not exceed the amount of shift predicted for undershoot, this seems to be a mere accident, as there is no evidence of gradient undershoot in that vowel, in view of the complete lack of correlation with duration.

Comparisons of open and close vowels have shown that the unrounded height-contrasting pairs are completely neutralised in unstressed position: the MANOVA was non-significant for [ə̆–ă], and the contrast score for [ĭ–ɛ̆] is only $\Lambda = 0.04$, which is a drop of 95 per cent compared to the stressed pair. Unstressed [ŭ–ɔ̆] are slightly more contrastive ($\Lambda = 0.15$,

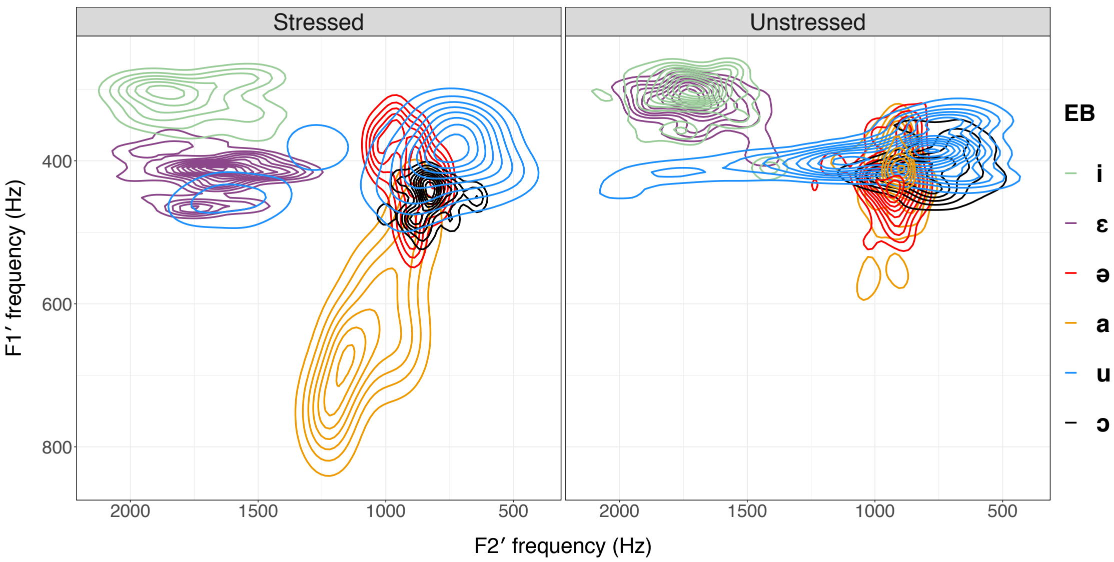


Figure 5.7: Probability density estimates of East Bulgarian S/U vowels in the $F_1' \times F_2'$ space.

70% loss). As can be seen in the PDEs in Figures 5.5 and 5.7, the F_1' estimate for [ɔ̆] is concentrated over slightly higher frequencies, while at the same time [ŭ] extends to higher values in its the F_2' estimate. F_1' frequency is the primary height discriminant in the stressed pairs. East Bulgarian stressed open vowels have longer durations than their close counterparts. This is not surprising in itself, as more open vowels tend to have longer durations in general (Lisker 1974). However, it is interesting that in East Bulgarian duration in fact plays an important, if secondary, role in distinguishing open and close stressed vowels.

Just as in West Bulgarian, I find no evidence of two distinct degrees of Unstressed Vowel Shift, or in any case of less reduction in immediately pretonic syllables. If at all different from other unstressed allophones, pretonic vowels are more reduced, while there tends to be slightly less reduction in word-final unstressed syllables.

One last observation to be made here concerns the contrast between East Bulgarian /u/ and /ə/. As can be seen from Figure 5.6 above and Table 5.1 (p. 117), differences in means are very small in respect of all three acoustic parameters; this is particularly clear for *stressed* /u/ and /ə/. There also appears to be a substantial overlap between the $F_1' \times F_2'$ probability density estimates of the two vowels in Figure 5.7—again, more unequivocally in stressed position. A MANOVA indicates that the overall duration $\times F_1' \times F_2'$ difference between East Bulgarian stressed /u/ and /ə/ is indeed non-significant ($p = 0.72$), which I would normally interpret as clear evidence for merger. In *unstressed* position the overall difference is significant ($p < 0.001$), albeit rather small in magnitude ($\Lambda = 0.17$).

However, since /u/ and /ə/ as a rule differ in lip rounding, they may be acoustically distinguished by another variable, such as the third formant frequency, a parameter which is not included in my standard multivariate model. Paired t-tests indeed reveal significant differences in F_3 frequency in both stressed and unstressed position. The F_3 frequency means, standard deviations and p-values are listed in Table 5.11. A second set of MANOVAs, this time with F_3 frequency added to the input variables, now reveal that East Bulgarian /u/ and /ə/ are significantly different in both stressed and unstressed position. Discriminant function analysis further indicates that, for stressed /u–ə/, F_3 frequency is the

	F_3 frequency (Hz)					Paired t-test	
	/u/		/ə/		Difference		
	Mean	SD	Mean	SD	in means	p	sig.
Stressed	2354	192	2247	102	107	0.0024	**
Unstressed	2383	169	2327	152	56	0.0006	***

Table 5.11: F_3 frequency of East Bulgarian /u/ and /ə/: group means, standard deviations and significance of difference.

sole non-negligible discriminant, whereas in unstressed position, the vowels are distinguished primarily by F_1' frequency, with F_3 frequency playing a small yet non-negligible role, too. The MANOVA and DFA results are presented in Table 5.12. Figure 5.8 shows the PDEs, discriminant weights (w), symmetric differences (Δ) and central tendencies for each of the four acoustic parameters of East Bulgarian /u/ and /ə/, including F_3 frequency.

	MANOVA			PDRC			
/u–ə/	p	sig.	Λ	Duration	F_1'	F_2'	F_3
Stressed	0.0013	**	0.18	0.06	0.10	0.00	0.84
Unstressed	0.0000	***	0.19	0.00	0.76	0.10	0.14

Table 5.12: MANOVA (p, Λ) and DFA (PDRC) results for East Bulgarian /u/ and /ə/ (with F_3 frequency). **Grey values** negligible PDRCs ($\theta = 0.125$)

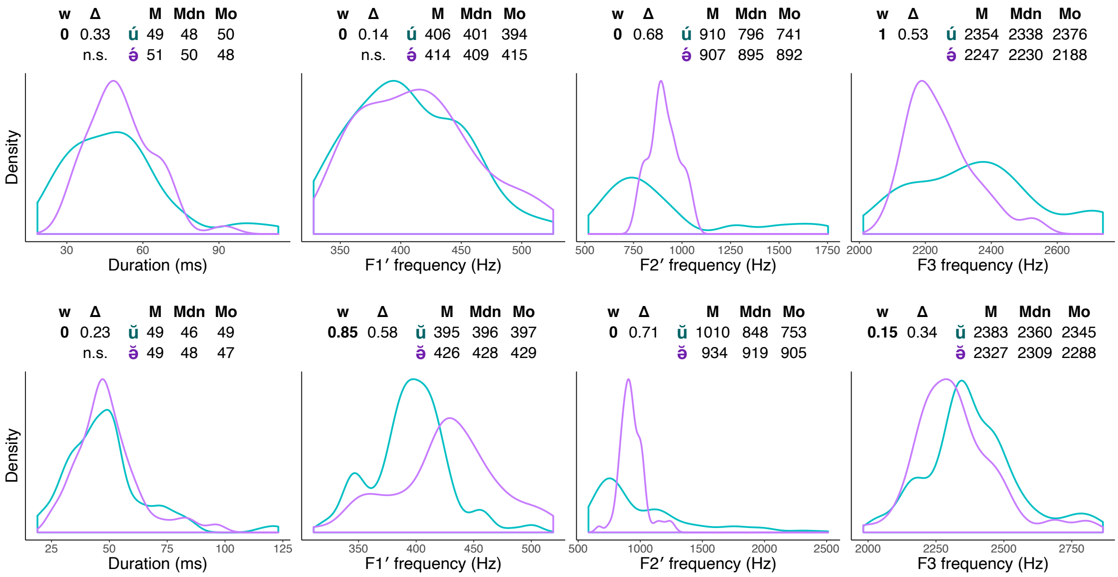


Figure 5.8: PDEs and summary statistics for East Bulgarian /u/ and /ə/. **w** discriminant weight (adjusted PDRC); **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

6
Istanbul Turkish

Contents

6.1 Mean comparisons and correlations

6.1.1 Means and distributions

The group means and standard deviations for the duration and normalised F_1 and F_2 frequencies of stressed and unstressed Istanbul Turkish vowels are listed in Table 6.1. Table 6.2 shows the same parameters for vowels in each syllable (1, 2, 3).

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
Phoneme	Stress	n	Mean	SD	Mean	SD	Mean	SD
/i/	+	98	60.03	18.83	329	33	1822	202
	−	196	51.54	18.84	319	37	1852	196
/ɛ/	+	98	78.42	16.39	455	53	1584	150
	−	196	58.64	17.20	421	39	1603	194
/y/	+	98	61.35	21.98	347	38	1405	101
	−	196	51.92	18.60	333	43	1489	139
/œ/	+	98	84.41	20.03	439	36	1310	101
	−	196	60.44	15.84	405	29	1333	122
/ɯ/	+	98	57.91	20.95	392	41	1008	108
	−	196	49.13	15.93	387	33	1064	165
/ɑ/	+	98	87.16	20.19	615	78	1039	108
	−	196	58.92	15.62	514	56	1045	129
/u/	+	98	61.66	21.59	382	39	833	83
	−	196	50.34	18.17	378	39	867	125
/ɔ/	+	98	79.65	22.79	466	45	857	85
	−	196	57.46	15.57	433	38	878	89

Table 6.1: Group means and standard deviations for Istanbul Turkish vowel duration, F_1' and F_2' by stress.

6.1.1.1 Duration

Figure 6.1 shows syllable-specific duration distributions and probability density estimates for Istanbul Turkish. Vowels are consistently longer in stressed position (σ_3) than when unstressed (σ_1, σ_2), with one minor exception: the difference between [y_3] and [y_2] is not statistically significant, but both are significantly longer than [y_1]. V_1 and V_2 are not significantly different for the open vowels, /ɛ, œ, ɑ, ɔ/, as well as /i/. In the remaining vowels, /y, ɯ, u/, V_2 is significantly longer than V_1.

6.1.1.2 F_1' frequency

F_1' frequency distributions and PDEs by syllable are plotted in Figure 6.2. In all open vowels F_1' is highest in the stressed syllable, and V_1 has significantly higher F_1' than V_2. For /i/ and /y/ F_1' is higher in V_3 than in V_1 but there are are no significant differences between V_2 and the other syllables. No syllable pair shows a significant difference for /ɯ/ and /u/.

6.1.1.3 F_2' frequency

The means in Table 6.2 and the F_2' frequency distributions in Figure 6.3 indicate that F_2' tends to be higher in V_1 than in V_3, while V_2 in most cases is not significantly different

	σ	n	Duration (ms) Mean	Duration (ms) SD	F_1' (Hz) Mean	F_1' (Hz) SD	F_2' (Hz) Mean	F_2' (Hz) SD
/i/	*1.*	98	49.83	19.91	315	35	1875	182
	2.	98	53.24	17.64	323	38	1829	207
	3.	98	60.03	18.83	329	33	1822	202
/ɛ/	*1.*	98	59.23	17.05	428	38	1613	176
	2.	98	58.06	17.42	415	39	1594	211
	3.	98	78.42	16.39	455	53	1584	150
/y/	*1.*	98	48.69	18.10	330	46	1501	133
	2.	98	55.15	18.61	337	39	1477	144
	3.	98	61.35	21.98	347	38	1405	101
/œ/	*1.*	98	60.22	15.39	410	32	1338	120
	2.	98	60.66	16.35	401	25	1329	124
	3.	98	84.41	20.03	439	36	1310	101
/ɯ/	*1.*	98	47.31	15.89	389	32	1121	172
	2.	98	50.95	15.84	385	34	1008	137
	3.	98	57.91	20.95	392	41	1008	108
/ɑ/	*1.*	98	59.23	16.39	533	53	1078	122
	2.	98	58.60	14.89	495	53	1012	128
	3.	98	87.16	20.19	615	78	1039	108
/u/	*1.*	98	47.47	18.21	377	40	872	120
	2.	98	53.22	17.75	379	39	861	129
	3.	98	61.66	21.59	382	39	833	83
/ɔ/	*1.*	98	58.46	15.54	440	40	896	84
	2.	98	56.47	15.62	427	36	861	91
	3.	98	79.65	22.79	466	45	857	85

Table 6.2: Group means and standard deviations for Istanbul Turkish vowel duration, F_1' and F_2' by syllable. **σ** syllable: *1.* initial, *2.* second, ***3.*** stressed.

from either one or the other adjacent syllable ($V_2 = V_1$ in /y, u/, $V_2 = V_3$ in /i, ɯ, ɔ/). For /ɑ/ F_2' is highest in the initial and lowest in the second syllable. Only the front open vowels, /ɛ, œ/, do not show any significant differences.

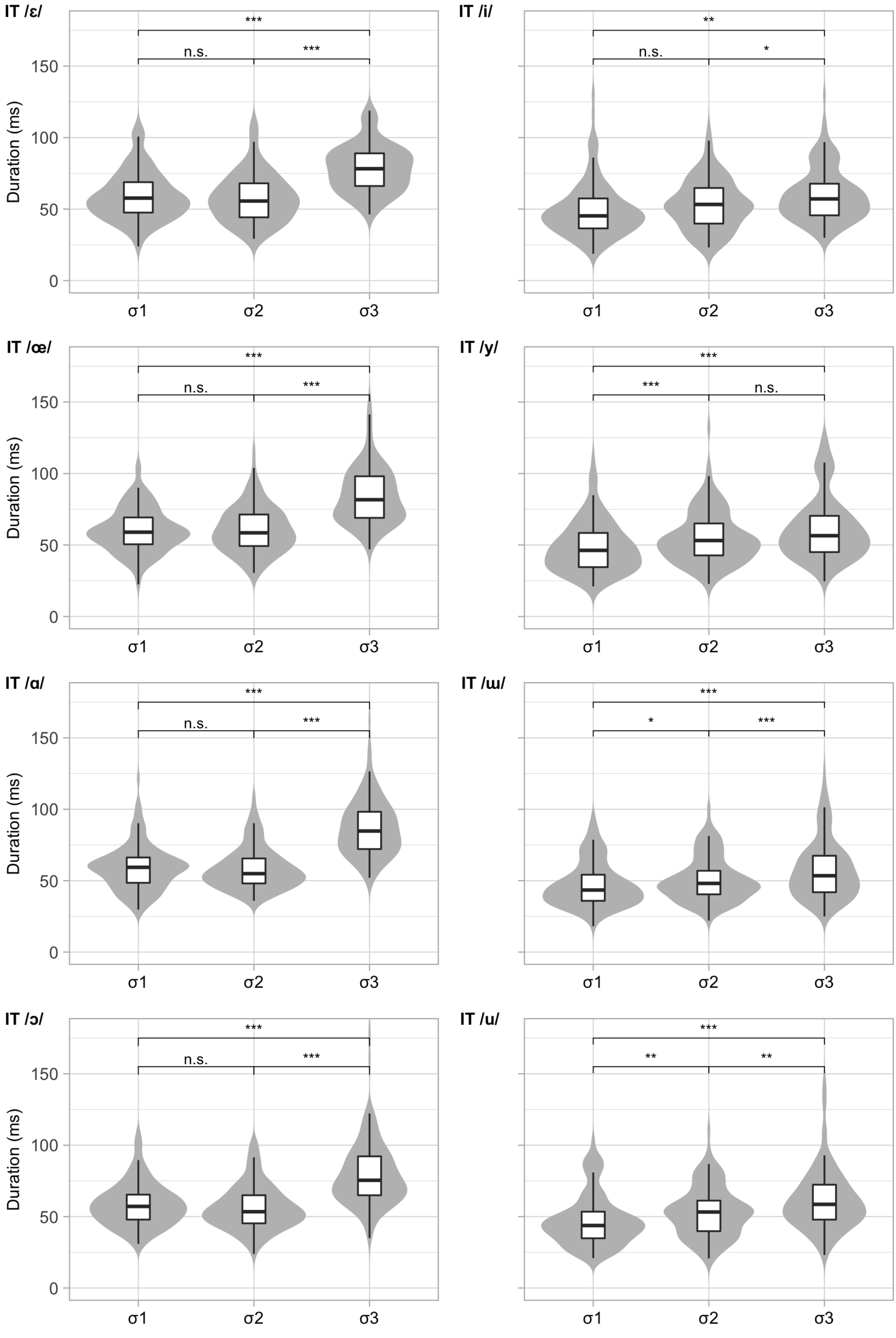


Figure 6.1: test Distribution of duration in Istanbul Turkish Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 6.1.3.

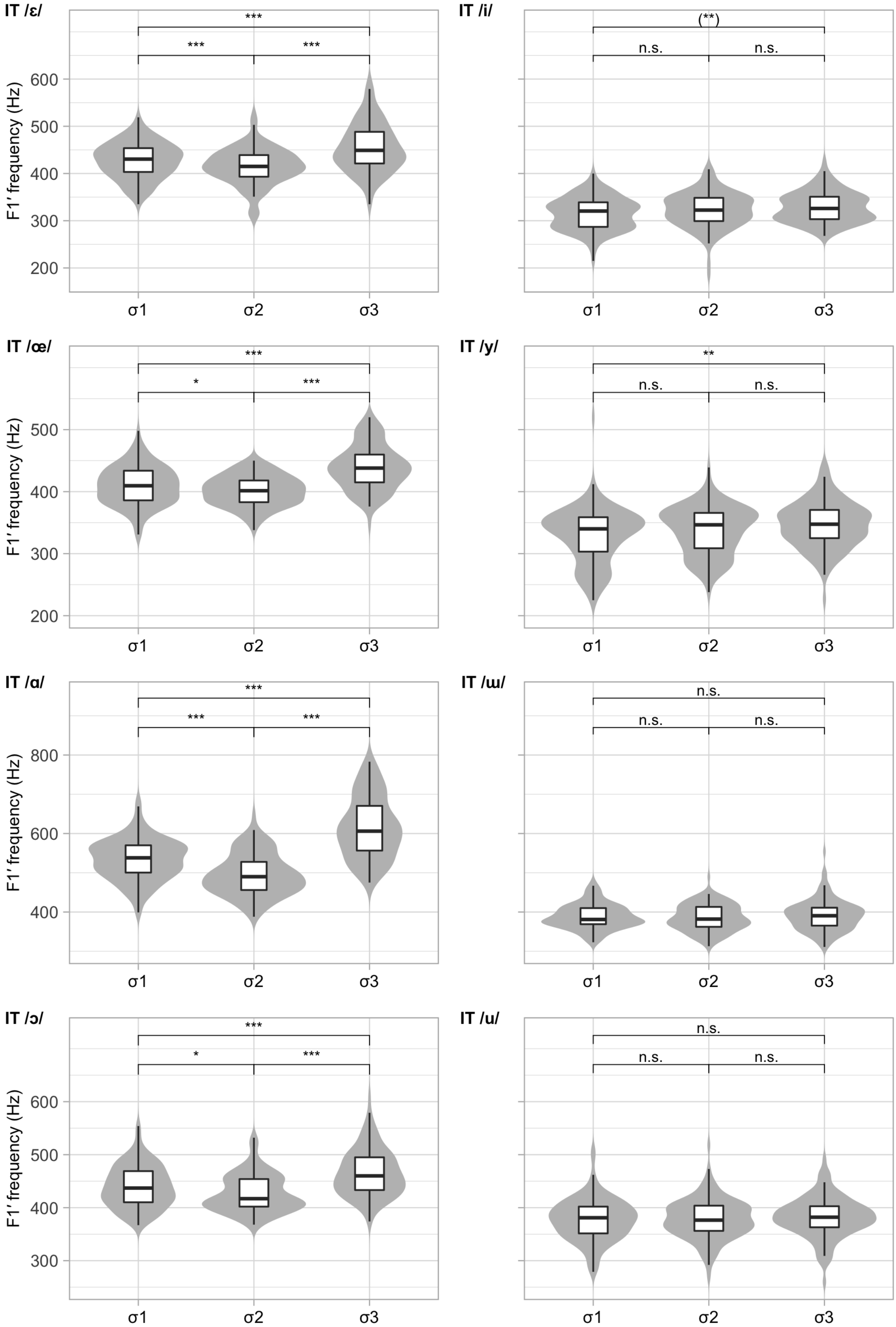


Figure 6.2: Distribution of F_1' frequency in Istanbul Turkish. Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 6.1.3; where in brackets, ANOVA n.s. (§ 6.1.2).

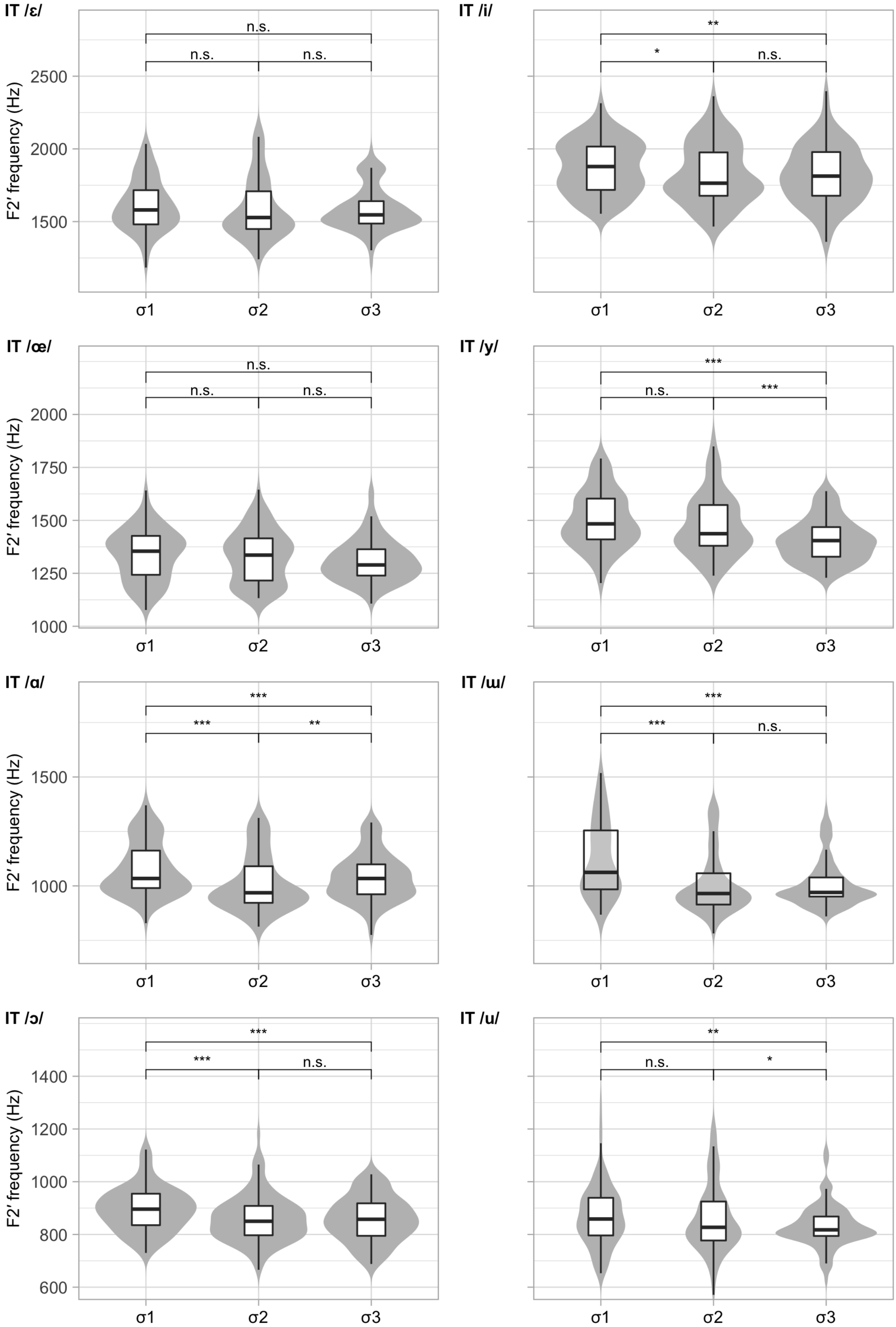


Figure 6.3: Distribution of F_2' frequency in Istanbul Turkish. Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 6.1.3.

6.1.2 Analysis of variance

Table 6.3 shows the repeated-measures ANOVA results for the effect of ‘syllable’ $(1, 2, 3)$ on each of the dependent variables (duration, F_1', F_2') for each Istanbul Turkish phoneme. There is a significant main effect on duration for all vowels. For F_1', open vowels show significant effects, while close vowels do not, with the exception of a marginally significant result for

***A.* Duration**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.77	0.5168	n.s.		2	26	14.25	0.0007	***	0.50
/ɛ/	0.75	0.4906	n.s.		2	26	54.51	0.0000	***	0.71
/y/	0.92	0.8072	n.s.		2	26	13.77	0.0008	***	0.48
/œ/	0.45	0.1322	n.s.		2	26	34.37	0.0000	***	0.69
/ɯ/	0.61	0.2861	n.s.		2	26	10.89	0.0020	**	0.49
/ɑ/	0.32	0.0559	n.s.		2	26	30.72	0.0000	***	0.72
/u/	0.73	0.4495	n.s.		2	26	22.59	0.0001	***	0.50
/ɔ/	0.43	0.1227	n.s.		2	26	28.64	0.0000	***	0.68

***B.* F_1' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.87	0.6985	n.s.		2	26	3.77	0.0537	n.s.	0.13
/ɛ/	0.13	0.0060	**	0.53	1.07	13.90	16.01	0.0058	**	0.28
/y/	0.35	0.0743	n.s.		2	26	4.06	0.0449	*	0.15
/œ/	0.75	0.4912	n.s.		2	26	18.61	0.0002	***	0.52
/ɯ/	0.68	0.3770	n.s.		2	26	0.43	0.6580	n.s.	0.02
/ɑ/	0.22	0.0218	*	0.56	1.12	14.58	19.56	0.0030	**	0.63
/u/	0.96	0.8963	n.s.		2	26	0.31	0.7369	n.s.	0.01
/ɔ/	0.68	0.3863	n.s.		2	26	21.91	0.0001	***	0.37

***C.* F_2' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.94	0.8602	n.s.		2	26	5.07	0.0254	*	0.04
/ɛ/	0.86	0.6815	n.s.		2	26	4.74	0.0305	*	0.01
/y/	0.95	0.8799	n.s.		2	26	20.02	0.0002	***	0.28
/œ/	0.46	0.1432	n.s.		2	26	2.80	0.1004	n.s.	0.03
/ɯ/	0.41	0.1093	n.s.		2	26	33.73	0.0000	***	0.80
/ɑ/	0.46	0.1400	n.s.		2	26	25.71	0.0000	***	0.23
/u/	0.71	0.4322	n.s.		2	26	4.58	0.0332	*	0.07
/ɔ/	0.91	0.7934	n.s.		2	26	4.53	0.0343	*	0.14

Table 6.3: Repeated-measures ANOVAs for the effect of ‘syllable’ on vowel duration, F_1' and F_2', for each Istanbul Turkish phoneme, with ‘speaker’ as case identifier. **GG** Greenhouse-Geisser correction; **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$.

/y/ ($p = 0.0449$). There is a significant main effect on F_2' frequency in all vowels except /œ/.

The F_2' ANOVA for Istanbul Turkish /ɛ/ is the only case—across the five varieties and three dependent variables—where a significant ANOVA ($p = 0.0305$) is not matched with any statistically significant differences in the pairwise comparisons (§ 6.1.3). This is probably because because the main effect is of a particularly small size: $\eta^2 = 0.01$.[1]

6.1.3 Pairwise comparisons

Dependent t-tests with Bonferroni correction ($\alpha = 0.05/3 \approx 0.0167$) were computed for the three parameters across syllable pairs to establish which comparisons are likely to have produced significant main effects in the ANOVAs. The results are detailed in Table 6.4 and the significance levels thus obtained are indicated in Figures 6.1, 6.2 and 6.3. The t-tests produced a significant difference in F_1' between Istanbul Turkish [i_3] and [i_1], even though the corresponding ANOVA showed no significant main effect (§ 6.1.2).

[1] Cohen (1988: 285–288) defines the following categories of magnitude for ANOVA effect sizes expressed as η^2: 'large' $\eta^2 \geq 0.14$, 'medium' $\eta^2 \geq 0.06$, 'small' $\eta^2 \geq 0.01$ (rounded to two decimal places).

***A.* Duration**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/	0.0019	**	0.0197	*	0.1318	n.s.
/ɛ/	0.0000	***	0.0000	***	1.0000	n.s.
/y/	0.0002	***	0.1135	n.s.	0.0003	***
/œ/	0.0000	***	0.0000	***	1.0000	n.s.
/ɯ/	0.0000	***	0.0000	***	0.0132	*
/ɑ/	0.0000	***	0.0000	***	1.0000	n.s.
/u/	0.0000	***	0.0015	**	0.0012	**
/ɔ/	0.0000	***	0.0000	***	0.4336	n.s.

***B.* F_1' frequency**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/†	0.0016	**	0.3870	n.s.	0.0592	n.s.
/ɛ/	0.0000	***	0.0000	***	0.0002	***
/y/	0.0033	**	0.0809	n.s.	0.2654	n.s.
/œ/	0.0000	***	0.0000	***	0.0453	*
/ɯ/	1.0000	n.s.	0.4403	n.s.	1.0000	n.s.
/ɑ/	0.0000	***	0.0000	***	0.0000	***
/u/	1.0000	n.s.	1.0000	n.s.	1.0000	n.s.
/ɔ/	0.0000	***	0.0000	***	0.0130	*

***C.* F_2' frequency**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/	0.0086	**	1.0000	n.s.	0.0267	*
/ɛ/	0.2118	n.s.	1.0000	n.s.	0.7744	n.s.
/y/	0.0000	***	0.0000	***	0.1822	n.s.
/œ/	0.0954	n.s.	0.4900	n.s.	1.0000	n.s.
/ɯ/	0.0000	***	1.0000	n.s.	0.0000	***
/ɑ/	0.0000	***	0.0062	**	0.0000	***
/u/	0.0033	**	0.0417	*	0.9185	n.s.
/ɔ/	0.0000	***	1.0000	n.s.	0.0004	***

Table 6.4: Pairwise comparisons of Istanbul Turkish syllable-specific allophones (dependent t-tests with Bonferroni correction). **σ** syllable; **sig.** significance level: ***** $p \leq 0.001$, **** $p \leq 0.01$, *** $p \leq 0.05$, **n.s.** $p > 0.05$. † ANOVA n.s. (§ 6.1.2).

6.1.4 Correlations

Pearson product-moment correlations between duration and the formant frequencies calculated for each syllable are listed in Table 6.5. The vast majority of syllable-specific allophones—19 out of 24—show significant positive correlations between duration and F_1' frequency, which means that gradient undershoot is prevalent in Istanbul Turkish.

The few and sporadic instances of significant F_2'–duration correlation may suggest a slight tendency for close back vowels to have lower F_2' frequencies at longer durations.

			Duration–F_1'				Duration–F_2'			
	σ	*n*	*r*	size	*p*	sig.	*r*	size	*p*	sig.
/i/	*1.*	98	0.16		0.1280	n.s.	0.27	S	0.0080	**
	2.	98	0.37	M	0.0000	***	0.19		0.0690	n.s.
	3.	98	0.22	S	0.0270	*	-0.05		0.6390	n.s.
/ɛ/	*1.*	98	0.24	S	0.0160	*	-0.09		0.4070	n.s.
	2.	98	0.45	M	0.0000	***	-0.04		0.6970	n.s.
	3.	98	0.40	M	0.0000	***	-0.15		0.1350	n.s.
/y/	*1.*	98	0.31	M	0.0040	**	0.09		0.4040	n.s.
	2.	98	0.20	S	0.0490	*	-0.02		0.8690	n.s.
	3.	98	0.33	M	0.0030	**	-0.20		0.0520	n.s.
/œ/	*1.*	98	0.05		0.6540	n.s.	-0.02		0.8420	n.s.
	2.	98	0.17	S	0.0446	*	-0.01		0.8890	n.s.
	3.	98	0.32	M	0.0060	**	-0.31	M	0.0020	**
/ɯ/	*1.*	98	0.19		0.0560	n.s.	-0.22	S	0.0300	*
	2.	98	0.20	S	0.0440	*	-0.15		0.1440	n.s.
	3.	98	0.32	M	0.0080	**	-0.13		0.2190	n.s.
/ɑ/	*1.*	98	0.31	M	0.0050	**	-0.10		0.3420	n.s.
	2.	98	0.36	M	0.0000	***	-0.20		0.0540	n.s.
	3.	98	0.52	L	0.0000	***	0.17		0.1000	n.s.
/u/	*1.*	98	0.09		0.4040	n.s.	-0.17		0.0890	n.s.
	2.	98	0.20	S	0.0350	*	-0.34	M	0.0010	***
	3.	98	0.14		0.1610	n.s.	-0.25	S	0.0120	*
/ɔ/	*1.*	98	0.18	S	0.0242	*	-0.10		0.3120	n.s.
	2.	98	0.21	S	0.0092	**	-0.09		0.4060	n.s.
	3.	98	0.34	M	0.0020	**	-0.08		0.4310	n.s.

Table 6.5: Pearson correlations of duration with F_1' and duration with F_2' in Istanbul Turkish. **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$. **σ** syllable (*1*, *2*, ***3***, *4*). Effect size (shown where $p \leq 0.05$): **L** large $r \geq 0.5$, **M** medium $r \geq 0.3$, **S** small $r \geq 0.1$ (Cohen 1988: 79–80).

6.2 Stress effects

6.2.1 Unstressed Vowel Shift

6.2.1.1 MANOVA (1)

MANOVAs were computed for each Istanbul Turkish vowel phoneme with stress as independent variable, and duration, F_1' and F_2' as dependent variables. Highly significant effects ($p \leq 0.001$) were found for all vowels, as shown in Table 6.6. While Pillai scores (Λ) for open vowels are not as high as in West (§ 4.2.1.1, p. 104) or East Bulgarian (§ 5.2.1.1, p. 125), the amount of unstressed shift open vowels undergo is appreciably greater than in close vowels.

	df_1	df_2	F	p	sig.	**UVS** = Λ
í, ĭ	3	290	5.88	0.0007	***	0.0573
ɛ́, ɛ̆	3	290	32.36	0.0000	***	0.2508
ý, y̆	3	290	14.14	0.0000	***	0.1276
œ́, œ̆	3	290	56.19	0.0000	***	0.3676
ɯ́, ɯ̆	3	290	7.16	0.0001	***	0.0690
ɑ́, ɑ̆	3	290	80.60	0.0000	***	0.4547
ú, ŭ	3	290	7.96	0.0000	***	0.0761
ɔ́, ɔ̆	3	290	40.33	0.0000	***	0.2944

Table 6.6: MANOVAs for effect of stress on $dur \times F_1' \times F_2'$ in each Istanbul Turkish vowel phoneme. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$; **UVS** Unstressed Vowel Shift; **Λ** Pillai score.

6.2.1.2 Discriminant function analysis (1)

Duration is the primary stress discriminant for all vowels except /y/, where a lower F_2' frequency in stressed position contributes more (Table 6.7). In all open vowels, as well as /i/, F_1' frequency plays a secondary role, although for /ɑ/ it is almost equal with duration. F_2' frequency is a secondary discriminant for /ɯ/, whereas stressed and unstressed /u/ are distinguished by duration alone.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
/i/	Duration	0.82	0.87	0.71	0.17	0.80
	F_1'	0.32	0.57	0.18		0.20
	F_2'	-0.36	-0.29	0.11		
/ɛ/	Duration	-0.83	-0.95	0.79	0.17	0.79
	F_1'	-0.32	-0.67	0.21		0.21
	F_2'	-0.04	0.10	0.00		
/y/	Duration	-0.50	-0.61	0.31	0.17	0.33
	F_1'	-0.15	-0.42	0.06		
	F_2'	0.76	0.83	0.63		0.67
/œ/	Duration	-0.74	-0.87	0.64	0.17	0.64
	F_1'	-0.50	-0.71	0.36		0.36
	F_2'	0.01	0.15	0.00		
/ɯ/	Duration	-0.75	-0.86	0.65	0.17	0.65
	F_1'	-0.05	-0.25	0.01		
	F_2'	0.51	0.66	0.34		0.35
/ɑ/	Duration	0.59	0.87	0.52	0.17	0.52
	F_1'	0.56	0.85	0.48		0.48
	F_2'	-0.09	-0.04	0.00		
/u/	Duration	-0.88	-0.96	0.85	0.17	1
	F_1'	-0.05	-0.18	0.01		
	F_2'	0.27	0.51	0.14		
/ɔ/	Duration	0.76	0.89	0.68	0.17	0.71
	F_1'	0.45	0.63	0.28		0.29
	F_2'	-0.17	-0.20	0.04		

Table 6.7: Discriminant function analysis of stress correlates in Istanbul Turkish. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); ***θ*** negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

6.2.1.3 Probability densities (1)

Probability density estimates for stressed and unstressed vowels are compared in Figures 6.4 (unrounded) and 6.5 (rounded). The tests of equal densities identified eight PDEs that are not significantly different: F_1' frequency of all close vowels and F_2' frequency of /i, ɛ, ɑ, ɔ/. All duration differences are significant.

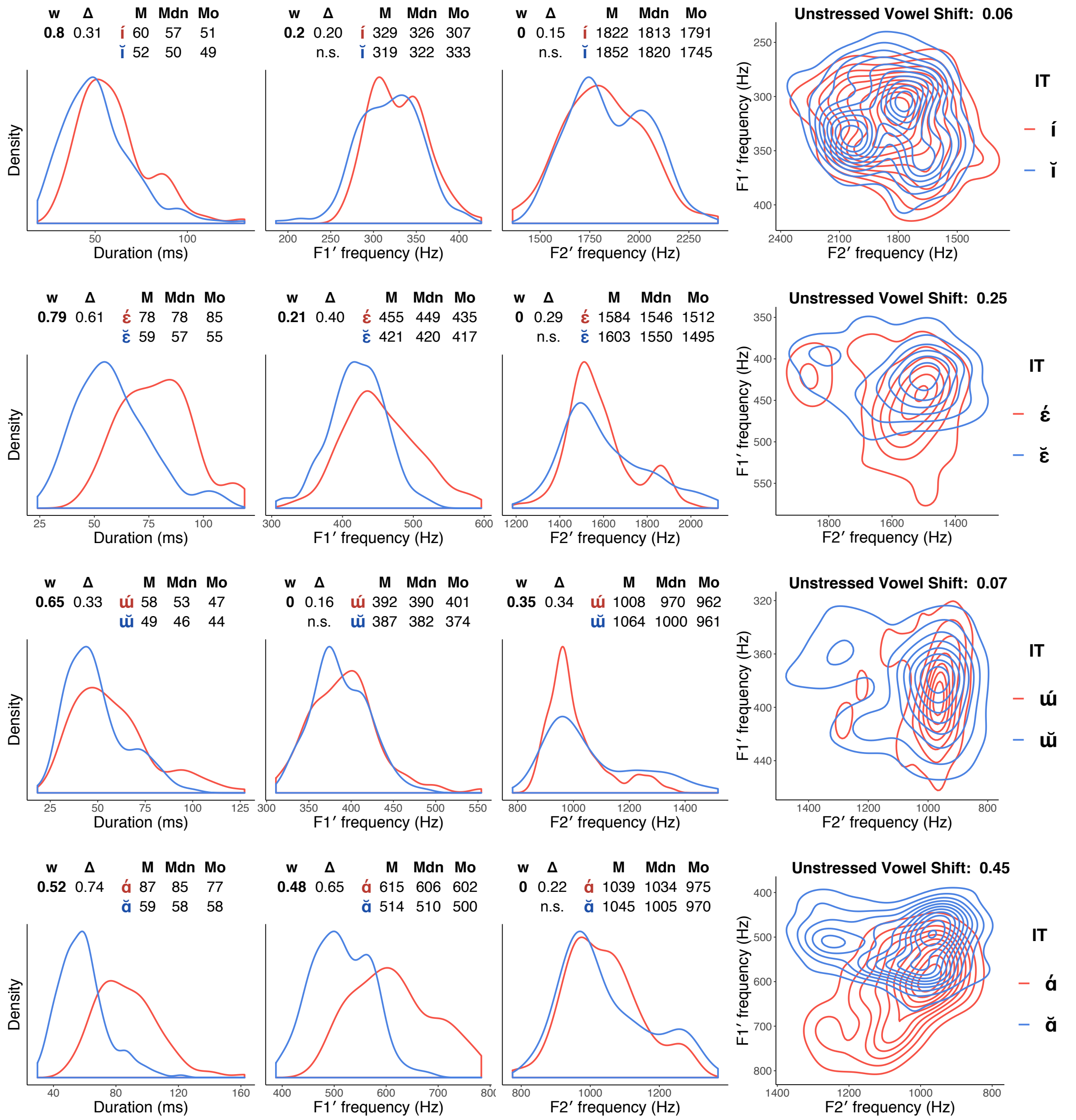


Figure 6.4: PDEs and summary statistics for Istanbul Turkish S/U unrounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

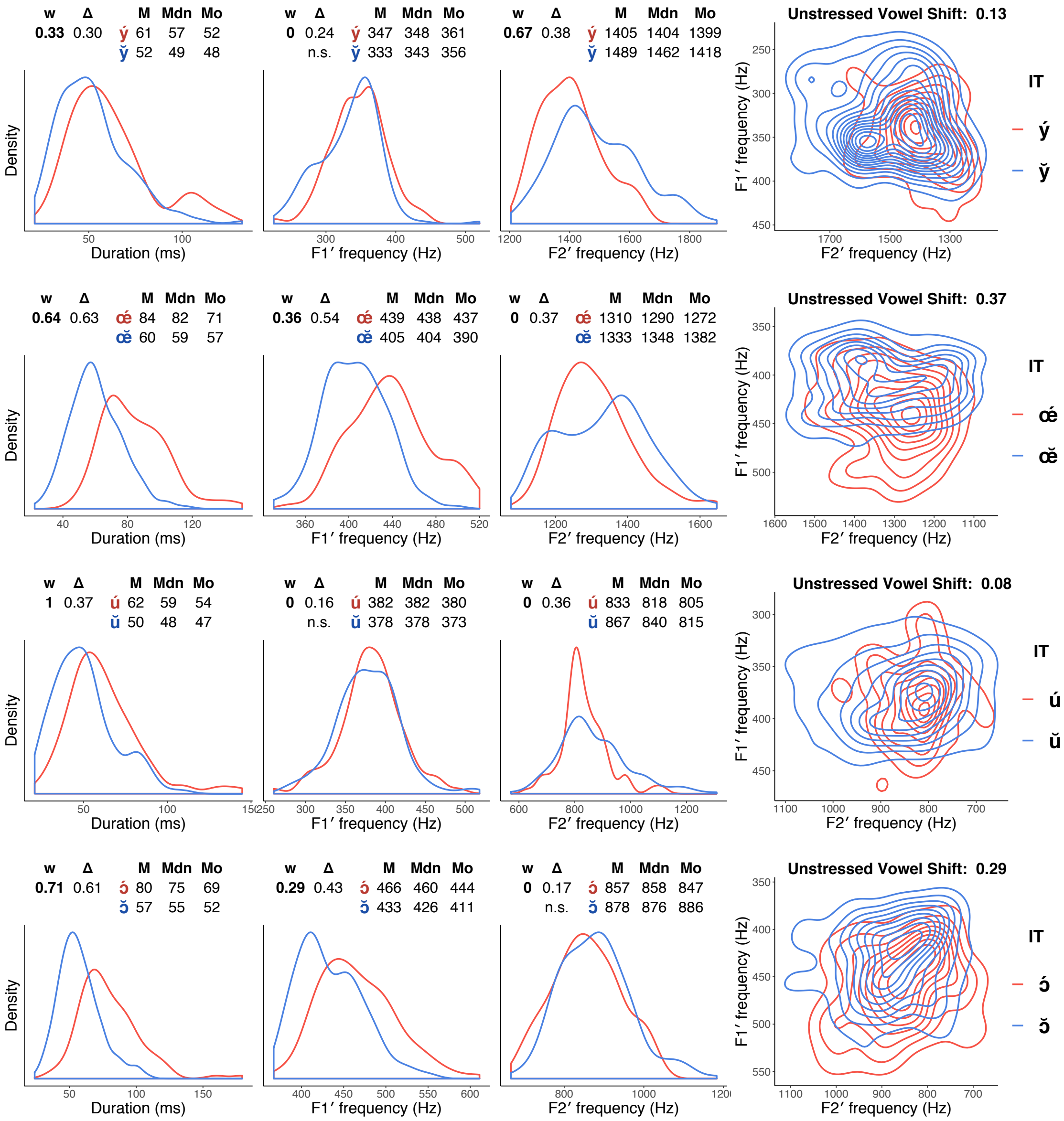


Figure 6.5: PDEs and summary statistics for Istanbul Turkish S/U rounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

6.2.1.4 Stressed and unstressed targets

We have seen that gradient undershoot predominates in Istanbul Turkish syllable-specific allophones (§ 6.1.4). To test whether separate unstressed targets may be in use as well, the *predicted* unstressed $\hat{F}_1$ frequencies of open vowels are compared to their *observed* mean unstressed $\bar{F}_1'$ frequencies in Table 6.8. In all four open vowels, the degree of observed F_1' frequency reduction in unstressed position is lower than the undershoot predicted for the corresponding unstressed mean durations, assuming stressed F_1' frequencies to be target values. This indicates that gradient undershoot under temporal pressure, on its own, can account for all Unstressed Vowel Shift in Istanbul Turkish, and that unstressed vowels do not implement separate targets.

	Predicted unstressed $\hat{F}_1$ frequency (Hz)	Observed unstressed $\bar{F}'_1$ frequency (Hz)	Residual value $\bar{F}'_1 - \hat{F}_1$
/ɛ/	400.47	421.29	20.82
/œ/	396.11	405.43	9.33
/ɑ/	451.95	514.15	62.21
/ɔ/	403.27	433.47	30.20

Table 6.8: Predicted and observed unstressed F'_1 frequencies of Istanbul Turkish open vowels.

6.2.2 Contrast and neutralisation

6.2.2.1 MANOVA (2)

Table 6.9 shows the outcome of MANOVAs comparing Istanbul Turkish open and close vowels. Contrast levels are generally high, both for stressed and unstressed vowel. The lowest score is found in unstressed /u–ɔ/: $\Lambda = 0.35$. The results also reveal low levels of neutralisation, which is highest in /u–ɔ/: 0.33 (33% contrast loss).

	df_1	df_2	F	p	sig.	**Contrast** $= \Lambda$	**Loss**
í, έ	3	192	150.71	0.0000	***	0.7019	
ĭ, ɛ̆	3	388	267.46	0.0000	***	0.6741	0.04
ý, œ́	3	192	104.82	0.0000	***	0.6209	
y̆, œ̆	3	388	162.43	0.0000	***	0.5567	0.10
ɯ́, ɑ́	3	192	217.47	0.0000	***	0.7726	
ɯ̆, ɑ̆	3	388	246.24	0.0000	***	0.6556	0.15
ú, ɔ́	3	192	68.35	0.0000	***	0.5164	
ŭ, ɔ̆	3	388	68.21	0.0000	***	0.3453	0.33

Table 6.9: MANOVAs for Istanbul Turkish O/C vowel pairs: effect of height on $dur \times F'_1 \times F'_2$. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$ **Λ** Pillai score; **Loss** $= (\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 1 - \breve{\Lambda}/\acute{\Lambda}$.

6.2.2.2 Discriminant function analysis (2)

Discriminant function analysis, presented in Table 6.10, identified F'_1 frequency as the sole height discriminant for back vowels, as well as the major discriminant in front vowels, for which F_2' frequency also plays a minor role. Duration does not contribute to the contrast in any of the pairs.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
í, ɛ́	Duration	-0.03	-0.52	0.02	0.17	
	F_1'	-0.85	-0.93	0.79		0.80
	F_2'	0.31	0.63	0.20		0.20
ĭ, ɛ̆	Duration	-0.12	0.23	-0.03	0.18	
	F_1'	0.90	0.94	0.85		0.83
	F_2'	-0.28	-0.63	0.18		0.17
ý, œ́	Duration	-0.12	-0.59	0.07	0.17	
	F_1'	-0.87	-0.95	0.83		1
	F_2'	0.20	0.52	0.10		
y̆, œ̆	Duration	0.05	0.30	0.02	0.17	
	F_1'	0.79	0.89	0.70		0.71
	F_2'	-0.43	-0.65	0.28		0.29
ɯ́, á	Duration	-0.01	0.66	-0.01	0.18	
	F_1'	1.05	1.00	1.04		1
	F_2'	-0.23	0.16	-0.04		
ɯ̆, ă	Duration	0.03	-0.37	-0.01	0.17	
	F_1'	-1.01	-1.00	1.01		1
	F_2'	0.01	0.08	0.00		
ú, ɔ́	Duration	0.21	0.51	0.11	0.17	
	F_1'	0.90	0.96	0.86		1
	F_2'	0.14	0.20	0.03		
ŭ, ɔ̆	Duration	-0.17	-0.35	0.06	0.17	
	F_1'	-0.95	-0.98	0.94		1
	F_2'	-0.04	-0.09	0.00		

Table 6.10: Discriminant function analysis of phonological vowel height in Istanbul Turkish. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

6.2.2.3 Probability densities (2)

All PDEs compared in Figures 6.6 (unrounded) and 6.7 (rounded) are significantly different except those of F_2' frequency for unstressed /ɯ–ɑ/. Any apparent symmetric differences in duration estimates or back vowel F_2' estimates are counterbalanced by the negligible role of these parameters as height discriminants.

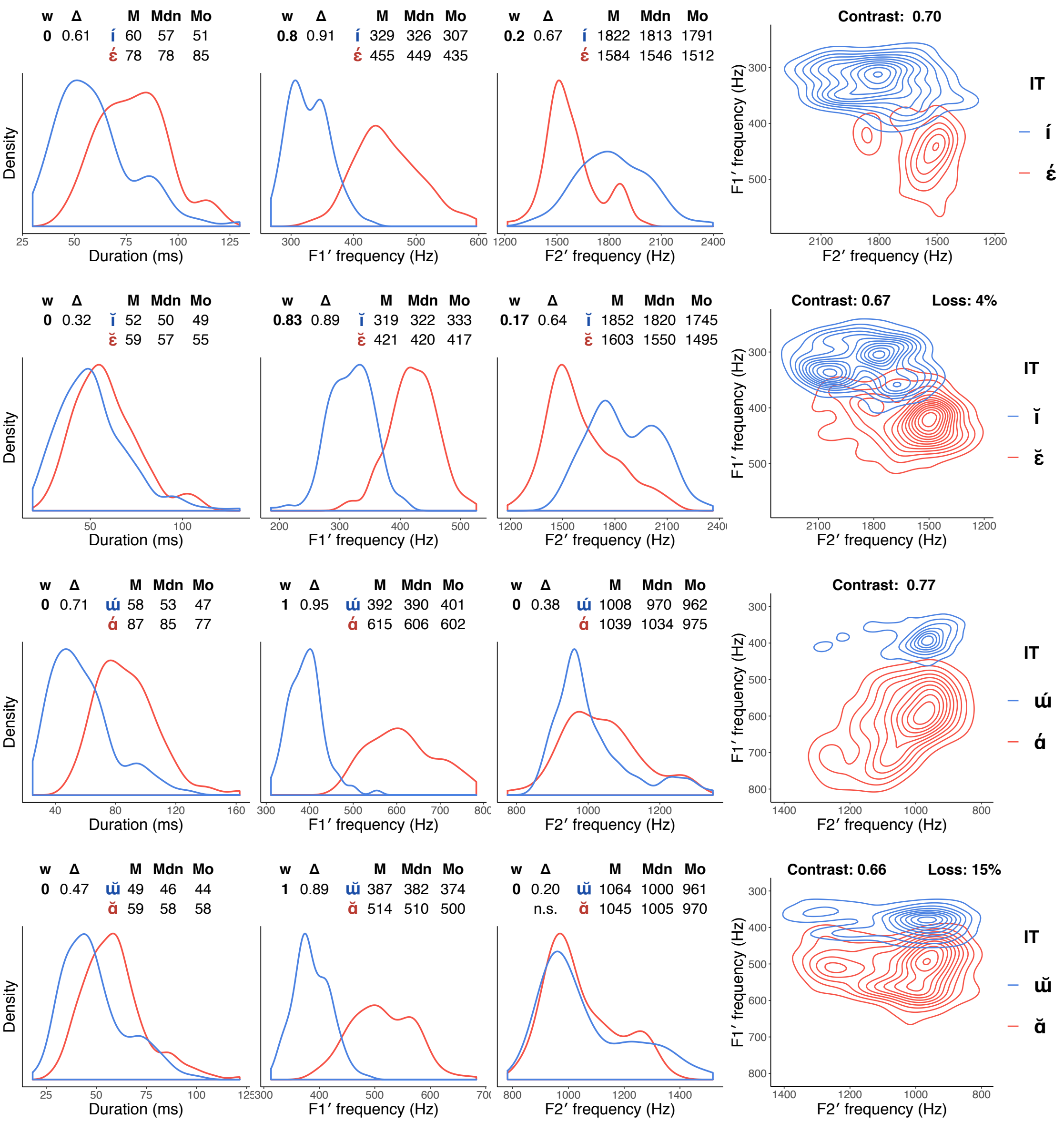


Figure 6.6: PDEs and summary statistics for Istanbul Turkish O/C unrounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

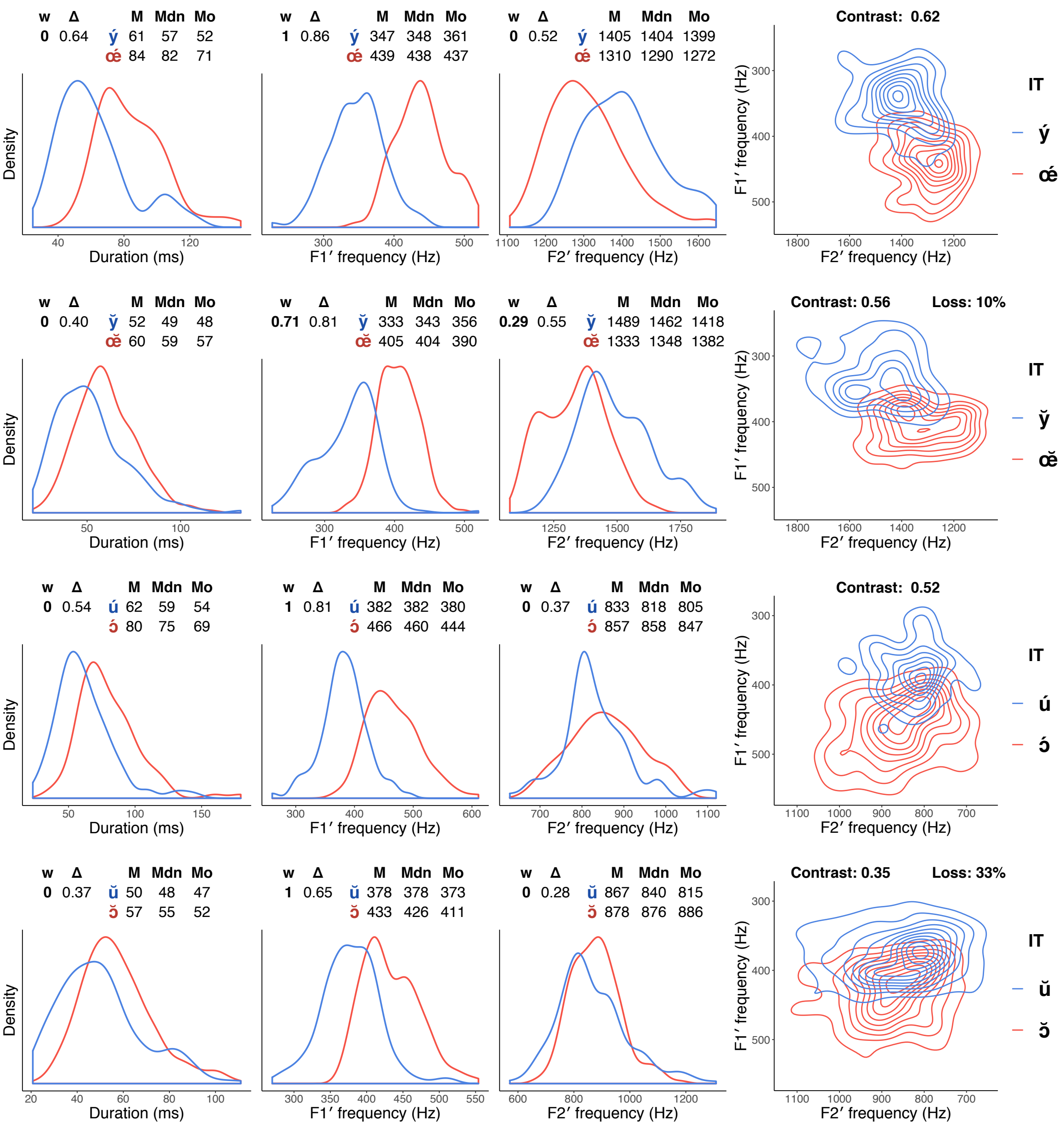


Figure 6.7: PDEs and summary statistics for Istanbul Turkish O/C rounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

6.3 Discussion of findings

In the comparisons of mean duration, F_1' and F_2' frequencies in this chapter, the independent variable was 'syllable', a categorical variable consisting of three groups: $\sigma_1, \sigma_2, \sigma_3$. I used three, rather than two (stressed vs unstressed), groups for two reasons. The first was to make the data and findings comparable to those in the Bulgarian experiments. Secondly, it has been claimed that Turkish word-initial syllables manifest a certain prominence or 'phonological strength' (Barnes 2006).

The data and analyses presented here only partly confirm that observation: while open vowels do have higher F_1' frequencies in first compared to second unstressed syllables, none of the vowels was found to be longer in initial syllables. The duration of open vowels was the same in the two unstressed syllables, while close vowels were in fact significantly shorter in initial than in second syllables. Stressed vowels, on the other hand, were significantly longer than vowels in either unstressed position (except for $[y_3] = [y_2]$). Significant differences in F_1' frequency were also found between stressed and unstressed open vowels, as well as partially for /i/ and /y/. As regards F_2' frequency, it tends to

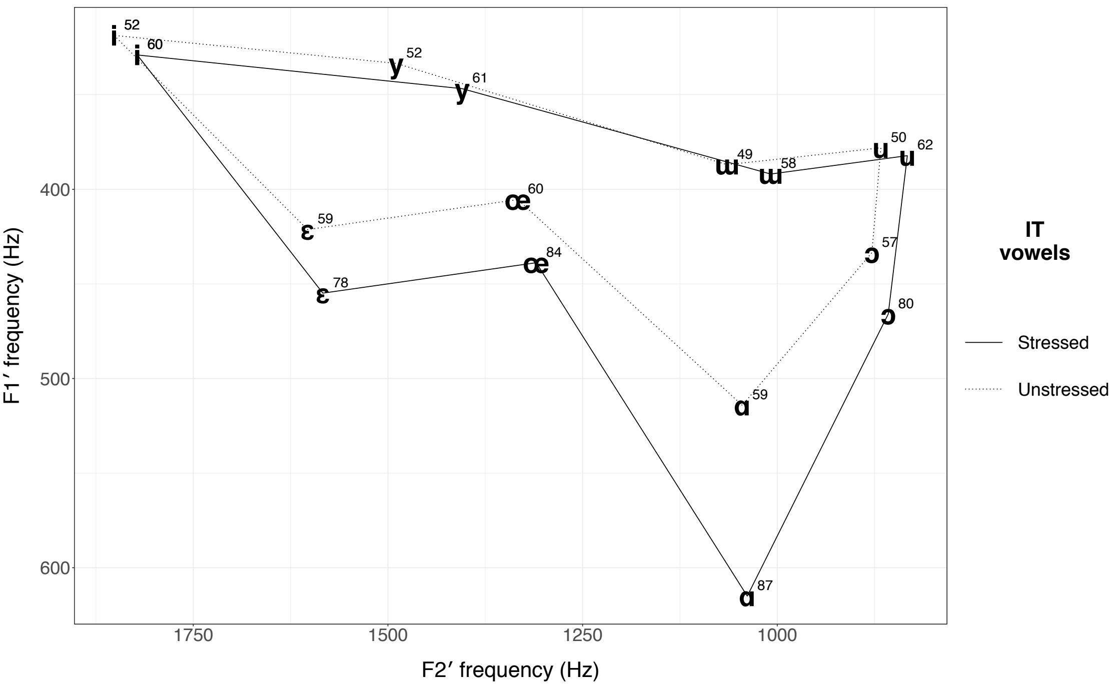


Figure 6.8: Istanbul T. S/U vowels in the $F_1' \times F_2'$ space (means). Numbers: mean dur. (ms).

be highest in initial and lowest in stressed syllables, which typologically is an unusual distinction between stressed and unstressed vowels. The differences in mean values thus summarised can be seen in Figure 6.8.

The importance of duration for stress in Istanbul Turkish was confirmed by my discriminant function analysis, which identified duration as the primary stress discriminant for all vowels except /y/ (where F_2' frequency plays a greater part). In most other vowels, /i, ɛ, œ, ɑ, ɔ/, F_1' frequency also plays a secondary role in distinguishing stressed from unstressed realisations. The evidence for /i/, however, is contradictory: the importance of F_1' frequency is supported by the *t*-tests and DFA but not by the ANOVA or the PDE comparison.

Significant positive correlations are prevalent between duration and F_1' frequency, while at the same time there is no evidence of separate unstressed vowel targets: the amount of observed spectral reduction in unstressed position does not exceed that of predicted undershoot. I therefore conclude that Unstressed Vowel Shift in Istanbul Turkish is entirely gradient.

Figures 6.9 and 6.10 display probability density contours of Istanbul Turkish stressed and unstressed vowels in the $F_1' \times F_2'$ frequency space. The degree of height neutralisation in

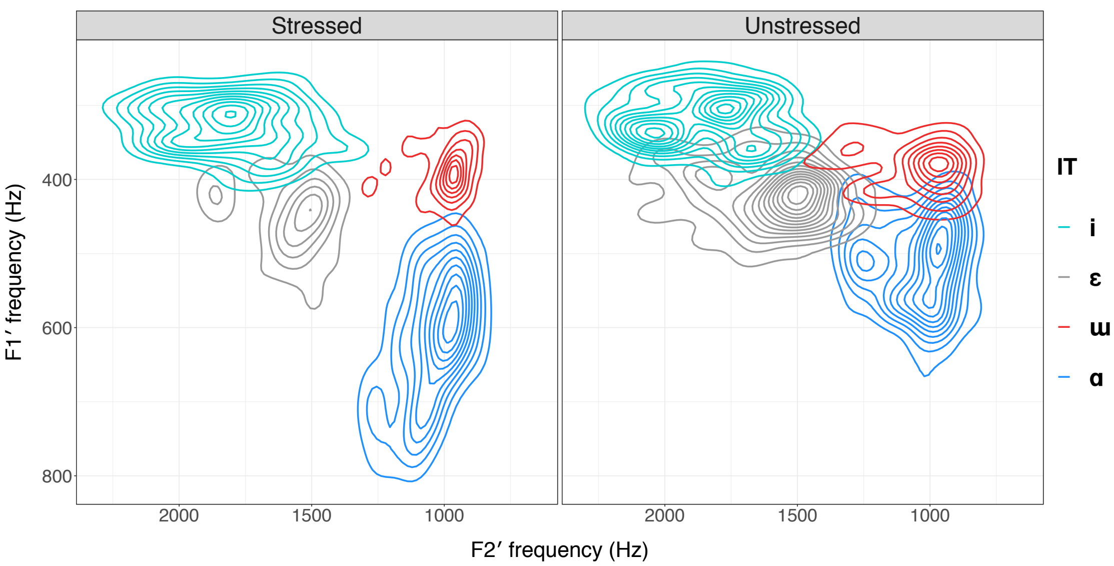


Figure 6.9: PDEs of Istanbul Turkish S/U unrounded vowels in the $F_1' \times F_2'$ space.

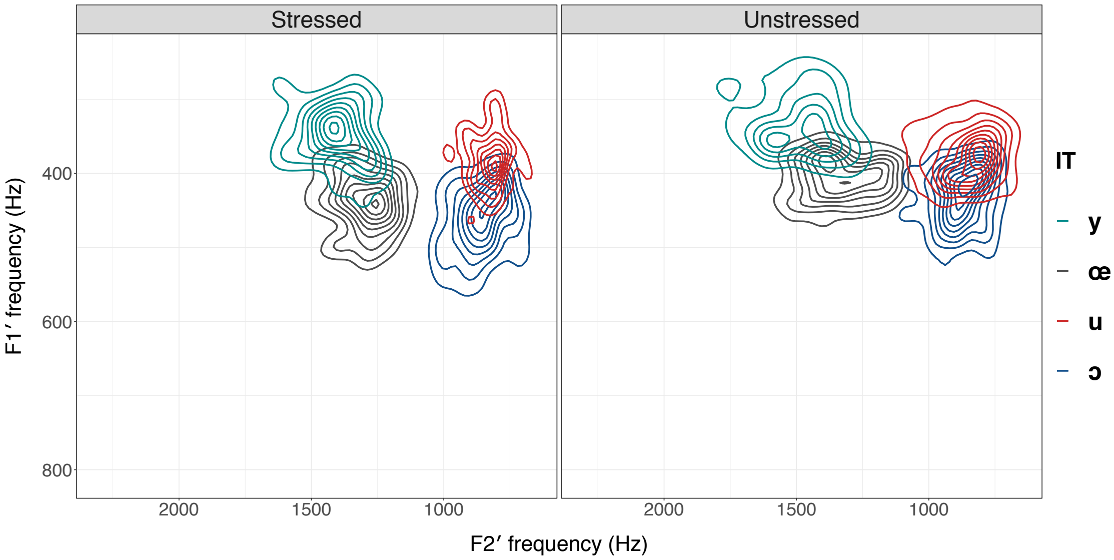


Figure 6.10: PDEs of Istanbul Turkish S/U rounded vowels in the $F_1' \times F_2'$ space.

unstressed syllables is rather low in Istanbul Turkish, especially compared to the Bulgarian varieties I have examined so far. This is hardly surprising, since—as I have demonstrated—Unstressed Vowel Shift is gradient and occurs as a function of time. F_1' frequency if the primary acoustic parameter that distinguishes open from close vowels in Istanbul Turkish; duration does not play a role, and the front vowels also rely on F_2' frequency to implement the contrast, but to a much lesser extent. This is a natural consequence of the shape of the vowel space: front *close* vowels are, as a rule, more advanced than front *open* vowels.

7

Bilingual Bulgarian

Contents

7.1 Mean comparisons and correlations

7.1.1 Means and distributions

The group means and standard deviations for the duration and normalised F_1 and F_2 frequencies of stressed and unstressed Bilingual Bulgarian vowels are listed in Table 7.1. Table 7.2 shows the same parameters for vowels in separate syllables.

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
Phoneme	Stress	n	Mean	SD	Mean	SD	Mean	SD
/i/	+	168	49.94	12.28	312	24	1774	152
	−	504	45.83	11.39	316	25	1794	153
/ɛ/	+	168	67.61	14.59	403	31	1635	156
	−	504	52.80	12.25	395	36	1591	166
/ə/	+	168	50.62	11.53	409	36	917	69
	−	504	49.50	13.40	419	42	923	108
/a/	+	168	73.32	16.86	600	83	1003	125
	−	504	53.39	14.34	520	68	961	106
/u/	+	168	50.21	13.53	402	62	809	155
	−	504	47.01	13.10	389	70	931	287
/ɔ/	+	168	66.53	15.41	455	54	798	65
	−	504	50.42	13.13	426	46	772	80

Table 7.1: Group means and standard deviations for Bilingual Bulgarian vowel duration, F_1' and F_2' by stress.

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
	σ	n	Mean	SD	Mean	SD	Mean	SD
/i/	*1.*	168	48.54	11.60	308	23	1863	176
	2.	168	43.46	9.68	310	22	1799	117
	3.	168	49.94	12.28	312	24	1774	152
	4.	168	45.49	12.21	330	25	1718	122
/ɛ/	*1.*	168	52.79	12.26	394	28	1652	193
	2.	168	48.36	9.33	373	31	1591	147
	3.	168	67.61	14.59	403	31	1635	156
	4.	168	57.26	13.23	419	35	1530	129
/ə/	*1.*	168	48.09	12.50	417	26	979	142
	2.	168	43.10	7.80	403	42	876	56
	3.	168	50.62	11.53	409	36	917	69
	4.	168	57.31	14.81	437	48	915	83
/a/	*1.*	168	53.14	13.70	551	76	1014	122
	2.	168	46.37	9.63	482	44	915	76
	3.	168	73.32	16.86	600	83	1003	125
	4.	168	60.65	15.36	529	61	954	90
/u/	*1.*	168	48.35	13.93	386	71	966	368
	2.	168	43.39	11.03	371	76	1048	260
	3.	168	50.21	13.53	402	62	809	155
	4.	168	49.27	13.46	409	58	779	81
/ɔ/	*1.*	168	50.56	11.84	432	48	784	73
	2.	168	42.86	9.73	421	47	762	86
	3.	168	66.53	15.41	455	54	798	65
	4.	168	57.83	13.11	424	43	771	79

Table 7.2: Group means and standard deviations for Bilingual Bulgarian vowel duration, F_1' and F_2' by syllable. **σ** syllable: *1.* initial, *2.* pretonic, ***3.*** stressed, *4.* final.

7.1.1.1 Duration

Syllable-specific duration distributions and probability density estimates for Bilingual Bulgarian can be seen in Figure 7.1. There are statistically significant, systematic differences in all syllable pairings for open vowels: stressed vowels are considerably longer than any unstressed allophones; in unstressed position, final syllables (σ_4) have the greatest duration, whereas pretonic (σ_2) vowels are the shortest. While differences in close vowels are less systematic, pretonic, second-syllable allophones tend to be the shortest here as well. [i_2] and [i_4] are not significantly different, and neither are [i_3] and [i_1], while the latter pair have longer durations than the former. [ə_4] is longer than [ə_3], which is not different from [ə_1], but all these allophones are longer than [ə_2]. /u/ is shortest in σ_2 as well, but no other pair shows a significant difference.

7.1.1.2 F_1' frequency

Figure 7.3 shows F_1' frequency distributions and PDEs for Bilingual Bulgarian. For /a/ and /ɔ/, F_1' frequency is highest in the stressed and lowest in the pretonic syllable. F_1' in stressed /ɛ/ is higher than in [ɛ_1] and [ɛ_2] but, perhaps surprisingly, slightly lower than in [ɛ_4]; it is lowest in [ɛ_2]. In close vowels, V_4 tends to have the highest and V_2 the lowest F_1' frequency, though these are not necessarily significantly different from allophones in other syllables.

7.1.1.3 F_2' frequency

The F_2' frequency distributions in Figure 7.3 and means in Table 7.2 do not reveal any systematic positional behaviour.

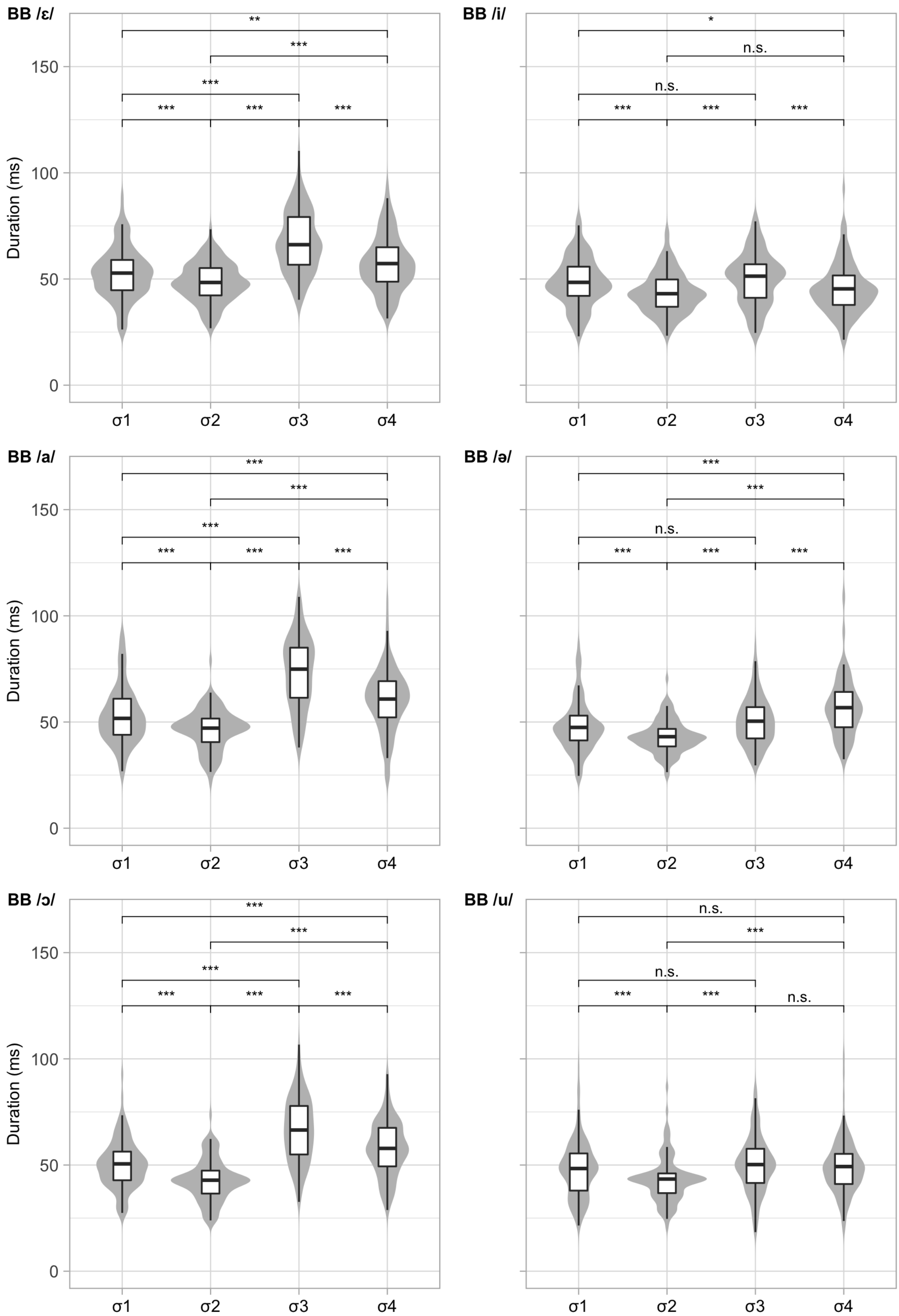


Figure 7.1: Distribution of duration in Bilingual Bulgarian. Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 7.1.3.

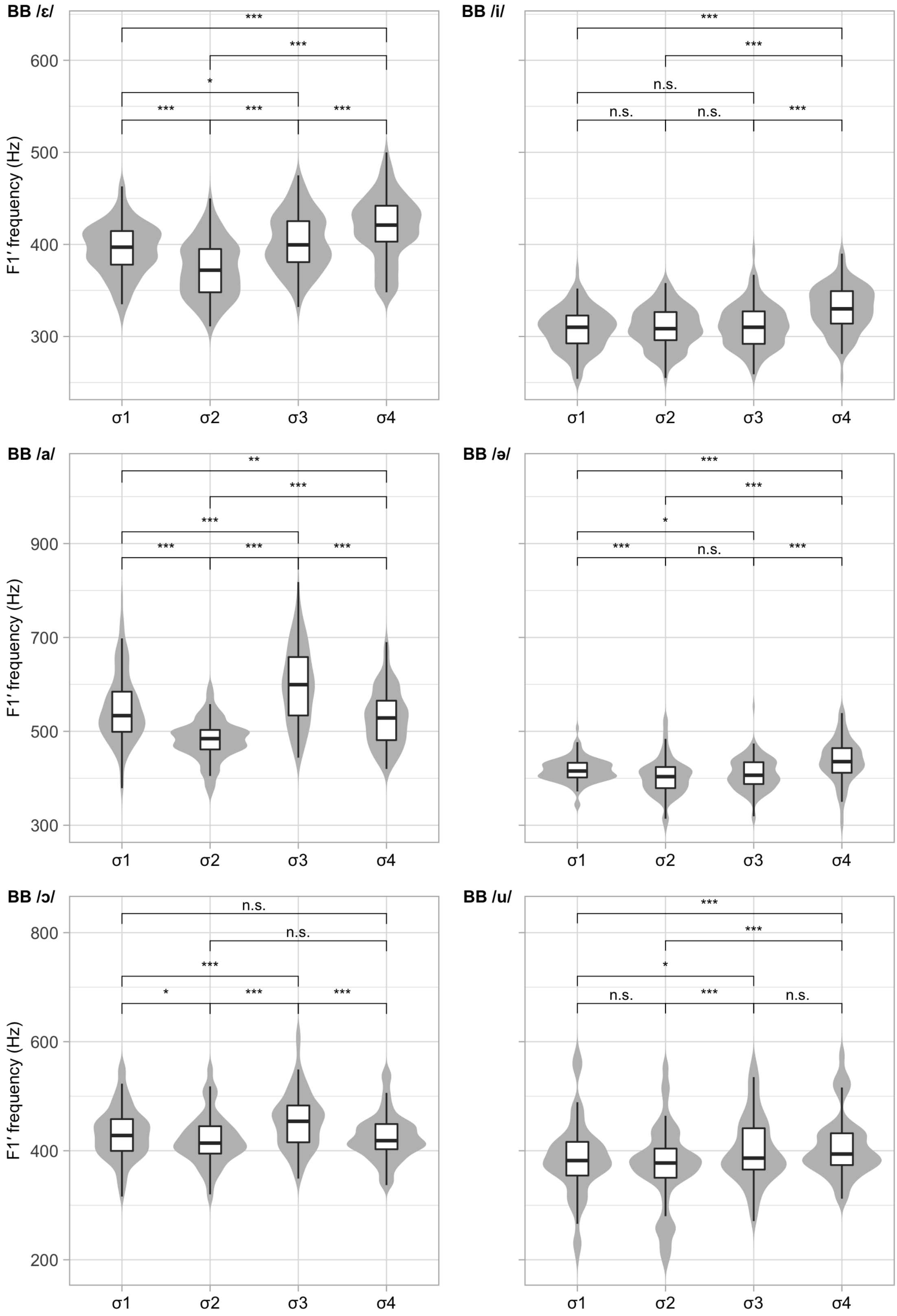


Figure 7.2: Distribution of F_1' frequency in Bilingual Bulgarian. Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; $\boldsymbol{\sigma}$: syllable. Significance from § 7.1.3.

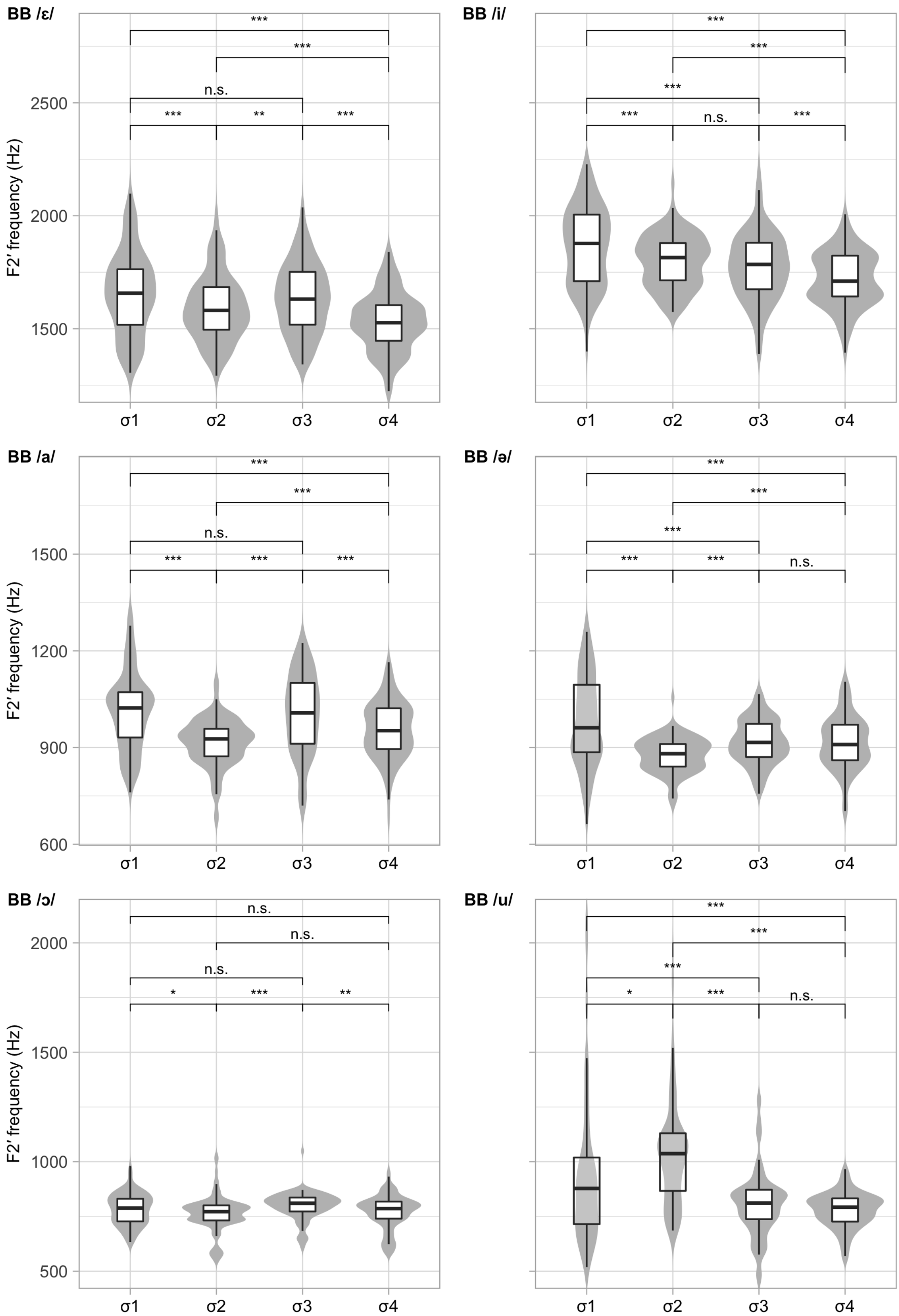


Figure 7.3: Distribution of F_2' frequency in Bilingual Bulgarian. Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 7.1.3.

7.1.2 Analysis of variance

The repeated-measures ANOVAs for Bilingual Bulgarian, with ‘speaker’ as case identifier, ‘syllable’ $(1, 2, 3, 4)$ as predictor variable and each of the acoustic parameters as dependent variables, yielded significant main effects for *all* phoneme–parameter pairings; the results are in Table 7.3.

***A.* Duration**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.85	0.8599	n.s.		3	39	3.77	0.0181	*	0.12
/ɛ/	0.61	0.3245	n.s.		3	39	17.62	0.0000	***	0.47
/ə/	0.71	0.5372	n.s.		3	39	16.65	0.0000	***	0.41
/a/	0.68	0.4707	n.s.		3	39	30.85	0.0000	***	0.55
/u/	0.33	0.0252	*	0.66	1.97	25.61	4.86	0.0166	*	0.12
/ɔ/	0.22	0.0038	**	0.60	1.80	23.40	26.69	0.0000	***	0.56

***B.* F_1' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.77	0.6918	n.s.		3	39	14.19	0.0000	***	0.26
/ɛ/	0.79	0.7278	n.s.		3	39	27.90	0.0000	***	0.40
/ə/	0.34	0.0290	*	0.62	1.87	24.25	11.15	0.0005	***	0.19
/a/	0.52	0.1783	n.s.		3	39	22.62	0.0000	***	0.49
/u/	0.47	0.1113	n.s.		3	39	4.04	0.0136	*	0.08
/ɔ/	0.66	0.4310	n.s.		3	39	12.05	0.0000	***	0.12

***C.* F_2' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.31	0.0170	*	0.57	1.72	22.3	12.82	0.0003	***	0.29
/ɛ/	0.54	0.2042	n.s.		3	39	10.99	0.0000	***	0.17
/ə/	0.40	0.0602	n.s.		3	39	14.81	0.0000	***	0.37
/a/	0.61	0.3375	n.s.		3	39	13.47	0.0000	***	0.21
/u/	0.07	0.0000	***	0.46	1.39	18.08	15.15	0.0004	***	0.40
/ɔ/	0.44	0.0897	n.s.		3	39	2.94	0.0448	*	0.09

Table 7.3: Repeated-measures ANOVAs for the effect of ‘syllable’ on vowel duration, F_1' and F_2', for each Bilingual Bulgarian phoneme, with ‘speaker’ as case identifier. **GG** Greenhouse-Geisser correction; **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

7.1.3 Pairwise comparisons

Table 7.4 lists the results of dependent t-tests with Bonferroni correction ($\alpha = 0.05/4 = 0.0125$) comparing the three parameters across syllable pairs in Bilingual Bulgarian, which were computed to estimate which comparisons are likely to have contributed to the significant main effects in the ANOVAs just reported. The significance levels obtained in this section are also shown in Figures 7.1, 7.2 and 7.3. There are no significant t-test results for Bilingual Bulgarian that are not supported by significant main effects from ANOVAs (§ 7.1.2).

***A.* Duration**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	1.0000	n.s.	0.0000	***	0.0006	***	0.0000	***	0.0493	*	0.2513	n.s.
/ɛ/	0.0000	***	0.0000	***	0.0000	***	0.0006	***	0.0053	**	0.0000	***
/ə/	0.3797	n.s.	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***
/a/	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***
/u/	0.9853	n.s.	0.0000	***	1.0000	n.s.	0.0001	***	1.0000	n.s.	0.0000	***
/ɔ/	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***

***B.* F_1' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.4760	n.s.	1.0000	n.s.	0.0000	***	1.0000	n.s.	0.0000	***	0.0000	***
/ɛ/	0.0146	*	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***
/ə/	0.0210	*	0.3136	n.s.	0.0000	***	0.0000	***	0.0000	***	0.0000	***
/a/	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0018	**	0.0000	***
/u/	0.0157	*	0.0000	***	0.9550	n.s.	0.1343	n.s.	0.0003	***	0.0000	***
/ɔ/	0.0000	***	0.0000	***	0.0000	***	0.0417	*	0.1750	n.s.	1.0000	n.s.

***C.* F_2' frequency**

	stressed–unstressed						unstressed–unstressed					
	(σ_3, σ_1)		(σ_3, σ_2)		(σ_3, σ_4)		(σ_1, σ_2)		(σ_1, σ_4)		(σ_2, σ_4)	
	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.0000	***	0.5723	n.s.	0.0001	***	0.0002	***	0.0000	***	0.0000	***
/ɛ/	1.0000	n.s.	0.0022	**	0.0000	***	0.0006	***	0.0000	***	0.0000	***
/ə/	0.0000	***	0.0000	***	1.0000	n.s.	0.0000	***	0.0000	***	0.0000	***
/a/	1.0000	n.s.	0.0000	***	0.0000	***	0.0000	***	0.0000	***	0.0000	***
/u/	0.0000	***	0.0000	***	0.0619	n.s.	0.0368	*	0.0000	***	0.0000	***
/ɔ/	0.3644	n.s.	0.0000	***	0.0037	**	0.0402	*	0.4373	n.s.	1.0000	n.s.

Table 7.4: Pairwise comparisons of Bilingual Bulgarian syllable-specific allophones (dependent t-tests with Bonferroni correction). **σ** syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

7.1.4 Correlations

Pearson correlations between duration and the formant frequencies, calculated for syllable-specific allophones, are given in Table 7.5. For /a/ there is a significant positive correlation in all syllables, while with /ɛ/ and /ɔ/ that is the case in two out four syllables, which suggests that some gradient undershoot is present in all open vowels. Thirteen syllable-specific allophones show significant positive correlations of duration with F_2' frequency, indicating that longer unrounded vowels as a rule have higher F_2' frequencies.

			Duration–F_1'				Duration–F_2'			
	σ	n	r	size	p	sig.	r	size	p	sig.
/i/	*1.*	84	-0.10		0.1820	n.s.	0.44	M	0.0000	***
	2.	84	0.09		0.2450	n.s.	0.27	S	0.0000	***
	3.	84	-0.21	S	0.0070	**	0.46	M	0.0000	***
	4.	84	-0.01		0.9070	n.s.	0.26	S	0.0010	***
/ɛ/	*1.*	84	0.36	M	0.0000	***	0.29	S	0.0000	***
	2.	84	0.25	S	0.0010	***	-0.04		0.5670	n.s.
	3.	84	-0.10		0.2200	n.s.	0.69	L	0.0000	***
	4.	84	0.13		0.0850	n.s.	0.19	S	0.0140	*
/ə/	*1.*	84	0.05		0.4860	n.s.	0.51	L	0.0000	***
	2.	84	0.25	S	0.0010	***	-0.08		0.3030	n.s.
	3.	84	-0.24	S	0.0020	**	0.26	S	0.0010	***
	4.	84	0.04		0.5830	n.s.	0.40	M	0.0000	***
/a/	*1.*	84	0.56	L	0.0000	***	0.60	L	0.0000	***
	2.	84	0.22	S	0.0050	**	0.09		0.2580	n.s.
	3.	84	0.61	L	0.0000	***	0.73	L	0.0000	***
	4.	84	0.41	M	0.0000	***	0.42	M	0.0000	***
/u/	*1.*	84	-0.14		0.0800	n.s.	0.05		0.4860	n.s.
	2.	84	-0.07		0.3910	n.s.	0.12		0.1190	n.s.
	3.	84	0.02		0.8140	n.s.	0.11		0.1390	n.s.
	4.	84	-0.07		0.3960	n.s.	0.02		0.8480	n.s.
/ɔ/	*1.*	84	0.19	S	0.0120	*	0.12		0.1170	n.s.
	2.	84	0.13		0.0920	n.s.	-0.06		0.4660	n.s.
	3.	84	0.20	S	0.0210	*	0.09		0.2510	n.s.
	4.	84	0.10		0.2010	n.s.	0.14		0.0730	n.s.

Table 7.5: Pearson correlations of duration with F_1' and duration with F_2' in Bilingual Bulgarian. **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$. **σ** syllable (*1*, *2*, ***3***, *4*). Effect size (shown where $p \leq 0.05$): **L** large $r \geq 0.5$, **M** medium $r \geq 0.3$, **S** small $r \geq 0.1$ (Cohen 1988: 79–80).

7.2 Stress effects

7.2.1 Unstressed Vowel Shift

7.2.1.1 MANOVA (1)

MANOVA results for the effect of stress on the dependent variables (duration, F_1', F_2') in Bilingual Bulgarian are shown in Table 7.6. For /ə/, $p = 0.0109$; all other vowels show highly significant effects ($p \leq 0.001$). The Unstressed Vowel Shift (Λ) found in Bilingual Bulgarian open vowels, while once again markedly stronger than in close vowels, is considerably weaker than in any of the other varieties (§§ 4.2.1.1, 5.2.1.1, 6.2.1.1, 8.2.1.1; pp. 104, 125, 146, 185). Close vowels undergo very little Unstressed Vowel Shift.

	df_1	df_2	F	p	sig.	**UVS** = Λ
í, ĭ	3	332	9.53	0.0000	***	0.0411
έ, ɛ̆	3	332	55.61	0.0000	***	0.1998
ə́, ə̆	3	332	3.75	0.0109	*	0.0165
á, ă	3	332	101.32	0.0000	***	0.3127
ú, ŭ	3	332	13.97	0.0000	***	0.0590
ɔ́, ɔ̆	3	332	73.17	0.0000	***	0.2473

Table 7.6: MANOVAs for effect of stress on $dur \times F_1' \times F_2'$ in each Bilingual Bulgarian vowel phoneme. **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$; **UVS** Unstressed Vowel Shift; **Λ** Pillai score.

7.2.1.2 Discriminant function analysis (1)

Whereas in West and East Bulgarian F_1' frequency predominated as the primary stress discriminant for open vowels, this is never the case in Bilingual Bulgarian. As can be seen from the DFA results in Table 7.7, Bilingual Bulgarian stressed and unstressed vowels are distinguished primarily (/a, ɔ/) or exclusively (/ɛ/) by duration. This tallies with the notably low degree of Unstressed Vowel Shift revealed by the MANOVA, compared to the monolingual varieties. Discriminant weight is unsystematic with close vowels, which is unsurprising, given the very low levels of Unstressed Vowel Shift.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
/i/	Duration	0.96	0.74	0.71	0.17	0.80
	F_1'	-0.33	-0.35	0.11		
	F_2'	-0.65	-0.27	0.17		0.20
/ɛ/	Duration	1.03	1.00	1.03	0.18	1
	F_1'	-0.06	0.20	-0.01		
	F_2'	-0.05	0.26	-0.01		
/ə/	Duration	-0.57	-0.29	0.16	0.17	
	F_1'	0.91	0.80	0.73		1
	F_2'	0.47	0.22	0.10		
/a/	Duration	0.80	0.87	0.70	0.22	0.61
	F_1'	0.59	0.76	0.45		0.39
	F_2'	-0.52	0.28	-0.15		
/u/	Duration	-0.45	-0.43	0.19	0.17	0.22
	F_1'	-0.40	-0.34	0.14		
	F_2'	0.83	0.81	0.67		0.78
/ɔ/	Duration	0.82	0.89	0.72	0.17	0.77
	F_1'	0.42	0.51	0.21		0.23
	F_2'	0.22	0.28	0.06		

Table 7.7: Discriminant function analysis of stress correlates in Bilingual Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

7.2.1.3 Probability densities (1)

As in preceding chapters, in Figure 7.4 I provide summary diagrams of probability density estimates of duration, F_1' and F_2' frequencies, accompanied by relevant statistics, to facilitate and enhance comparison of stressed and unstressed vowels and their acoustic properties. The significance test, or test of equal densities in Bowman and Azzalini's (1997) terms, detected four non-significant pairs: the F_1' and F_2' estimates for /i/, the duration estimate for /ə/ and the F_1' estimate for /u/. As usual, there are some visible symmetric differences (Δ) that are not matched with an important discriminant status (w), perhaps most notably the differences between stressed and unstressed F_2' estimates for /a/ and /ɔ/.

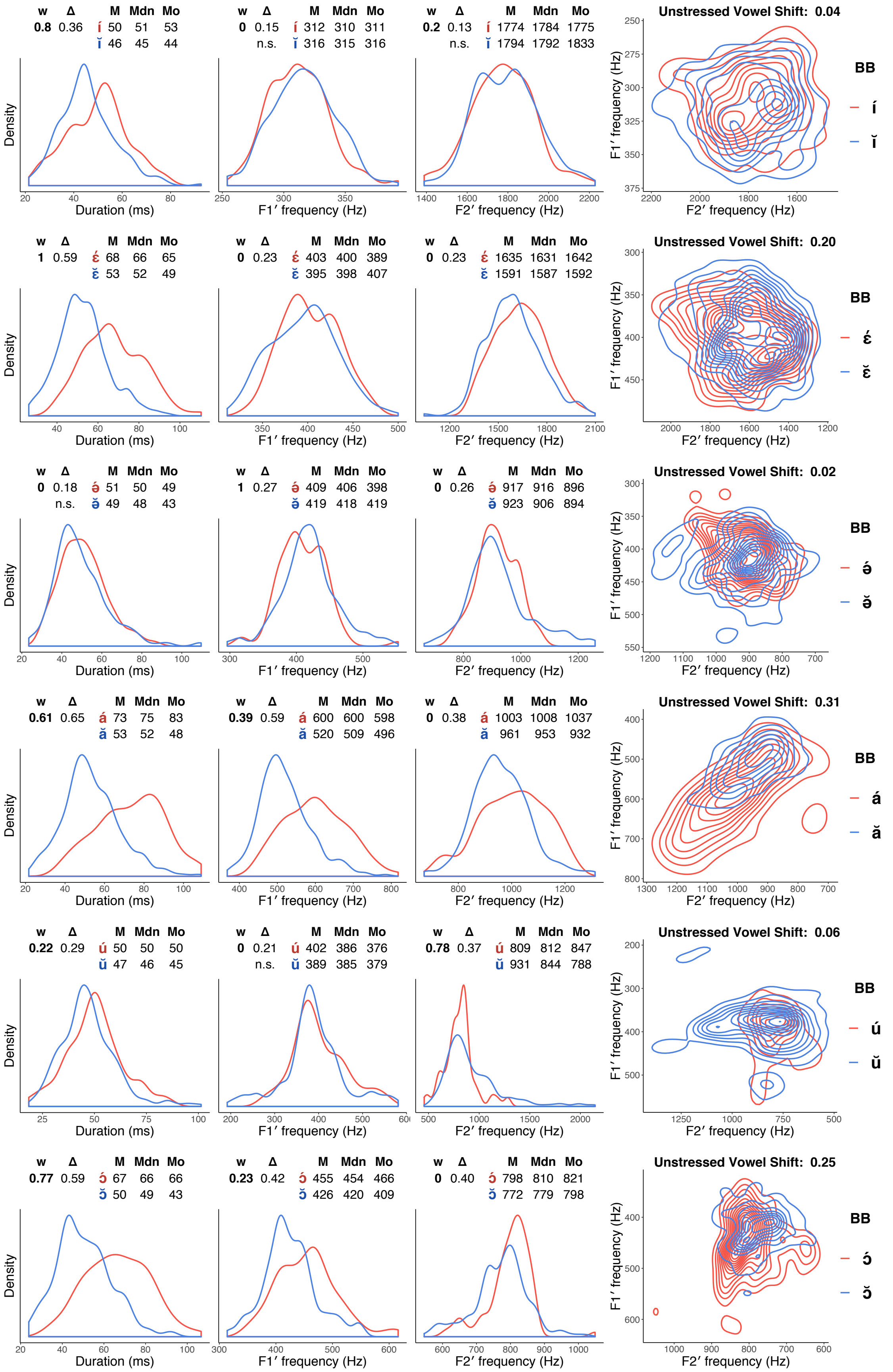


Figure 7.4: PDEs and summary statistics for Bilingual B. S/U vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

7.2.1.4 Stressed and unstressed targets

Predicted unstressed $\hat{F}_1$ frequencies were computed and compared to *observed* mean unstressed $\bar{F}_1'$ frequencies of open vowels, in order to establish whether there are likely to be separate unstressed targets. The results in Table 7.8 show that, unlike what we saw in the monolingual Bulgarian varieties (§ 4.2.1.4, p. 108 and § 5.2.1.4, p. 128), the extent of unstressed F_1' reduction in Bilingual Bulgarian is always smaller than the corresponding predicted undershoot (hence positive residuals), which suggests that no separate unstressed targets are involved in this variety and that Unstressed Vowel Shift can be attributed to gradient undershoot for all open vowels.

	Predicted unstressed $\hat{F}_1$ frequency (Hz)	Observed unstressed $\bar{F}_1'$ frequency (Hz)	Residual value $\bar{F}_1' - \hat{F}_1$
/ɛ/	386.41	395.35	8.94
/a/	468.22	520.48	52.26
/ɔ/	406.84	425.62	18.78

Table 7.8: Predicted and observed unstressed F_1' frequencies of Bilingual Bulgarian open vowels.

7.2.2 Contrast and neutralisation

7.2.2.1 MANOVA (2)

MANOVAs comparing Bilingual Bulgarian open and close vowels, reported in Table 7.9, evidence high levels of contrast for stressed and unstressed /i–ɛ/ and stressed /ə–a/, ranging between 0.81 and 0.65 in Pillai scores. Contrast levels fall progressively in unstressed /ə–a/ (0.46), stressed /u–ɔ/ (0.35) and unstressed /u–ɔ/ (0.21). While in all other varieties the back rounded vowels have been least contrastive among stressed and unstressed vowels alike, here the stressed /u–ɔ/ contrast is at a particularly low level, suggesting that a stress-independent merger may be underway, probably at different stages for different speakers or subgroups.

	df_1	df_2	F	p	sig.	**Contrast** $= \Lambda$	**Loss**
í, ɛ́	3	164	463.38	0.0000	***	0.8072	
ĭ, ɛ̆	3	500	609.07	0.0000	***	0.6454	0.20
ə́, á	3	164	277.90	0.0000	***	0.7152	
ə̆, ă	3	500	287.05	0.0000	***	0.4617	0.35
ú, ɔ́	3	164	60.79	0.0000	***	0.3546	
ŭ, ɔ̆	3	500	89.27	0.0000	***	0.2106	0.41

Table 7.9: MANOVAs for Bilingual Bulgarian O/C vowel pairs: effect of height on $dur \times F_1' \times F_2'$. **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$ **Λ** Pillai score; **Loss** $= (\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 1 - \breve{\Lambda}/\acute{\Lambda}$.

7.2.2.2 Discriminant function analysis (2) & Probability densities (2)

As regards the relative shares different acoustic parameters contribute to discriminating between open and close vowels, the DFA results in Table 7.10 are mostly predictable given what has been observed so far. F_1' frequency is the primary or sole discriminant for unrounded vowels. Duration is slightly more important than F_1' in distinguishing between /u/ and /ɔ/ in stressed position. With unstressed /u–ɔ/ duration plays no important role; F_1' is concentrated at higher-frequency modes for [ɔ̆], but this distinction is secondary to F_2' frequency as a discriminant because of the rather wide range spanned by [ŭ], as can be appreciated from the PDE diagram in Figure 7.5.

Once again, there are some apparent symmetrical differences (Δ) with only negligible discriminant weights (w). Predictably, this mostly involves F_2' estimates: [í–ɛ́, ə́–á, ə̆–ă, ú–ɔ́].

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
í, ɛ́	Duration	-0.61	-0.51	0.31	0.17	0.37
	F_1'	-0.67	-0.79	0.53		0.63
	F_2'	0.43	0.38	0.16		
ĭ, ɛ̆	Duration	0.12	0.33	0.04	0.17	
	F_1'	0.80	0.92	0.74		0.77
	F_2'	-0.35	-0.63	0.22		0.23
ə́, á	Duration	-0.31	-0.72	0.22	0.22	0.19
	F_1'	-0.97	-0.97	0.94		0.81
	F_2'	0.36	-0.46	-0.16		
ə̆, ă	Duration	-0.23	0.20	-0.05	0.19	
	F_1'	1.08	0.99	1.06		1
	F_2'	-0.07	0.26	-0.02		
ú, ɔ́	Duration	-0.75	-0.79	0.59	0.17	0.59
	F_1'	-0.61	-0.67	0.41		0.41
	F_2'	0.07	0.08	0.01		
ŭ, ɔ̆	Duration	0.25	0.27	0.07	0.17	
	F_1'	0.61	0.63	0.38		0.41
	F_2'	-0.73	-0.75	0.55		0.59

Table 7.10: Discriminant function analysis of phonological vowel height in Bilingual Bulgarian. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

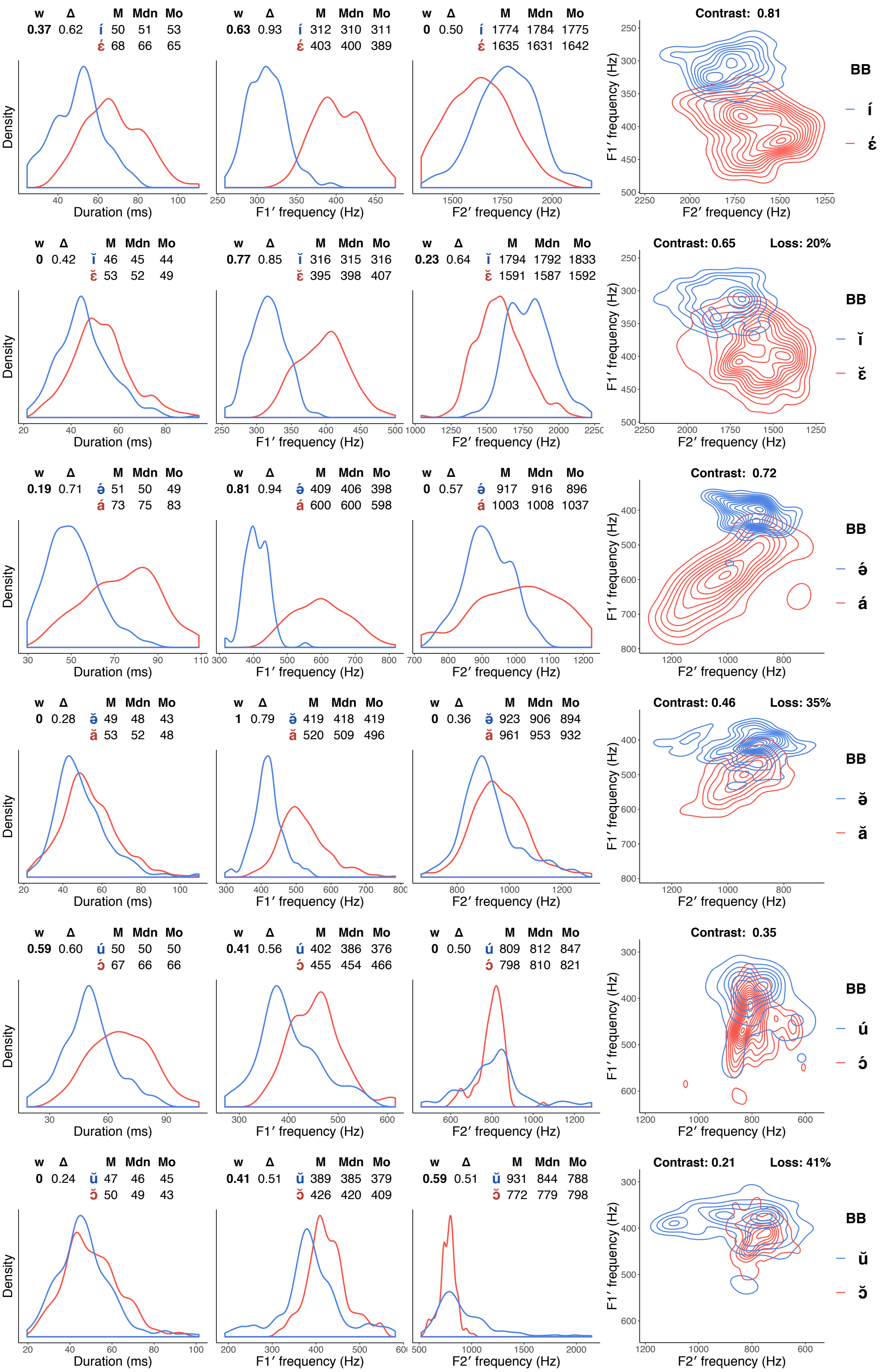


Figure 7.5: PDEs and summary statistics for Bilingual B. o/c vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** non-significant ($p > 0.05$).

7.3 Discussion of findings

Duration in Bilingual Bulgarian is longest in stressed open vowels, just as in the other varieties. In unstressed open vowels, it is longest word-finally and shortest in immediately pretonic syllables. F_1' frequency, on the other hand, does not follow the pattern of duration as clearly as in the varieties I have studied so far: while stressed /a/ and /ɔ/ do have the highest F_1' frequencies, this is not the case with /ɛ/, where I recorded a slightly higher value in the final syllable than in stressed position. No clear generalisations can be made about close vowels, except that pretonic allophones have the shortest durations. Mean values for stressed and unstressed vowels are plotted in Figure 7.7; the close front and

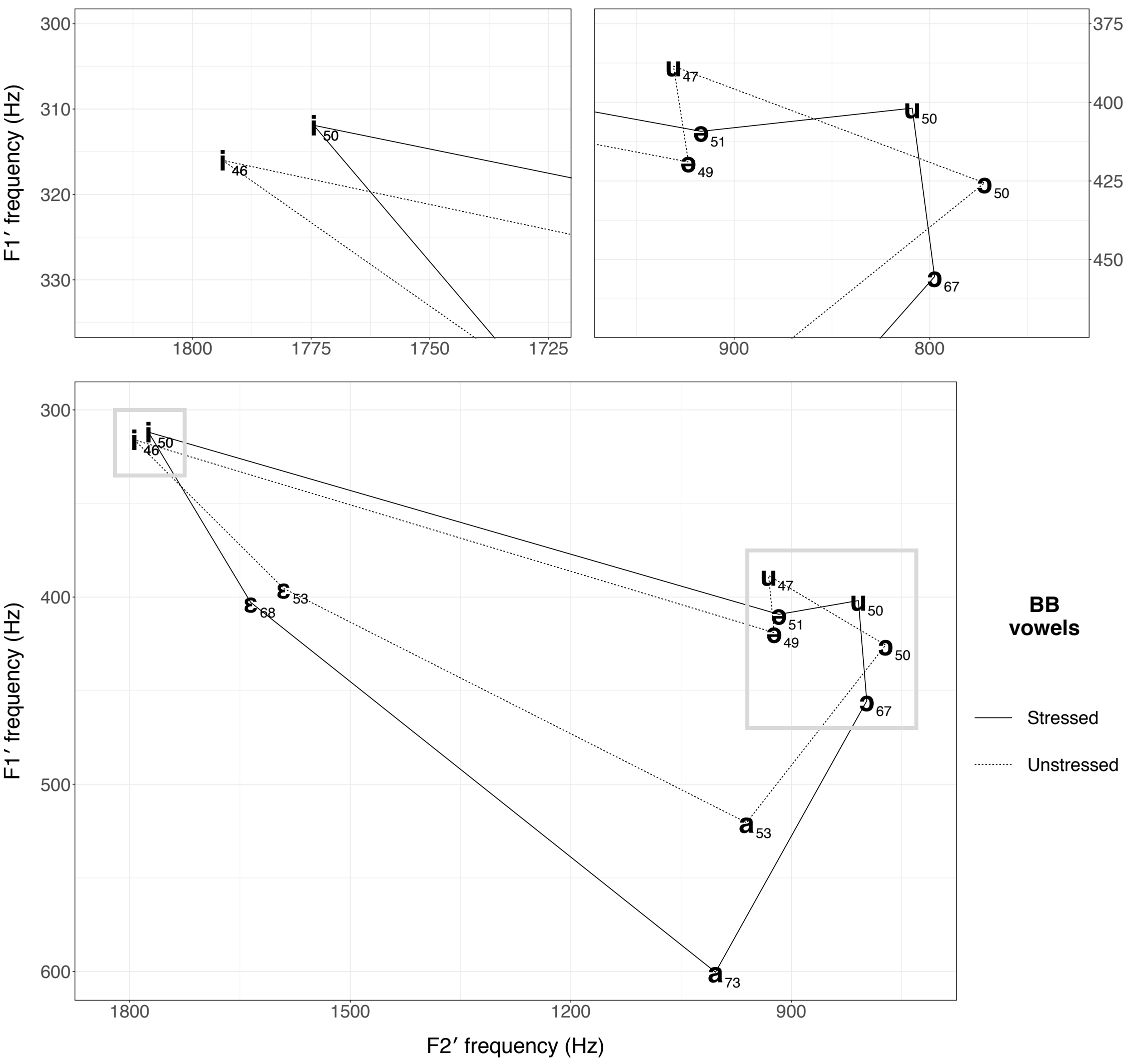


Figure 7.6: Bilingual Bulgarian S/U vowels in the $F_1' \times F_2'$ frequency space (means). Numbers next to vowels: mean durations (ms); top panels: enlarged views of grey frames in main chart.

close back corners of the vowel space have been magnified in the top panels.

Clearer patterns begin to emerge once evidence from multivariate and discriminant tests is considered. MANOVAs indicate considerably lower levels of Unstressed Vowel Shift in Bilingual Bulgarian open vowels than in any other variety under investigation. Moreover, unlike the monolingual Bulgarian varieties, Bilingual Bulgarian attaches greater weight to duration than F_1' frequency as stress discriminants. Close vowels show very little stress-dependent variation.

Correlation analysis has pointed to varying degrees of gradience in open vowels: there are less consistent correlations in /ɛ/ and /ɔ/ than in /a/. F_1' frequency decrease in unstressed position does not exceed the amount of predicted undershoot, which means that it is not necessary to postulate separate unstressed targets to account for Unstressed Vowel Shift in Bilingual Bulgarian: gradient undershoot alone is a sufficient explicans.

Finally, the second set of MANOVAs, comparing open and close vowels, has revealed that the level of neutralisation in unstressed position is low for the Bilingual Bulgarian front vowels, /i–ɛ/, somewhat higher for /ə–a/ and higher still for /u–ɔ/, but overall the extent of contrast loss is not very high. Although unstressed /u–ɔ/ have a very low

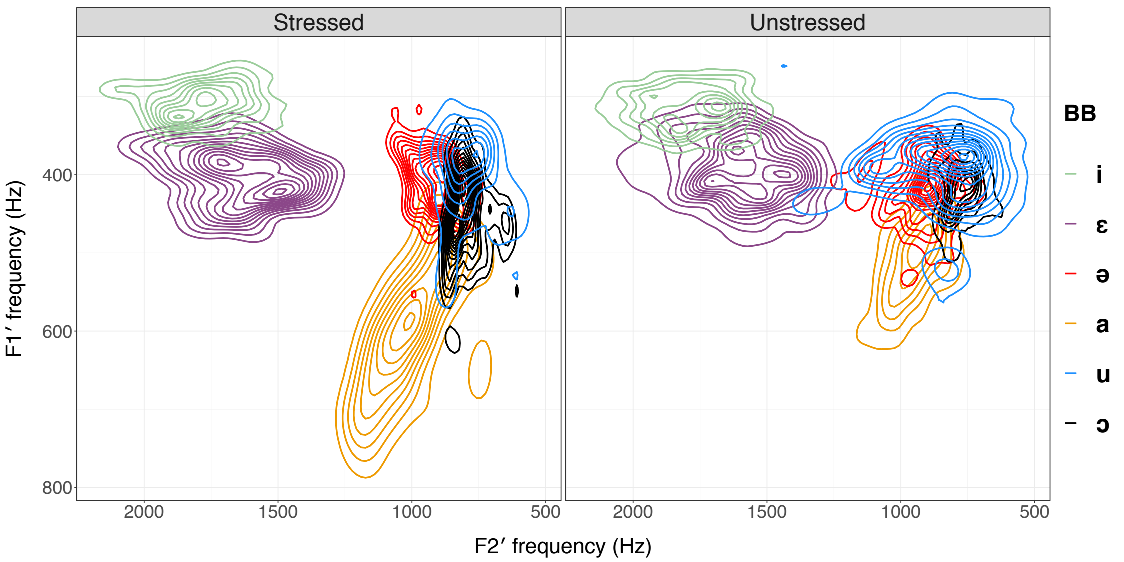


Figure 7.7: PDEs of Bilingual Bulgarian S/U vowels in the $F_1' \times F_2'$ space.

contrast score, $\Lambda = 0.21$, I report a neutralisation ratio of only 0.41 (or 41% loss) for this pair, because the two vowels are not particularly contrastive even in stressed position ($\Lambda = 0.36$), as can be observed in the plot of $F_1' \times F_2'$ estimates in Figure 7.7. This leads me to speculate that the rounded vowels in Bilingual Bulgarian may be undergoing merger in all positions, regardless of stress. Or, perhaps, that the merger has been generalised from unstressed to stressed position.

8
Bilingual Turkish

Contents

8.1 Mean comparisons and correlations

8.1.1 Means and distributions

The group means and standard deviations for the duration and normalised F_1 and F_2 frequencies of stressed and unstressed Bilingual Turkish vowels are listed in Table 8.1. Table 8.2 shows the same parameters for vowels in separate syllables (1, 2, 3).

			Duration (ms)		F_1' (Hz)		F_2' (Hz)	
Phoneme	Stress	n	Mean	SD	Mean	SD	Mean	SD
/i/	+	84	52.79	16.44	314	28	1763	143
	−	168	48.35	15.50	308	26	1778	149
/ɛ/	+	84	79.98	16.52	417	28	1658	163
	−	168	54.14	12.33	383	32	1619	152
/y/	+	84	54.32	18.51	330	32	1483	151
	−	168	47.64	12.23	308	33	1499	126
/œ/	+	84	84.78	20.32	414	38	1346	140
	−	168	54.69	14.88	374	29	1352	130
/ɯ/	+	84	57.83	17.01	420	46	950	146
	−	168	45.66	11.11	400	41	934	141
/ɑ/	+	84	88.67	18.46	619	80	1044	107
	−	168	53.85	9.94	523	71	951	118
/u/	+	84	55.45	15.80	386	46	801	138
	−	168	47.67	11.14	403	69	1014	376
/ɔ/	+	84	82.36	19.32	469	54	805	88
	−	168	51.43	12.13	426	52	799	106

Table 8.1: Group means and standard deviations for Bilingual Turkish vowel duration, F_1' and F_2' by stress.

8.1.1.1 Duration

Figure 8.1 shows duration distributions and probability density estimates for each vowel in different syllables in Bilingual Turkish. Inter-syllabic differences are very consistent across all vowels: stressed vowels are longer than unstressed ones, while there is no statistically significant difference between unstressed vowels in initial and second syllables. There is one partial exception to this robust pattern: stressed /i/ is longer than [i_2] but not [i_1]. Significance levels are very high ($p \leq 0.001$) for all vowels except the close front /i/ and /y/ (where $p > 0.01$, see § 8.1.3).

8.1.1.2 F_1' frequency

F_1' frequency distributions and PDEs by phoneme can be seen in Figure 8.2. In all open vowels, as well as /ɯ/, F_1' is highest in stressed position and lowest in the second syllable. With /y/, F_1' is also higher when the vowel is stressed, but there is no difference between [y_1] and [y_2]. [u_3] appears to have lower F_1' than [u_2] (according to the t-test), and there are no significant differences across syllables for /i/.

	σ	n	Duration (ms)		F_1' (Hz)		F_2' (Hz)	
			Mean	SD	Mean	SD	Mean	SD
/i/	*1.*	84	50.04	17.66	306	21	1831	147
	2.	84	46.67	12.88	310	30	1725	132
	3.	84	52.79	16.44	314	28	1763	143
/ɛ/	*1.*	84	53.72	11.75	396	29	1641	165
	2.	84	54.55	12.95	371	30	1598	135
	3.	84	79.98	16.52	417	28	1658	163
/y/	*1.*	84	47.33	13.30	308	29	1537	116
	2.	84	47.95	11.13	309	36	1462	126
	3.	84	54.32	18.51	330	32	1483	151
/œ/	*1.*	84	55.80	17.36	384	26	1386	146
	2.	84	53.58	11.91	364	28	1318	102
	3.	84	84.78	20.32	414	38	1346	140
/ɯ/	*1.*	84	45.97	11.43	406	36	1015	145
	2.	84	45.35	10.84	395	44	853	76
	3.	84	57.83	17.01	420	46	950	146
/ɑ/	*1.*	84	53.04	9.37	551	71	1014	120
	2.	84	54.65	10.48	494	58	889	75
	3.	84	88.67	18.46	619	80	1044	107
/u/	*1.*	84	48.52	11.01	396	67	848	150
	2.	84	46.81	11.26	410	72	1179	454
	3.	84	55.45	15.80	386	46	801	138
/ɔ/	*1.*	84	52.13	12.46	441	48	826	97
	2.	84	50.74	11.82	411	52	773	108
	3.	84	82.36	19.32	469	54	805	88

Table 8.2: Group means and standard deviations for Bilingual Turkish vowel duration, F_1' and F_2' by syllable. **σ** syllable: *1.* initial, *2.* second, ***3.*** stressed.

8.1.1.3 F_2' frequency

As can be seen from the F_2' distributions and PDEs in Figure 8.3, vowels in second syllables tend to have the lowest F_2' frequency, although they do not necessarily differ significantly from *both* allophones in surrounding syllables. This is reversed in /u/: [u_2] has significantly higher F_2' than [u_1] and [u_3].

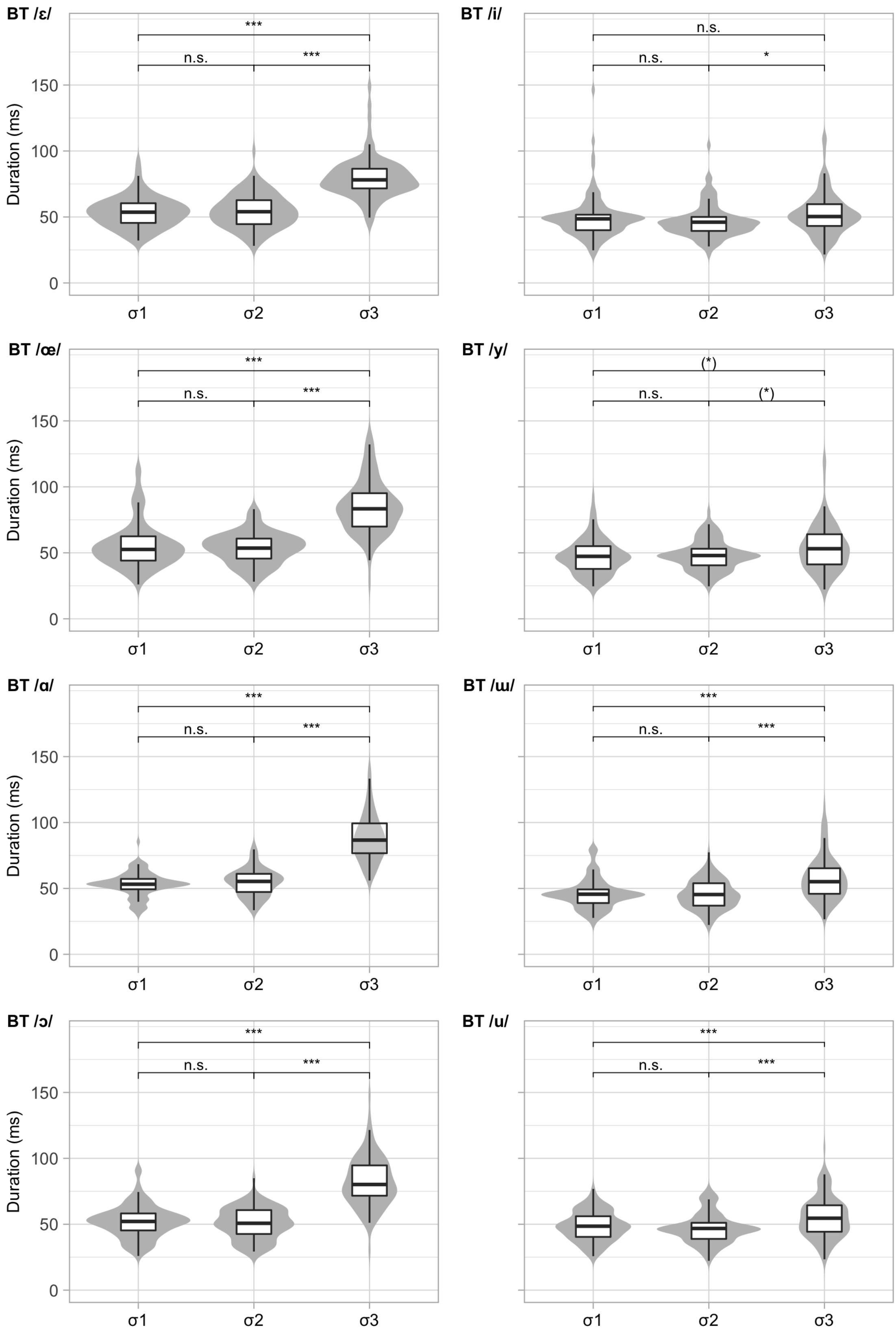


Figure 8.1: Distribution of duration in Bilingual Turkish (BT). Box: from Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 8.1.3; where in brackets, ANOVA n.s. (§ 6.1.2).

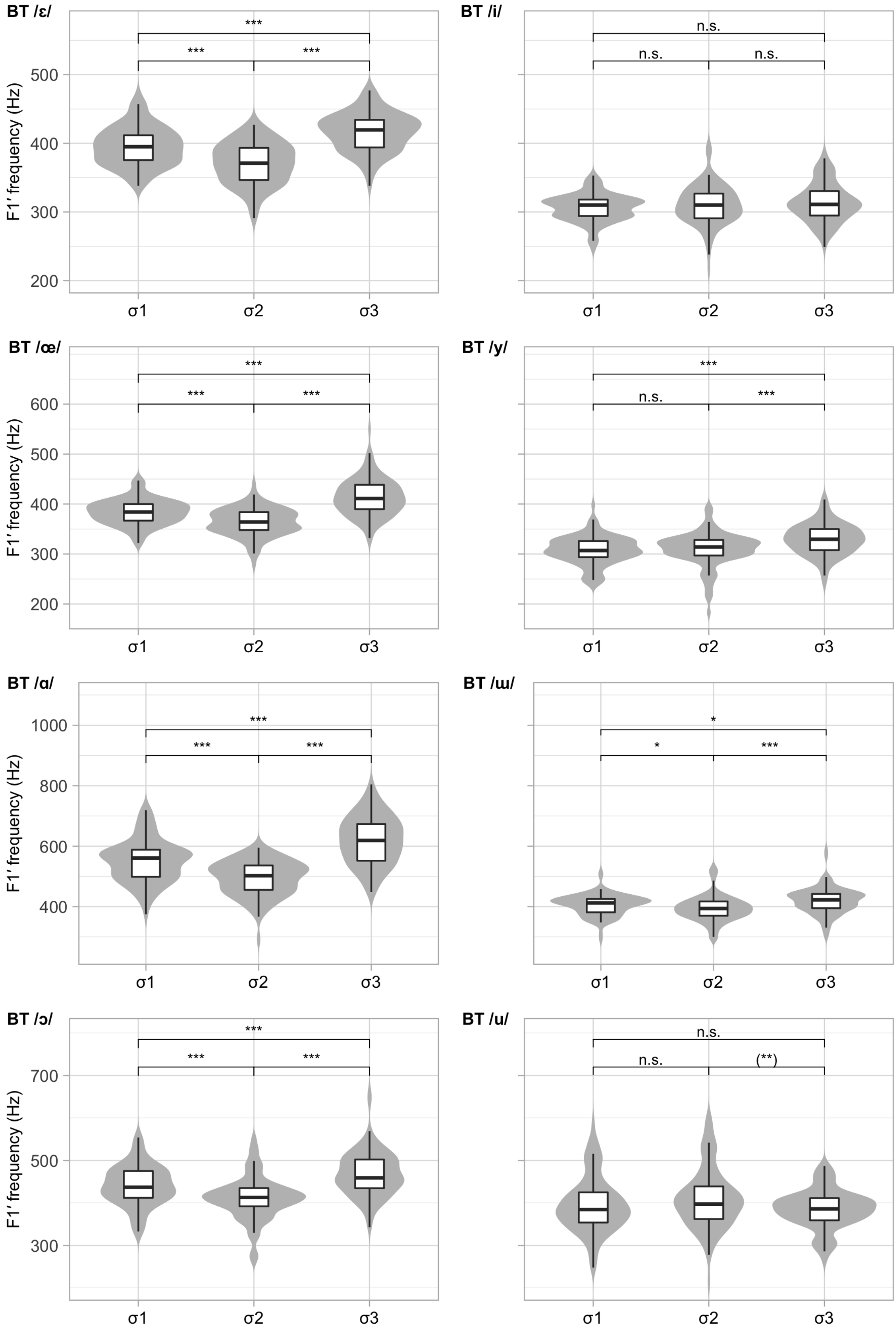


Figure 8.2: Distribution of F_1' frequency in Bilingual Turkish (BT). Box: Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 8.1.3; where in brackets, ANOVA n.s. (§ 8.1.2).

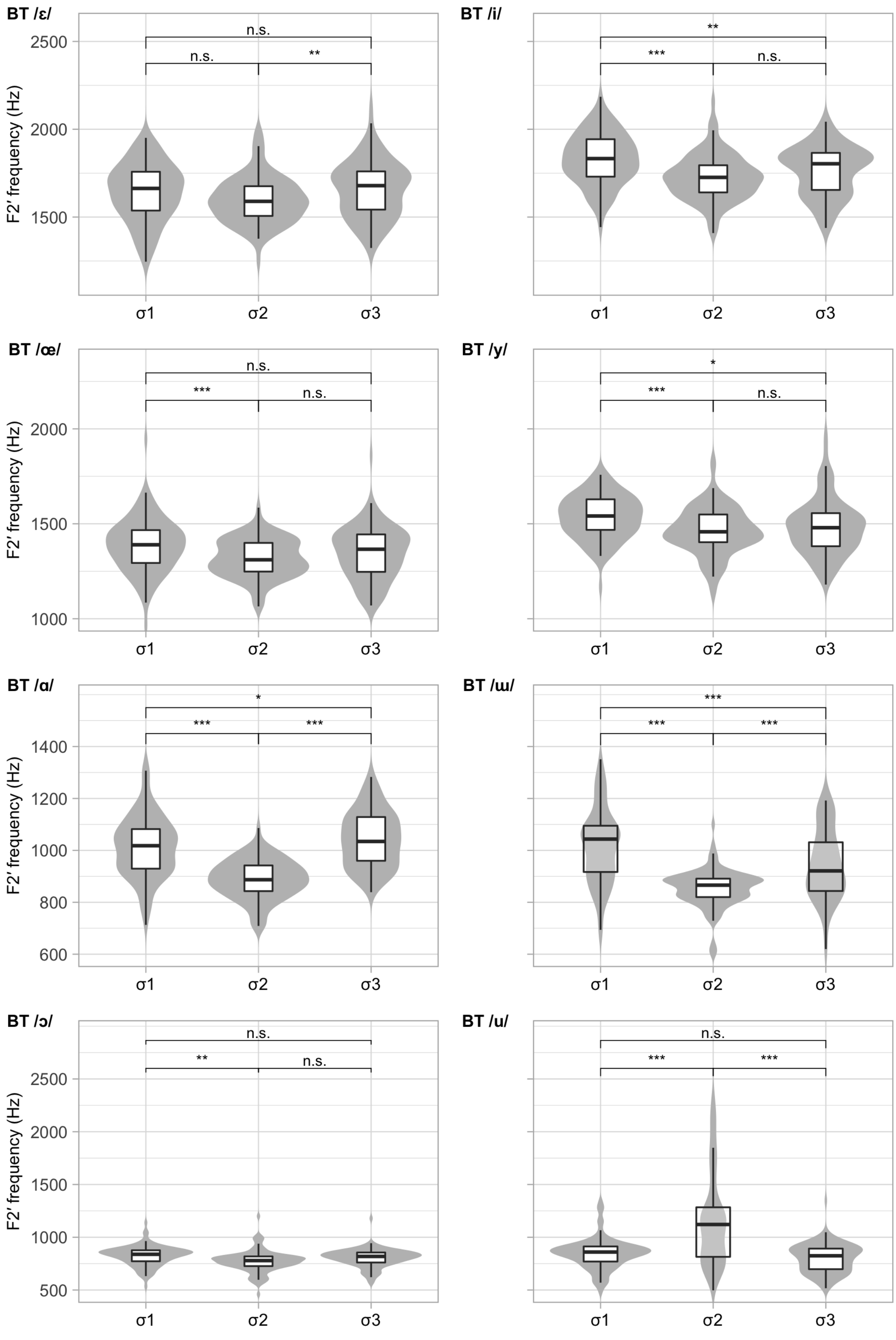


Figure 8.3: Distribution of F_2' frequency in Bilingual Turkish (BT). Box: Q_1 to Q_3; line in box: median; whiskers: min/max (up to 1.5 IQR from $Q_{1,3}$); violin plot: PDE; **σ**: syllable. Significance from § 8.1.3; where in brackets, ANOVA n.s. (§ 8.1.2).

8.1.2 Analysis of variance

Table 8.3 lists the repeated-measures ANOVA results for the effect of 'syllable' on duration, F_1' and F_2' in each Bilingual Turkish vowel. The effect on duration is significant in all vowels except /y/; in /i/, it is marginally significant: $p = 0.0500$. For F_1' frequency, there are significant main effects in all vowels except /i/ and /u/. All vowels show significant effects on F_2' frequency.

***A.* Duration**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.59	0.0441	*	0.71	1.42	18.50	3.93	0.0500	*	0.10
/ɛ/	0.52	0.0201	*	0.68	1.35	17.58	51.76	0.0000	***	0.68
/y/	0.65	0.0774	n.s.		2	26	3.32	0.0518	n.s.	0.12
/œ/	0.93	0.6375	n.s.		2	26	55.21	0.0000	***	0.62
/ɯ/	0.63	0.0598	n.s.		2	26	18.07	0.0000	***	0.43
/ɑ/	0.38	0.0032	**	0.62	1.24	16.08	95.77	0.0000	***	0.80
/u/	0.85	0.3762	n.s.		2	26	7.51	0.0027	**	0.19
/ɔ/	0.68	0.1024	n.s.		2	26	70.30	0.0000	***	0.72

***B.* F_1' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.87	0.4198	n.s.		2	26	1.20	0.3180	n.s.	0.04
/ɛ/	0.83	0.3198	n.s.		2	26	56.02	0.0000	***	0.54
/y/	0.87	0.4199	n.s.		2	26	7.60	0.0025	**	0.21
/œ/	0.87	0.4277	n.s.		2	26	31.83	0.0000	***	0.55
/ɯ/	0.84	0.3393	n.s.		2	26	6.38	0.0056	**	0.15
/ɑ/	0.66	0.0844	n.s.		2	26	24.35	0.0000	***	0.48
/u/	0.92	0.6048	n.s.		2	26	2.49	0.1029	n.s.	0.05
/ɔ/	0.79	0.2444	n.s.		2	26	26.73	0.0000	***	0.35

***C.* F_2' frequency**

	Mauchly's test			GG	ANOVA					
	W	p	sig.	$\hat{\varepsilon}$	df_1	df_2	F	p	sig.	η^2
/i/	0.97	0.8111	n.s.		2	26	12.39	0.0002	***	0.21
/ɛ/	0.72	0.1387	n.s.		2	26	3.98	0.0310	*	0.05
/y/	0.77	0.2096	n.s.		2	26	6.06	0.0069	**	0.14
/œ/	0.83	0.3357	n.s.		2	26	8.13	0.0018	**	0.11
/ɯ/	0.95	0.7313	n.s.		2	26	33.27	0.0000	***	0.63
/ɑ/	0.68	0.0997	n.s.		2	26	48.28	0.0000	***	0.42
/u/	0.08	0.0000	***	0.52	1.04	13.55	18.29	0.0007	***	0.47
/ɔ/	0.95	0.7532	n.s.		2	26	4.97	0.0149	*	0.12

Table 8.3: Repeated-measures ANOVAs for the effect of 'syllable' on duration, F_1' and F_2', for each Bilingual T. phoneme, with 'speaker' as case identifier. **GG** Greenhouse-Geisser correction; **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

8.1.3 Pairwise comparisons

The results of dependent t-tests with Bonferroni correction ($\alpha = 0.05/3 = 0.0167$) comparing the three parameters in syllable pairs are reported Table 8.4. In two cases, marked with daggers (†) in the table, the t-tests produced significant results, while the corresponding ANOVAs (§ 8.1.2) showed no significant main effects.

***A.* Duration**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/	0.8722	n.s.	0.0180	*	0.3057	n.s.
/ɛ/	0.0000	***	0.0000	***	1.0000	n.s.
/y/†	0.0322	*	0.0231	*	1.0000	n.s.
/œ/	0.0000	***	0.0000	***	0.7284	n.s.
/ɯ/	0.0000	***	0.0000	***	1.0000	n.s.
/ɑ/	0.0000	***	0.0000	***	0.6802	n.s.
/u/	0.0004	***	0.0000	***	0.7311	n.s.
/ɔ/	0.0000	***	0.0000	***	1.0000	n.s.

***B.* F_1' frequency**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/	0.0555	n.s.	1.0000	n.s.	0.7655	n.s.
/ɛ/	0.0000	***	0.0000	***	0.0000	***
/y/	0.0000	***	0.0002	***	1.0000	n.s.
/œ/	0.0000	***	0.0000	***	0.0000	***
/ɯ/	0.0423	*	0.0001	***	0.0422	*
/ɑ/	0.0000	***	0.0000	***	0.0000	***
/u/†	0.5522	n.s.	0.0078	**	0.3403	n.s.
/ɔ/	0.0002	***	0.0000	***	0.0000	***

***C.* F_2' frequency**

	(σ_3, σ_1)		(σ_3, σ_2)		(σ_1, σ_2)	
	p	sig.	p	sig.	p	sig.
/i/	0.0023	**	0.1355	n.s.	0.0000	***
/ɛ/	1.0000	n.s.	0.0045	**	0.0706	n.s.
/y/	0.0190	*	0.8459	n.s.	0.0000	***
/œ/	0.0728	n.s.	0.2768	n.s.	0.0001	***
/ɯ/	0.0008	***	0.0000	***	0.0000	***
/ɑ/	0.0399	*	0.0000	***	0.0000	***
/u/	0.0836	n.s.	0.0000	***	0.0000	***
/ɔ/	0.2861	n.s.	0.0738	n.s.	0.0012	**

Table 8.4: Pairwise comparisons of Bilingual Turkish syllable-specific allophones (dependent t-tests with Bonferroni correction). **σ** syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$. † ANOVA n.s. (§ 8.1.2).

8.1.4 Correlations

Pearson product-moment correlations between duration and the formant frequencies, calculated for syllable-specific allophones, are listed in Table 8.5. There are significant positive correlations of F_1' with duration in ten allophones in total, and in at least two out of the three allophones of each open vowel, which points to prevalent gradient undershoot in Bilingual Turkish.

There are ten statistically significant F_2'–duration correlations, two of which are negative.

			Duration–F_1'				Duration–F_2'			
	σ	n	r	size	p	sig.	r	size	p	sig.
/i/	*1.*	84	0.01		0.9360	n.s.	0.16		0.1550	n.s.
	2.	84	0.01		0.9120	n.s.	0.06		0.5850	n.s.
	3.	84	0.00		0.9730	n.s.	0.16		0.1520	n.s.
/ɛ/	*1.*	84	0.26	S	0.0190	*	0.19		0.0870	n.s.
	2.	84	0.32	M	0.0030	**	0.18		0.1110	n.s.
	3.	84	0.16		0.1510	n.s.	0.35	M	0.0010	***
/y/	*1.*	84	0.05		0.6550	n.s.	0.11		0.3130	n.s.
	2.	84	0.06		0.6010	n.s.	0.34	M	0.0010	***
	3.	84	0.18		0.1050	n.s.	0.27	S	0.0140	*
/œ/	*1.*	84	0.35	M	0.0010	***	0.24	S	0.0280	*
	2.	84	0.27	S	0.0130	*	0.21		0.0550	n.s.
	3.	84	0.04		0.7550	n.s.	0.25	S	0.0230	*
/ɯ/	*1.*	84	0.11		0.3110	n.s.	0.13		0.2400	n.s.
	2.	84	0.24	S	0.0260	*	-0.09		0.4250	n.s.
	3.	84	0.09		0.4130	n.s.	0.44	M	0.0000	***
/ɑ/	*1.*	84	0.35	M	0.0010	***	0.20		0.0640	n.s.
	2.	84	0.23	S	0.0320	*	-0.12		0.2850	n.s.
	3.	84	0.47	M	0.0000	***	0.58	L	0.0000	***
/u/	*1.*	84	-0.07		0.5550	n.s.	-0.31	M	0.0040	**
	2.	84	0.13		0.2420	n.s.	0.23	S	0.0380	*
	3.	84	-0.14		0.1970	n.s.	-0.05		0.6810	n.s.
/ɔ/	*1.*	84	0.25	S	0.0220	*	-0.11		0.3400	n.s.
	2.	84	0.15		0.1780	n.s.	-0.29	S	0.0070	**
	3.	84	0.28	S	0.0301	*	0.10		0.3550	n.s.

Table 8.5: Pearson correlations of duration with F_1' and duration with F_2' in Bilingual Turkish. **sig.** significance level: ********* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$. **σ** syllable (*1*, *2*, ***3***, *4*). Effect size (shown where $p \leq 0.05$): **L** large $r \geq 0.5$, **M** medium $r \geq 0.3$, **S** small $r \geq 0.1$ (Cohen 1988: 79–80).

8.2 Stress effects

8.2.1 Unstressed Vowel Shift

8.2.1.1 MANOVA (1)

The results of MANOVAs measuring the effect of stress on the dependent variables (duration, F_1', F_2') for each Bilingual Turkish vowel are shown in Table 8.6. There are highly significant effects ($p \leq 0.001$) for all vowels but /i/ ($p = 0.0390$). As in all other varieties, open vowels show substantially greater unstressed shift than close vowels. Interestingly, Pillai scores (Λ) for Bilingual Turkish open vowels are noticeably higher than those for both Istanbul Turkish (§ 6.2.1.1, p. 146) and Bilingual Bulgarian (§ 7.2.1.1, p. 166): in fact, they are similar to the levels reported for the monolingual Bulgarian varieties (§§ 4.2.1.1, 5.2.1.1; pp. 104, 125).

	df_1	df_2	F	p	sig.	**UVS** $= \Lambda$
í, ĭ	3	248	2.83	0.0390	*	0.0331
ɛ́, ɛ̆	3	248	74.04	0.0000	***	0.4725
ý, y̆	3	248	11.82	0.0000	***	0.1251
œ́, œ̆	3	248	87.36	0.0000	***	0.5138
ɯ́, ɯ̆	3	248	17.80	0.0000	***	0.1772
á, ă	3	248	129.08	0.0000	***	0.6096
ú, ŭ	3	248	15.48	0.0000	***	0.1577
ɔ́, ɔ̆	3	248	84.70	0.0000	***	0.5061

Table 8.6: MANOVAs for effect of stress on $dur \times F_1' \times F_2'$ in each Bilingual Turkish vowel phoneme. **df** degrees of freedom; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$; **UVS** Unstressed Vowel Shift; **Λ** Pillai score.

8.2.1.2 Discriminant function analysis (1)

Discriminant function analysis of Bilingual Turkish stressed and unstressed vowels (Table 8.7) singles out duration as the primary cue to stress among the three acoustic parameters examined: it is the sole non-negligible discriminant (out of F_1', F_2' and duration) for /ɑ/ and /ɔ/, whereas in /ɛ, œ, i, ɯ/ F_1' frequency plays a secondary part as well. With /y/ F_1' frequency is more important than duration. The only case in which F_2' plays a non-negligible role is with /u/, where it is in fact the primary discriminant, followed closely by duration.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
/i/	Duration	-0.78	-0.72	0.56	0.17	0.64
	F_1'	-0.59	-0.55	0.32		0.36
	F_2'	0.44	0.26	0.12		
/ɛ/	Duration	0.85	0.93	0.79	0.17	0.78
	F_1'	0.34	0.64	0.22		0.22
	F_2'	-0.09	0.17	-0.01		
/y/	Duration	0.55	0.59	0.32	0.17	0.34
	F_1'	0.76	0.83	0.63		0.66
	F_2'	-0.28	-0.16	0.04		
/œ/	Duration	0.76	0.84	0.64	0.17	0.65
	F_1'	0.52	0.66	0.35		0.35
	F_2'	-0.38	-0.03	0.01		
/ɯ/	Duration	0.89	0.93	0.83	0.17	0.82
	F_1'	0.36	0.51	0.18		0.18
	F_2'	-0.10	0.12	-0.01		
/ɑ/	Duration	0.91	0.98	0.89	0.17	1
	F_1'	0.19	0.66	0.13		
	F_2'	-0.03	0.45	-0.01		
/u/	Duration	-0.66	-0.68	0.45	0.17	0.46
	F_1'	0.08	0.32	0.03		
	F_2'	0.71	0.74	0.53		0.54
/ɔ/	Duration	0.92	0.96	0.89	0.17	1.00
	F1′	0.23	0.49	0.11		
	F2′	0.06	0.04	0.00		

Table 8.7: Discriminant function analysis of stress correlates in Bilingual Turkish. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC × SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5|\overline{PDRC}|$).

8.2.1.3 Probability densities (1)

Comparisons of probability density estimates for Bilingual Turkish stressed and unstressed vowels are displayed in Figures 8.4 and 8.5. Differences between stressed and unstressed F_2' estimates are non-significant for all vowels except /ɑ/ and /u/. For /u/ F_2' frequency does play a part as a stress discriminant, while for /ɑ/ it does not.

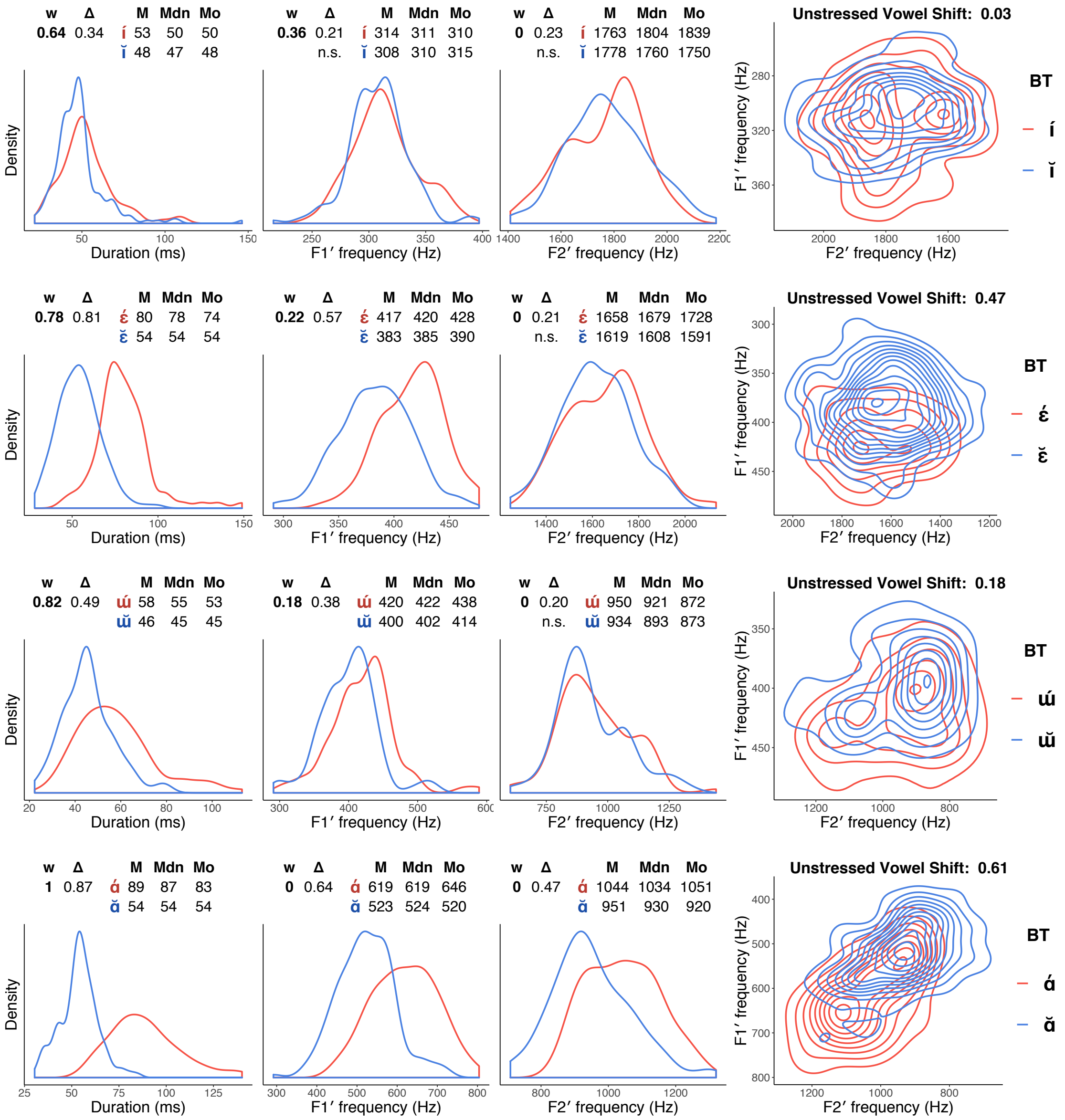


Figure 8.4: PDEs and summary statistics for Bilingual Turkish S/U unrounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

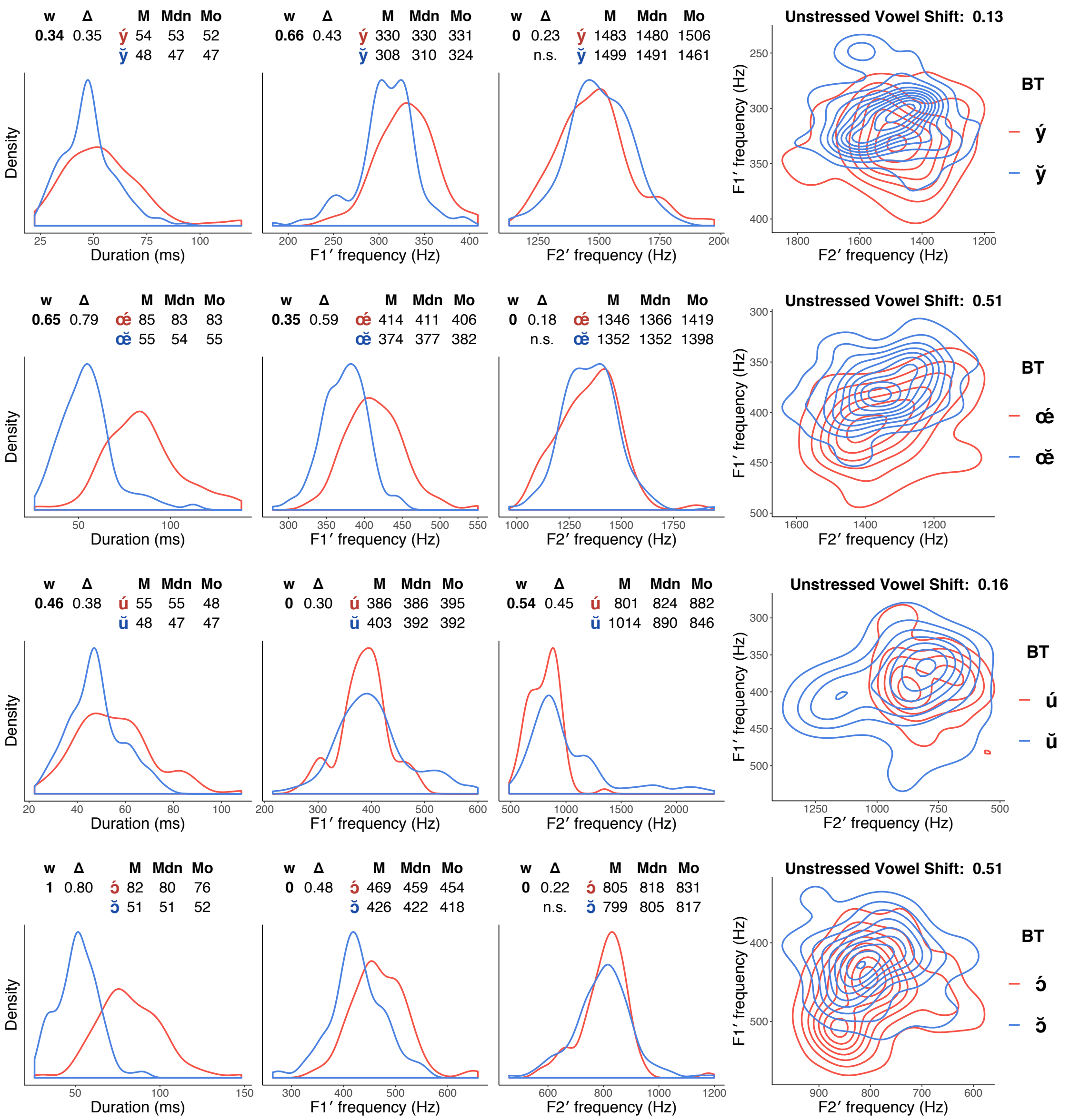


Figure 8.5: PDEs and summary statistics for Bilingual Turkish S/U rounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

8.2.1.4 Stressed and unstressed targets

Table 8.8 lists the predicted unstressed $\hat{F}_1$ frequencies of Istanbul Turkish open vowels, their observed mean unstressed $\bar{F}_1'$ frequencies, and corresponding residual values, $\bar{F}_1' - \hat{F}_1$. The Unstressed Shift of back open vowels can be explained by gradient undershoot, since observed F_1' frequency reduction does not exceed predicted undershoot. The front vowels, on the other hand, show more spectral reduction than the undershoot predicted for their mean unstressed durations, which points to separate, closer targets for unstressed

Bilingual Turkish /ɛ/ and /œ/. In other words, in Bulgarian Turkish two distinct reduction strategies may operate at once: Unstressed Shift appears to be gradient in back vowels, but categorical in front vowels.

	Predicted unstressed $\hat{F}_1$ frequency (Hz)	Observed unstressed $\bar{F}_1'$ frequency (Hz)	Residual value $\bar{F}_1' - \hat{F}_1$
/ɛ/	392.42	383.12	-9.30
/œ/	391.41	373.88	-17.54
/ɑ/	476.75	522.51	45.76
/ɔ/	412.78	426.24	13.45

Table 8.8: Predicted and observed unstressed F_1' frequencies of Bilingual Turkish open vowels.

8.2.2 Contrast and neutralisation

I have used two-dimensional, $F_1' \times F_2'$ frequency PDE contour plots to summarise neutralisation patterns in the closing section of each experimental chapter, as these clearly display spectral overlap. The diagrams for stressed and unstressed rounded vowels in Bilingual Turkish, shown in Figure 8.10 on page 196, revealed noticeable and unexpected overlap in unstressed position between two vowels that differ not only in phonological height but also in backness: Bilingual Turkish [ŭ] and [œ̆]. This prompted me to go back to the analysis stage and apply my standard neutralisation tests to this rather unusual pair as well. Results for contrast and neutralisation in Bilingual Turkish /u–œ/ are presented at the bottom of each table and diagram in this section.

8.2.2.1 MANOVA (2)

All MANOVAs comparing Bilingual Turkish height-contrasting vowels, as well as /u–œ/, given in Table 8.9, were highly significant ($p < 0.001$). Height contrast scores are high for all pairs except unstressed /u–ɔ/ ($\Lambda = 0.21$). As a result, of all close–open pairs, only /u–ɔ/ neutralise to a substantial extent in unstressed position (63% contrast loss); neutralisation is low in the rest of the height-contrasting pairs.

The distinctiveness of Bilingual Turkish /u–œ/, which is at an expected high level in stressed syllables ($\Lambda = 0.81$), drops considerably in unstressed position, to $\Lambda = 0.49$.

	df_1	df_2	F	p	sig.	**Contrast** = Λ	**Loss**
í, ɛ́	3	164	229.66	0.0000	***	0.8077	
ĭ, ɛ̆	3	332	225.86	0.0000	***	0.6712	0.17
ý, œ́	3	164	150.84	0.0000	***	0.7340	
y̆, œ̆	3	332	194.89	0.0000	***	0.6378	0.13
ɯ́, ɑ́	3	164	144.83	0.0000	***	0.7260	
ɯ̆, ɑ̆	3	332	132.84	0.0000	***	0.5455	0.25
ú, ɔ́	3	164	71.24	0.0000	***	0.5658	
ŭ, ɔ̆	3	332	29.26	0.0000	***	0.2091	0.63
ú, œ́	3	164	236.16	0.0000	***	0.8120	
ŭ, œ̆	3	332	77.87	0.0000	***	0.4130	0.49

Table 8.9: MANOVAs for Bilingual Turkish O/C vowel pairs and /u–œ/: effect of height on $dur \times F_1' \times F_2'$. **df** degrees of freedom; **sig.** significance level: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, **n.s.** $p > 0.05$ **Λ** Pillai score; **Loss** = $(\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 1 - \breve{\Lambda}/\acute{\Lambda}$.

This results in a rather high neutralisation rate, indeed markedly higher than in the first three height-contrasting pairs.

8.2.2.2 Discriminant function analysis (2)

As the DFA results in Table 8.10 indicate, F_1' frequency is the primary height discriminant for all vowel pairs except unstressed /u–ɔ/; for unstressed /ɯ–ɑ/ it is the only non-negligible discriminant. For all stressed pairs duration plays a secondary role, although for [ú–ɔ́] F_1' frequency has only a slender lead. F_2' frequency is secondary for [ĭ–ɛ̆, y̆–œ̆], tertiary for [ý–œ́], but primary for [ŭ–ɔ̆], for which F_1' frequency is also of minor importance.

For the pair /u–œ/, F_2' frequency is the primary discriminant, which was expected. In addition, F_1' frequency plays a secondary role un unstressed position and duration is a marginally important discriminant in stressed syllables.

		SDFC	SC	PDRC	θ	Adjusted PDRC (w)
í, ɛ́	Duration	0.37	0.63	0.24	0.17	0.26
	F_1'	0.78	0.87	0.68		0.74
	F_2'	-0.27	-0.32	0.09		
ĭ, ɛ̆	Duration	0.09	0.23	0.02	0.17	
	F_1'	0.85	0.90	0.76		0.78
	F_2'	-0.40	-0.53	0.21		0.22
ý, œ́	Duration	0.46	0.61	0.28	0.17	0.28
	F_1'	0.67	0.76	0.51		0.51
	F_2'	-0.49	-0.42	0.21		0.21
y̆, œ̆	Duration	0.15	0.28	0.04	0.17	
	F_1'	0.79	0.82	0.65		0.68
	F_2'	-0.55	-0.56	0.31		0.32
ɯ́, ɑ́	Duration	0.36	0.74	0.27	0.20	0.24
	F_1'	0.88	0.95	0.84		0.76
	F_2'	-0.27	0.39	-0.11		
ɯ̆, ɑ̆	Duration	0.16	0.48	0.08	0.17	
	F_1'	0.97	0.97	0.94		1
	F_2'	-0.20	0.09	-0.02		
ú, ɔ́	Duration	-0.62	-0.74	0.46	0.17	0.46
	F_1'	-0.68	-0.79	0.54		0.54
	F_2'	-0.03	-0.02	0.00		
ŭ, ɔ̆	Duration	-0.24	-0.34	0.08	0.17	
	F_1'	-0.58	-0.39	0.23		0.25
	F_2'	0.90	0.77	0.69		0.75
ú, œ́	Duration	0.27	0.65	0.17	0.17	0.18
	F_1'	0.15	0.33	0.05		
	F_2'	0.84	0.92	0.78		0.82
ŭ, œ̆	Duration	-0.29	-0.37	0.11	0.17	
	F_1'	0.64	0.38	0.24		0.27
	F_2'	-0.87	-0.75	0.65		0.73

Table 8.10: Discriminant function analysis of Bilingual Turkish O/C vowel pairs and /u–œ/. **SDFC** standardised discriminant function coefficient; **SC** structure coefficient; **PDRC** parallel discriminant ratio coefficient (PDRC = SDFC $\times$ SC); $\boldsymbol{\theta}$ negligibility threshold ($\theta = 0.5\overline{|PDRC|}$).

8.2.2.3 Probability densities (2)

All PDE comparisons, which are presented in Figures 8.6 and 8.7, yielded significant differences. A number of observable symmetric differences (Δ) in duration and F_2' frequency have only negligible discriminant status ($w = 0$) in open–close pairs.

Unstressed /u/ and /œ/ overlap over sizeable portions of their F_1' and F_2' ranges. For the main discriminant, F_2' frequency, the two density peaks are well separated, which results in a large symmetric difference.

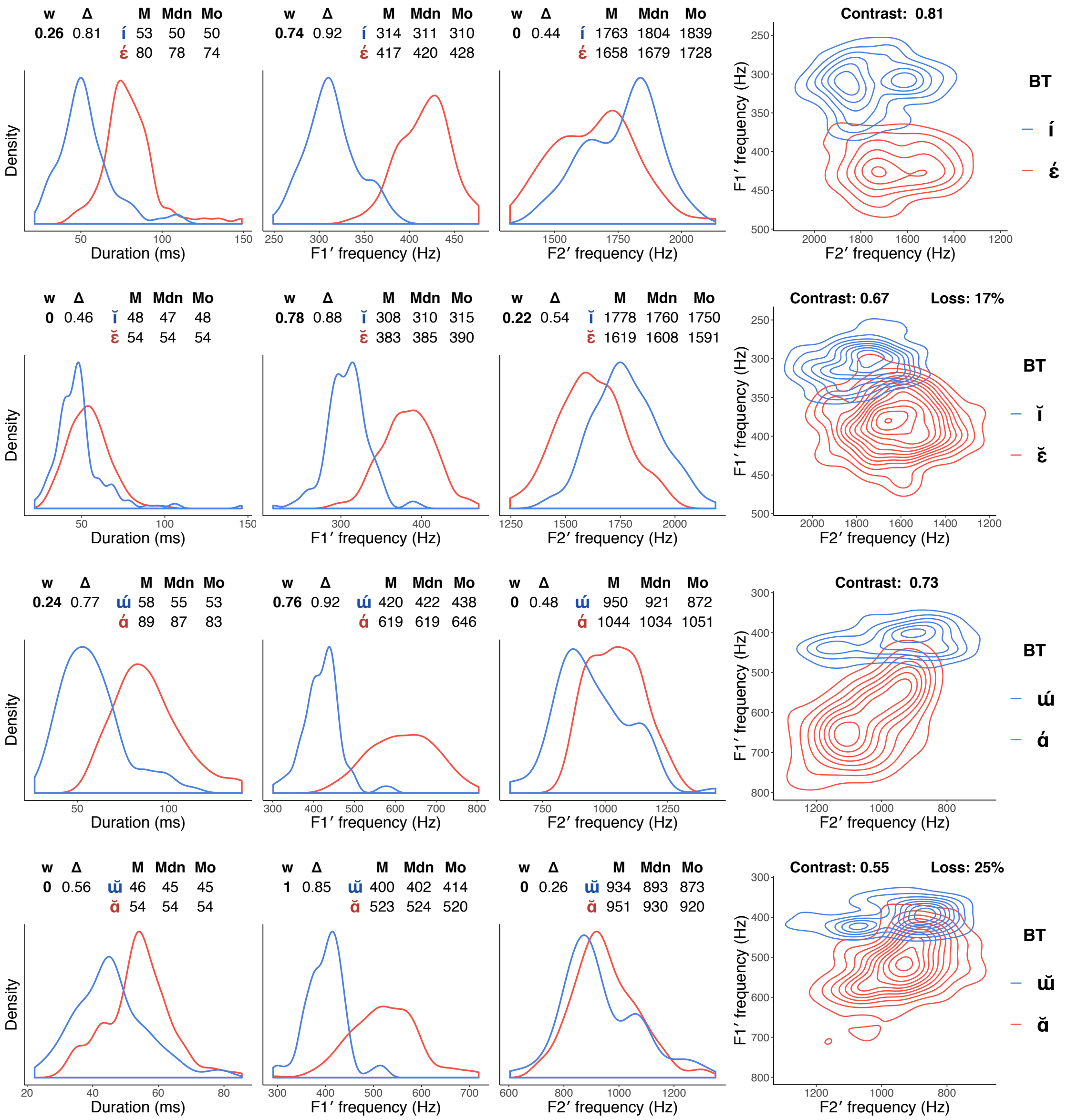


Figure 8.6: PDEs and summary statistics for Bilingual Turkish O/C unrounded vowels. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode; **n.s.** $p > 0.05$.

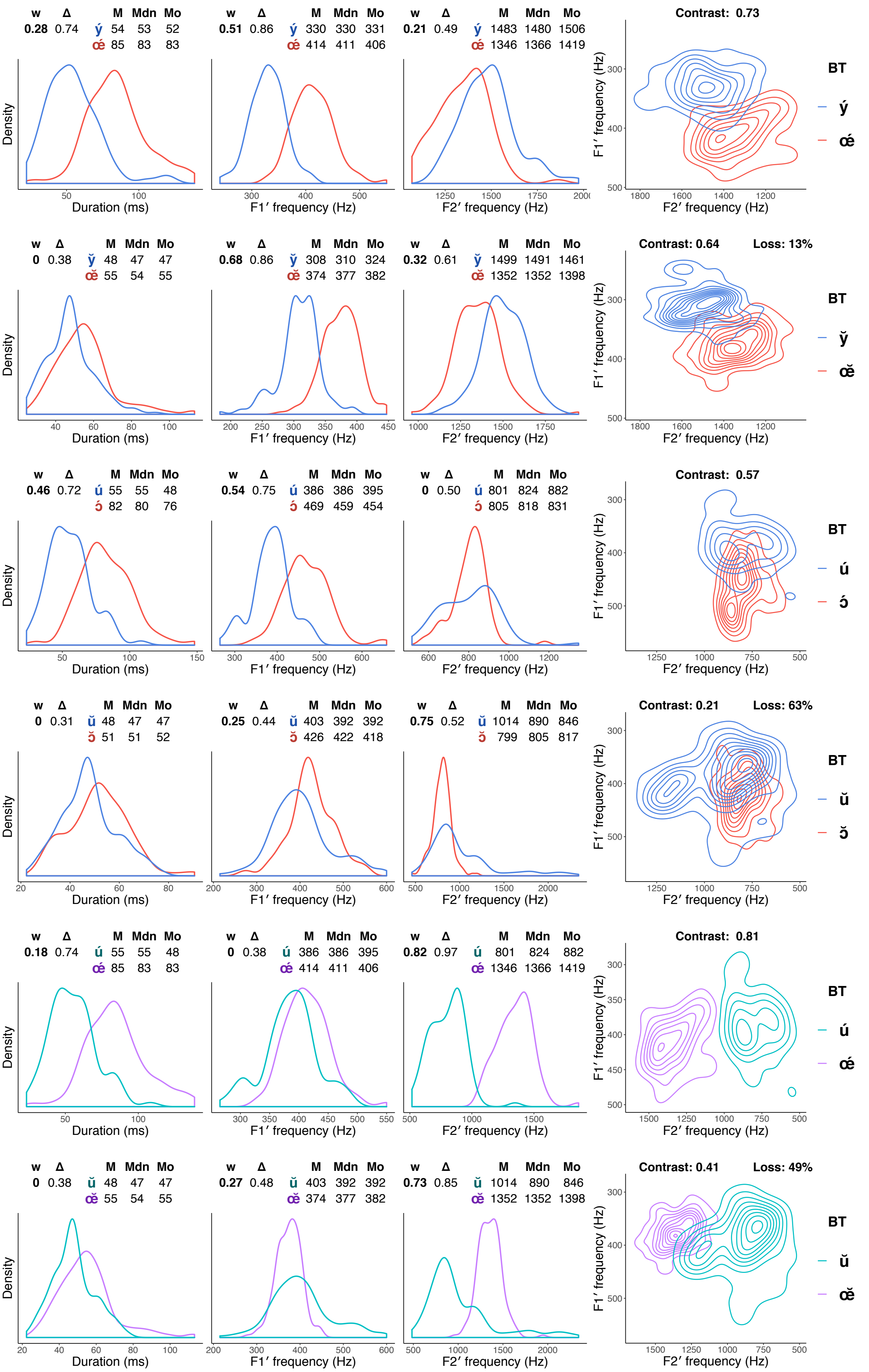


Figure 8.7: PDEs and summary statistics for Bilingual Turkish o/ɔ rounded vowels and /u–œ/. **w** discriminant weight; **Δ** symmetric difference; **M** mean; **Mdn** median; **Mo** mode.

8.3 Discussion of findings

Stressed vowels are, as a rule, longer than unstressed vowels in Bilingual Turkish. Duration differences are not significant only in Bilingual Turkish /y/, while in /i/ they are marginally significant ($p = 0.05$). For open vowels and /ɯ/, F_1' frequency, too, is highest in stressed position. Unlike duration, however, F_1' frequency is also differentiated in unstressed position: it is higher in word-initial than in second syllables. There are no significant differences for /i/ and /u/ (according to the ANOVAs). While in Istanbul Turkish (Chapter 6) F_2' frequency tended to be lower in stressed than in unstressed syllables, in Bilingual Turkish it tends to be lowest in non-initial unstressed syllables. Figure 8.8 displays mean stressed and unstressed formant frequencies for visual comparison, with mean durations indicated in superscript indices.

Significant positive duration–F_1' frequency correlations are prevalent in Bilingual Turkish open vowels. At the same time, we have seen that the front vowels, /ɛ, œ/, undergo a degree of F_1' frequency decrease in unstressed syllables that is greater than the extent of

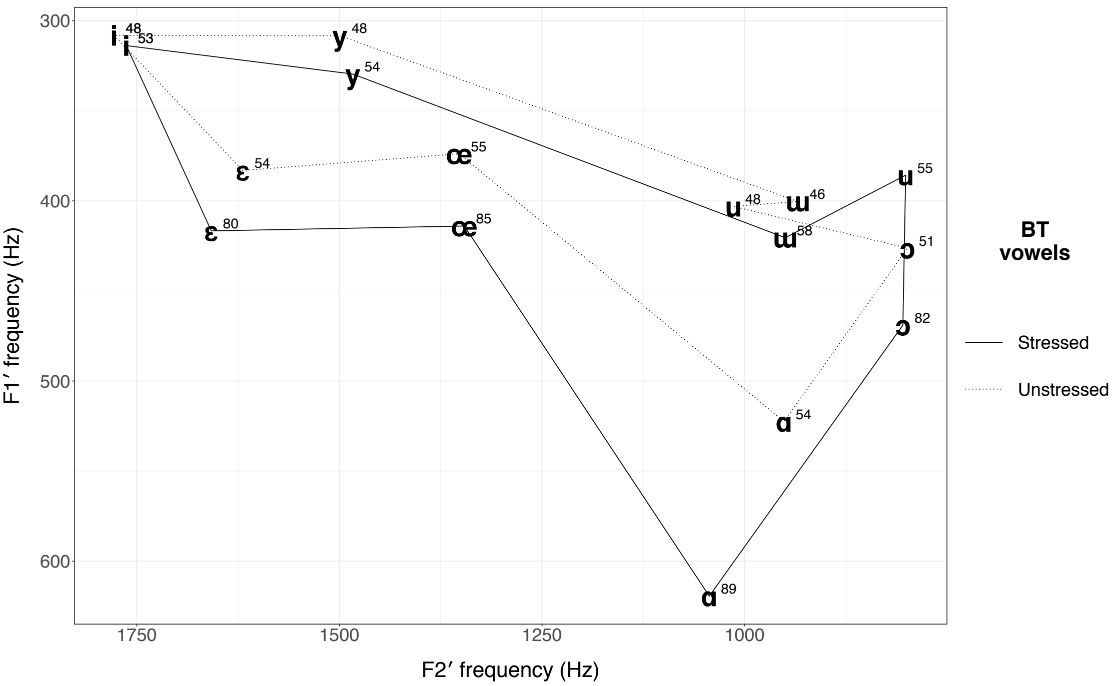


Figure 8.8: Bilingual Turkish S/U vowels in the $F_1' \times F_2'$ frequency space (means). Numbers next to vowels: mean durations (ms).

predicted undershoot. This suggests that two Unstressed Vowel Shift mechanisms may operate in different parts of the system: a categorical target switch in the front vowels, and gradient undershoot in /ɑ/. Despite the fact that the Unstressed Vowel Shift of Bilingual Bulgarian /ɔ/ is within the range of predicted undershoot, it is highly likely to be categorical, as it results in a rather high neutralisation rate, a contrast loss of 63 per cent. This approaches the neutralisation rates found in East (70%) and West (78%) Bulgarian (pp. 111, 131), where the overlap of unstressed /u–ɔ/ is known to be perceptually neutralising (Sabev 2015).

Another interesting fact the data have revealed is that, in both bilingual and monolingual Turkish, there are no significant durational differences between unstressed syllables, while at the same time F_1' frequency is significantly higher in initial than in other unstressed syllables. This indicates that F_1' frequency is not entirely pegged to duration.

Bilingual Turkish has scored higher in global (i.e. $dur \times F_1' \times F_2'$) Unstressed Vowel Shift than both Istanbul Turkish and Bilingual Bulgarian. At the same time, contrast levels remain high, and neutralisation levels low. The only exception is /u–ɔ/, which neutralise to a considerably higher degree than any other height-contrasting pair. This

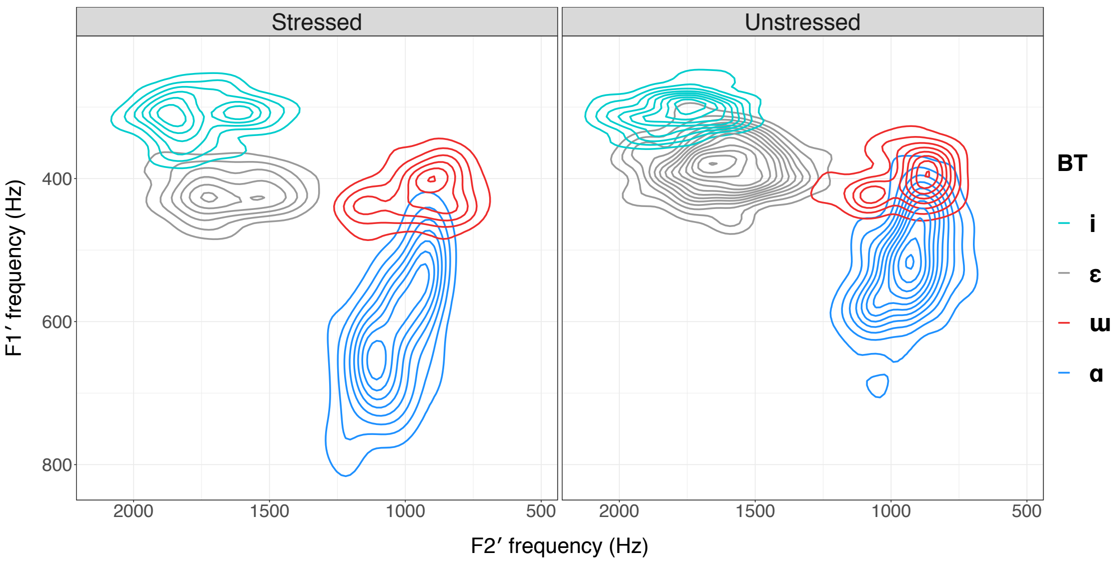


Figure 8.9: PDEs of Bilingual Turkish S/U unrounded vowels in the $F_1' \times F_2'$ space.

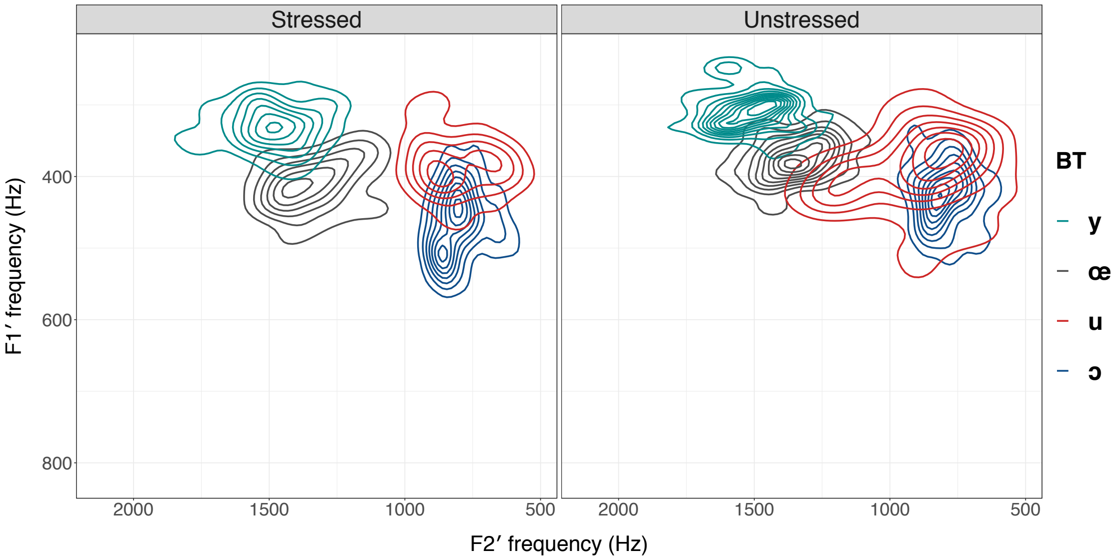


Figure 8.10: PDEs of Bilingual Turkish S/U rounded vowels in the $F_1' \times F_2'$ space.

is clearly conveyed by the two-dimensional $F_1' \times F_2'$ plots in Figure 8.10. The contour maps for unrounded vowels are in Figure 8.9.

I have also reported an appreciable degree of neutralisation of Bilingual Turkish /u/ and /œ/ in unstressed position. This is unexpected, as the two vowels are also contrastive for phonological backness, which is not predicted to be affected by Unstressed Vowel Shift to any considerable extent. The partial neutralisation observed here may be the result of transfer of a tendency for /u/-fronting from Bulgarian, which does not have front rounded vowels, to Bilingual Turkish, which does.

9

Cross-varietal comparison

Contents

This chapter brings together the results and findings reported in detail for each variety in Chapters 4–8 and explores them from a comparative perspective. I discuss variation in vowel quality, Unstressed Vowel Shift and contrast neutralisation across the varieties and assess earlier views against my findings. After a cross-dialectal investigation of Bulgarian (§ 9.1) and Turkish (§ 9.2), I examine the interaction of the two bilingual phonologies with each other and with ambient Bulgarian (§ 9.3).

9.1 Bulgarian

9.1.1 Vowel quality

9.1.1.1 Stressed vowels

In Chapters 4, 5 and 7, I examined the vowel systems of three modern varieties of Bulgarian: West, East and Bilingual Bulgarian, respectively. The study of West Bulgarian was based on a sample drawn from speakers who grew up and live in Sofia. The East and Bilingual Bulgarian samples were sourced from monolingual and bilingual residents of the northeastern town of Tărgovište and nearby villages. Western and eastern dialects of Bulgarian are not expected to differ substantially in terms of stressed vowel qualities and inventories: as a rule, both western and eastern varieties have six contrastive vowels in stressed position, which form three height-contrasting pairs, /i–ɛ, ə–a, u–ɔ/. Where cross-dialectal differences in *stressed* vowels exist, they normally involve lexical incidence, but not phonological contrast or phonetic realisation. For example, in some eastern dialects one may find /a/, e.g. /daʒd/ 'rain', /san/ 'sleep, dream', that corresponds to /ə/ in the West, /dəʒd, sən/. This is restricted to a specific lexical set: apart from this, /ə/ and /a/ are contrastive in the East. Similarly, in certain lexical items we find /ɛ/ in the West, e.g. /ˈʃɛpa/ 'a handful', /mɛ/ 'me' (ACC), /tɛ/ 'you.ACC.SG', /sɛ/ '-self' (reflexive clitic), but /ə/ in some eastern varieties, /ˈʃəpa, mə, tə, sə/ (Stojkov 2002: 96ff).

It is, however, realistic to expect at least some minor differences in stressed vowel quality across different dialects, and indeed this is apparent from a visual inspection of the mean F_1' and F_2' frequencies plotted in Figure 9.1. The two eastern varieties, East and Bilingual Bulgarian, appear to have rather similar formant frequencies, whereas the West Bulgarian close vowels, /i, ə, u/, stand out as being more advanced (i.e., having higher F_2' frequencies). To assess cross-varietal differences more accurately, I conducted multivariate analysis of variance with dialect as independent variable and the first two

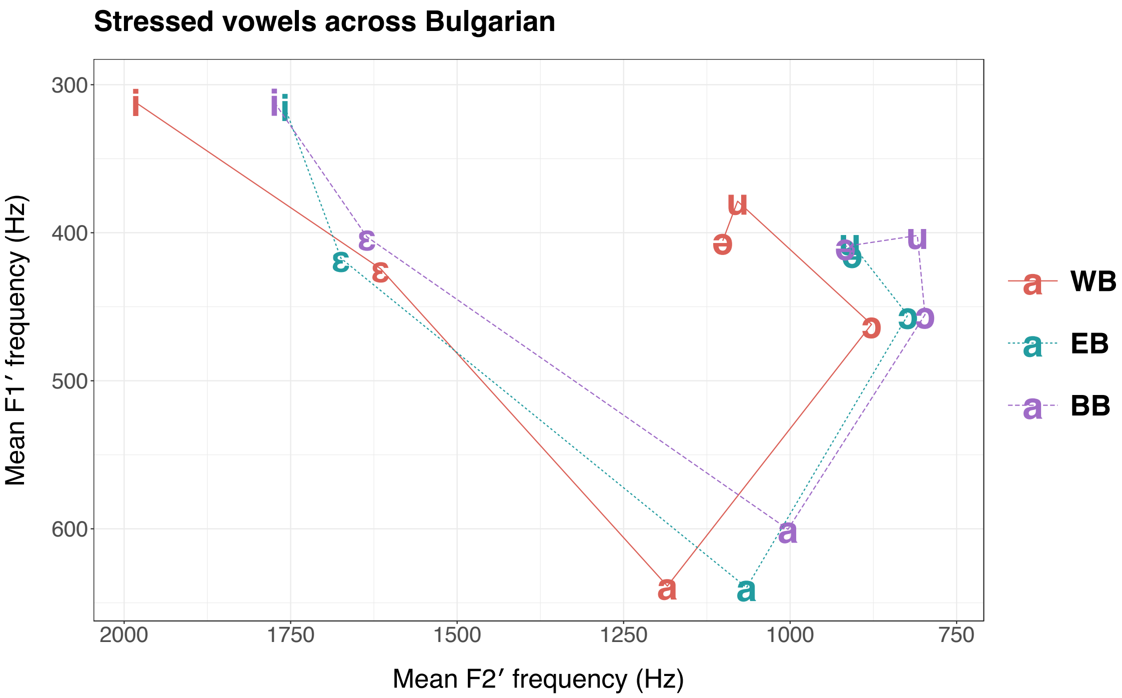


Figure 9.1: Stressed vowels in the $F_1' \times F_2'$ frequency space across Bulgarian varieties.

formant frequencies as dependent variables. Duration has not been normalised in this study and is therefore not included in the cross-dialectal comparisons that follow.[1] As usual, I take the Pillai scores (Λ) of significant MANOVAs, shown in Figure 9.2, as a measure of global ($F_1' \times F_2'$) distinctness.

The results confirm my preliminary observations: differences between East and Bilingual Bulgarian are either non-significant (/i, ə, ɔ/) or otherwise very small. Both differ from West Bulgarian more substantially, except for West and East Bulgarian /ɛ/ and /ɔ/, which show little difference. Figure 9.2 also shows the non-negligible discriminants, in order of importance, for any comparisons that gave higher Pillai scores ($\Lambda > 0.05$). F_2' frequency is the sole or primary discriminant in the vast majority of cases. All vowels but /ɛ/ have higher F_2' frequencies in West Bulgarian than in the eastern dialects. F_1' frequency plays a role only in distinguishing West Bulgarian /u/ and Bilingual Bulgarian /ɛ/, both of which appear to be somewhat closer than their counterparts in the other varieties.

1 Duration is only taken into consideration in the comparison of Bilingual Bulgarian and Bilingual Turkish (§ 9.3), since the samples have been sourced from the same speakers.

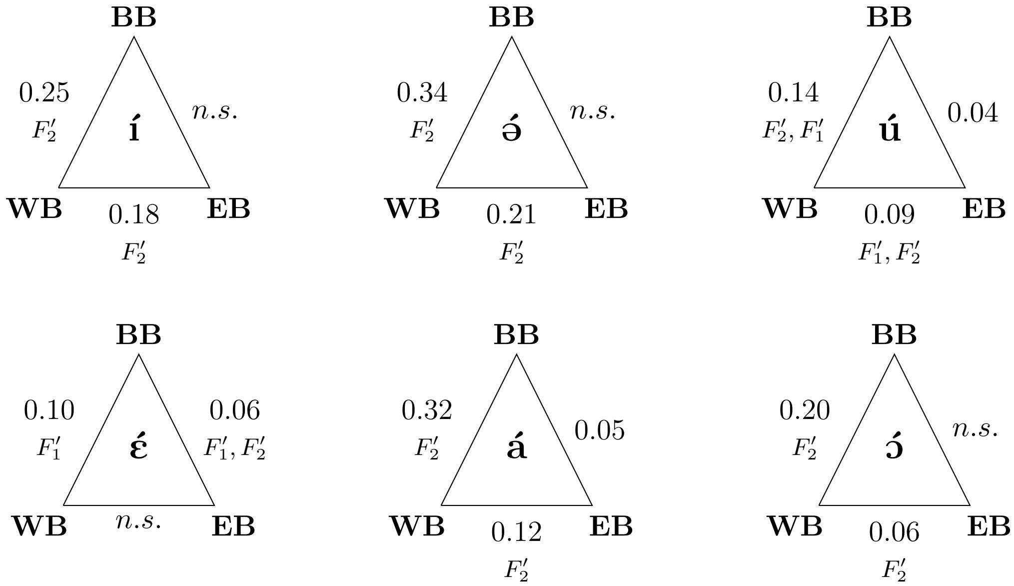


Figure 9.2: Pillai scores (Λ) and principal discriminants (where $\Lambda > 0.05$) for stressed vowel differences across Bulgarian varieties. **n.s.** non-significant MANOVA ($p > 0.05$).
BB Bilingual Bulgarian, **EB** East Bulgarian, **WB** West Bulgarian.

Probability density estimates indicate that in the monolingual varieties there is a degree of /u/-fronting in stressed position.[2] The F'_2 estimates are bimodal or multimodal and extend over a wide range, with the highest peaks at the lower frequencies and lower density peaks closer to the high frequency end. This suggests that there may be a minority of speakers with rather advanced targets, while for the majority it remains a clearly back vowel.[3] The F'_2 frequency modes for West and East Bulgarian stressed /u/ are lower than those for stressed /ɔ/. However, the fronted data points in the samples have pushed the mean F'_2 frequencies upwards, causing West and East Bulgarian /u/ to appear rather more advanced than /ɔ/ in Figure 9.1. There is no comparable evidence of stressed /u/-fronting in Bilingual Bulgarian: despite the slightly higher F'_2 frequency mode and mean, and a more spread-out PDE for /u/ than for /ɔ/, the /u/ estimate remains very compact compared to what is found in the monolingual varieties. /u/-fronting is also present in unstressed position: somewhat suppressed in the West, but intensified in the East. Interestingly, in unstressed position Bilingual Bulgarian joins the monolingual varieties in having a PDE that extends to considerably higher F'_2 frequencies.

[2] See diagrams on pp. 111, 113 for West Bulgarian; pp. 131, 133 for East Bulgarian; pp. 172, 174 for Bilingual Bulgarian.

[3] This is indeed the case, as will become clear from the examination of /u/-fronting by speaker in § 9.1.4.

In all three Bulgarian varieties, the vowels in the unrounded close–open pairs, /i–ɛ, ə–a/, are highly contrastive in stressed position: Pillai scores are invariably higher than 0.70, sometimes exceeding 0.80. The contrast between the back rounded vowels, /u–ɔ/, on the other hand, is appreciably lower: 0.51 in West and 0.48 in East Bulgarian. This likely to be linked to the shape of the vowel space: there is less vertical extent in the back than further forward, suggesting that back height-contrasting vowels may be universally less distinct than central and front vowels. Lower contrastiveness may also have to do with another factor, the low functional load of the /u–ɔ/ pair in Bulgarian, which is discussed later in this chapter (§ 9.1.3.3). The overlap between stressed /u/ and /ɔ/ reaches a strikingly high level in Bilingual Bulgarian, with a Pillai score of only 0.35. This casts doubt on how contrastive these vowel qualities are in this variety: there may be a merger process underway that is unconditioned, i.e. independent of stress. Or, perhaps, merger first took place in unstressed position but was then extended to all contexts, since all other open–close pairs remain highly contrastive when unstressed. At the same time, stressed Bilingual Bulgarian /ɔ/ is significantly and considerably longer than stressed Bilingual Bulgarian /u/, and duration is indeed the primary discriminant between the two (Figure 7.5, p. 172). Any definitive conclusion regarding the contrastiveness and status of Bilingual Bulgarian /u–ɔ/, however, would require additional research: most importantly, a perceptual study.

A potential unconditioned merger of Bilingual Bulgarian /u–ɔ/ may not be the only respect in which the vowel inventories of the three Bulgarian dialects differ from one another. Recall that East Bulgarian exhibits very low contrast levels in the close back pair, /u–ə/: $\Lambda = 0.18$ in stressed, and 0.19 in unstressed syllables (p. 134). The little distinctness that exists is contributed exclusively by the third formant frequency in stressed position, and primarily by F_1' frequency in unstressed syllables. Given such low levels of acoustic contrast, it would not be surprising if /u/ and /ə/ were perceptually indistinguishable or poorly distinguishable in East Bulgarian.

Leaving these interesting matters aside for further investigation, at this stage we may conclude that differences between East and Bilingual Bulgarian stressed vowel qualities are insignificant or very small, while West Bulgarian stressed vowels are generally more advanced (excepting /ɛ/). Nothing in the spectral make-up of the vowel systems promises a sharp divergence in unstressed position.

9.1.1.2 Unstressed vowels

Differences in unstressed vowels are, on the whole, both greater and more numerous. They involve the locations of vowels in the acoustic space, the amount of stressed-to-unstressed shift, and the extent of height neutralisation. While it is reasonable to expect greater absolute Unstressed Vowel Shift to result in categorical reduction and higher neutralisation levels, as we shall see in the following sections, such dependencies are not guaranteed.

The mean values plotted in Figure 9.3 show that the F_1' frequencies of unstressed open vowels are highest in Bilingual Bulgarian. East Bulgarian has the lowest F_1' frequencies for the unrounded open vowels, /ɛ, a/, while East Bulgarian /ɔ/ comes in between its West and Bilingual Bulgarian counterparts. East Bulgarian also has the most compact unstressed spectral space, in terms of both formant frequencies, while Bilingual Bulgarian has the widest F_1' frequency span. West Bulgarian unstressed /ə, u, ɔ/ have lower F_1'

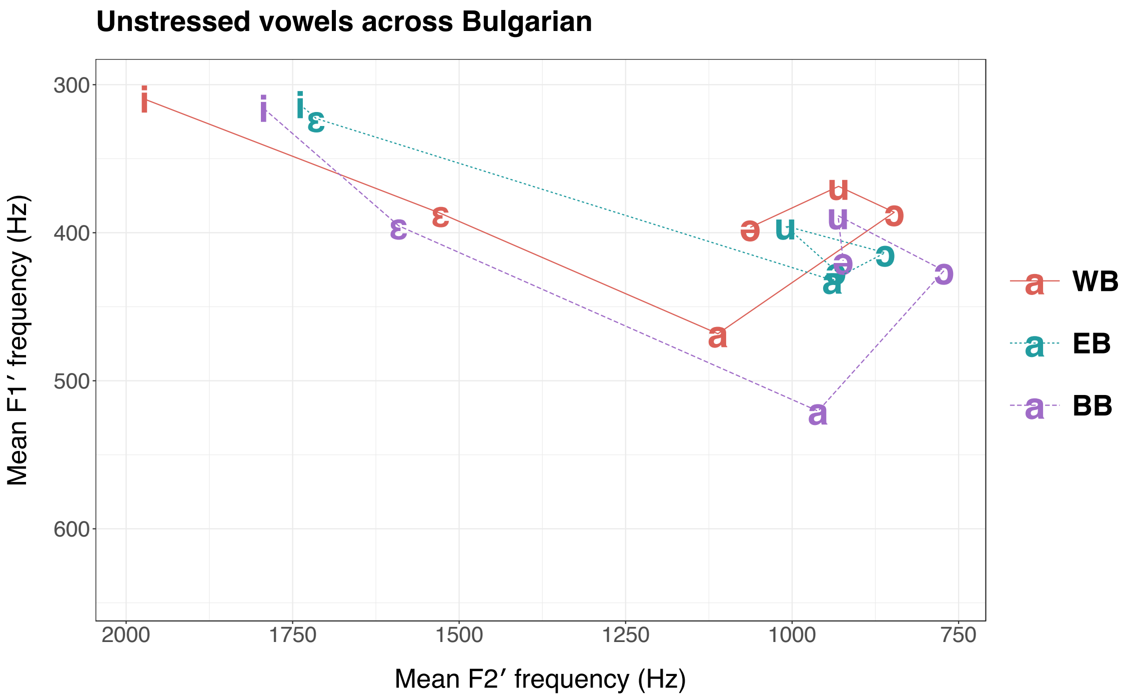


Figure 9.3: Unstressed vowels in the $F_1' \times F_2'$ frequency space across Bulgarian varieties.

frequencies, while West Bulgarian unstressed /i, ə, a/ have higher F_2' frequencies, than the same vowels in the eastern varieties. In both stressed and unstressed position, the F_2' gap between the front vowels, /i/ and /ɛ/, is appreciably larger in West Bulgarian that elsewhere. As with the stressed vowels, the mean F_2' frequency of /u/ is pumped up by /u/-fronting, which in unstressed position occurs in all three varieties: unstressed /u/ has higher F_2' frequency means, but lower modes, than /ɔ/ (pp. 111, 131, 172). The mean F_2' frequencies of the close non-front vowels, /ə/ and /u/, differ with respect to each other across the three varieties: from higher for /u/ in East Bulgarian, to nearly identical in Bilingual Bulgarian, to higher for /ə/ in West Bulgarian.

Further detail can be gleaned from the Pillai scores and principal discriminants reported in Figure 9.4. While there is little difference between East and Bilingual Bulgarian *stressed* vowels across the board, in unstressed position this is only true of the close vowels; /ɛ/ and /a/ differ considerably in F_1 frequency. West Bulgarian is noticeably different from both other varieties in all vowels except /u/ and /ɛ/, which are similar to their Bilingual Bulgarian counterparts.

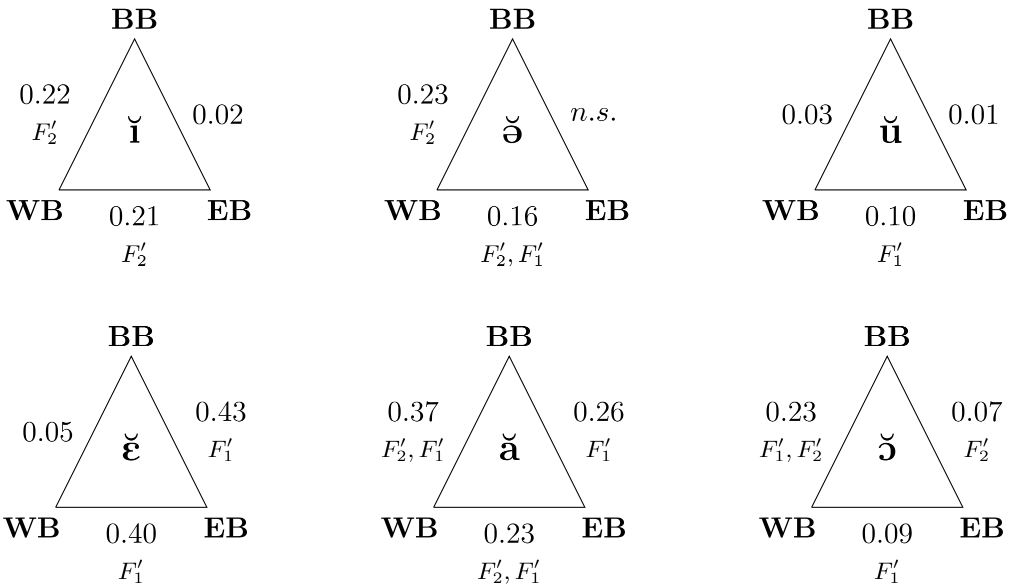


Figure 9.4: Pillai scores (Λ) and principal discriminants (where $\Lambda > 0.05$) for unstressed vowel differences across Bulgarian varieties. **n.s.** non-significant MANOVA ($p > 0.05$).
BB Bilingual Bulgarian, **EB** East Bulgarian, **WB** West Bulgarian.

9.1.2 Unstressed Vowel Shift

By contrast with stressed vowels, cross-dialectal differences in unstressed vowels involve predominantly the first formant frequency, which is indicative of different degrees and patterns of open vowel raising in unstressed position. I have used Pillai scores to measure Unstressed Vowel Shift, a global difference between stressed and unstressed token distributions in a three-dimensional duration $\times F_1' \times F_2'$ space. The Pillai scores for each stressed–unstressed vowel pair in each of the Bulgarian varieties are summarised in Figure 9.5. Close vowels, /i, ə, u/, show very little Unstressed Vowel Shift compared to open vowels, which is to be expected. Unstressed Vowel Shift involves reduction in F_1' frequency and duration, and in most cases close vowels cannot be raised much further if they are to remain vocoid. The little Unstressed Vowel Shift that there is, therefore, stems primarily from temporal reduction, which is also comparatively small, as close vowels are inherently shorter than open vowels. As regards open vowels, Bilingual Bulgarian exhibits levels of Unstressed Vowel Shift that are considerably lower than those of both monolingual varieties. The 'shape' of the Bilingual Bulgarian pattern, on the other hand, is similar to that in West Bulgarian: there is most Unstressed Shift in /a/, somewhat less in /ɔ/ and least in /ɛ/. East Bulgarian has the greatest amount of Unstressed Vowel Shift, and while its Pillai scores for /a/ and /ɔ/ are comparable to those in West Bulgarian, the Unstressed Vowel Shift score for /ɛ/ is the highest one among all vowels in all varieties.

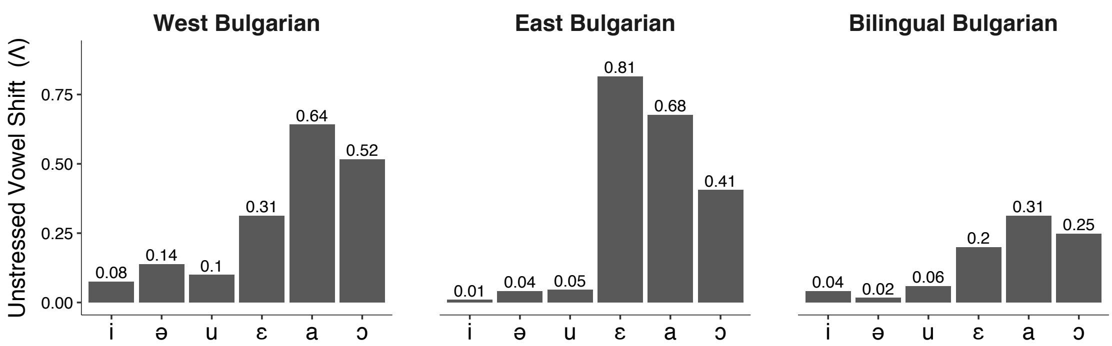


Figure 9.5: Unstressed Vowel Shift across Bulgarian varieties, based on the effect of stress on duration, F_1' and F_2' frequencies in MANOVA.

Discriminant function analysis has revealed that stressed and unstressed open vowels are, as a rule, differentiated by a combination of F_1' frequency and duration, with the monolingual varieties normally attaching greater importance to the spectral shift, and Bilingual Bulgarian prioritising duration. West Bulgarian /ɛ/, however, differs from the other open vowels in every single aspect of the analysis of stress-conditioned differences, including discriminant ranking: duration outweighs F_1' frequency as a marker of stress. The second formant frequency does not play an important role in distinguishing stressed and unstressed open vowels in any of the varieties, and can therefore be left out of consideration in assessing individual acoustic parameters in Unstressed Vowel Shift.

To establish whether Unstressed Vowel Shift is gradient or categorical, I calculated Pearson's correlations of duration and F_1' frequency for each syllable-specific allophone, and considered a predominance of significant positive correlations in open vowels to be a clear indication that gradient F_1' frequency undershoot is in place. Significant positive correlations predominate in West Bulgarian /ɛ, a/ and Bilingual Bulgarian /a/, and are found in half of the allophones of the other open vowels in these varieties. Unstressed Vowel Shift in Bilingual Bulgarian is, therefore, to a large extent a gradient phenomenon, in contrast to East Bulgarian, where there is partial correlation only in the vowel /a/, so Unstressed Vowel Shift must then be categorical. West Bulgarian is inconsistent across vowels and speakers, as I explain below.

Gradience does not logically rule out a separate underlying target for the unstressed vowel, as both gradient undershoot and a categorical target switch may coexist in a grammar and apply simultaneously. In addition, a speech community need not be homogeneous in this respect: some speakers may have separate stressed and unstressed targets, while for others differences may result from undershoot only. To estimate whether separate unstressed targets are likely to be present, I calculated a *predicted* first formant frequency $\hat{F}_1$ for each open vowel in each variety and compared it to the corresponding *observed* mean unstressed first formant frequency $\bar{F}_1'$. Predicted $\hat{F}_1$ frequency refers to the F_1 frequency that is estimated for the mean duration of an unstressed vowel, based on the mean F_1' frequency of that vowel in stressed position, which I view as a target realisation. The calculation of predicted undershoot was done using Lindblom's (1963) model, which determines F_1 frequency on the basis of vowel duration and a predefined target frequency for the vowel. The procedure is explained in Chapter 3 (p. 92). If the observed mean unstressed $\bar{F}_1'$ frequency does not fall below the frequency predicted by undershoot, that is, if there is less observed than predicted reduction of F_1 frequency in unstressed position, then the observed reduction can be attributed exclusively to undershoot. If, however, observed values are lower than the predicted ones—in other words, if there is more actual reduction than is predicted for undershoot—then the observed degree of reduction cannot be explained by the operation of undershoot alone. In a case like this, where $\bar{F}_1' < \hat{F}_1$, it would be justified to posit a separate unstressed vowel target, which is closer than the target for that vowel in stressed position. There may still be gradience in the implementation of both targets, if there are significant positive duration–F_1' frequency correlations to suggest that.

Whenever observed values are higher than predicted ones (i.e. Unstressed Vowel Shift is within the bounds of undershoot), the residual value $\bar{F}_1' - \hat{F}_1$ will be a positive number. When there is more reduction than can be subsumed under undershoot (i.e. lower observed than predicted values), the residual will be negative. Figure 9.6 shows the residual values calculated for open vowels in the Bulgarian varieties. All three open vowels reduce less than predicted for undershoot in Bilingual Bulgarian, indicating that Unstressed Vowel Shift is entirely gradient in that variety.

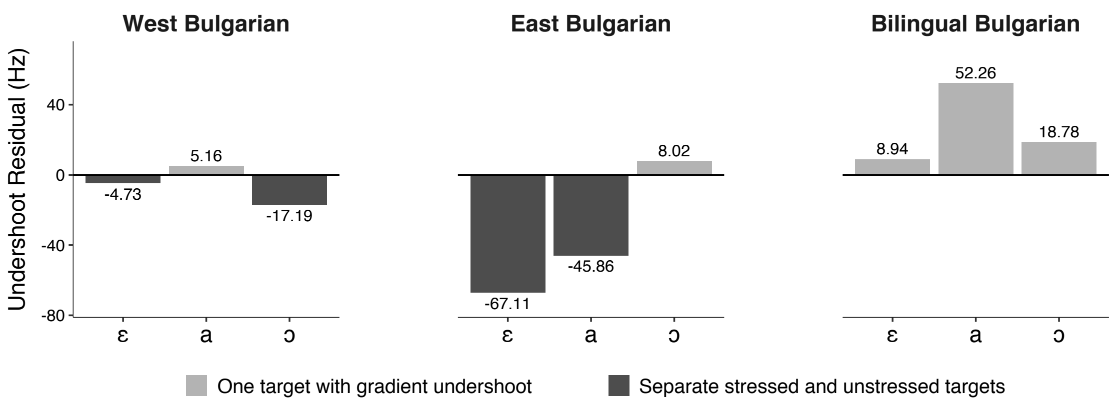


Figure 9.6: Differences (residual values) between observed mean unstressed $\bar{F}_1'$ and predicted unstressed $\hat{F}_1$ frequencies of open vowels across Bulgarian varieties ($\bar{F}_1' - \hat{F}_1$).

In East Bulgarian, /ɛ/ and /a/ have high Unstressed Vowel Shift scores which are matched with high negative observed–predicted residuals, indicating a categorical stressed–unstressed target switch. East Bulgarian /ɔ/, on the other hand, does not reduce in F_1' frequency quite to the extent allowed by the predicted undershoot, as can be seen seen from the positive residual value of 8 Hz. However, this East Bulgarian vowel does not correlate F_1' frequency with duration in any of its syllable-specific allophones, so it is doubtful that a positive residual could be a meaningful indicator of gradience in this case. The amount of observed reduction is less than predicted by gradient undershoot indeed, but there is no evidence that gradient undershoot takes place in the first place (there are no correlations), so it seems reasonable to assume that there is a separate unstressed target that simply happens to be within the bounds of hypothetical, mathematically predicted undershoot.

West Bulgarian is perhaps the most peculiar of the three Bulgarian dialects with respect to evidence for a stressed–unstressed target split in open vowels. /a/ has the highest Unstressed Vowel Shift score ($\Lambda = 0.64$), which is followed fairly closely by /ɔ/ ($\Lambda = 52$). Stressed and unstressed /ɛ/ differ by a markedly lower, though still substantial, Pillai score ($\Lambda = 0.31$). This is not matched by the pattern of target estimations. /ɔ/ clearly has a stronger observed than predicted F_1 frequency reduction—and this happens to be the case for all talkers in the sample—which indicates that unstressed realisations cannot be accounted for by gradient undershoot alone and must, therefore, be implementations of a separate unstressed target. Observed F_1' frequency reduction is slightly stronger (hence a negative residual) in unstressed /ɛ/, and slightly weaker (positive residual) in unstressed /a/, than what is predicted for bare undershoot. The small size of deviations from the predicted undershoot $\hat{F}_1$ frequency value prompted me to consider the participants in the West Bulgarian experiment individually, which uncovered a state of affairs where, rather than the majority of talkers gravitating towards the predicted undershoot baseline, about half had markedly greater reduction than predicted undershoot, and were therefore implementing separate unstressed targets. West Bulgarian may, as it appears, be moving towards a pattern of generalised categorical Unstressed Vowel Shift, although this is still counterbalanced—or indeed masked—by the predominance gradience. At this point I should emphasise that categorical (two-target) Unstressed Vowel Shift does not necessarily entail categorical merger with another phoneme: it may be an instance of sub-phonemic split, in which a target splits without either of the new targets merging with a third one.

I acknowledge that further experimental work on speech production and perception is needed to ascertain the presence of separate unstressed targets with greater confidence. A possible production experiment would be to elicit prolonged renditions of unstressed syllables by placing them in prosodic contexts suited to the purpose, for example, or by explicitly instructing participants to speak slowly. If open unstressed vowels have significantly lower F_1' frequencies than stressed vowels of comparable durations (produced at a faster speech rate), then there will be more conclusive evidence of separate targets.

9.1.3 Contrast and neutralisation

9.1.3.1 Contrast levels

As we saw earlier, the stressed unrounded vowel pairs, /i–ɛ, ə–a/, are highly contrastive in all of the Bulgarian dialects. The contrast between stressed /u/ and /ɔ/ is somewhat weaker in the monolingual varieties and very weak in Bilingual Bulgarian. Stressed and unstressed contrast scores are summarised in Figure 9.7. It is evident that the three phonologies differ substantially in the levels and patterns of unstressed contrast. In Bilingual Bulgarian there is only a small reduction of contrastiveness and unstressed open–close pairs have the same contrast ranking as stressed pairs: strongest in /i–ɛ/,

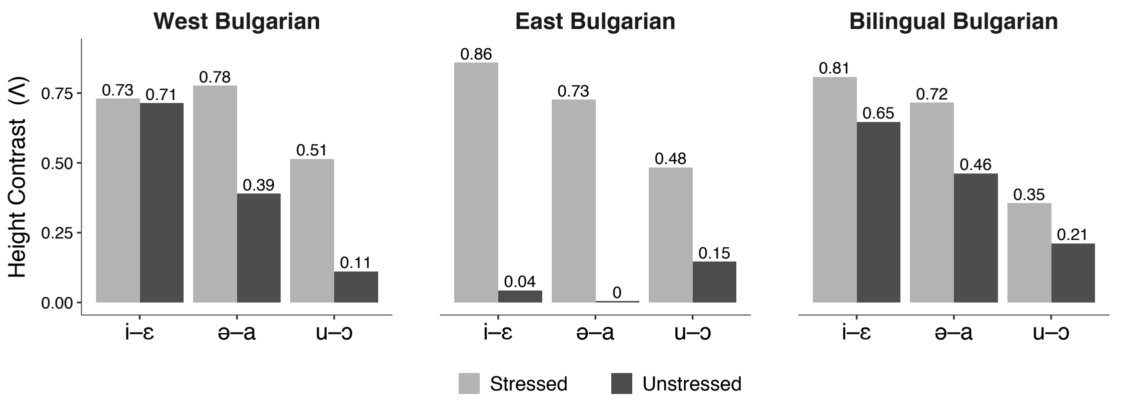


Figure 9.7: The Height contrast across Bulgarian varieties, based on the effect of phoneme identity on duration, F_1' and F_2' frequencies in MANOVA.

followed by /ə–a/ and weakest in /u–ɔ/. In all three varieties unstressed contrast between the back rounded vowels is very weak. There is practically no contrast in the unstressed pairs /i–ɛ/ and /ə–a/ in East Bulgarian. In West Bulgarian unstressed /i–ɛ/ remain virtually as contrastive as in stressed position, while West Bulgarian /ə–a/ and /u–ɔ/ are considerably less contrastive in unstressed than in stressed syllables.

9.1.3.2 Neutralisation

Figure 9.8 shows the rate of neutralisation—or contrast loss—for each vowel in unstressed position, which I define as the ratio of the stressed–unstressed contrast difference to the stressed contrast score. It is important to relativise the stressed–unstressed difference to the level of contrast in stressed position, because there will always be some degree of overlap between any two adjacent phonemes. A relativised score thus takes into account the amount of overlap that is tolerated between canonical realisations. Notice that neutralisation rates are also not necessarily predictable from the Unstressed Vowel Shift scores for open vowels (Figure 9.5): a moderate degree of Unstressed Vowel Shift in West Bulgarian /ɛ/ does not lead to (practically) any neutralisation of unstressed /i–ɛ/; at the same time, although /ɔ/ undergoes less Unstressed Shift than /a/ in West and Bilingual Bulgarian, /u–ɔ/ neutralise more than /ə–a/ in those varieties.

Neutralisation is strongest in East Bulgarian: it is evident that there is virtually no contrast between the 'open' and close vowels in the unstressed pairs /i–ɛ/ and /ə–a/. These appear to be clear examples of complete neutralisation and, if for the moment we

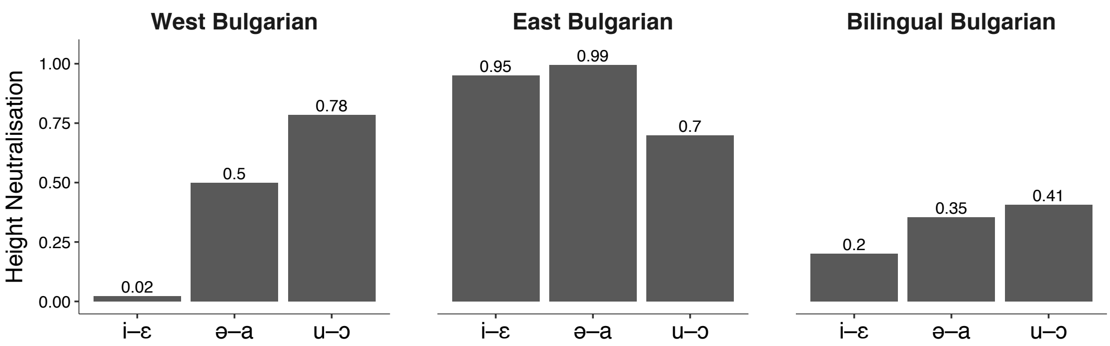


Figure 9.8: Height neutralisation across Bulgarian varieties ($\frac{\acute{\Lambda}-\breve{\Lambda}}{\acute{\Lambda}}$).

assume that to be the case with /u–ɔ/ as well, I can confirm that East Bulgarian, unlike the other two varieties examined, does bear out phonological generalisations of the type I discussed in Chapter 2 (§ 2.1.4, p. 33), which maintain that all open vowels raise and merge with close vowels in unstressed syllables. This can be formalised in various ways, for example by postulating a rule that deletes a feature like `[+low]`, `[-high]`, `[open]` or `[A]` from any unstressed vowel. A derivation like this makes a crucial assumption: that the height feature, let it be privative `[open]`, is in the underlying representation. However, it is unclear how a child who only hears [i, ə, u], and never [ɛ, a, ɔ], in unstressed syllables could arrive at underlying open vowels in unstressed syllables. An argument for such an assumption can be sought in alternations that result from the interaction of the morphological and accentual systems of the language. Bulgarian has free stress and rich inflectional and derivation morphology. A vowel that is stressed in one form may alternate with an unstressed vowel in another, morphologically related form. Take the nouns [rəˈka] ‘hand, arm’ and [bəˈʃta] ‘father’, for example. Their related adjectives are [ˈrəʧin][4,5] ‘manual’ and [ˈbaʃtin] ‘father’s, fatherly, paternal’, respectively. It can thus be claimed that the nouns are underlyingly /rəˈka/ but /baˈʃta/, and that `[open]` is deleted from the unstressed vowel in the latter word to derive the correct surface form [bəˈʃta]. However, such alternations, while not infrequent, are not at all ubiquitous: there are no stress alternations for the overwhelming majority of lexical items. Moreover, the height contrast is a common source of spelling mistakes, which occur in both stress-alternating and non-alternating morphemes. This indicates that there is not an algorithm that learners can apply systematically to arrive at ‘correct’ height specifications for unstressed vowels. Spelling errors in unstressed vowels that take part in alternations also cast doubt on how ‘alive’ connections between such alternating forms are in the mental lexicon. It may also be the case that the frequency of stress-alternating allomorphs determines whether they are stored as a single entry or separately. To sum up, at this point it does not seem feasible that unstressed East Bulgarian vowels may be specified as `[open]`, which is then deleted or replaced in the derivation. The obvious alternative is that all unstressed vowels are

[4] This would correspond to [ˈrəʧɛn] in West Bulgarian, where unstressed /ɛ/ is not raised much and does not merge with /i/.

[5] Historically, and in a certain layer of the lexicon, $k \rightarrow ʧ$ before a front vowel.

specified as `[close]` (`[+high]`, etc.) or not specified at all, in a model with underspecified close vowels. There would be no underlying height distinctions in unstressed vowels and any such differences implied by orthography would have to be learnt by rote, as they would be nothing more than relics from a historical state of the language when contrast was more pervasive. However, there are reasons to remain cautious about concluding that East Bulgarian neutralisation is unequivocally complete because of complications that arise from /u/-fronting, which I discuss in § 9.1.4 below.

In West Bulgarian the three unstressed pairs show three distinct levels of neutralisation: there is none in /i–ɛ/, it is very high—possibly complete—in /u–ɔ/, and partial yet substantial in /ə–a/. Here I should recall that in earlier work I found that both West Bulgarian /u–ɔ/ and /ə–a/ are perceptually neutralised in unstressed syllables despite the differing degrees of acoustic overlap (Sabev 2015). West Bulgarian unstressed /ə–a/, therefore, is a classic example of near-merger, in that 'from the productive viewpoint, there are two categories; from the perceptual viewpoint, only one' (Labov 1994: 368). Near-mergers are notoriously difficult to account for in formal terms (Port 1996), and West Bulgarian /ə–a/ is no exception: acoustic overlap is clearly incomplete, which may only arise from different unstressed /a/ and /ə/ articulations. Different articulations must have been learnt somehow, so for the learner the difference must have been identifiable in the acoustic signal. And yet, adult speakers fail to distinguish perceptually between unstressed /a/ and /ə/ (in both identification and discrimination tasks). Moreover, orthographic confusion in unstressed /ə–a/ and /u–ɔ/ is widespread among West Bulgarian speakers as well (though it would be interesting to see whether /a–ə/ are confused less than /u–ɔ/). It could be that a child reconstructs an articulatory distinction from the acoustic signal at an appropriate developmental stage of category acquisition, when she is more receptive to very subtle variation. With time, this slight articulatory difference is internalised, but its acoustic effect ceases to be auditorily perceptible. There may also be non-negligible differences in degree of perceptual neutralisation across speakers: some adults may be more successful in perceiving (and spelling) the difference than others.

In Bilingual Bulgarian, there is clearly little neutralisation in the unstressed pairs /i–ɛ/ and /ə–a/. With regard to the rounded vowels, /u–ɔ/, as I noted earlier, it is not clear how distinct these are even in stressed position, and further research is needed.

We have seen that Unstressed Vowel Shift is gradient in Bilingual Bulgarian and at least partly so (i.e. for some speakers) in West Bulgarian. As a product of Unstressed Vowel Shift, neutralisation, too, must be a gradient phenomenon whenever caused by gradient Unstressed Vowel Shift, not only in an averaged static sense, as near-mergers are often described, but also dynamically: more neutralisation should be expected at higher speech rates, in casual speech, etc. I now turn to another factor that has been demonstrated to affect neutralisation: functional load.

9.1.3.3 Phoneme frequencies and functional load

In seeking further insight into the mergers examined here, I calculated vowel phoneme frequencies using a comprehensive word-frequency dictionary extracted from the Bulgarian National Corpus (BulNC 2011), a corpus of 1.2 billion words in texts of various styles dating from 1945 to the present day. Vowel phoneme frequency may be calculated as the ratio of the number of occurrences of a given vowel to the total instances of all vowels either in a list of unique morphemes (type frequency) or a corpus, which of course contains many recurring word-forms (token frequency). The former approach estimates frequency within the lexicon, while the latter adds a usage perspective to that, by also taking into account morpheme frequencies.

In contemporary Bulgarian orthography, vowel letters faithfully correspond to (at least historically) underlying phonemes in the vast majority of cases: /i ɛ ə a u ɔ/ are regularly written as ⟨и е ъ а у о⟩, respectively; in addition, ⟨я⟩ and ⟨ю⟩ stand for /a/ and /u/, respectively, when preceded by a palatalised consonant or /j/. There is one crucial exception to this otherwise systematic grapheme–phoneme correspondence: in a limited number of identifiable cases, the phoneme /ə/ is rendered orthographically by ⟨a⟩ or ⟨я⟩ rather than the normal ⟨ъ⟩: this happens in a set of present tense personal endings of the verb,[6] which I had to alter to ensure that such orthographically irregular instances of underlying /ə/ were not misrepresented in the data.

Since word-form frequency data were readily available, I calculated token-based phoneme frequencies. The results are shown Figure 9.9,[7] in which the thickness of black lines between phonemes represents relative functional load (discussed below) and coloured broken lines and dots indicate the distinctive feature(s) commonly assumed to underpin phoneme pairings that cross them. Clearly /u/ is the rarest vowel in Bulgarian: its occurrence amounts to only four per cent of all vowel tokens. The second least common vowel phoneme is /ə/ at 11% (and irregular instances of ⟨**-a**⟩ /ə/ have been counted as /ə/ in the calculation). This means that it is the two least frequent vowels that are most strongly affected by neutralisation in West and Bilingual Bulgarian.

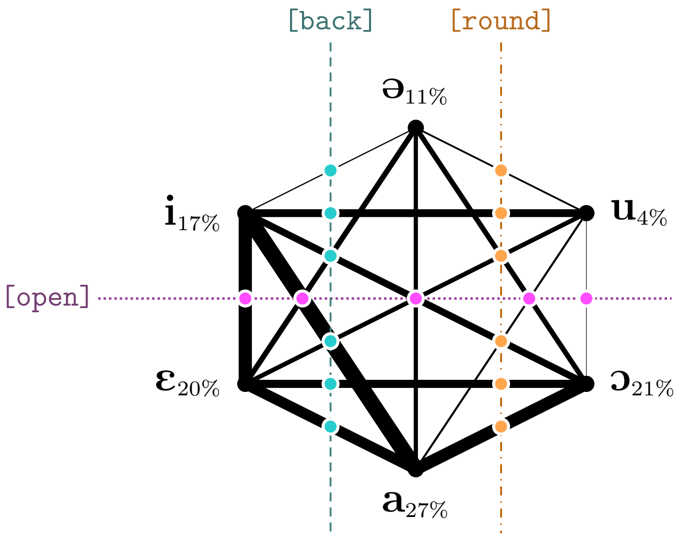


Figure 9.9: Functional load and phoneme frequencies in Bulgarian. Thickness of black lines: relative functional load; coloured lines: distinctive features in phoneme-pair lines that cross them.

6 Class I 1.sg ⟨**-a**⟩ /ə/, 3.pl ⟨**-ат**⟩ /ət/; Class II 1.sg ⟨**-я**⟩ [jə], 3.pl ⟨**-ят**⟩ [jət]; Class III 3.pl ⟨**-ат**⟩ /ət/. The list does not include Class III 1.sg ⟨-ам⟩ /am/, 2.sg ⟨-аш⟩ /aʃ/, 3.sg ⟨-а⟩ /a/, 1.pl ⟨-аме⟩ /amɛ/, 2.pl ⟨-ате⟩ /atɛ/ (Mirčev 1978; Mladenov 1979). Evidence that such endings still contain underlying /ə/, and that it has not been replaced by /a/ under orthographic influence in the majority of dialects (including the ones studied here), comes from the fact that they can be both stressed and unstressed—depending on the verb—and the stressed endings have [ə], e.g. ⟨чета, четат⟩ West Bulgarian [tʃɛˈt**ə**, tʃɛˈt**ə**t], East Bulgarian [tʃiˈt**ə**, tʃiˈt**ə**t] 'I read, they read'.

7 The diagrams in Figures 9.9 and 9.17 (p. 231) were inspired by Mielke's (2008: 31) octagonal graph of Turkish vowels, intended to illustrate the large number of binary vowel pairings that result from exhaustively combining only three distinctive features.

The functional load hypothesis was put forward over a century ago by Gilliéron (1918) and it states that 'the probability of phoneme loss should be inversely related to the amount of "work" that the phoneme does in distinguishing words in communication' (Wedel et al. 2013). The idea has since received a good deal of attention, and a considerable body of research has been devoted to defining and quantifying functional load, and examining its role in language change, including Trubetzkoy (1939); Martinet (1952); Hockett (1967); Surendran and Niyogi (2006); Blevins and Wedel (2009); Martin and Peperkamp (2017), among many others. Wedel et al. (2013) is a large-scale investigation of the hypothesis based on sound change data from a variety of languages, which for the first time provides sound statistical evidence that the likelihood of phoneme merger is indeed inversely related to functional load.

Phoneme functional load can be quantified simply as a count of minimal pairs in a list of lexemes or morphemes. Raw minimal pair count may be sufficient when comparing contrasts within a single language, but it does not provide a meaningful measure when different languages are compared, as the word lists used are unlikely to be of the same size. Alternatively, the raw count may be relativised to the total number of words in the list, which results in a ratio that can be used to compare functional loads from different lists. Yet another approach is to relativise the minimal pair count to the number of *potential* minimal pairs, that is, to divide it by the number of words that contain either of the members of the phoneme pair, thus taking into account their relative frequencies (Hall et al. 2017; Martin and Peperkamp 2017). In this way, the same minimal pair count will render a higher functional load if the phonemes are rare than if at least one of them is more frequent. In fact this method combines the traditional notion of functional load with that of predictability of distribution: two frequent sounds with few minimal pairs will have more predictable distributions than two equally frequent sounds with more minimal pairs.

Functional loads relative to potential minimal pairs were calculated using Phonological CorpusTools (Hall et al. 2017). The results for all vowel pairs are ranked in Figure 9.10 and show that /u–ɔ/ is the pair that has by far the lowest load in the language, and that /ə–a/ also scores rather low. Note that this a consequence not only of the low relative

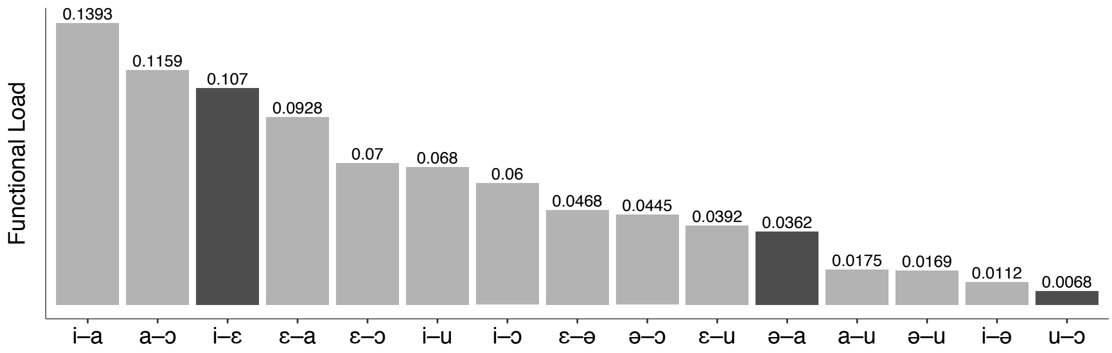


Figure 9.10: Bulgarian vowel pairs ranked by functional load (calculated as the number of minimal pairs relative to ‘potential minimal pairs’).

frequencies of /u/ and /ə/, but also of the high frequencies of their open counterparts, /ɔ, a/, since minimal pair count is relativised to the number of words that could potentially be in a minimal pair. The third vowel pair that is distinguished by height only, /i–ɛ/, has a considerably higher functional load: in fact, the third highest of all fifteen phoneme pairings.

These findings provide further, and in fact very concrete, evidence in support of the functional load hypothesis by demonstrating that even though a single phonological contrast (height) is being suppressed in a certain context, the degree of neutralisation may be differentiated across phoneme pairs in a way that is without doubt inversely related to the functional loads of those pairs. That is precisely what we see in West and Bilingual Bulgarian, in which we know Unstressed Vowel Shift, and therefore neutralisation, to be partially or entirely gradient. East Bulgarian, on the other hand, is the exact opposite: its Unstressed Vowel Shift is categorical and all three vowel pairs are completely neutralised, without regard to functional load. From these fundamentally distinct neutralisation patterns, it appears that phonetic implementation is indeed sensitive to factors such as frequency and functional load. We also see from East Bulgarian that those factors can eventually be overridden, when certain realisations become consistently different enough from canonical realisations to be detached into phonological categories of their own; once phonologised, the new categories may have very similar realisations to the ones that gave rise to the split, but their implementation is no longer sensitive to the same pressures. Unfortunately, we do not know enough about the timing and sequence of events that shaped present-day East Bulgarian phonology, but it would be safe to assume that when they merged, /i/ and /ɛ/ had roughly as high a functional load as they do today. Perhaps it was not until the pairs with low functional load, /u–ɔ/ and /ə–a/, collapsed that /i–ɛ/ merged as well, but at present there is only indirect evidence for this speculation, namely the neutralisation patterns found in the other dialects.

9.1.4 /u/-fronting

The question of the merger of unstressed /u–ɔ/ is complicated by /u/-fronting. The speech production sample that provided the basis for Sabev (2015) did not contain evidence of /u/-fronting in West Bulgarian and no significant spectral differences emerged between unstressed /ɔ/ and /u/. By contrast, my current data do reveal such fronting regardless of stress in the monolingual varieties, as well as in Bilingual Bulgarian unstressed /u/.[8] F_2' frequency plays an important role (w) in discriminating between /u/ and /ɔ/ in unstressed position, and we also find considerable symmetric differences (Δ) between the F_2' probability density estimates for the two unstressed vowels; the results reported on pages 111, 131 and 172 are summarised in Table 9.1. The F_2' estimates for /u/ are bimodal

	West B.	East B.	Bilingual B.
$w_{F_2'}(\breve{u}, \breve{ɔ})$	0.37	0.43	0.59
$\Delta_{F_2'}(\breve{u}, \breve{ɔ})$	0.33	0.36	0.51

Table 9.1: Discriminant weight (w) and symmetric difference (Δ) of F_2' frequency for [ŭ–ɔ̆].

or multimodal in all these cases, suggesting that the speech communities are not uniform in this respect. Higher F_2' frequencies have lower probability densities, which indicates that the fronted realisations are in the minority within the samples. Bulgarian /u/-fronting is a recent process: it has been noted by Andreeva et al. (2013) and is likely to be ongoing.

Although it is beyond the scope of this thesis to investigate inter-speaker variation, I found it important to verify whether the fronted tokens in my data belong to identifiable subgroups of participants. On the basis of a visual inspection of the probability density estimates, I shall define 'fronted /u/', or [ʉ], as any token of /u/ that has an F_2' frequency

8 The reason for this discrepancy between my 2015 study and the present one appears to be that, in 2015, I included only female talkers' data in the sample, whereas—as it becomes clear below—Bulgarian /u/-fronting is (as of the time of data collection) a primarily male phenomenon.

of 1 000 Hz or higher.[9] This cut-off point appears to be appropriate for all varieties and both stressed and unstressed allophones. It transpires that it is indeed the same speakers—roughly a third of all participants in each variety and predominantly male—who contribute the majority (≥ 60%) of fronted /u/ tokens, and who also have predominantly (> 50%) fronted /u/ in their own speech.

A breakdown of the occurrence and distribution of /u/-fronting in the Bulgarian varieties is given in Table 9.2. With regard to West Bulgarian *stressed* /u/, for example, we see that 36 per cent of all tokens are fronted (i.e. F_2' frequency ≥ 1 000 Hz). Four (out of twelve), or 33%, of the West Bulgarian participants have been identified as fronters, which means that more than half of each of these speakers' stressed /u/ tokens are fronted. One of these fronters is female and three are male. On average, 82 per cent of the fronters' /u/ tokens are fronted. Of all fronted stressed /u/ tokens in this dialect, 77 per cent come from the speech of fronters.

The stressed fronters in West and East Bulgarian also happen to be in the unstressed fronters' group. It can be noted that in the East Bulgarian sample, unstressed fronting is twice as widespread as stressed fronting.

	West B.		East B.		Bilingual B.	
	σ́	σ̆	σ́	σ̆	σ́	σ̆
[ʉ] incidence in dialect	36%	30%	21%	39%	8%	31%
Fronters: N and %	4 (33%)	4 (33%)	2 (25%)	4 (50%)		5 (36%)
By gender	1f, 3m	1f, 3m	2m	1f, 3m		1f, 4m
[ʉ] incidence in fronters	82%	63%	67%	64%		62%
[ʉ] tokens contributed by fronters alone	77%	60%	80%	70%		61%

Table 9.2: Bulgarian /u/-fronting. **[ʉ]** fronted /u/ (F_2' ≥ 1 000 Hz); **Fronters** speakers with > 50% [ʉ]; **f** female, **m** male.

9 A word of caution is in order here, concerning the term '/u/-fronting'. It is a convenient and familiar label, but I should emphasise that my findings are based on F_2 frequencies, i.e. an acoustic variable. An increase in F_2 frequency may result from tongue body fronting or lip unrounding (or both), and it is impossible to speculate about its articulatory cause(s) from acoustic data alone.

Having established that fronted /u/ realisations are largely attributable to the same speakers, I removed those speakers' tokens from the data and recalculated the MANOVAs comparing unstressed /u/ and /ɔ/ (pp. 109, 129, 170). While all three tests remained significant, there was a substantial drop in contrast scores. Table 9.3 compares the Pillai scores (Λ) for unstressed /u–ɔ/ with and without the data from /u/-fronters.

	West B.	East B.	Bilingual B.
Λ(ŭ, ɔ̆) *with* /u/-fronters	0.11	0.15	0.21
Λ(ŭ, ɔ̆) *without* /u/-fronters	0.04	0.07	0.08

Table 9.3: Contrast scores (Λ) for unstressed /u–ɔ/ with and without /u/-fronters.

A crucial insight to be gleaned from Bulgarian /u/-fronting is that if it affects unstressed /u/ but not unstressed /ɔ/, as my data indicate, then the ostensible merger of the two unstressed vowels cannot, after all, have been complete. If one of the vowels can be targeted by a process to the exclusion of the other, then the two must represent separate, if largely overlapping, categories. Further research into the matter is therefore likely to shed more light on the nature of unstressed vowel neutralisation in Bulgarian, but more importantly, also to contribute to a better understanding of a particular type of near-merger, one that may appear to be acoustically complete (Andreeva et al. 2013; Sabev 2015), unless and until a subsequent change reveals that the contrast has not been completely lost, at least for an identifiable part of the speech community.

9.1.5 Assessment of earlier views

I now return to a number of persistent claims and assumptions that have been prominent in the literature on vowel reduction and neutralisation in Bulgarian, in order to assess them against my findings from the experiments on West, East and Bilingual Bulgarian. The first three received views, which concern the qualities of reduced vowels, their degrees of reduction and neutralisation, originate from influential work by Dimităr Tilkov, which has been fully or partially echoed in numerous subsequent publications (Tilkov 1970, Tilkov et al. 1982, Scatton 1984, Boyadžiev and Tilkov 1997, Boyadžiev et al. 1998, Ternes and Vladimirova-Buhtz 1999, Žobov 2004, Barnes 2006, Tilkov and Boyadžiev

2013 and earlier editions). These traditional views, discussed at some length in § 2.1.2 (pp. 18ff), can be outlined as follows.

1. Of the three vowel pairs /i–ɛ/, /ə–a/, /u–ɔ/, only /ə–a/ and /u–ɔ/ neutralise the height contrast in unstressed position in Standard and West Bulgarian. The front pair is neutralised in eastern dialects only. Tilkov et al. (1982) further claim that the degree of overlap is greater in unstressed /ə–a/ than in /u–ɔ/.

2. The neutralised realisations are intermediate between the heights of the two canonical stressed realisations. In other words, open vowels raise, while close vowels lower, in unstressed position.

3. The exact height of a reduced realisation is determined by the unstressed vowel's position relative to the stressed syllable, and two degrees, or grades, of reduction are recognised. 'First-degree reduction' occurs in a syllable immediately preceding the stressed one (the first pretonic) and results in a more open realisation. 'Second-degree reduction' takes place in all other unstressed positions and yields closer realisations.

The traditional literature in Bulgarian does not explicitly address the question whether Bulgarian vowel reduction is categorical or gradient, even though the second part of claim (1) above refers to different degrees of overlap and thus implies gradience. The two reduction grades in (3) are framed in rather discrete terms, but again without express mention of categoricality or gradience. Wood and Pettersson (1988), on the other hand, studied the speech of two West Bulgarian speakers and concluded that their reduction was gradient.[10] Based on this claim and the account of Bulgarian vowel reduction in Tilkov et al. (1982), Barnes (2006) speculates about differences between West and East Bulgarian reduction. I conclude this section by weighing up his claims, summarised in (4).

4. Unstressed vowel reduction is categorical and neutralising in East Bulgarian, but gradient and non-neutralising in West Bulgarian, with a possible exception: that the reduction of /a/ may be 'phonologized as a merger for some speakers' (Barnes 2006: 32–36).

[10] Recall that this conclusion is not unproblematic (§ 2.1.3.1, p. 26).

I consider each claim in the above order.

9.1.5.1 Pair ranking by degree of neutralisation in West Bulgarian: /ə–a/ > /u–ɔ/ > /i–ɛ/ (none in /i–ɛ/)

This can be confirmed only with regard to West Bulgarian /i–ɛ/: there is indeed no neutralisation in this pair. The contrast scores are 0.73 for stressed and 0.71 for unstressed position, resulting in a minimal neutralisation rate of 0.02, i.e. only 2 per cent of the contrast is lost in unstressed position (p. 109).

As regards the non-front pairs, their degrees of neutralisation are the opposite to what is traditionally claimed. The neutralisation rates are 0.5 for /ə–a/ and 0.78 for /u–ɔ/. This claim should therefore be revised: the pair /u–ɔ/ is neutralised to a much higher degree than /ə–a/, not the other way around.

Some of the traditional sources also state that /i–ɛ/ may neutralise only in eastern dialects, which is very true of my East Bulgarian variety, where neutralisation rates are overall very high for all three pairs: /i–ɛ/ 0.95, /ə–a/ 0.99, /u–ɔ/ 0.7. It is also only in this variety, and none other, that we find more neutralisation in non-front unrounded than in rounded vowels (pp. 129, 208).

9.1.5.2 Midway neutralisation: open V̆s raise, while close V̆s lower

All open vowels in West and East Bulgarian have significantly higher F_1' frequencies in stressed than any of the unstressed syllables (pp. 95, 116). In Bilingual Bulgarian this is also generally the case, although there is one partial exception: unstressed /ɛ/ in final syllables has higher F_1' frequency than stressed /ɛ/ (p. 157). I can therefore confirm the first part of the claim, that open vowels are raised in unstressed syllables, which of course is to be expected.

It is the second part of the claim, that close vowels are lowered when unstressed, which is counterintuitive, as duration is significantly and consistently shorter in unstressed syllables according to the findings I have reported. Moreover, a number of recent studies have demonstrated close vowels not to be more open in unstressed syllables (Andreeva et al. 2013; Sabev 2015; Dokovova et al. 2019).

In the present investigation of West Bulgarian, there are significant stressed–unstressed differences in the F_1' frequency of close vowels in two or three out of nine cases (p. 95), in which the unstressed allophones actually have *lower* frequencies: [ə́] > [$ə_1$], [ə́] > [$ə_2$], and [ú] $\overset{?}{>}$ [u_2], though for the last comparison only the *t*-test, but not the ANOVA, is significant. Bulgarian /ə/ is of course a 'close' vowel only in terms of phonological contrast; phonetically, it is close-mid, and thus it has the 'headroom' to raise under temporal pressure, an amount of free space that the proper close vowels, [i] and [u], lack: they cannot be raised much further without causing friction.

Things are slightly more complicated in East Bulgarian (which falls outside the scope of descriptions of Standard Bulgarian anyway). There we find one significantly closer unstressed allophone: [í] > [i_2] in F_1' frequency. There are also one or two cases of higher F_1' frequencies in unstressed than in stressed syllables: [i_4] > [í], [$ə_4$] $\overset{?}{>}$ [ə́]. However, these involve word-final syllables that are more likely to be strengthened as a result of prosodic boundary effects rather than word-level accentuation, since vowels in other unstressed syllables are not significantly different from stressed vowels.

In Bilingual Bulgarian there are five stressed–unstressed pairs of close vowel allophones that show significant differences in F_1' frequency. Two have higher stressed frequencies: [ú] > [u_1], [ú] > [u_2]. Another two have higher frequencies in final than in stressed syllables, which can again be ascribed to boundary effects: [i_4] > [í], [$ə_4$] > [ə́]. The remaining one, [$ə_1$] > [ə́], is the only instance of an unstressed close vowel in a non-final syllable with a higher F_1' frequency than its stressed counterpart, a difference of 8 Hz (pp. 158, 161). This is both exceptional and very small in magnitude.

The findings summarised above provide resounding evidence that the second part of Claim (2), that Bulgarian unstressed closer vowels are lowered in unstressed position, should be rejected. Of course the trivial part of the claim, that unstressed open vowels raise, is perfectly valid.

9.1.5.3 Two distinct degrees of reduction: $\underset{2}{\breve{V}}\ \underset{1}{\breve{V}}\ \acute{V}\ \underset{2}{\breve{V}}$

In order to test the claim that first pretonic vowels reduce less than other unstressed vowels, the target items for the Bulgarian experiments were designed to be penultimately stressed four-syllable nonsense words. I shall discuss only open vowels, because there is none or very little variation in close vowels, as we saw above.

For all West Bulgarian open vowels, F_1' frequencies are significantly *lower* in immediately pretonic than in both word-initial and final syllables. This is also matched with parallel significant differences in duration, with the exception of West Bulgarian [ε_1] and [ε_2], whose durations are not significantly different. This is clear evidence that pretonic vowels actually reduce more, not less, than other unstressed vowels in this variety.

In East Bulgarian, vowels in pretonic and initial syllables are not significantly different in either F_1' frequency or duration. [a_2] $<$ [a_4] with respect to both parameters, and [a_1] $<$ [a_4] in duration only. Here as well, pretonic vowels do *not* reduce to a lesser degree, although evidence of the opposite is more patchy compared to West Bulgarian.

Bilingual Bulgarian is as consistent as West Bulgarian in having the greatest degree of reduction in pretonic vowels: second-syllable vowels have the lowest F_1' frequencies and shortest durations in all cases except that [$ɔ_2$] and [$ɔ_4$] have equal durations.

These findings have refuted a third received view—to the best of my knowledge for the first time—which is that Bulgarian unstressed vowels are less reduced in immediately pretonic than in other unstressed syllables. If anything, we find *more* spectral and durational reduction in that position, not less: open vowels have the shortest durations and lowest F_1' frequencies in immediately pretonic syllables. It is interesting to note that this traditional claim echoes the two-degree vowel reduction system standardly reported for Russian (Shvedova 1980; Timberlake 2004; Iosad 2012), where a penultimately stressed four-syllable word has a sonority-sequenced, single-peak prominence profile, x X X́ x. My sample of contemporary (and pan-dialectal, as it were) Bulgarian speech is at odds with this. I have in fact discovered a more punctuated, low-level 'trochaic' pattern: X x X́ X.

9.1.5.4 Neutralising and categorical reduction in East Bulgarian vs non-neutralising and gradient reduction in West Bulgarian

Unstressed Vowel Shift in East Bulgarian is indeed categorical: there are significant and large differences between stressed and unstressed open vowels in terms of F_1' frequency and duration; F_1' frequency and duration are not correlated; and the amount of F_1' frequency reduction in unstressed syllables exceeds the amount predicted for gradient undershoot.

My investigation of East Bulgarian has also consistently pointed to complete neutralisation: unstressed contrast scores are very low for all three pairs, neutralisation rates are very high, and there is no sensitivity to functional load. I can, to a large extent, agree with Barnes (2006) that East Bulgarian unstressed vowel reduction is both categorical and neutralising. However, I must once again emphasise that neutralisation may not be as complete as it appears, as I have have presented evidence of the fronting of unstressed /u/, but not /ɔ/.

West Bulgarian is less neutralising than East Bulgarian, but clearly not 'non-neutralising'. Unstressed /u–ɔ/ may be completely neutralised for most speakers (and in fact have a higher neutralisation rate than in East Bulgarian); unstressed /ə–a/ are partially but still substantially neutralised (and not perceptually distinguishable: Sabev 2015), while /i–ɛ/ are not neutralised at all. Consequently, I can only agree with the 'non-neutralising' generalisation if it is taken to mean 'not completely neutralising in all three pairs'.

Finally, we have seen that significant positive correlations of F_1' frequency and duration predominate in West Bulgarian, indicating that gradient undershoot does occur. This does not, however, rule out separate unstressed targets, which would be categorical by definition. My analysis has shown the Unstressed Shift of /ɔ/ to be consistently categorical, whereas for /ɛ/ and /a/ speakers vary.

9.2 Turkish

9.2.1 Vowel quality

The mean formant frequencies of stressed vowels in the Turkish varieties examined in Chapters 6 and 8 are plotted in Figure 9.11. The organisation of the $F_1' \times F_2'$ frequency space corroborates a phonological arrangement of the eight contrastive vowels into six symmetrical classes according to three features: `[round]`, `[back]` and a height feature such as `[open]`. Rounded vowels appear to the right of their unrounded counterparts, which is to be expected: lip rounding elongates the vocal tract, lowering its resonant frequencies, especially the second. There are only two *contrastive* heights, even though the vowels are distributed over a range of visually distinct degrees of openness along the F_1' frequency axis. In particular, the back half of the vowel space may appear to be divided into three heights—/ɯ, u/, /ɔ/ and /ɑ/—because /ɑ/ has a markedly higher F_1' frequency than /ɔ/. However, just as /ɔ/ is matched by only one closer back rounded vowel, /u/, there is only one back unrounded vowel that is closer than /ɑ/, viz. /ɯ/. Moreover, there are two types of suffix in Turkish: one which can have any of the close vowels, /i, y, ɯ, u/,

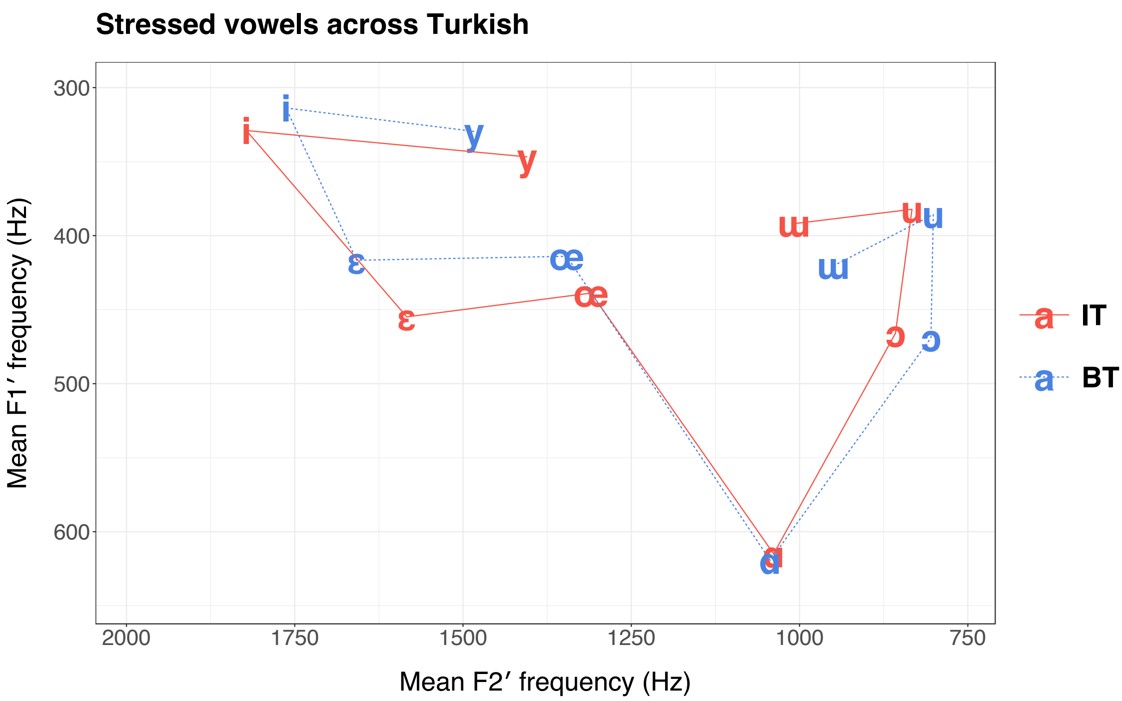


Figure 9.11: Stressed vowels in the $F_1' \times F_2'$ frequency space across Turkish varieties.

depending on the backness and rounding of the vowel in the preceding syllable, and a second type, which alternates /ɛ/ with /ɑ/ according to the backness of the preceding vowel. This pattern indicates that /ɛ, ɑ/ form a class that is defined by a shared feature specification which distinguishes it from the vowels occurring in the first type of suffix.

As should be expected, there are certain differences in vowel quality across the two geographically separated varieties. To assess the extent and nature of these differences, MANOVAs were computed for each vowel with dialect as independent variable and the two formant frequencies as dependent variables, followed by discriminant function analysis. The following observations can be made based on the mean formant frequencies in Figure 9.11, interpreted in the context of the MANOVA and DFA results summarised in Table 9.4. Front vowels generally have lower F_1' frequencies in Bilingual Turkish, where there is also a smaller F_2' frequency distance between /i/ and /y/; in addition, Bilingual Turkish /ɯ/ and /ɔ/ have somewhat lower F_2' frequencies. At the same time, the F_1' frequency of /ɯ/ is appreciably higher in Bilingual than in Istanbul Turkish, which is probably the effect of Bulgarian transfer in Bilingual Turkish, as there is little difference between Bilingual Turkish /ɯ/ and Bilingual Bulgarian /ə/ (§ 9.3).

	MANOVA		PDRC			MANOVA		PDRC	
	p	Λ	F_1'	F_2'		p	Λ	F_1'	F_2'
í	0.0004	0.08	0.68	0.32	**ɯ́**	0.0000	0.15	0.65	0.35
ɛ́	0.0000	0.19	0.79	0.21	**ɑ́**	0.9233			
ý	0.0000	0.13	0.38	0.62	**ú**	0.1668			
œ́	0.0000	0.13	0.80	0.20	**ɔ́**	0.0001	0.09	0.03	0.97

Table 9.4: MANOVA p-values, Pillai scores (Λ) and parallel discriminant ratio coefficients (PDRC) comparing Istanbul Turkish and Bilingual Turkish stressed vowels. **Grey values**: negligible PDRCs ($\theta = 0.25$).

In unstressed position, open vowels have lower F_1' frequencies than their stressed counterparts, resulting in a vertically contracted vowel space, as can be seen in Figure 9.12. Despite this natural consequence of Unstressed Vowel Shift, an appreciable F_1' frequency distance is maintained between close and open vowels even in unstressed position, except

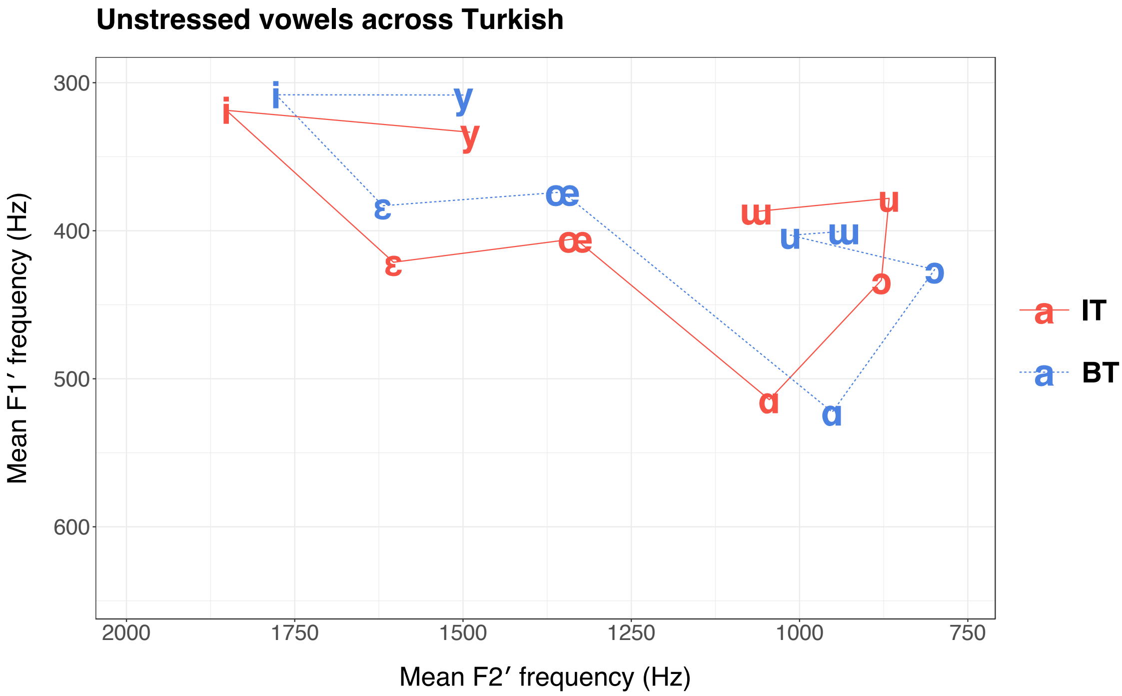


Figure 9.12: Unstressed vowels in the $F_1' \times F_2'$ frequency space across Turkish varieties.

for Bilingual Turkish /u–ɔ/. MANOVA and DFA results comparing the unstressed vowels of the two Turkish varieties are shown in Table 9.5. The differences noted for stressed vowels are present here as well, and there are also a couple of additional ones. Front vowels have lower F_1' frequencies in Bilingual Turkish, where there is also less distance in F_2' frequency between /i/ and /y/. Three of the back vowels, /ɯ, ɑ, ɔ/, have lower F_2' frequencies in Bilingual than in Istanbul Turkish. Bilingual Turkish unstressed /u/, on the other hand, has a conspicuously higher mean F_2' frequency than the unstressed close back rounded vowel in Istanbul Turkish. Bilingual Turkish unstressed /u/ in fact has a higher mean F_2' frequency

	MANOVA		PDRC			MANOVA		PDRC	
	p	Λ	F_1'	F_2'		p	Λ	F_1'	F_2'
ĭ	0.0000	0.07	0.38	0.62	ɯ̆	0.0000	0.17	0.16	0.84
ɛ̆	0.0000	0.22	1.01	-0.01	ɑ̆	0.0000	0.14	0.06	0.94
y̆	0.0000	0.10	1.00	0.00	ŭ	0.0000	0.09	0.38	0.62
œ̆	0.0000	0.25	0.96	0.04	ɔ̆	0.0000	0.14	0.02	0.98

Table 9.5: MANOVA p-values, Pillai scores (Λ) and parallel discriminant ratio coefficients (PDRC) comparing Istanbul Turkish and Bilingual Turkish unstressed vowels. **Grey values** negligible PDRCs ($\theta = 0.25$).

than Bilingual Turkish unstressed /ɯ/. Moreover, there is a greater distance in F_2' than in F_1' frequency between Bilingual Turkish unstressed /u/ and /ɔ/, which is reflected in the contrast metrics for the two: the primary discriminant is F_2' frequency ($w_{F_2'} = 0.75$), with a symmetric difference of $\Delta_{F_2'} = 0.52$ (p. 193). Unstressed /u/-fronting in the Bulgarian speech of the bilingual community was discussed in § 9.1.4 (p. 216). Here we see evidence that the process has been transferred into Bilingual Turkish. It should be noted that whereas fronted /u/ in Bulgarian does not encroach on the acoustic or auditory space of another vowel—there are no front rounded vowels in Bulgarian—the phonological consequences of /u/-fronting are rather different for Turkish. I come back to this issue later (§ 9.2.4).

9.2.2 Unstressed Vowel Shift

Open vowels undergo considerably greater Unstressed Vowel Shift than close vowels in Turkish as well (Figure 9.13). Bilingual Turkish has higher Pillai scores (Λ) and less difference among individual open vowels than Istanbul Turkish. Bilingual Turkish /ɑ/ is shifted the most but the remaining three vowels, /ɛ, œ, ɔ/, have similar scores. Istanbul Turkish open vowels, on the other hand, are more separated from one another in terms of Unstressed Vowel Shift scores: /ɑ/ > /œ/ > /ɔ/ > /ɛ/. Discriminant function analysis has revealed that duration is always the primary dimension distinguishing stressed and unstressed open vowels in both Istanbul (p. 146) and Bilingual Turkish (p. 186). While F_1' frequency plays a secondary role for Istanbul Turkish and Bilingual Turkish /ɛ, œ/, Istanbul Turkish /ɔ/, and virtually an equal role for Istanbul Turkish /ɑ/, its contribution to distinguishing stressed and unstressed Bilingual Turkish /ɑ/ and /ɔ/ is, somewhat

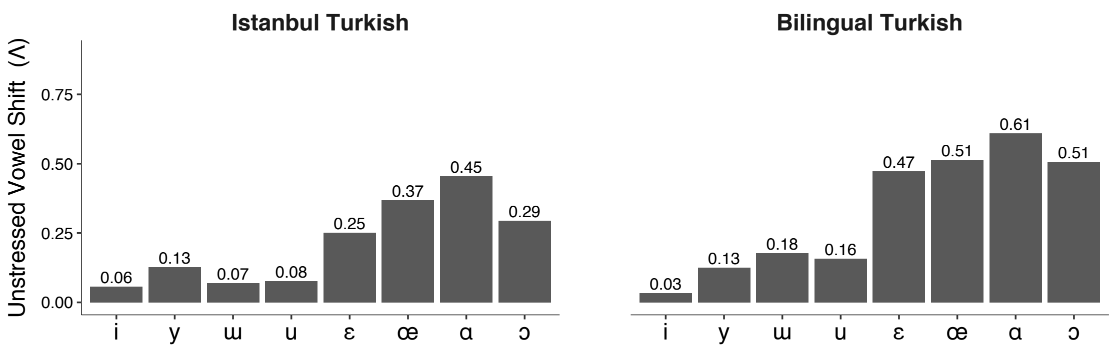


Figure 9.13: Unstressed Vowel Shift in Istanbul and Bilingual Turkish.

surprisingly, negligible ($w < \theta$), despite the sizeable symmetric differences ($\Delta_{F_1'} = 0.64$ for Bilingual Turkish /ɑ/ and 0.48 for Bilingual Turkish /ɔ/; pp. 148, 187). It can also be noted that Bilingual Turkish /ɯ/ and /u/ exhibit more Unstressed Shift than other close vowels in either variety. In the former case this is primarily attributable to durational reduction, and in the latter to /u/-fronting (i.e. a difference in F_2' frequency).

In Istanbul Turkish there are significant positive correlations of F_1' frequency and duration in all allophones of the open vowels, with one single exception: [œ$_1$]. In Bilingual Turkish, on the other hand, correlation is less general: it is lacking in stressed syllables for /ɛ/ and /œ/, as well as in [ɔ$_2$]. This indicates that gradient undershoot is the norm in Istanbul Turkish syllable-specific allophones, but less consistently so in the bilingual variety. As regards the observed mean unstressed $\bar{F}_1'$ frequencies of open vowels compared with the predicted frequencies that should result from undershoot according to Lindblom (1963) (§ 3.2.3.4, p. 92), there is less actual than predicted reduction in all vowels in Istanbul Turkish, as well as in the bilingual back vowels (Figure 9.14). In all these cases, then, Unstressed Vowel Shift can be explained by time-induced gradient undershoot. By contrast, Bilingual Turkish front vowels exhibit a greater drop in F_1' frequency than predicted for undershoot, which suggests that separate unstressed targets are likely to be in place for Bilingual Turkish /ɛ/ and /œ/.

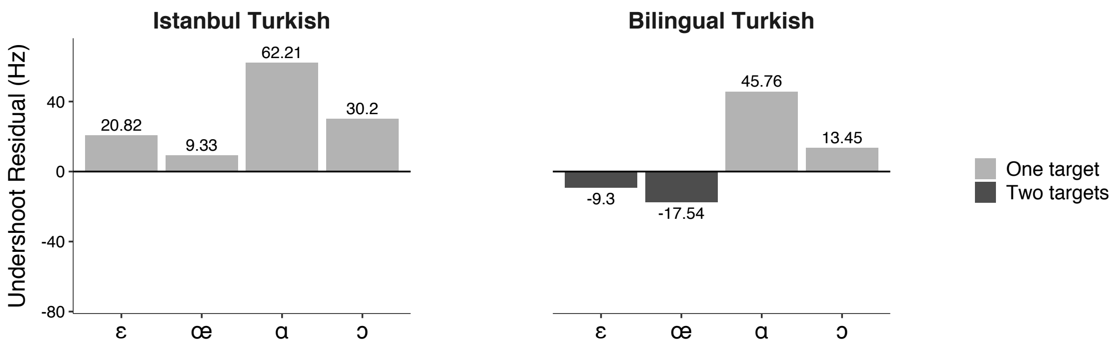


Figure 9.14: Differences (residual values) between observed mean unstressed $\bar{F}_1'$ and predicted unstressed $\hat{F}_1$ frequencies of open vowels in the Turkish varieties ($\bar{F}_1' - \hat{F}_1$).

One last point should be made about double targets. The fact that observed unstressed F_1' frequency reduction is within the range of predicted undershoot does not rule out the presence of a separate unstressed target. In other words, categorical Unstressed Vowel Shift may, logically, be masked by co-existing gradient undershoot. That is likely to be the case with Bilingual Turkish /ɔ/, for example, since as we shall see in § 9.2.3 below, there is a substantial degree of neutralisation of Bilingual Turkish unstressed /u–ɔ/, while at the same time there is less vertical space for back vowels to reduce in. If there are speakers who, in their production, distinguish /ɔ/ from /u/ in stressed but not in unstressed position, then stressed and unstressed /ɔ/ must implement different targets.

The observations above reveal a number of differences between the two Turkish varieties: Unstressed Vowel Shift is demonstrably gradient and not very strong in Istanbul Turkish, whereas in Bilingual Turkish it is evidently stronger and there are reasons to suspect that it is also categorical in the case of the front vowels and probably /ɔ/. The heightened Unstressed Vowel Shift in Bilingual Turkish is probably due to Bulgarian influence, and I come back to this question in § 9.3.2. Unstressed Vowel Shift scores for Bilingual Turkish open vowels are either comparable to, or come in between, those reported for West and East Bulgarian (p. 204). In addition, the Unstressed Shift of /ɛ/ is clearly categorical in East Bulgarian and variably so in West Bulgarian, which may have stimulated Bilingual Turkish to phonologise separate targets for unstressed /ɛ/ and, by analogy, /œ/.

9.2.3 Contrast and neutralisation

Height contrast levels in Turkish stressed vowels (Figure 9.15) are closely comparable to those in Bulgarian (Figure 9.7, p. 208). In both Istanbul and Bilingual Turkish, however, contrast scores remain generally high in unstressed position as well, unlike what is observed in the monolingual varieties of Bulgarian. As in Bulgarian, the back rounded pair, /u–ɔ/, has the lowest contrast score in both Turkish varieties. In Bilingual Turkish the score is particularly low in unstressed position ($\Lambda = 0.21$), which stands out against the backdrop of otherwise predominantly strong contrasts. Since contrast differences between stressed and unstressed pairs are generally small, neutralisation ratios (Figure 9.16) are correspondingly low, with the exception of Bilingual Turkish /u–ɔ/, where neutralisation is conspicuously

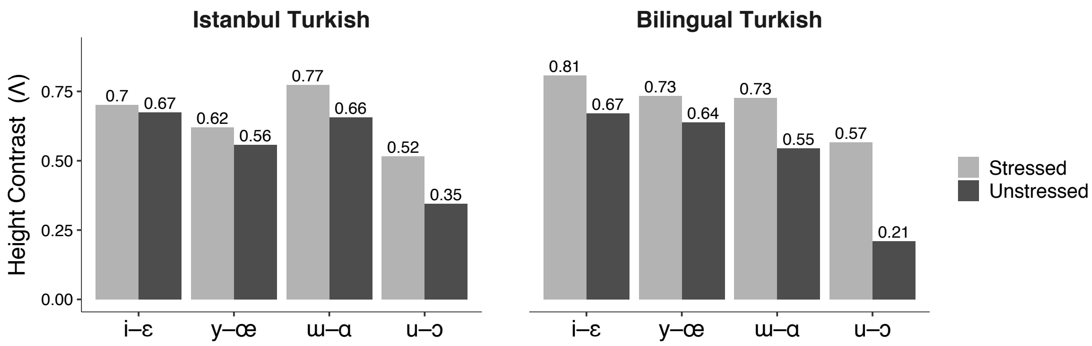


Figure 9.15: The height contrast in Istanbul and Bilingual Turkish.

high. As we saw in § 9.1.3 (p. 208), the Bilingual Bulgarian back rounded pair has very low contrast scores not only in unstressed, but also in stressed position, indicating that the neutralisation may be undergoing generalisation (by analogical levelling, as it were). In Bilingual Turkish, on the other hand, the /u–ɔ/ contrast score is low only in unstressed position, which results in a high neutralisation ratio. This may therefore seem like another transfer effect in which the source is ambient monolingual Bulgarian, since the Bilingual Turkish merger is stress-dependent and not generalised. However, in § 9.3.2 I propose an explanation from internal, L1–L2 transfer.

As we have seen, Bilingual Turkish Unstressed Vowel Shift scores are high: they are comparable to those in monolingual Bulgarian and considerably higher than in Istanbul Turkish. Nonetheless, Bilingual Turkish resists height neutralisation in unstressed position in all pairs apart from /u–ɔ/. This is an important observation as it provides clear proof that, while often linked, Unstressed Vowel Shift and contrast neutralisation are in

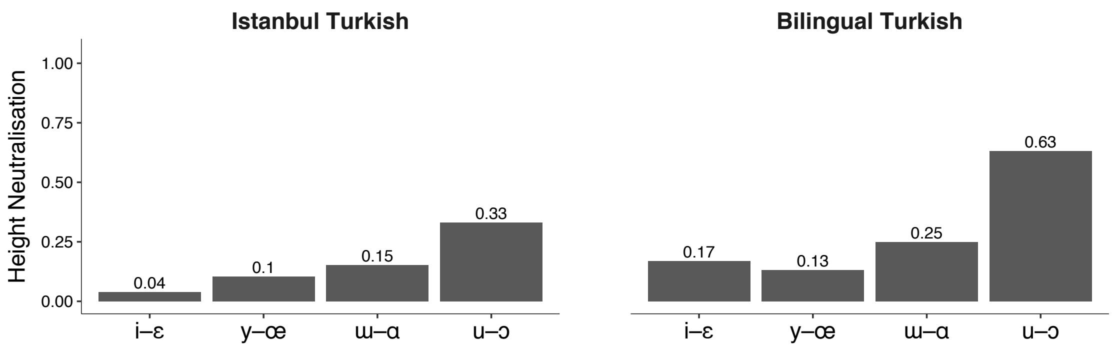


Figure 9.16: Height neutralisation in Istanbul and Bilingual Turkish.

fact separate phenomena: stronger Unstressed Vowel Shift does not necessarily lead to greater neutralisation.

Token frequencies of Turkish vowel phonemes and the functional load of phoneme pairs were calculated from a frequency dictionary of over 1.3 million word-forms (Bilgin 2016) compiled from the Boğaziçi University Corpus (Sak et al. 2008), which contains 491 million words of text sourced from Turkish language newspapers and general websites. Functional load was calculated relative to potential minimal pairs, i.e. with the same method as was used for Bulgarian above (§ 9.1.3.3, p. 212). Vowel letters were counted, ⟨i e ü ö ı a u o⟩ representing Turkish /i ɛ y œ ɯ ɑ u ɔ/, respectively. Figure 9.17 shows the token frequency of each vowel phoneme (as a percentage of all vowel tokens) and the relative functional load of each phoneme pair (as the thickness of black lines); coloured lines and dots indicate the distinctive feature(s) traditionally assumed to distinguish the phoneme pairs that cross them. The twenty-six vowel pairs are next ranked according to functional load in Figure 9.18; darker columns highlight pairs that are contrastive in terms of phonological height only.

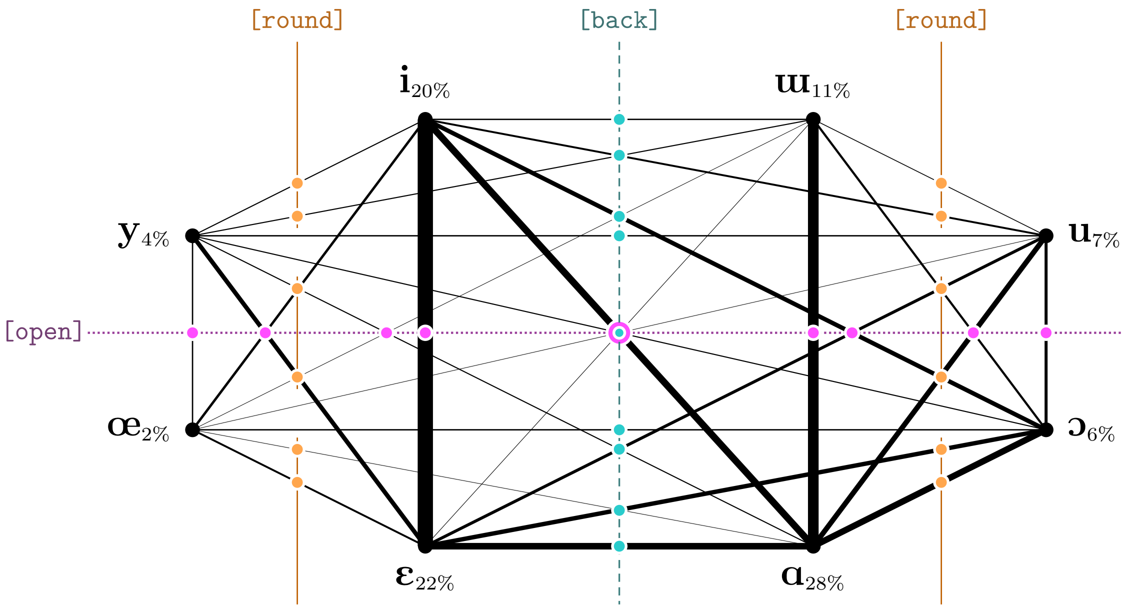


Figure 9.17: Functional load and phoneme frequencies in Turkish. Thickness of black lines: relative functional load; coloured lines: distinctive features in phoneme-pair lines that cross them.

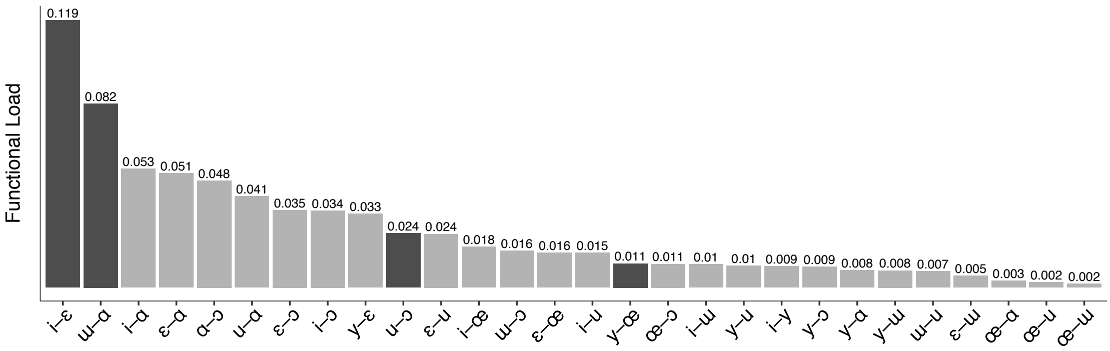


Figure 9.18: Turkish vowel pairs ranked by functional load (calculated as the number of minimal pairs relative to 'potential minimal pairs').

Overall, unrounded vowels are considerably more frequent than rounded vowels in Turkish. This is less pronounced only in the close back unrounded /ɯ/, which even though more frequent than any rounded vowel, is markedly less frequent than any of the other unrounded vowels. The unrounded height-contrasting pairs, /i–ɛ/ and /ɯ–ɑ/, have by far the highest functional load of all possible vowel pairings in Turkish. The stressed and unstressed contrast scores for those pairs, as we have seen, are correspondingly high (Figure 9.15), and their neutralisation ratios are therefore low (Figure 9.16). The rounded heigh-contrasting pairs, /y–œ/ and /u–ɔ/, have much lower functional load but this is not matched by symmetrical contrast and neutralisation profiles. The back rounded vowels are the least contrastive in general and show the greatest degree of overlap in unstressed position—quite possibly to a perceptually neutralising extent in Bilingual Turkish. The front rounded vowels, on the other hand, remain highly contrastive in stressed and unstressed syllables alike, despite the fact that the Unstressed Vowel Shift score for /œ/ is higher than (Istanbul Turkish), or equal to (Bilingual Turkish), that for /ɔ/. This difference in systemic behaviour between front and back rounded pairs may partly arise from the greater amount of vertical space available for front vowels, as well as the fact that the F_2' frequency discriminant for /y–œ/ has greater weight (w) and symmetric difference (Δ) in unstressed than in stressed position (pp. 153, 193), meaning that the diminished difference in F_1' frequency there may be offset by increased distinctness in the second formant frequency.

9.2.4 /u/-fronting

As we saw in § 9.1.4 above (p. 216), in Bulgarian, fronted /u/ realisations (defined as F_2' frequency $\geq$ 1 000 Hz) make up about a third of the /u/ tokens, in both stressed and unstressed syllables in the monolingual varieties, but only in unstressed position in Bilingual Bulgarian. In all three varieties, the fronted realisations come from approximately a third of all speakers, who are predominantly male and the majority of whose /u/ tokens are fronted.

The probability density estimates of Bilingual Turkish /u/ provide a clear indication of fronting in unstressed position (p. 188), and the F_2' frequency of 33 per cent of Bilingual Turkish /u/ tokens is indeed higher than 1 000 Hz.[11] While this proportion is comparable to the rates reported for Bulgarian (Table 9.2, p. 217), Bilingual Turkish /u/-fronting is much more widely and sparsely distributed across speakers: 66 per cent of fronted /u/ instances come from 8 (out of 14, or 57%) speakers (3 female, 5 male), whose fronted /u/ tokens range from 42 to 50 per cent of their total /u/ tokens. All five Bilingual Bulgarian /u/-fronters are also among the eight Bilingual Turkish fronters, and there is another three (2 female, 1 male) who front in Turkish but not in Bulgarian. This draws a picture that is both intriguing and complicated. In contrast to Bulgarian, Bilingual Turkish /u/-fronting it is not attributable to a clearly identifiable minority whose /u/ realisations are predominantly fronted: Bilingual Turkish /u/-fronting is found in more speakers but on the individual level it is less frequent.

The lower individual rate of occurrence, which happens to be consistent across all Bilingual Turkish fronters, requires an explanation. The systemic implications of /u/-fronting are very different for the two languages. Bulgarian does not have contrastive front rounded vowels, while Turkish does, so internal factors are very likely to be involved. While /u/-fronting puts no contrast at risk in Bulgarian, in Turkish it could easily compromise the front–back contrast, and the speakers' linguistic awareness of that contrast may give rise to resistance to change that would result in merger. Even though such resistance appears to be in place on the individual level, as can be inferred from the lower incidence of

[11] By contrast, only two per cent of the *stressed* tokens of Bilingual Turkish /u/ exceed 1 000 Hz of F_2' frequency.

fronting within individual speakers, the number of speakers who exhibit moderate fronting is greater than in any Bulgarian dialect, which results in a dialect-wide rate of fronting that is statistically comparable to that of Bulgarian: a third of all attested tokens of /u/ are fronted. Bilingual Turkish fronting must be at least partly induced by ambient Bulgarian, for more bilingual speakers front in Turkish than in Bulgarian, albeit less consistently.

A sufficient extent of /u/-fronting should, logically, result in a merger with the corresponding *close* front rounded vowel, /y/, as predicted by traditional feature theories illustrated in Rule (9.1).

$$\begin{bmatrix} \texttt{+syllabic} \\ \texttt{+high} \\ \texttt{+}\mathit{back} \\ \texttt{+round} \end{bmatrix} \rightarrow [\texttt{-}\mathit{back}] \quad = \quad \begin{bmatrix} \texttt{+syllabic} \\ \texttt{+high} \\ \texttt{-}\mathit{back} \\ \texttt{+round} \end{bmatrix} \tag{9.1}$$

However, this is not what happens: fronted Bilingual Turkish /u/ merges (partially) not with Bilingual Turkish /y/, but with Bilingual Turkish /œ/ instead. This is evident from the probability density estimates of Bilingual Turkish rounded vowels in Figure 8.5 (p. 188), which are reproduced in Figure 9.19. For that reason, MANOVAs comparing /u/ and /œ/ were included in the analysis of Bilingual Turkish (Table 8.9, p. 190). While the two vowels are highly contrastive in stressed position, $\acute{\Lambda} = 0.81$, the contrast score is substantially reduced in unstressed syllables, $\breve{\Lambda} = 0.41$, giving rise to an appreciably high neutralisation ratio, $(\acute{\Lambda} - \breve{\Lambda})/\acute{\Lambda} = 0.49$. By way of comparison, the contrast scores for stressed and unstressed /u–y/ are both high: $\acute{\Lambda} = 0.86$ and $\breve{\Lambda} = 0.70$, respectively, yielding a low neutralisation ratio of 0.19.

The contrast scores for Bilingual Turkish unstressed /u–œ/ of three of the speakers are particularly low ($\Lambda < 0.30$), for two of whom individual MANOVAs are in fact non-significant ($p > 0.05$). This means that there is an identifiable minority of Bilingual Turkish speakers whose /u–œ/ neutralisation is rather advanced. If Rule (9.1) above is to be consistent with reality, then, its structural change has to be '$\rightarrow \begin{bmatrix} \texttt{-back} \\ \texttt{-high} \end{bmatrix}$'. In other words, not only the backness, but also the height specification of the input must change. The probability density estimate of unstressed Bilingual Turkish /u/ supports this (Figure 9.19): fronted realisations tend to also be more open. To verify this lowering

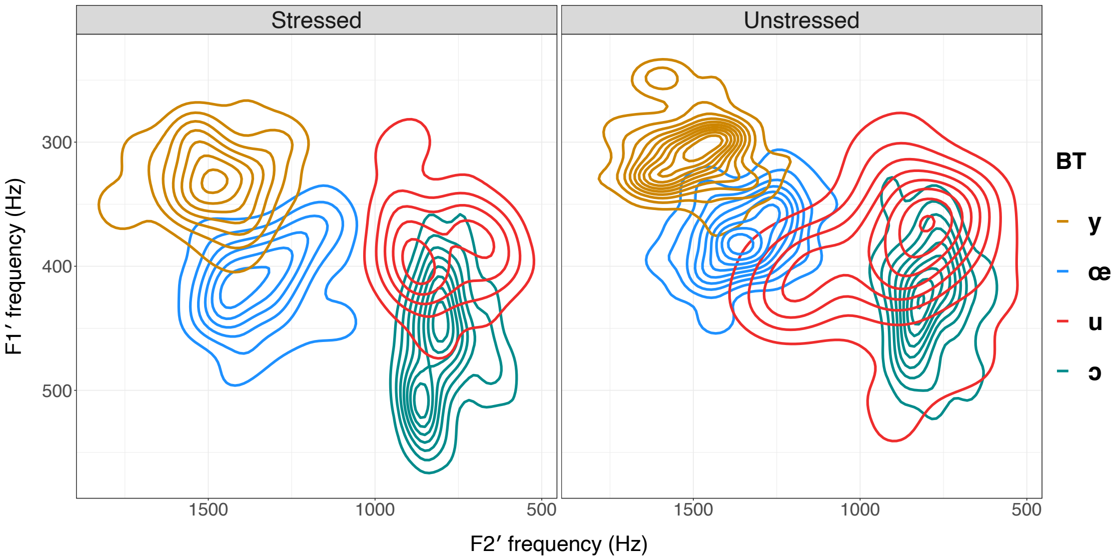


Figure 9.19: Unstressed /u/-fronting in Bilingual Turkish (PDEs).

hypothesis, I calculated Pearson's correlation between the F_1' and F_2' frequencies of Bilingual Turkish unstressed /u/ and found that there is indeed a highly significant ($p < 0.0001$) positive correlation ($r = 0.35$) between the two formant frequencies. The correlation coefficient rises to $r = 0.49$ when only fronted tokens ($F_2' \geq 1\,000\,\text{Hz}$) are considered. It is difficult to speculate why /u/-fronting should be accompanied by lowering; I return to this issue and assess it from a wider cross-varietal perspective in § 9.3.3.

9.2.5 Assessment of earlier views

In this final section on Turkish stressed and unstressed vowels, I assess, against my findings, three views about positionally conditioned vowel duration and quality that have previously been expressed.

First, Konrot (1981) and Levi (2005) investigate the importance of vowel duration, amplitude/intensity and fundamental frequency as acoustic correlates of word stress in Turkish, and both conclude that duration does not contribute to a stressed–unstressed distinction to any significant or non-negligible extent. In addition, Konrot (but not Levi) also examines formant frequencies, and does not find significant differences between stressed and unstressed vowels in terms of 'formant structure', which he defines and reports as $F_2 - F_1$ differences in hertz.

Secondly, it has been claimed that Turkish word-initial syllables manifest a certain prominence or ‘phonological strength’. Barnes (2006: 184ff) writes that ‘Turkish shows clear strengthening of domain-initial consonants’ and further reports results from a production experiment showing that ‘mean durations of initial-syllable vowels are significantly longer than those of the vowels of second syllables’. He then speculates that ‘in Turkish stress is not even weakly correlated with vowel duration (Konrot 1981), leaving that phonetic resource available for use in signaling word boundaries’.

Finally, Barnes (2006) also repeatedly asserts that languages with vowel harmony are generally resistant to unstressed vowel reduction. His argument for this claim is that vowel harmony and (neutralising) vowel reduction eliminate different contrasts. Turkish vowels occurring in non-initial syllables may realise any combination of distinctive features (except that `[+round]` and `[-high]` are incompatible, thus disallowing /œ/ and /ɔ/). Backness and rounding, however, are determined by the vowel in the preceding syllable, making it impossible for these features to be contrastive in non-initial syllables. Vowel height, therefore, is the only feature that is truly contrastive in all syllables. Neutralising vowel reduction, on the other hand, eliminates distinctive height while normally keeping backness and rounding contrastive. One of the aims of this study has been to assess whether there are grounds to believe that vowel harmony and vowel reduction are indeed incompatible.

9.2.5.1 ‘Duration and F_1' frequency are not correlates of stress’

Spectral and durational differences between stressed and unstressed vowels, referred to as Unstressed Vowel Shift here, were measured by the Pillai score output of MANOVAs calculated for the effect of stress on a combination of three response variables: duration, F_1' frequency and F_2' frequency. The tests were significant for all vowels in both varieties, meaning that stress does have a significant effect on the durational and/or spectral properties of Turkish vowels, which is clearly at odds with the earlier observations reported by Konrot (1981) and Levi (2005). The stress effects I have found are considerably stronger in open than in close vowels, which is to be expected. In Istanbul Turkish, the mean Unstressed Vowel Shift scores are $\bar{\Lambda} = 0.34$ for open and $\bar{\Lambda} = 0.08$ for close vowels. As we saw earlier, Unstressed Vowel Shift is stronger in Bilingual Turkish, where the mean Pillai scores are $\bar{\Lambda} = 0.53$ for open and $\bar{\Lambda} = 0.12$ for close vowels.

Discriminant function analysis was used to ascertain the relative weight of the three MANOVA response variables in distinguishing between stressed and unstressed vowels. Overall, duration serves as a primary discriminant and F_1' frequency often plays a secondary role. The mean discriminant weights of the three acoustic parameters are summarised in Table 9.6, alongside the corresponding mean Unstressed Vowel Shift scores ($\bar{\Lambda}$).

	Istanbul Turkish				Bilingual Turkish			
	$\bar{\Lambda}_{(\acute{v},\breve{v})}$	Dur.	F_1'	F_2'	$\bar{\Lambda}_{(\acute{v},\breve{v})}$	Dur.	F_1'	F_2'
Open vowels	0.34	0.66	0.33	0.01	0.53	0.80	0.20	0.00
Close vowels	0.08	0.63	0.07	0.30	0.12	0.54	0.29	0.17

Table 9.6: Mean Pillai scores and parallel discriminant ratio coefficients for duration, F_1' and F_2' frequencies in Turkish Unstressed Vowel Shift.

The significant differences between stressed and unstressed Turkish vowels as identified by MANOVAs are additionally supported by *t*-tests that were used to break down the significant main effects of syllable on each acoustic parameter (obtained in ANOVAs). In both varieties, stressed vowels have significantly longer durations, while stressed open vowels also have significantly higher F_1' frequencies, than unstressed vowels in both initial and second syllables (§ 6.1.1, p. 136, and § 8.1.1, p. 176).

Even though other acoustic correlates of stress than the ones studied here, such as f_0 and intensity, may have greater perceptual salience and discriminant power in distinguishing stressed from unstressed vowels in Turkish, as argued by Konrot (1981) and Levi (2005), the results I have reported show beyond any doubt that open vowels undergo a significant degree of durational and spectral reduction in unstressed position.

9.2.5.2 'Initial syllables are stronger and therefore longer'

In each experimental chapter, the assessment of stress effects is preceded by an analysis of vowels in individual syllables. For Turkish the predictor is a categorical variable consisting of three groups—$\sigma_1, \sigma_2, \acute{\sigma}_3$—which allows vowels in initial unstressed syllables to be compared with other unstressed vowels.

The results reported in Chapters 6 and 8 contradict Barnes's (2006) claim that vowels are longer in initial than in second unstressed syllables. The duration of open vowels has been found to be the same in the two unstressed syllables. This also holds true of Bilingual Bulgarian close vowels, whereas in Istanbul Turkish close vowels in initial syllables are in fact significantly shorter than unstressed vowels in second syllables.

An important observation to be made in this context is that, although open vowels in initial and second syllables do not differ in duration, F_1' frequency is significantly higher in initial syllables. This puts the question whether initial syllables are somehow stronger than other unstressed syllables into another, perhaps more interesting, perspective. Turkish initial-syllable vowels can be thought of as linguistically 'important' in the sense that they determine the backness and (sometimes) rounding features for the rest of the word in the process of vowel harmony. It may therefore be in some way 'desirable' for realisations of first-syllable vowels to be fairly close to their targets with respect to all distinctive features, including height. In Keating's (1996) framework, this would mean that Turkish initial-syllable vowels have narrow target windows. Other unstressed vowels may have wider target windows and therefore be more susceptible to undershoot.

The differences in F_1' frequency reported here may potentially be interpreted as lending even greater support to the strong-σ_1 hypothesis than the earlier argument based on longer duration, which I have not been able to confirm. Despite open vowels in initial syllables being as short as other unstressed vowels, they appear to be more resistant to spectral reduction, since they have significantly higher F_1' frequencies.

9.2.5.3 'Vowel Reduction and Vowel Harmony cannot coexist'

As we have seen, Turkish vowels exhibit an undeniable degree of Unstressed Vowel Shift. F_1' frequency reduction is less pronounced than durational reduction, but is nevertheless present. Barnes's (2006) claim that vowel reduction is incompatible with vowel harmony concerns categorical and neutralising vowel reduction; he does not deny that gradient F_1' frequency undershoot may exist in any language. I have demonstrated that Unstressed Vowel Shift in Istanbul Turkish is indeed gradient and that it does not result in considerable open–close vowel neutralisation.

Bilingual Turkish Unstressed Vowel Shift is different in several important ways. First, it is measurably stronger than in Istanbul Turkish: Pillai scores are appreciably higher. Secondly, as we saw in § 9.2.2 (p. 227), there are various reasons to suspects that Bilingual Turkish /ɛ, œ/ and /ɔ/ may have separate stressed and unstressed targets, at least for some of the speakers. Lastly and most importantly, the data and analyses presented here have revealed strong neutralisation in Bilingual Turkish unstressed /u–ɔ/. The rate of contrast loss in Bilingual Turkish /u–ɔ/ approaches that found in East Bulgarian and is very likely to be perceptually neutralising.

Bilingual Turkish, therefore, is a language in which vowel harmony and neutralising vowel reduction coexist, and this finding is not undermined by the fact that neutralisation occurs only in the pair /u–ɔ/, but not in /i–ɛ/, /y–œ/ or /ɯ–ɑ/. If there is anything that this apparent asymmetry calls into question, it is the assumption that all open and corresponding close vowels are distinguished by the same cognitive contrast. A single height feature would traditionally be axiomatically assumed for a two-height inventory, such that would predict a logical proportional relation like (9.2).

$$i : \varepsilon \;=\; y : œ \;=\; ɯ : ɑ \;=\; u : ɔ \qquad (9.2)$$

However, in Bilingual Turkish considerable neutralisation occurs only in one of the four pairs, which is difficult to reconcile with the idea that a single universal feature underpins the contrast in all pairs. The data are more amenable to an emergentist explanation: Bilingual Turkish /ɔ/ is distinct from Bilingual Turkish /u/ but the distinction is largely lost in unstressed position. The same is not true of the distinctions in the remaining three pairs, which suggests that the /u–ɔ/ distinction has not been interpreted as sufficiently similar to the properties that distinguish the vowels in the other pairs. In other words, a distinctive feature that would render (9.2) true has not emerged. I return to emergent features in § 10.3.

The high degree of neutralisation found in Bilingual Turkish unstressed /u–ɔ/ is more than likely to be the result of transfer from the bilingual speakers' ambient or own Bulgarian. That the neutralisation is induced by contact, however, in no way diminishes the fact that there is a phonology in which neutralising vowel reduction coexists with vowel harmony. It only further validates Thomason and Kaufman's (1988) widely corroborated observation:

> From Meillet, Sapir, and the Prague linguists to Weinreich to the most modern generativists, the heirs of Saussure have proposed linguistic constraints on linguistic interference. These constraints are all based ultimately on the premise that the structure of a language determines what can happen to it as a result of outside influence. And they all fail. As far as the strictly linguistic possibilities go, *any linguistic feature can be transferred from any language to any other language*; and implicational universals that depend solely on linguistic properties are similarly invalid.
>
> (Thomason and Kaufman 1988: 13–14; emphasis added)

9.3 The bilingual varieties

In the preceding sections of this chapter I considered the bilingual varieties of Bulgarian and Turkish in the context of the other dialects of the same languages. I now turn to comparing them with each other and, where relevant, also with the monolingual dialects, in order to assess the presence, direction and sources of transfer.

9.3.1 Vowel quality and duration

9.3.1.1 Stressed vowels

The mean F_1' and F_2' frequencies of Bilingual Bulgarian and Bilingual Turkish stressed vowels are plotted in Figure 9.20. Since the same speakers provided the data for both varieties, unnormalised vowel duration, which I have so far considered only in intra-varietal analyses, can be useful for this particular cross-varietal comparison. Mean vowel durations in milliseconds are therefore also indicated in Figure 9.20. Table 9.7 summarises *p*-values, Pillai scores and parallel discriminant ratio coefficients obtained from MANOVAs and DFAs comparing Bilingual Bulgarian stressed /i ɛ ə a u ɔ/ with Bilingual Turkish stressed

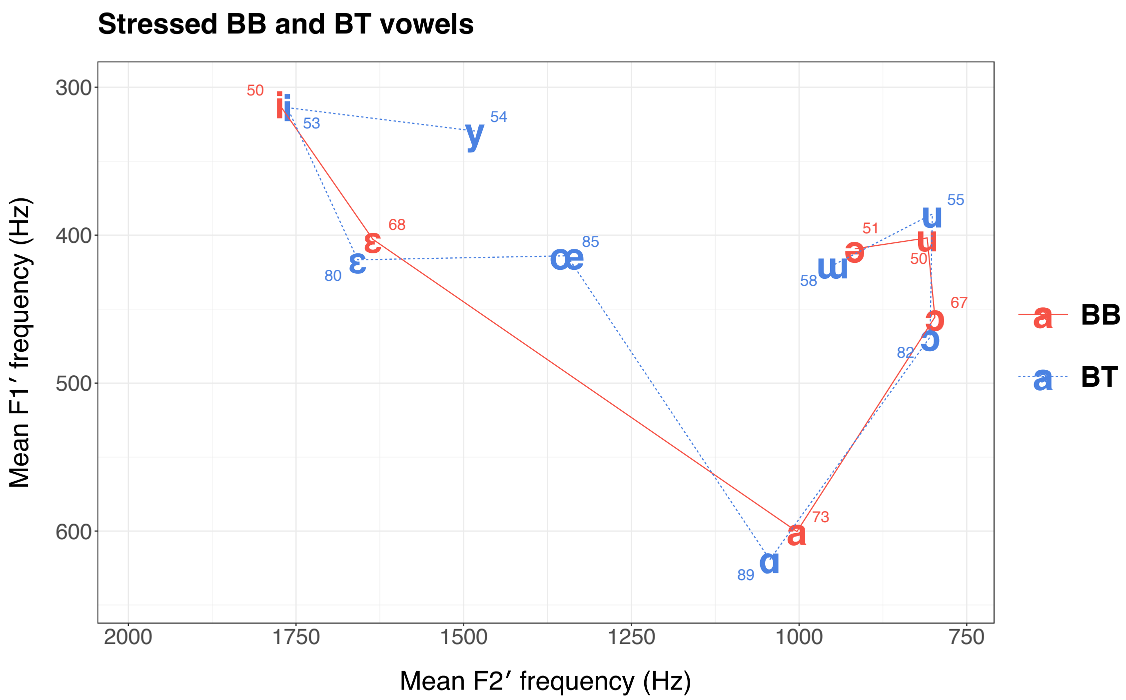


Figure 9.20: Bilingual Bulgarian and Bilingual Turkish stressed vowels in the $F_1' \times F_2'$ frequency space. Numbers: mean durations (ms).

	2D				3D				
	MANOVA		PDRC		MANOVA		PDRC		
BB–BT	p	Λ	F_1'	F_2'	p	Λ	Dur.	F_1'	F_2'
í–í	0.7291				0.2320				
έ–έ	0.0009	0.05	0.87	0.13	0.0000	0.18	0.83	0.19	-0.02
ə́–ɯ́	0.0039	0.04	0.44	0.56	0.0001	0.08	0.63	0.23	0.14
á–ɑ́	0.0418	0.03	0.07	0.93	0.0000	0.17	0.98	0.00	0.02
ú–ú	0.0791				0.0067	0.05	0.59	0.38	0.03
ɔ́–ɔ́	0.1555				0.0000	0.18	0.93	0.08	0.00

Table 9.7: MANOVA (p, Λ) and DFA (PDRC) results comparing Bilingual Bulgarian (BB) and Bilingual Turkish (BT) stressed vowels. **2D** formant frequencies only; **3D** formant frequencies and duration. **Grey values** negligible PDRCs (PDRC $< \theta$; $\theta_{2D} = 0.25$; $\theta_{3D} = 0.1\dot{6}$).

/i ɛ ɯ ɑ u ɔ/, respectively. Two sets of MANOVAs and DFAs have been computed: the first, '2D', is based on the first two formant frequencies only (as in the Bulgarian and Turkish sections of this chapter); the second, '3D', includes duration as well, since it is a valid acoustic parameter to be considered in this cross-varietal comparison.

Corresponding Bilingual Turkish and Bulgarian vowels appear very close to each other in the $F_1' \times F_2'$ frequency space, which indicates that there is little qualitative difference between the vowels of the two varieties. This is confirmed by the 2D MANOVA results: there are no significant differences between Bilingual Bulgarian and Bilingual Turkish stressed /i, u, ɔ/, while the differences in the remaining matching pairs, Bilingual Bulgarian vs Bilingual Turkish stressed /ɛ, ə–ɯ, a–ɑ/, are very small ($\Lambda = 0.05, 0.04, 0.03$, respectively). This means that, in all likelihood, the bilingual speakers have the same targets for these six stressed vowels in both languages.

We have seen that qualitative differences between Bilingual and East Bulgarian stressed vowels are also very small: three out of six are significant, but their Pillai scores do not exceed $\Lambda = 0.06$ (Figure 9.2, p. 200). The comparison of Bilingual and Istanbul Turkish vowels, on the other hand, revealed appreciably greater differences: six out of eight MANOVAs were significant, with Pillai scores ranging from 0.08 to 0.19 (Table 9.4, p. 225). As we saw in Chapter 2 (§ 2.3, p. 65), although Turkish was once the dominant language for this bilingual community, it has now been overtaken, to some extent, by Bulgarian. In terms of stressed vowel quality, Bilingual Bulgarian is now practically the same as East Bulgarian, while Bilingual Turkish is practically the same as Bilingual Bulgarian. This suggests that the bilinguals' stressed vowel quality in Turkish is strongly influenced by Bulgarian, which could be either the bilinguals' own Bulgarian or the ambient East Bulgarian they are exposed to on a daily basis. Since East and Bilingual Bulgarian are very similar in stressed vowel quality, and since there is nothing in the results reported so far that could tip the scales towards either of the two as a more probable source of transfer, I also performed a multivariate comparison of the F_1' and F_2' frequencies of East Bulgarian stressed vowels with the corresponding six vowels in Bilingual Turkish. The MANOVAs yielded highly revealing results, which are presented in Table 9.8. While differences in stressed vowel quality between East and Bilingual Bulgarian, as well as between Bilingual Bulgarian and Bilingual Turkish, are extremely small, they are by and large non-existent between East Bulgarian and Bilingual Turkish. Five of the six MANOVAs are non-significant. The only significant test is for /u/, with a Pillai score of $\Lambda = 0.08$ and roughly equal weights of the two discriminants. It is therefore reasonable to conclude that the stressed vowel targets of both Bilingual Bulgarian and Bilingual Turkish have been transferred from ambient East Bulgarian, and that the cross-linguistic transfer (East Bulgarian to Bilingual Turkish) has resulted in perfect replication,[12] while the cross-dialectal (but intra-linguistic) transfer has lead to very close approximation, though not exact replication. The significant difference between East Bulgarian and Bilingual Turkish stressed /u/ is exceptional and must be

	MANOVA		PDRC	
East B. – Bilingual T.	p	Λ	F_1'	F_2'
í–í	0.9361			
έ–έ	0.8463			
ə́–ɯ́	0.1338			
á–ɑ́	0.4108			
ú–ú	0.0047	0.08	0.47	0.53
ɔ́–ɔ́	0.0918			

Table 9.8: MANOVA (p, Λ) and DFA (PDRC) results comparing East Bulgarian and Bilingual Turkish stressed vowels.

[12] Naturally, this excludes the Bilingual Turkish front rounded vowels, /y/ and /œ/, as they have no systemic analogues in Bulgarian.

linked to the fronting and lowering of stressed /u/ by a substantial minority of East Bulgarian speakers. A similar process is not attested in Bilingual Turkish stressed /u/, although it is in the unstressed allophone (see § 9.1.4, p. 216; § 9.2.4, p. 233; § 9.3.3, p. 249). That this underpins the single significant difference is evident from the East Bulgarian and Bilingual Turkish mean formant frequencies for stressed /u/: East Bulgarian $\bar{F}_1' = 406\,\text{Hz}$, $\bar{F}_2' = 910\,\text{Hz}$ (p. 116); Bilingual Turkish $\bar{F}_1' = 386\,\text{Hz}$, $\bar{F}_2' = 801\,\text{Hz}$ (p. 176).

By contrast to vowel quality, duration differs considerably across the two bilingual varieties: Bilingual Turkish stressed vowels are substantially longer than their counterparts in Bilingual Bulgarian. This is particularly pronounced in the open vowels, /ɛ, a–ɑ, ɔ/, for which the 3D Pillai scores rise to $\Lambda = 0.18, 0.17, 0.18$, respectively, with duration contributing between 83 and 98 per cent of the overall difference. Although I have not undertaken formal cross-varietal comparisons of vowel duration (apart from the present one of Bilingual Turkish and Bilingual Bulgarian), a casual look at the mean stressed durations of open vowels in Bilingual and East Bulgarian (pp. 116, 157), on the one hand, and Bilingual and Istanbul Turkish (pp. 136, 176), on the other, suggests that there are only modest differences across the dialects of each language, and that the Turkish varieties have appreciably longer open vowels than both Bilingual and East Bulgarian. Thus, while it is highly probable that Bilingual Turkish vowel qualities have been transferred from East Bulgarian, there is no parallel interference with regard to stressed vowel duration.

9.3.1.2 Unstressed vowels

The mean formant frequencies and durations of Bilingual Bulgarian and Bilingual Turkish unstressed vowels can be seen in Figure 9.21. Table 9.9 summarises the outcomes of 2D (F_1' and F_2' frequencies only) and 3D (formant frequencies and duration) MANOVAs and DFAs. The differences between the two bilingual varieties are once again very small, but by contrast with the stressed vowels, Bilingual Bulgarian and Bilingual Turkish unstressed vowels are very much alike not only in terms of formant frequencies, but also in terms of duration. 2D and 3D Pillai scores do not exceed $\Lambda = 0.5$. With such low overall differences, the weight distribution between individual discriminants is practically immaterial: for example, 65 per cent of the 5% 3D-difference between Bilingual Bulgarian [ə̆] and Bilingual

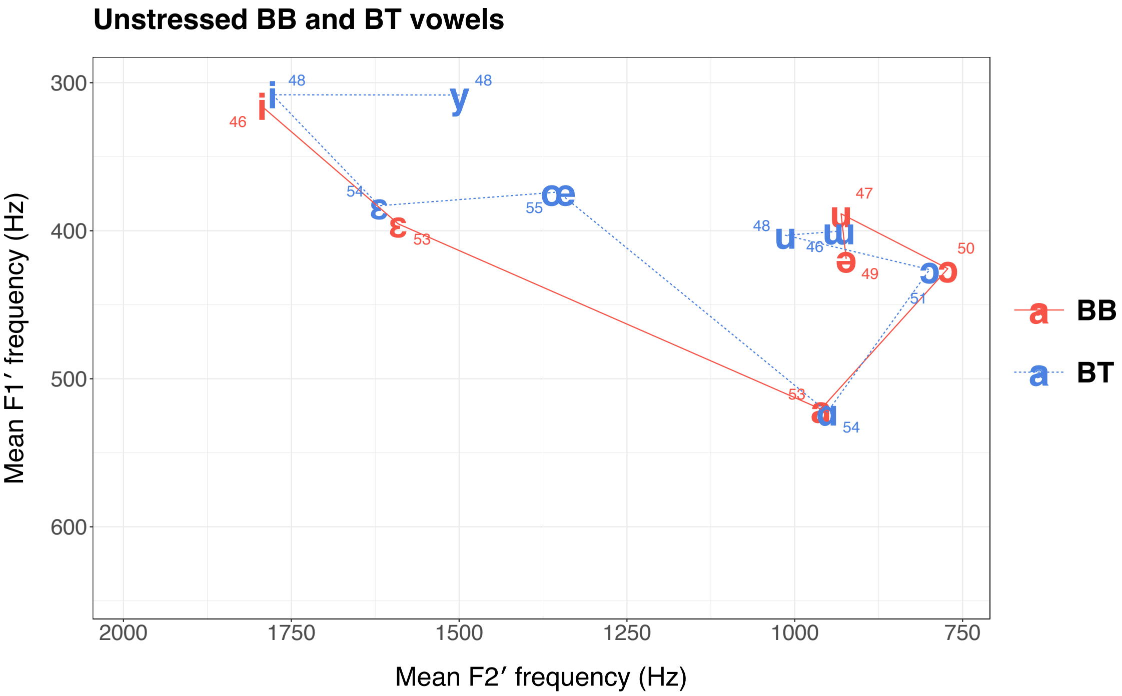


Figure 9.21: Bilingual Bulgarian and Bilingual Turkish unstressed vowels in the $F_1' \times F_2'$ frequency space. Numbers: mean durations (ms).

Turkish [ɯ̆] is attributable to F_1' frequency, which means that, arithmetically, the two vowels differ in F_1' frequency by a mere $5\% \times 0.65 =$ **3.25%**.

The analysis of Bilingual and Istanbul Turkish vowels performed earlier (§ 9.2.1, p. 224) detected considerable differences both in stressed and—more markedly—in unstressed

	2D				**3D**				
	MANOVA		PDRC		MANOVA		PDRC		
BB–BT	p	Λ	F_1'	F_2'	p	Λ	Dur.	F_1'	F_2'
ĭ–ĭ	0.0012	0.02	0.89	0.11	0.0001	0.03	0.30	0.58	0.12
ɛ̆–ɛ̆	0.0002	0.02	0.84	0.16	0.0001	0.03	0.14	0.78	0.08
ə̆–ɯ̆	0.0000	0.04	0.96	0.04	0.0000	0.05	0.29	0.65	0.05
ă–ɑ̆	0.3620				0.5230				
ŭ–ŭ	0.0021	0.02	0.36	0.64	0.0052	0.02	0.03	0.35	0.62
ɔ̆–ɔ̆	0.0019	0.02	0.01	0.99	0.0045	0.02	0.05	0.00	0.94

Table 9.9: MANOVA (p, Λ) and DFA (PDRC) results comparing Bilingual Bulgarian (BB) and Bilingual Turkish (BT) unstressed vowels. **2D** formant frequencies only; **3D** formant frequencies and duration. **Grey values** negligible PDRCs (PDRC $< \theta$; $\theta_{2D} = 0.25$; $\theta_{3D} = 0.1\dot{6}$). **BB** Bilingual Bulgarian, **BT** Bilingual Turkish.

syllables. Bilingual Turkish unstressed front vowels are closer, while Bilingual Turkish unstressed back vowel are more retracted, with the exception of Bilingual Turkish [ŭ], which is more advanced than its Istanbul Turkish counterpart. Bilingual and East Bulgarian vowels, on the other hand, compare differently in stressed and unstressed position: while stressed vowels show a high degree of similarity across the two varieties, unstressed open vowels are clearly distinct (§ 9.1.1.2, p. 202): unstressed /ɛ/ and /a/ are much more open, whereas unstressed /ɔ/ is more retracted, in Bilingual Bulgarian. As far as unstressed vowels are concerned, therefore, there is no evidence of transfer from East Bulgarian to the bilingual varieties.

9.3.2 Unstressed Vowel Shift and neutralisation

As we saw in the preceding sections, Bilingual Bulgarian stressed vowels have qualities that are very close to those in East Bulgarian. At the same time open unstressed vowels differ considerably. Bilingual Bulgarian unstressed open vowels are also different from their West Bulgarian counterparts (apart from /ɛ/, which shows very little Unstressed Vowel Shift in West Bulgarian). The F_1' frequency reduction observed in Bilingual Bulgarian open unstressed vowels is consistently within the range of predicted undershoot, which is not the case in either of the monolingual varieties (Figure 9.6, p. 206). It is not surprising, therefore, that the undershoot-induced Unstressed Vowel Shift scores in Bilingual Bulgarian are considerably lower than the Pillai scores that quantify the categorical Unstressed Vowel Shift of East and West Bulgarian (Figure 9.5, p. 204). The clear differences between Bilingual Bulgarian and both monolingual varieties indicate that Bilingual Bulgarian has its own pattern of less pronounced Unstressed Vowel Shift, which may very well result from a substratal effect of a once more dominant Turkish phonology.

Unstressed Vowel Shift in Bilingual Turkish is stronger than in both Istanbul Turkish (Figure 9.13, p. 227) and the speakers' own Bulgarian (Figure 9.22). Given these facts, it may be tempting to speculate that Bilingual Turkish Unstressed Vowel Shift is shaped by transfer from ambient (East or West) Bulgarian. However, the near-identity of Bilingual Turkish and Bilingual Bulgarian unstressed vowels, as evidenced in the minimal Pillai scores reported in Table 9.9 above, points to another explanation. While in stressed position

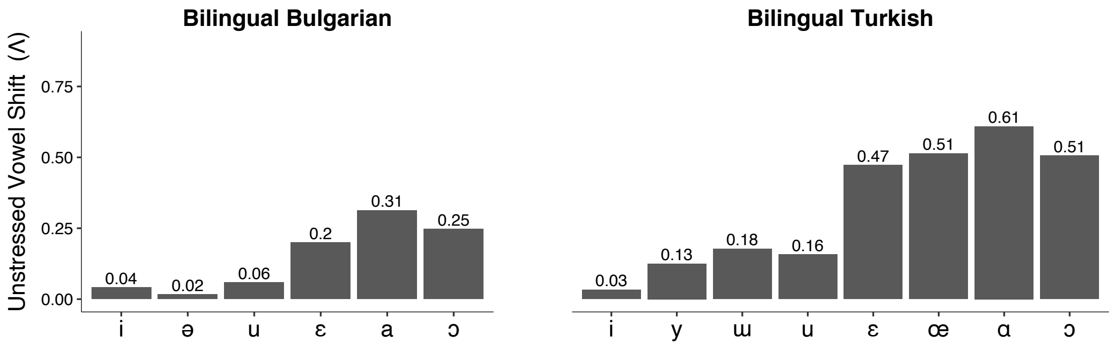


Figure 9.22: Unstressed Vowel Shift in Bilingual Bulgarian and Bilingual Turkish.

corresponding vowels are spectrally very similar or identical across the two varieties, open vowels are also significantly longer in Bilingual Turkish than in Bilingual Bulgarian. In other words, in stressed position we find qualitative but not durational transfer from Bulgarian to Bilingual Turkish. This results in a situation where the bilingual varieties have identical (or remarkably similar) vowel qualities in all positions, while durational differences between stressed and unstressed vowels are considerably larger in Bilingual Turkish. The higher Unstressed Vowel Shift scores in Bilingual Turkish in Figure 9.22 are therefore explained primarily by the longer stressed vowel durations found in Bilingual Turkish. At the same time, even though the spectral differences between Bilingual Turkish and Bilingual Bulgarian appear to be small, Unstressed Vowel Shift is within the range of predicted undershoot only in Bilingual Bulgarian (pp. 206, 228). Bilingual Turkish stressed vowels replicate East Bulgarian vowel quality (Table 9.8, p. 243) while maintaining longer durations, whereas Bilingual Turkish unstressed vowels appear to emulate the undershoot-derived Bilingual Bulgarian unstressed vowels (Table 9.9, p. 245), but the purely gradient stressed–unstressed relation of Bilingual Bulgarian is lost in Bilingual Turkish.

The bilingual varieties very clearly illustrate that contrast and neutralisation are not trivially predictable from Unstressed Vowel Shift scores. Bilingual Turkish exhibits a greater degree of Unstressed Vowel Shift, which is also likely to be categorical for some of the vowels. Nonetheless, as Figure 9.23 shows, Bilingual Turkish contrast levels for unstressed height-contrasting vowel pairs are not lower than those in Bilingual Bulgarian. In fact, the contrast for Bilingual Turkish unstressed /ɯ–ɑ/ is noticeably higher than the score for Bilingual

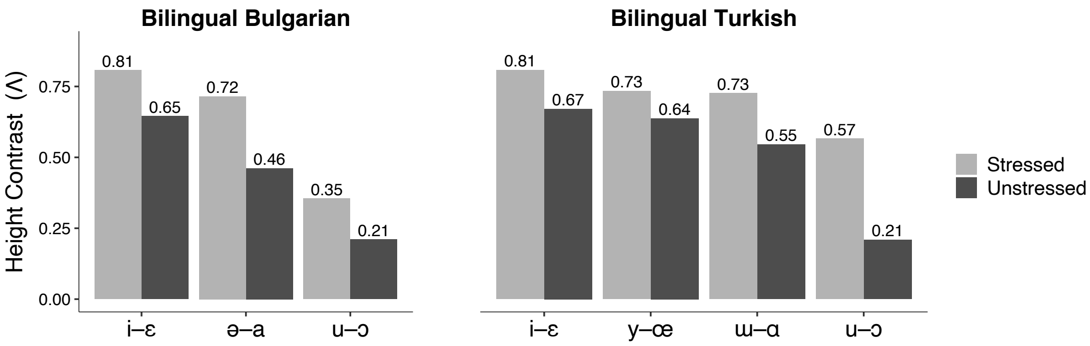


Figure 9.23: The height contrast in Bilingual Bulgarian and Bilingual Turkish.

Bulgarian unstressed /ə–a/. In other words, even though stressed–unstressed differences are greater in Bilingual Turkish (i.e. there is more Unstressed Vowel Shift), unstressed open–close vowel distributions overlap less (i.e. contrast is stronger) than in Bilingual Bulgarian. F_1' frequency is the sole non-negligible discriminant for Bilingual Turkish [ɯ̆–ɑ̆] and Bilingual Bulgarian [ə̆–ă], but the symmetric difference is greater in Bilingual Turkish, $\Delta_{F_1'}$(ɯ̆, ɑ̆) = 0.85, than in Bilingual Bulgarian, $\Delta_{F_1'}$(ə̆, ă) = 0.79 (pp. 172, 192). Neutralisation ratios are correspondingly lower in Bilingual Turkish (Figure 9.24) except in the case of /u–ɔ/. Bilingual Bulgarian and Bilingual Turkish have equal contrast scores for unstressed /u–ɔ/ ($\Lambda = 0.21$), but the pair's score in stressed position is exceptionally low in Bilingual Bulgarian ($\Lambda = 0.35$), which means that only a fairly small proportion of the stressed contrast is lost in unstressed position, hence a lower neutralisation ratio.

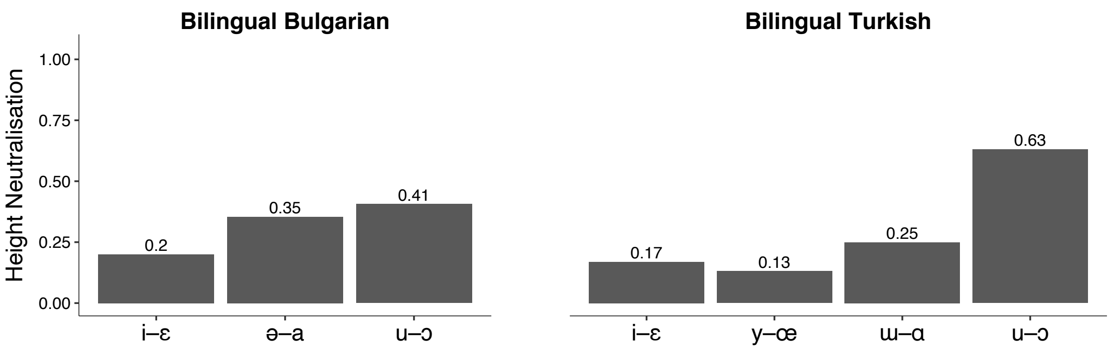


Figure 9.24: Height neutralisation in Bilingual Bulgarian and Bilingual Turkish.

9.3.3 /u/-fronting

In both Bilingual Bulgarian and Bilingual Turkish, /u/-fronting occurs in unstressed position and approximately a third of all unstressed /u/ tokens are fronted (F_2' frequency $\geq$ 1 000 Hz) in both varieties (pp. 216, 233). This is also roughly the rate of /u/-fronting that I have reported for East and West Bulgarian, with the important difference that in the monolingual varieties the process occurs in both stressed and unstressed syllables. In addition, while in all Bulgarian varieties fronted tokens are concentrated and predominate in the speech of about a third of the talkers, in Bilingual Turkish /u/-fronting is more widely distributed across the community, but less frequent in the speech of individual speakers.

Table 9.10 summarises the distribution patterns of /u/-fronting in the bilingual varieties. In Bilingual Bulgarian, 31 per cent of unstressed /u/ tokens are fronted. Five (one female and four male), or 36%, of the participants have produced predominantly fronted /u/ tokens and have therefore been identified as fronters (> 50% for each fronter and 62% on average for all fronters). 61 per cent of all fronted /u/ tokens in the dialect come from the speech of the five fronters. In Bilingual Turkish, 33 per cent of all unstressed /u/ tokens are fronted. However, there is no single participant more than half of whose /u/ tokens are fronted. No major fronters can therefore be identified in Bilingual Turkish by the criterion used for Bulgarian (> 50% fronted tokens).

	Bilingual Bulgarian		Bilingual Turkish	
	σ́	σ̆	σ́	σ̆
[ʉ] incidence in dialect	8%	31%	2%	33%
Fronters: N and %		5 (36%)		0
By gender		1f, 4m		
[ʉ] incidence in fronters		62%		N/A
[ʉ] tokens contributed by fronters alone		61%		N/A

Table 9.10: /u/-fronting in Bilingual Bulgarian and Bilingual Turkish. **[ʉ]** fronted /u/ ($F_2' \geq$ 1 000 Hz); **Fronters** speakers with > 50% [ʉ]; **f** female, **m** male; **N/A** not applicable.

Two male participants, who happen to be amongst the fronters in Bulgarian, may be singled out as near-fronters in Turkish, with exactly 50 per cent of fronted tokens each. The fronted tokens of these two speakers together make up only 7 per cent of all fronted tokens in the dialect. If, however, we extend the group of moderate fronters to include all speakers with at least 40 per cent of fronted /u/ tokens, then we find that it consists of 8 (3 female and 5 male), or 57%, of the participants. These eight moderate fronters are the source of 66 per cent of unstressed fronted /u/ tokens in Bilingual Turkish. All five Bulgarian fronters also happen to be in the moderate fronters' group in Turkish. Lowering the personal fronting threshold to 40 per cent for Bilingual Bulgarian, on the other hand, does not lead to a corresponding rise in the number of fronters: there are no participants in the 40–50% range.

It thus transpires that more bilingual speakers exhibit /u/-fronting in Turkish than in Bulgarian, albeit less frequently. Once again, this points to transfer that at least partly originates from the monolingual (i.e. ambient) Bulgarian varieties rather than the bilinguals' own Bulgarian. All five Bilingual Bulgarian /u/-fronters also front in Turkish, but there are an additional three Turkish fronters who do not front in Bulgarian. The Turkish-only fronters must have borrowed this feature from ambient Bulgarian, while Turkish-and-Bulgarian fronters have access to both ambient and own Bulgarian as potential origins of transfer.

In § 9.2.4 (p. 233) I demonstrated that Bilingual Turkish /u/-fronting is accompanied by lowering, such that fronted /u/ partially merges with Bilingual Turkish /œ/ rather than /y/. From the $F_1' \times F_2'$ frequency PDE plot in Figure 9.19 (p. 235) it is evident that fronted /u/ tokens tend to have higher F_1' frequencies and this is statistically confirmed by a significant positive correlation between the first two formant frequencies. To verify whether and to what extent /u/-fronting also co-occurs with lowering in the Bulgarian dialects, I calculated Person's correlations of the two formant frequencies (i) for all tokes of /u/, (ii) for the fronted tokens ($F_2' \geq 1\,000$ Hz), and (iii) for the unfronted tokens ($F_2' < 1\,000$ Hz). The results are listed in Table 9.11. Since in Bilingual Turkish and Bilingual Bulgarian there is no /u/-fronting in stressed position, only correlations in unstressed syllables have been calculated for those varieties.

		All /u/		Fronted [ʉ]		Unfronted [u]	
		p	*r*	*p*	*r*	*p*	*r*
Bilingual T.	σ̆	0.0000	0.35	0.0001	0.49	0.748	
Bilingual B.	σ̆	0.0833		0.0000	0.42	0.752	
East B.	σ́	0.0042	0.41	0.0029	0.83	0.408	
	σ̆	0.0000	0.42	0.0077	0.36	0.3814	
West B.	σ́	0.1759		0.1557		0.5123	
	σ̆	0.7401		0.0207		0.0036	-0.15

Table 9.11: /u/-fronting and lowering: Pearson's correlation of F_1' and F_2' frequencies. **Fronted [ʉ]** $F_2' \geq 1\,000\,\text{Hz}$; **Unfronted [u]** $F_2' < 1\,000\,\text{Hz}$.

The *p*-values and correlation coefficients (r) make abundantly clear that /u/-fronting goes hand in hand with lowering in the varieties spoken in eastern Bulgaria (East Bulgarian, Bilingual Bulgarian, Bilingual Turkish), whereas in West Bulgarian there is no lowering whatsoever. There are no significant positive correlations in the unfronted token sets of any of the four varieties. In all lowering dialects there are significant positive correlations in the fronted token sets, and in Bilingual Turkish and East Bulgarian (but not Bilingual Bulgarian) there are also overall significant positive correlations for all /u/ tokens. These overall correlations have smaller effect sizes than the correlations in fronted [ʉ] in Bilingual Turkish and for East Bulgarian stressed /u/, which is to be expected. Oddly enough, the overall correlation for East Bulgarian unstressed /u/ is somewhat stronger ($r = 0.42$) than the correlation in fronted tokens ($r = 0.36$), even though unfronted tokens are not correlated. Perhaps 1 000 Hz is not an optimal cutoff point to define the fronting of East Bulgarian unstressed /u/. All significant positive correlations are in the medium range of effect sizes, i.e. $r \in [0.3, 0.5)$, excepting that for East Bulgarian stressed fronted /u/, where the effect size is large, $r \geq 0.5$ (Cohen 1988: 79–80). There are no significant positive correlations in West Bulgarian; the only significant correlation in that variety is for unstressed unfronted /u/, its effect size is small, i.e. $r \in [0.1, 0.3)$, and it is negative. This points to a slight tendency for more advanced realisations of West Bulgarian *unfronted* unstressed /u/ to be closer, rather than more open. However, this does not appear to be relevant to the parallel fronting–lowering of /u/, as observed in the other varieties.

The analysis of /u/-lowering in relation to /u/-fronting has thus revealed two distinct patterns across the fronting dialects (that is, all but Istanbul Turkish): a pattern attested in all varieties spoken in eastern Bulgaria (East Bulgarian, Bilingual Bulgarian and Bilingual Turkish), where fronting is correlated with lowering, and the West Bulgarian pattern, in which there is fronting but no lowering. Bilingual Turkish differs from all other fronting dialects in that its /u/-fronting is not attributable to a clearly identifiable subgroup of speakers. All Bilingual Bulgarian fronters front their /u/'s in Turkish as well, but there are other speakers who front in Turkish but not in Bulgarian, and for these exclusively Turkish fronters the process can only have been transferred from their ambient (but not own) Bulgarian, which may be either monolingual East Bulgarian or, indeed, the Bulgarian of Bilingual Bulgarian fronters, if they regularly interact in that language with them. The source of transfer is not, however, likely to be ambient West Bulgarian (which they will often encounter on television or the radio, for example), since West Bulgarian /u/-fronting follows a different pattern. Even though /u/-fronting has been detected in a greater proportion of Bilingual Turkish speakers (more than half) than in the other fronting varieties (about a third), Bilingual Turkish fronters front less frequently than other fronters. This may be because, unlike Bulgarian, /u/-fronting in Turkish may lead to a merger with a front rounded vowel, as I pointed out in § 9.2.4 (p. 233).

A final observation that needs to be made here concerns a monolingual–bilingual divide that has transpired from my analysis: in West and East Bulgarian /u/-fronting occurs in both stressed and unstressed position, whereas in Bilingual Bulgarian and Bilingual Turkish it is restricted to unstressed syllables. This may be because the process originated as a strategy to avoid unstressed /u–ɔ/ neutralisation in all Bulgarian dialects that was subsequently generalised to all positions in West and East, but not in Bilingual Bulgarian. Bilingual Bulgarian closely interacts with Bilingual Turkish, which resists the fronting to some extent, because of a risk of potential merger with another vowel—a risk that bilingual speakers may be more sensitive to in stressed than in unstressed position. Alternatively, /u/-fronting may have arisen independently of stress in the monolingual varieties, from which it was transferred into Bilingual Bulgarian and Bilingual Turkish but in a way that only affects unstressed vowels, for which overall contrast sensitivity may be somewhat dampened. The former scenario, in which unstressed fronting originated in all Bulgarian dialects, but was generalised to stressed position only in the monolingual varieties, is more plausible, because Bilingual Turkish /u/-fronting has a distribution pattern that is clearly distinct from what is found in Bulgarian.

There are no doubt other possible and likely scenarios that could have led to the status quo across these dialects in contact. To verify any hypotheses on this related and unforeseen issue is beyond not only the intended scope of the present study, but—more importantly—the data it is based on.

9.4 Categorising continuous metrics

Throughout this study I have used the Pillai score (Λ) to quantify contrast and Unstressed Vowel Shift. The Pillai score is a continuous output variable of multivariate analysis of variance, which has been computed here from three explanatory variables: F_1' frequency, F_2' frequency and duration. The metric has proved a valuable tool in comparing vowel categories within and across dialects. Apart from its application to comparison, however, a Pillai score, which in theory may vary from 0 (complete overlap) to 1 (complete separation), is of limited use, in view of its continuous nature. It may therefore be desirable to group Pillai values into categories, such as high, medium, and low. The main difficulty with such categorisation lies in the fact that there are no obvious cut-off points in a continuous variable. One simple approach could be to divide the scale into equal segments, so the cut-offs would be at 0.5 for two groups, or at 0.33 and 0.67 for three groups. Alternatively, observations may be divided into equally-sized groups, in which case the limits would be set at the median or the tertiles of the sample distribution (Altman 2005). Such groupings may be aesthetically pleasing and useful for descriptive purposes, but since they are defined by arbitrary cut-off points, they would have no linguistic significance.

A practical resolution to this impasse may be sought by mapping onto the Pillai scale another output variable, one that is more amenable to categorical interpretation and is derived from the same input variables. Contrast between vowels as measured by the Pillai statistic may, for example, be matched against perceptual distinctness as determined in an identification or discrimination experiment, for which a threshold of accuracy of $\geq 75\%$ correct responses could be set to distinguish between high and low contrastiveness (Port 1996). In addition, it can be estimated whether participants' performance was significantly different from chance (e.g. by comparing d'-values with 0, i.e. chance). Non-significant results would indicate no perceptible contrast. In this way it can be established what intervals of Pillai values correspond to perceptually defined categories, such as 'Zero', 'Low', and 'High' contrast, and approximate cut-off points can be estimated between them. Although different cut-offs may need to be identified for different vowel pairs (or different F_2' frequency ranges), the cut-offs should, ideally, be sufficiently stable across linguistic varieties.

In the absence of a parallel perceptual study to draw data from, I shall substitute a machine learning classifier, the ***k*-nearest-neighbours algorithm**, for a forced-choice identification task in order to categorise the Pillai scores for Unstressed Vowel Shift and contrast, as well as neutralisation ratios, that were reported in earlier chapters. k-nearest-neighbours (k-NN) is a simple statistical learning algorithm in which new observations are assigned to categories according to their proximity to stored and category-labelled observations: a new data point, x_0, is classified using majority vote among its k nearest neighbours, $x_1, \ldots, x_k$, in an n-dimensional space (Hastie et al. 2009: 463ff). In our case, a query (i.e. new) vowel token will be assigned to the category (stressed–unstressed or open–close) that is shared by the majority of k nearest existing tokens in the three-dimensional $F_1' \times F_2' \times$ duration space. Since the k-NN classifier is used in lieu of a perception experiment here, query tokens can be thought of as representing vowel stimuli, and the nearest existing tokens as a hearer's memories of auditory vowel experiences that are judged most similar to the new stimulus. In other words, the k-NN algorithm will serve as a simplified model of speech perception that is very much in the spirit of exemplar theory (e.g. Johnson 1996; Pierrehumbert 2001).

9.4.1 Unstressed Vowel Shift

The first test aims to asses how reliably vowels can be classified as stressed versus unstressed on the basis of the explanatory variables, F_1' and F_2' frequencies and duration. Since the three variables differ in the range of values they are measured in, all values were rescaled to the interval $[0, 1]$ prior to analysis ($x_{v\,\text{rescaled}} = \dfrac{x_v - x_{v\,\min}}{x_{v\,\max} - x_{v\,\min}}$, where $v \in \{F_1', F_2', \text{dur}\}$). For each vowel phoneme in each variety, 25 per cent of all tokens were randomly selected to be used as a test set, and the remaining 75 per cent to serve as a training set. The stressed-to-unstressed token ratio in the two sets was kept the same as in the entire data set for the vowel, i.e. 1 : 3 for Bulgarian and 1 : 2 for Turkish vowels. An optimal number of nearest neighbours, k, to be used by the classifier for each vowel was selected using the `train()` function of the R package caret (**c**lassification **a**nd **re**gression **t**raining; Kuhn

2009). The function divides each training set itself into two random 25%–75% subsets, let them be called TrainSet25 and TrainSet75, respectively, and classifies each token from TrainSet25, x_0, as stressed or unstressed according to the majority category label among k data points in TrainSet75 that have the smallest Euclidean distances from x_0. k is varied between 5, 7 and 9 over twenty-five repetitions and the k-value which results in the highest average classification accuracy is selected as optimal k for that phoneme in that variety. The tokens from the test set (the original 25% partition) were then classified based on k-nearest neighbours in the entire training set (TrainSet25 + TrainSet75), using the optimal k as earlier determined, and a confusion matrix was created for the algorithm predictions for the test set data, using the `confusionMatrix()` function of the `caret` package. Two statistics were used in assessing the classifier: its accuracy rate, or the proportion of correct classifications, and an 'Accuracy $>$ No Information Rate' p-value. The No Information Rate (NIR) refers to the accuracy achievable by always predicting the majority class label, and the p-value indicates whether the accuracy of the classifier is significantly higher than NIR, or in other words, whether it is significantly different from chance.

Based on these statistics, the ***k*-NN outcomes** for Unstressed Vowel Shift have been grouped as follows. A non-significant result ($p > 0.05$) indicates that the classifier fails to distinguish between stressed and unstressed allophones reliably, which in linguistic terms here is taken to mean there is no perceptible difference between the stressed and unstressed realisations of a vowel, or that there is **Zero** Unstressed Vowel Shift. For classifications with significant outcomes ($p \leq 0.05$), an accuracy rate of 75% or higher indicates that stressed and unstressed tokens can be reliably distinguished, that is, that the degree of Unstressed Vowel Shift is **High**, while accuracy of less than 75% is interpreted as a **Low** degree of Unstressed Vowel Shift. The results of the k-NN classification are shown in Table 9.12, matched with the corresponding Pillai scores for each vowel (pp. 104, 125, 146, 166, 185). The data are arranged in ascending order according to Pillai scores, in order to assess whether there are any immediately obvious cut-off points that can be estimated for the Pillai scale based on k-NN outcomes.

						Unstressed Vowel Shift
		***k*-Nearest Neighbours**				Pillai score
Vowel		Accuracy	*p*	sig.	Outcome	(Λ)
						↓
East Bulgarian	/i/	0.73	0.6986	n.s.	Zero	(0.01)
Bilingual Bulgarian	/ə/	0.77	0.3324	n.s.	Zero	0.02
Bilingual Turkish	/i/	0.60	0.8844	n.s.	Zero	0.03
East Bulgarian	/ə/	0.81	0.2048	n.s.	Zero	0.04
Bilingual Bulgarian	/i/	0.76	0.4000	n.s.	Zero	0.04
East Bulgarian	/u/	0.73	0.6986	n.s.	Zero	0.05
Istanbul Turkish	/i/	0.67	0.5551	n.s.	Zero	0.06
Bilingual Bulgarian	/u/	0.76	0.4704	n.s.	Zero	0.06
Istanbul Turkish	/ɯ/	0.71	0.2697	n.s.	Zero	0.07
West Bulgarian	/i/	0.76	0.4000	n.s.	Zero	0.08
Istanbul Turkish	/u/	0.70	0.3591	n.s.	Zero	0.08
West Bulgarian	/u/	0.75	0.5413	n.s.	Zero	0.10
Bilingual Turkish	/y/	0.68	0.4527	n.s.	Zero	0.13
Istanbul Turkish	/y/	0.66	0.6501	n.s.	Zero	0.13
West Bulgarian	/ə/	0.79	0.1636	n.s.	Zero	0.14
Bilingual Turkish	/u/	0.70	0.3491	n.s.	Zero	0.16
Bilingual Turkish	/ɯ/	0.70	0.3491	n.s.	Zero	0.18
Bilingual Bulgarian	/ɛ/	0.79	0.1222	n.s.	Zero	0.20
Bilingual Bulgarian	/ɔ/	0.78	0.2129	n.s.	Zero	0.25
Istanbul Turkish	/ɛ/	0.70	0.3591	n.s.	Zero	0.25
Istanbul Turkish	/ɔ/	0.74	0.1302	n.s.	Zero	0.29
Bilingual Bulgarian	/a/	0.77	0.2695	n.s.	Zero	0.31
West Bulgarian	/ɛ/	0.77	0.2695	n.s.	Zero	0.31
Istanbul Turkish	/œ/	0.82	0.0031	**	High	0.37
East Bulgarian	/ɔ/	0.94	0.0008	***	High	0.41
Istanbul Turkish	/ɑ/	0.85	0.0005	***	High	0.45
Bilingual Turkish	/ɛ/	0.83	0.0040	**	High	0.47
Bilingual Turkish	/ɔ/	0.90	0.0000	***	High	0.51
Bilingual Turkish	/œ/	0.86	0.0005	***	High	0.51
West Bulgarian	/ɔ/	0.88	0.0000	***	High	0.52
Bilingual Turkish	/ɑ/	0.92	0.0000	***	High	0.61
West Bulgarian	/a/	0.95	0.0000	***	High	0.64
East Bulgarian	/a/	0.94	0.0008	***	High	0.68
East Bulgarian	/ɛ/	1.00	0.0000	***	High	0.81

Table 9.12: *k*-NN classification of stressed–unstressed vowels and Pillai scores for Unstressed Vowel Shift. Λ-values in brackets: MANOVA non-significant.

As can be seen from the results, the vowels are grouped into two categories according the *k*-NN outcomes, Zero and High, and there is no overlap between them in terms of Pillai scores: Zero ranges from 0.01 to 0.31 and High from 0.37 to 0.81. (No significant test had an accuracy rate of less than 75%.) It does appear, therefore, that a single cut-off point can be estimated between Zero and High for all vowels, and it is located within a small section of the Pillai scale: somewhere between 0.32 and 0.36. Figure 9.25 plots Pillai scores for Unstressed Vowel Shift (y-axis) against mean F_2' frequencies (x-axis), with the High vs Zero levels indicated by different colours and point shapes. The horizontal line at $\Lambda = 0.34$ represents the estimated cut-off point (the midpoint of the $[0.32, 0.36]$ cut-off interval).

It can be observed from the two fitted regression lines that Pillai scores for Unstressed Vowel Shift vary with F_2' frequency. The downward-sloping dashed linear regression line indicates that, overall, Unstressed Vowel Shift tends to decrease as F_2' frequency increases, or that front vowels tend to exhibit less Unstressed Vowel Shift than back vowels. On the other hand, the local regression curve, fitted using the LOESS (locally estimated scatterplot smoothing) method (Jacoby 2000),[13] while confirming this trend,

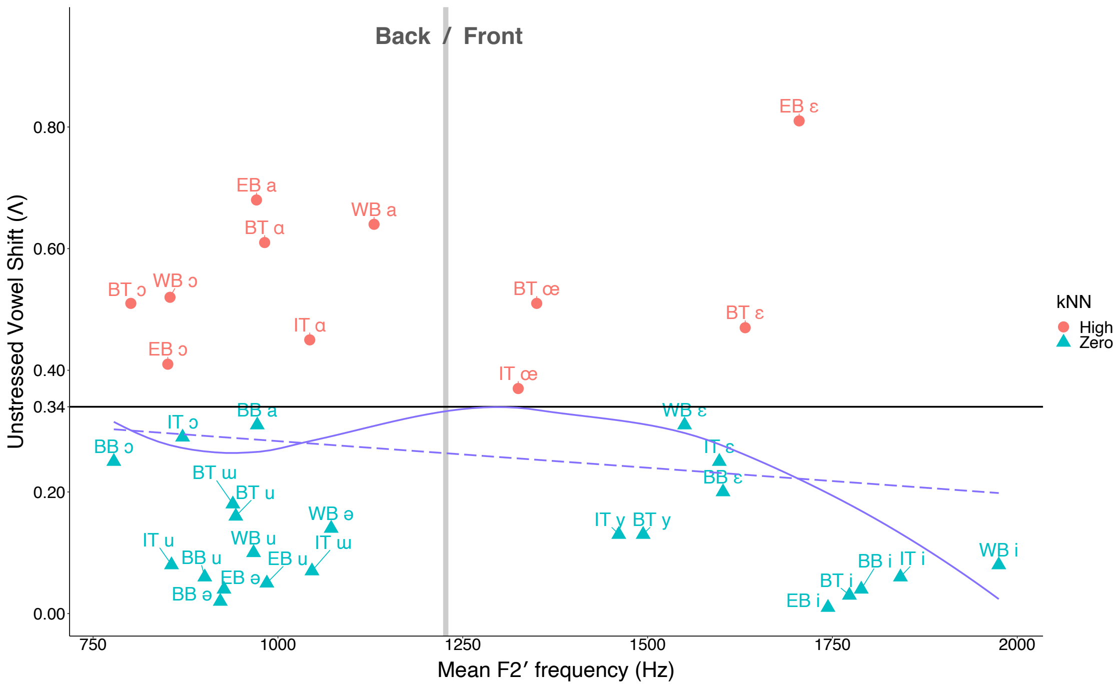


Figure 9.25: Unstressed Vowel Shift (Λ), mean F_2' frequencies and k-NN outcomes for vowel phonemes across the five varieties.
Horizontal solid line at $\Lambda = 0.34$: estimated cut-off separating Λ categories (**High** vs **Zero**) based on k-NN outcomes; dashed line fitted by linear regression; curve fitted by LOESS regression.
BB Bilingual Bulgarian, **BT** Bilingual Turkish, **EB** East Bulgarian, **IT** Istanbul Turkish, **WB** West Bulgarian.

[13] LOESS regression was performed using the `loess()` function of the base package `stats` in R.

also draws a more complex picture which is, at first sight, difficult to interpret. We have established beyond doubt, however, that Unstressed Vowel Shift is a process that affects only *open* vowels to any significant extent. The response of the local regression curve to the multitude of negligibly low Pillai scores for close vowels is likely to be affecting its shape in ways that would preclude valid generalisations about Unstressed Vowel Shift within the class of vowels for which it matters the most, i.e. open vowels. It may be more useful, therefore, to fit regression lines for open vowels only. Notice also that East Bulgarian /ɛ/ is an extreme outlier in the overall topology, and should probably also be left out if a general trend is to be determined.

Unstressed Vowel Shift scores for open vowels only, except East Bulgarian /ɛ/, are plotted again in Figure 9.26. While the straight dashed line fitted by linear regression still suggests a slight tendency for more advanced vowels to reduce less, the local regression curve is now considerably more amenable to linguistic interpretation: back vowels reduce more if unrounded, whereas front vowels reduce more if rounded. This apparent mirror effect can be easily accounted for by what Jakobson et al. (1952) deem to be 'optimal'

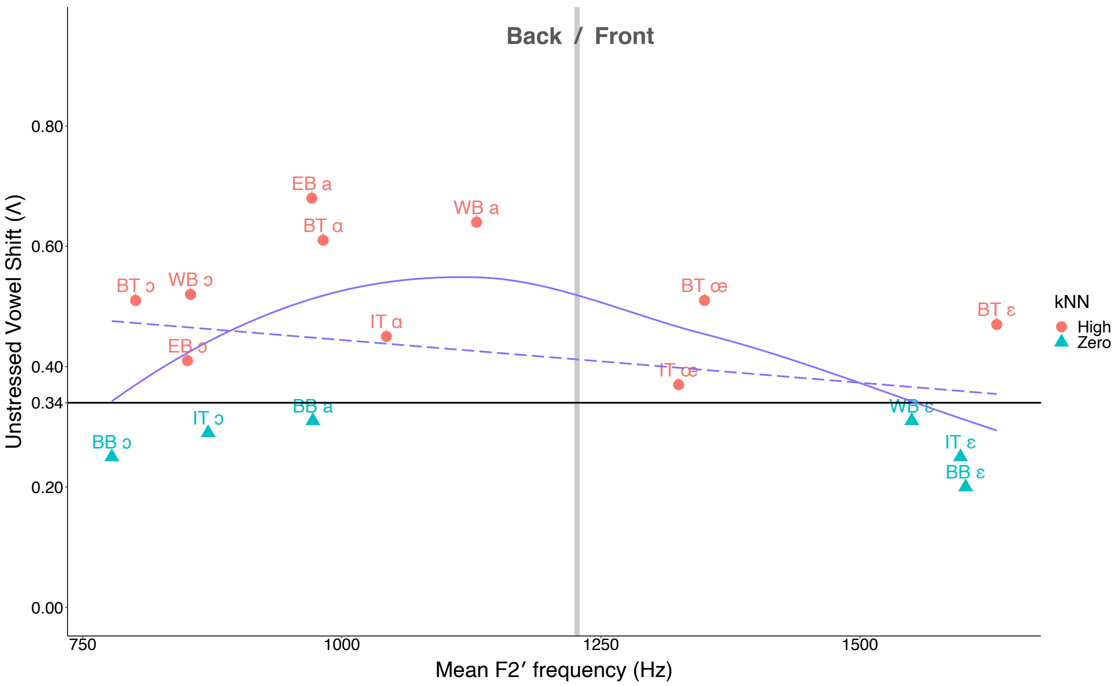


Figure 9.26: As in Figure 9.25, with close vowels and East Bulgarian /ɛ/ removed.

combinations for tonality features: front unrounded (`acute + plain`) and back rounded (`grave + flat`) are optimal, on account of their distinctness from each other and (resulting) cross-linguistic prevalence, compared to the non-optimal tonality feature pairings front rounded (`acute + flat`) and back unrounded (`grave + plain`). The shape of the local regression curve indicates that Jakobson et al.'s (1952) distinction between optimal and non-optimal combinations of backness and roundness features is also relevant to Unstressed Vowel Shift: non-optimal phonemes appear to reduce more.

A single cut-off point at about $\Lambda = 0.34$ can clearly dichotomise the data at hand. However, with data from more languages, it may well turn out that a different type of cut-off line needs to be drawn along the F_2' frequency continuum: perhaps a sloping one, to reflect differences between back and front vowels, or a more complex curved one, to account for differences between optimal and non-optimal combinations of backness and roundness.

9.4.2 Contrast

The same procedure as described for Unstressed Vowel Shift above was followed to train and test *k*-NN classifiers for phoneme identity within height-contrasting pairs, separately for stressed and unstressed token sets. Since there was an equal number of close and open vowels in each set, the No Information Rate was always 0.5. A non-significant difference from this rate indicates that the token sets cannot be reliably distinguished, i.e. that there is **Zero** contrast between them. A significant test with an accuracy rate of less than 75% is interpreted as **Low** contrast, while a rate of 75% or higher means that the level of contrast is **High**. The results from the *k*-NN tests for all vowel pairs, matched with corresponding Pillai scores for contrast (pp. 109, 129, 150, 170, 189) are listed in Table 9.13, once again arranged by Pillai scores in ascending order.

As can be seen from the table, the categories of *k*-NN outcome do not render a perfect categorisation of the Pillai scale for contrast. The Bilingual Bulgarian pair [ŭ–ɔ̆] emerged as High although there is one pair, Istanbul Turkish [ŭ–ɔ̆], which has a higher Pillai score but was identified as Low. In addition, the Pillai value for Bilingual Bulgarian [ŭ–ɔ̆] is only marginally higher than that for Bilingual Turkish [ŭ–ɔ̆], which is Low according to

Vowel pair		*k*-Nearest Neighbours			Contrast	
		Accuracy	*p*	sig.	Outcome	Pillai score (Λ)
						↓
East Bulgarian	[ə̆–ă]	0.51	0.4531	n.s.	Zero	(0.00)
East Bulgarian	[ĭ–ɛ̆]	0.56	0.2048	n.s.	Zero	0.04
West Bulgarian	[ŭ–ɔ̆]	0.61	0.0003	***	Low	0.11
East Bulgarian	[ŭ–ɔ̆]	0.63	0.0222	*	Low	0.15
Bilingual Turkish	[ŭ–ɔ̆]	0.69	0.0003	***	**Low**	0.2091
Bilingual Bulgarian	[ŭ–ɔ̆]	0.75	0.0000	***	**High**	0.2106
Istanbul Turkish	[ŭ–ɔ̆]	0.69	0.0001	***	**Low**	0.3453
Bilingual Bulgarian	[ú–ɔ́]	0.75	0.0000	***	**High**	0.3546
West Bulgarian	[ə̆–ă]	0.77	0.0000	***	High	0.39
Bilingual Bulgarian	[ə̆–ă]	0.88	0.0000	***	High	0.46
East Bulgarian	[ú–ɔ́]	0.79	0.0033	**	High	0.48
West Bulgarian	[ú–ɔ́]	0.89	0.0000	***	High	0.51
Istanbul Turkish	[ú–ɔ́]	0.83	0.0000	***	High	0.52
Bilingual Turkish	[ɯ̆–ɑ̆]	0.87	0.0000	***	High	0.55
Istanbul Turkish	[y̆–œ̆]	0.87	0.0000	***	High	0.56
Bilingual Turkish	[ú–ɔ́]	0.88	0.0000	***	High	0.57
Istanbul Turkish	[ý–œ́]	0.90	0.0000	***	High	0.62
Bilingual Turkish	[y̆–œ̆]	0.87	0.0000	***	High	0.64
Bilingual Bulgarian	[ĭ–ɛ̆]	0.87	0.0000	***	High	0.65
Istanbul Turkish	[ɯ̆–ɑ̆]	0.93	0.0000	***	High	0.66
Bilingual Turkish	[ĭ–ɛ̆]	0.92	0.0000	***	High	0.67
Istanbul Turkish	[ĭ–ɛ̆]	0.93	0.0000	***	High	0.67
Istanbul Turkish	[í–ɛ́]	0.90	0.0000	***	High	0.70
West Bulgarian	[ĭ–ɛ̆]	0.94	0.0000	***	High	0.71
Bilingual Bulgarian	[ə́–á]	0.95	0.0000	***	High	0.72
East Bulgarian	[ə́–á]	0.83	0.0008	***	High	0.73
Bilingual Turkish	[ɯ́–ɑ́]	0.98	0.0000	***	High	0.73
West Bulgarian	[í–ɛ́]	0.93	0.0000	***	High	0.73
Bilingual Turkish	[ý–œ́]	0.90	0.0000	***	High	0.73
Istanbul Turkish	[ɯ́–ɑ́]	0.96	0.0000	***	High	0.77
West Bulgarian	[ə́–á]	1.00	0.0000	***	High	0.78
Bilingual Bulgarian	[í–ɛ́]	0.98	0.0000	***	High	0.81
Bilingual Turkish	[í–ɛ́]	0.98	0.0000	***	High	0.81
East Bulgarian	[í–ɛ́]	1.00	0.0000	***	High	0.86

Table 9.13: *k*-NN classification of open–close vowels and Pillai scores for contrast. Λ-values in brackets: MANOVA non-significant

the *k*-NN outcome. Notice also that even though Bilingual Bulgarian stressed [ú–ɔ́] differs from Istanbul Turkish [ŭ–ɔ̆] by a very small difference in Pillai score, the former appears to be High and the latter Low. It should be noted, however, that the accuracy rate for both Bilingual Bulgarian stressed and unstressed /u–ɔ/ is precisely 0.75, which is the lowest value I have chosen for the High category. If, then, we were to shift the category definition only slightly upwards, for example, by changing the $\geq 75\%$ condition for High to $> 75\%$, or if we were to assign Bilingual Bulgarian stressed and unstressed /u–ɔ/ to a **Borderline** category of their own (so as not to completely disregard the issue), we would still be able to identify a single narrow cut-off section between High and a lower category on the Pillai scale: between 0.36 and 0.38, as indicated by the dividing line under Bilingual Bulgarian [ú–ɔ́] in Table 9.13. Separating Zero and Low contrast does not pose a difficulty: a cut-off point can be estimated at about $\Lambda = 0.075$.

In Figure 9.27 Pillai scores for contrast are grouped into four categories—Zero, Low, Borderline and High—and plotted against F_2' frequency. The solid horizontal lines at $\Lambda = 0.08$ and 0.37 represent estimated cut-offs for Zero-vs-Low and Borderline-vs-High, respectively. (No obvious line can be drawn between Low and Borderline.) The dashed

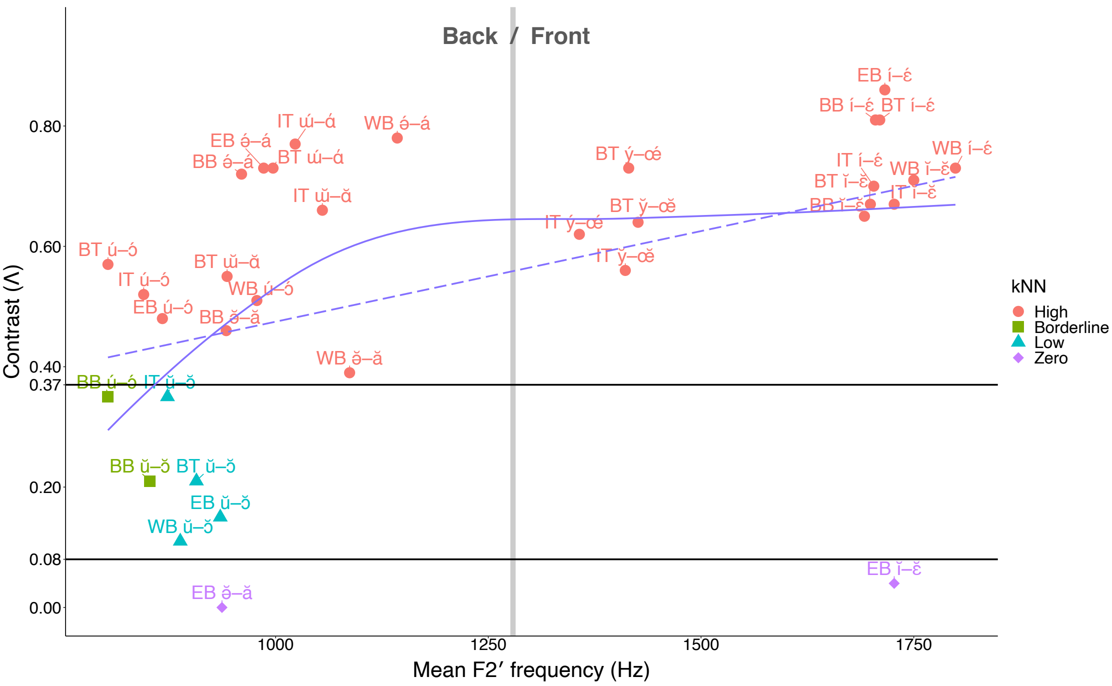


Figure 9.27: Contrast scores (Λ), mean F_2' frequencies and k-NN outcomes for vowel pairs across the five varieties.
Horizontal lines at $\Lambda = 0.08$ and 0.37: estimated cut-offs for **Zero–Low** and **Borderline–High** based on k-NN outcomes; dashed line fitted by linear regression; curve fitted by LOESS regression.
BB Bilingual Bulgarian, **BT** Bilingual Turkish, **EB** East Bulgarian, **IT** Istanbul Turkish, **WB** West Bulgarian.

linear regression line indicates that front vowel pairs overall tend to be more contrastive for height than back vowels, which is consistent with the tendency for front vowels to exhibit somewhat less Unstressed Vowel Shift, as we established above (§ 9.4.1). From the curve fitted by local regression it appears that the relation between contrastiveness and F_2' frequency has a quasi-logarithmic shape: there is a steep rise in contrast from lower to higher F_2' frequencies in the back region, which then flattens for front vowels. No general separation of optimal versus non-optimal combinations of backness and roundness features holds for the height contrast in the way it does for Unstressed Vowel Shift, which once again shows that, although related, Unstressed Vowel Shift and corresponding levels of contrast do not necessarily result in the same patterns. What is more, despite the fact that back unrounded vowels reduce more, they are generally more height-contrastive than back rounded vowels.

9.4.3 Neutralisation

The *k*-NN algorithm was also used to discretise the neutralisation metric I introduced and applied in the experimental chapters, namely the ratio of contrast lost in unstressed position to contrast in stressed position (neutralisation $= \frac{\acute{\Lambda} - \breve{\Lambda}}{\acute{\Lambda}}$). A somewhat different procedure was followed here from the one used to categorise Pillai scores for Unstressed Vowel Shift and contrast. To categorise neutralisation ratios, *all* stressed tokens of each vowel pair were used as a training set, while *all* corresponding unstressed tokens served as a test set. In other words, each *unstressed* token was classified as open or close according to the majority label of *k* nearest *stressed* (or 'canonical') tokens. The purpose of these tests was to establish to what extent the height contrast, as it obtains in stressed position, can be relied upon to classify unstressed vowels. The results thus obtained were then mapped onto the neutralisation scale. The categories are defined as follows. A non-significant test indicates that unstressed open and close vowels cannot be distinguished by reference to corresponding stressed vowels; this is interpreted as **Total** neutralisation. A significant test with an accuracy rate of less than 75% is indicative of a **High** neutralisation level, and significant results of at least 75% accuracy identify cases that exhibit **Low** levels of neutralisation. The results from the *k*-NN tests for all vowel pairs, matched with and arranged by corresponding neutralisation ratios (pp. 109, 129, 150, 170, 189) are shown in Table 9.14.

Vowel pair		k-Nearest Neighbours: Accuracy	p	sig.	Outcome	Neutralisation Ratio $\left(\frac{\acute{\Lambda}-\breve{\Lambda}}{\acute{\Lambda}}\right)$ ↓
West Bulgarian	/i–ɛ/	0.91	0.0000	***	Low	0.02
Istanbul Turkish	/i–ɛ/	0.90	0.0000	***	Low	0.04
Istanbul Turkish	/y–œ/	0.86	0.0000	***	Low	0.10
Bilingual Turkish	/y–œ/	0.78	0.0000	***	Low	0.13
Istanbul Turkish	/ɯ–ɑ/	0.82	0.0000	***	Low	0.15
Bilingual Turkish	/i–ɛ/	0.83	0.0000	***	Low	0.17
Bilingual Bulgarian	/i–ɛ/	0.88	0.0000	***	Low	0.20
Bilingual Turkish	/ɯ–ɑ/	0.81	0.0000	***	Low	0.25
Istanbul Turkish	/u–ɔ/	0.76	0.0000	***	Low	0.33
Bilingual Bulgarian	/ə–a/	0.81	0.0000	***	Low	0.35
Bilingual Bulgarian	/u–ɔ/	0.67	0.0000	***	High	0.41
West Bulgarian	/ə–a/	0.62	0.0000	***	High	0.50
Bilingual Turkish	/u–ɔ/	0.66	0.0000	***	High	0.63
East Bulgarian	/u–ɔ/	0.62	0.0000	***	High	0.70
West Bulgarian	/u–ɔ/	0.58	0.0000	***	High	0.78
East Bulgarian	/i–ɛ/	0.50	0.4765	n.s.	Total	0.95
East Bulgarian	/ə–a/	0.52	0.2980	n.s.	Total	0.99

Table 9.14: k-NN classification of unstressed open–close vowels according to nearest stressed vowels with corresponding neutralisation ratios.

As can be seen, this continuous variable is successfully categorised by the corresponding k-NN outcome categories. The interval separating Low and High neutralisation is small, $[0.36, 0.40]$, whereas the one between the High and Total categories is considerably larger, $[0.79, 0.94]$. As before, cut-off points are estimated at the midpoints of these intervals (approximately at 0.38 and 0.87), and this is shown in Figure 9.28, where neutralisation ratios are plotted against F_2' frequency. The dashed straight line, fitted by linear regression, indicates that back vowels overall have a stronger tendency for height neutralisation in unstressed position than front vowels. The local regression line appears to be strongly and unevenly curved. The peaks, however, occur very near the x-axis (F_2' frequency) locations of two obvious outliers on the y-axis (Neutralisation), East Bulgarian /ə–a/ and /i–ɛ/. Given the overall paucity of data points (seventeen), the curve's response to these extreme observations must inevitably be very sensitive. And indeed, Figure 9.29 shows that if the two outliers are removed, the curve flattens drastically and now adds

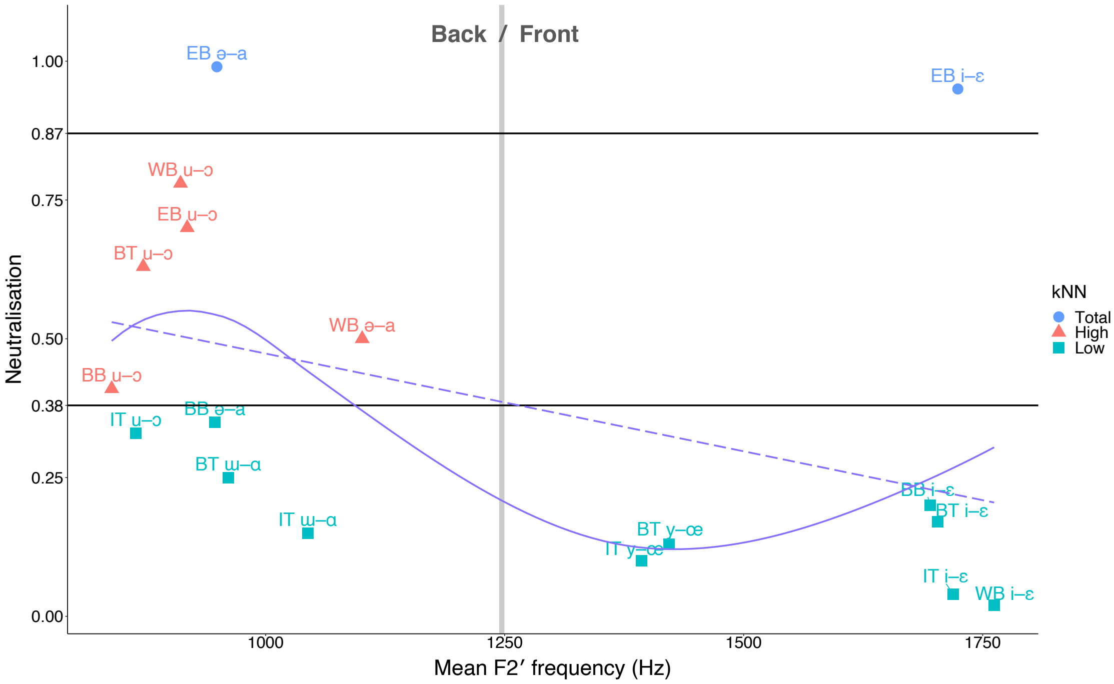


Figure 9.28: Neutralisation ratios ($\frac{\acute{\Lambda}-\breve{\Lambda}}{\acute{\Lambda}}$), mean F_2' frequencies and k-NN outcomes for vowel pairs across the five varieties.
Horizontal solid lines at $\Lambda = 0.38$ and 0.87: estimated cut-offs for **Low–High** and **High–Total** based on k-NN outcomes; dashed line fitted by linear regression; curve fitted by LOESS regression.
BB Bilingual Bulgarian, **BT** Bilingual Turkish, **EB** East Bulgarian, **IT** Istanbul Turkish, **WB** West Bulgarian.

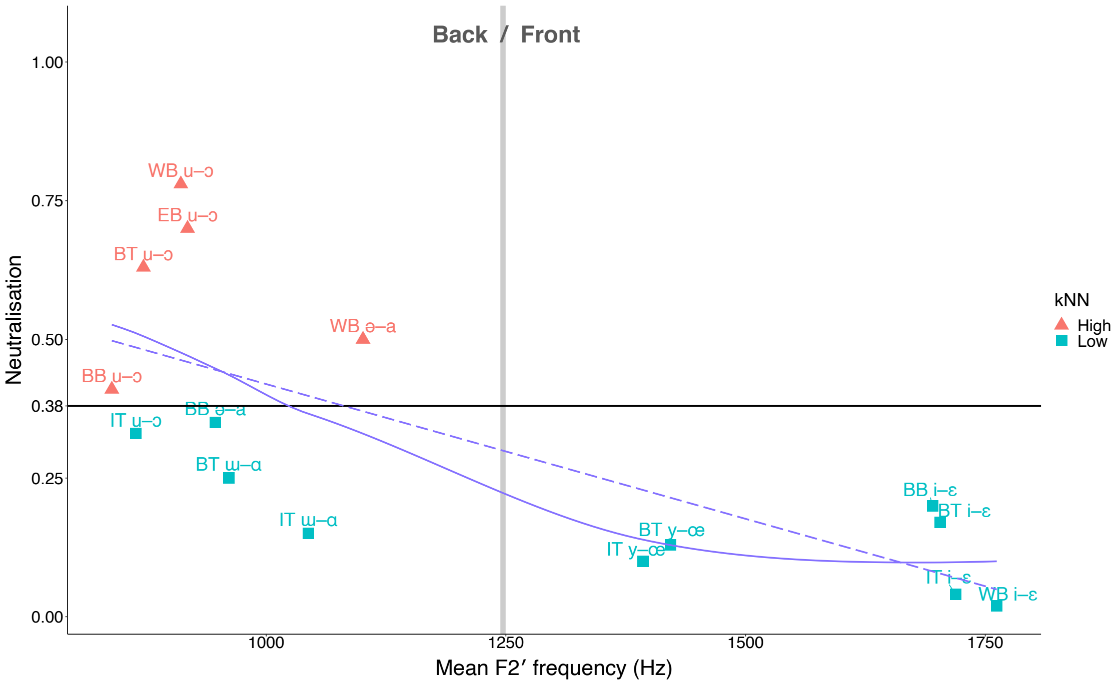


Figure 9.29: As in Figure 9.28, with East Bulgarian /ə–a/ and /i–ɛ/ removed.

little to what can be inferred from the linear regression line (that more advanced vowels tend to neutralise less), apart perhaps from mirroring the trend for back unrounded vowels to be more height-contrastive (§ 9.4.2) with a subtler inverse trend for less height neutralisation, compared to back rounded vowels.

9.4.4 Summary and concluding remarks

In this section I have demonstrated that two continuous metrics I have used to compare vowels, Pillai scores and neutralisation ratios, can be reliably discretised into linguistically interpretable categories derived from the outcomes of k-NN classifications based on the same input variables as are used for the continuous metrics: vowel duration and formant frequencies. I have identified two categories of Unstressed Vowel Shift (Zero and High), three clear-cut categories of contrast (Zero, Low/Borderline and High) and three neutralisation categories (Low, High and Total).

One last observation needs to be made here: the k-NN classifier has produced fundamentally different results for Unstressed Vowel Shift, on the one hand, and contrast and neutralisation, on the other. About two-thirds of the outcomes from classifying vowels as stressed versus unstressed were not significantly different from chance (§ 9.4.1), while the prediction of height classes (open vs close) rendered a considerably smaller proportion of non-significant results: less than six per cent (§§ 9.4.2, 9.4.3). This can be explained with the fact that there are acoustic variables other than the formant frequencies and duration that are strong cues to linguistic stress, in particular the fundamental frequency and intensity, whereas the height contrast hinges primarily on the first formant frequency. In addition, even in varieties with high levels of Unstressed Vowel Shift, a clear dichotomy between stressed and unstressed realisations is found only in open vowels, that is, only in half of the vowel inventory.

9.5 On the number of contrastive heights

In § 2.1.1 (p. 13ff), I contrasted two competing theoretical views of contrastive vowel height. In *SPE*-type (Chomsky and Halle 1968) frameworks, distinctive features are defined in absolute phonetic terms and three potentially contrastive vowel heights are distinguished (high, mid, low) through combinations of two features, `[±high]` and `[±low]`. Jakobson et al. (1952), on the other hand, recognise a single height feature, `diffuse/compact`, that is interpreted in relative terms, i.e. as 'higher' vs 'lower'. My portrayal of the vowel inventories investigated here has been consonant with the latter approach: I have assumed a single height contrast, whose terms I have labelled close/open. In this final section of Chapter 9, I compare the two approaches to phonological vowel height in the light of my findings.

Table 9.15 presents the height feature specifications for Bulgarian and Turkish vowels according to the *SPE* and *PSA* (Jakobson et al. 1952) approaches. In *SPE*, the high–mid pairs, *i–ɛ, y–œ, u–ɔ*, are identically distinguished: the high vowels are `[+high]`, the mid `[-high]`. Bulgarian *ə–a*, on the other hand, are contrasted as `[-low]` versus `[+low]`, respectively, whereas Turkish *ɯ–ɑ* differ with respect to both features: *ɯ* is $\begin{bmatrix}\texttt{+high}\\ \texttt{-low}\end{bmatrix}$ and *ɑ* is $\begin{bmatrix}\texttt{-high}\\ \texttt{+low}\end{bmatrix}$. The categorical segment replacements that result from Unstressed Vowel Shift in East Bulgarian are listed in (9.3). To formalise these replacements, an *SPE*-type analysis would need to postulate two separate rules for unstressed mid and low vowels; these are given in (9.4) and (9.5).[14]

		i	ɛ	y	œ	ə	ɯ	a/ɑ	u	ɔ
SPE	`[±high]`	+	−	+	−	−	+	−	+	−
	`[±low]`	−	−	−	−	−	−	+	−	−
PSA	`Diffuse/Compact`	D	C	D	C	D	D	C	D	C

Table 9.15: *SPE* (Chomsky and Halle 1968) and *PSA* (Jakobson et al. 1952) height features for Bulgarian and Turkish vowels.

[14] Notice that Rules (9.4) and (9.5) must apply in this counter-feeding order: (9.4) must precede (9.5), because if the order were reversed so that (9.5) applied to a, `[-high, +low]`, first, then the output, `[-high, -low]`, would feed into (9.4), and East Bulgarian unstressed /a/ would surface as [ɯ] (or [ɨ]), which is not its actual unstressed realisation.

East Bulgarian Vowel Reduction

$$\begin{array}{ccc} \varepsilon & \rightarrow & i \\ a & \rightarrow & ə \\ ɔ & \rightarrow & u \end{array} \Bigg/ \overset{\breve{\sigma}}{\underset{\_\_}{|}} \tag{9.3}$$

Mid Vowel Reduction

$$\begin{bmatrix} \texttt{-high} \\ \texttt{-low} \end{bmatrix} \rightarrow [\texttt{+high}] \Big/ \overset{\breve{\sigma}}{\underset{\_\_}{|}} \tag{9.4}$$

Low Vowel Reduction

$$[\texttt{+low}] \rightarrow [\texttt{-low}] \Big/ \overset{\breve{\sigma}}{\underset{\_\_}{|}} \tag{9.5}$$

If there happens to be some significant difference in the reductive behaviour of low (*a/ɑ*) and mid vowels (*ε, ɔ*), it could be interpreted as empirical evidence that the two vowel classes are indeed raised by different processes. In search of such differences, we shall briefly revisit how vowels are grouped into the categories of Unstressed Vowel Shift and neutralisation that were defined by *k*-NN outcomes in the previous section. Two categories of Unstressed Vowel Shift were identified in § 9.4.1 (p. 255), Zero and High. The results for the open (i.e. mid or low) vowels of each of the five varieties are summarised in Table 9.16. As can be seen, the low vowels, Bulgarian /a/ and Turkish /ɑ/, always occur in the same category as at least one mid vowel. Similarly, when we consider the

	Unstressed Vowel Shift	
	Zero	*High*
West Bulgarian	ɛ	**a**, ɔ
East Bulgarian	ɛ, **a**, ɔ	
Istanbul Turkish	ɛ, ɔ	œ, **ɑ**
Bilingual Bulgarian	ɛ, **a**, ɔ	
Bilingual Turkish	ɛ, œ, **ɑ**, ɔ	

Table 9.16: Open vowel phonemes across levels of Unstressed Vowel Shift.

	Height neutralisation		
	Total	*High*	*Low*
West Bulgarian		**ə–a**, u–ɔ	i–ɛ
East Bulgarian	i–ɛ, **ə–a**	u–ɔ	
Istanbul Turkish			i–ɛ, y–œ, **ɯ–ɑ**, u–ɔ
Bilingual Bulgarian		u–ɔ	i–ɛ, **ə–a**
Bilingual Turkish		u–ɔ	i–ɛ, y–œ, **ɯ–ɑ**

Table 9.17: Heigh-contrasting vowel pairs across levels of contrast.

distribution of height-contrasting phoneme pairs across the three neutralisation categories (§ 9.4.3, p. 263) in Table 9.17, we find no evidence of uniqueness for Bulgarian /ə–a/ or Turkish /ɯ–ɑ/: they are never in a category of their own.

Absence of evidence for difference, of course, is not evidence for absence of difference. We should seek other avenues to test the three-height analysis, for example by exploring the implications of the strict proportional relations that absolute *SPE* features impose on vowels, such as (9.6):

$$\varepsilon : i \;=\; \text{ɔ} : u \;=\; \text{ə} : \text{ɯ} \;=\; \begin{bmatrix} \texttt{-}high \\ \texttt{-low} \end{bmatrix} : \begin{bmatrix} \texttt{+}high \\ \texttt{-low} \end{bmatrix} \tag{9.6}$$

ə is $\begin{bmatrix} \texttt{-high} \\ \texttt{-low} \end{bmatrix}$, just like ɛ and ɔ, which means that it must also feed into Rule (9.4) above. However, this does not happen: Bulgarian unstressed /ə/ is not raised to [ɯ],[15] as is evidenced by the vowel's comparatively low Pillai scores for Unstressed Vowel Shift, as well as its consistent membership of the Zero shift category based on *k*-NN outcomes. The low Unstressed Vowel Shift of /ə/ can be contrasted with that of other phonetically non-high vowels in Table 9.18, which summarises Unstressed Vowel Shift scores and *k*-NN outcomes.[16]

Rule (9.4), $\begin{bmatrix} \texttt{-high} \\ \texttt{-low} \end{bmatrix} \rightarrow \texttt{[+high]}$, then, does not apply to Bulgarian /ə/ and we must conclude that ə cannot have the same height specification as ɛ and ɔ. A more relativistic interpretation of distinctive features, as in the framework advanced by Jakobson et al.

[15] Or [ɨ]: *SPE* does not contrast central and back vowels.

[16] It is also worth noting that, even though the phoneme /u/ may have somewhat higher than expected F_1' frequencies (and thus appear to approach the mid region) in some of the dialects, notably East (p. 132) and Bilingual Bulgarian (p. 173), its reductive behaviour does not differ from that of other close vowels, as can be appreciated in Table 9.18.

	i	y	ə/ɯ	u	ɛ	œ	a/ɑ	ɔ
West B.	0.08		0.14	0.10	0.31		0.64*	0.52*
East B.	0.01		0.04	0.05	0.81*		0.68*	0.41*
Istanbul T.	0.06	0.13	0.07	0.08	0.25	0.37*	0.45*	0.29
Bilingual B.	0.04		0.02	0.06	0.20		0.31	0.25
Bilingual T.	0.03	0.13	0.18	0.16	0.47*	0.51*	0.61*	0.51*

Table 9.18: Summary of Pillai scores for Unstressed Vowels Shift and *k*-NN outcomes.
* 'High' *k*-NN outcome ('Zero' for the rest).

(1952), will be necessary to postulate an adequate rule for categorical Unstressed Vowel Shift. If lower vowels are specified as [compact] or [open] (or [-high], etc.), and higher vowels as [diffuse] or [close] (or [+high], etc.), then Unstressed Vowel Shift in East Bulgarian is accurately and exhaustively captured by Rule (9.7).

$$\texttt{[open]} \rightarrow \texttt{[close]} \Big/ \underset{\text{\_\_}}{\overset{\breve{\sigma}}{|}} \tag{9.7}$$

As we saw earlier, in none of the four remaining varieties is Unstressed Vowel Shift categorical in *all* open vowels. In addition, Table 9.18 reminds us of how variable Unstressed Vowel Shift can be across comparable vowels in different varieties. Accounting for both the unity of the phonological processes involved and their divergent outcomes is a theoretical challenge, which I return to in the next chapter (§ 10.3).

10
General discussion

Contents

In this chapter I recapitulate my findings and consider their wider implications. Throughout this study, I have used the term **Unstressed Vowel Shift** to refer to any systematic differences between stressed and unstressed realisations of vowel phonemes. Unstressed Vowel Shift largely overlaps with the traditional notion of 'unstressed vowel *reduction*' while circumventing the connotations of categoricality and contrast neutralisation that 'vowel reduction' has come to imply. Categorical target split, especially such that results in merger, is indeed a frequent *effect* of Unstressed Vowel Shift. As a result, contrast neutralisation is sometimes assumed to be a condition for vowel reduction to be acknowledged. This is an unjustified assumption that is, unfortunately, rather widespread in Slavonic linguistics. By examining five varieties of two languages that are fundamentally distinct in genealogical and typological terms, but are geographically adjacent, or indeed overlapping, I have tried to demonstrate that Unstressed Vowel Shift is a process that can and should be studied in its own right, because very similar observable patterns may have very different systemic consequences, which are often not clearly predictable. Unstressed Vowel Shift may, but does not have to, result in the phonologisation of separate unstressed targets, which in turn may, but again do not have to, merge with the targets of other phonemes. Unstressed Vowel Shift may also trigger a push chain which, while evading one merger, may result in another. In the present study I have encountered and reported all of these widely diverse effects of Unstressed Vowel Shift.

10.1 Unstressed Vowel Shift

The quality of stressed vowels, which I have (often implicitly) equated with canonical vowel quality, is not uniform across the five dialects. I have found most unity amongst the varieties that coexist areally, i.e. those spoken in eastern Bulgaria: East Bulgarian, Bilingual Bulgarian and Bilingual Turkish. The more standard—and geographically detached—West Bulgarian and Istanbul Turkish are demonstrably, though not greatly, different from their sister dialects. West Bulgarian vowels (except /ɛ/) tend to be more advanced, whereas Istanbul Turkish front vowels tend to be more open. While these general differences are also present in unstressed vowels, they are of course obscured by the varying degrees and effects of Unstressed Vowel Shift.

Unstressed Vowel Shift results in a systematic decrease of (*a*) vowel duration and (*b*) F_1' frequency (or articulatory raising, by assumption). Durational reduction is observed in both open and close vowels, while spectral (F_1' frequency) reduction is a regular property of unstressed *open* vowels alone. Contrary to the received view of Bulgarian vowel reduction (§ 2.1.2), I have not found any evidence of close vowel lowering in unstressed position: close vowels are spectrally stable across stress conditions. My findings have refuted another traditional claim, that vowels in immediately pretonic syllables reduce to a lesser extent than other unstressed vowels: Unstressed Shift in pretonic vowels is either equal to, or often even greater than Unstressed Vowel Shift in other positions.

Unstressed Vowel Shift does not, in any of the five varieties I have examined, involve any system-wide variation in F_2' frequency (or backness). Spectrally, therefore, Unstressed Vowel Shift results in an overall bottom-up F_1'-frequency contraction of the acoustic two-formant vowel space, or a vertical contraction of the x-backness – y-height articulatory space. Such vertical contraction is most obvious in East Bulgarian, where the unstressed vowel space is virtually flattened (Figure 5.6, p. 132), much less dramatic in West Bulgarian (p. 112), and least conspicuous in Bilingual Bulgarian (p. 173; see also Figure 9.3, p. 202). The difference in vowel space shrinkage between Bilingual (p. 194) and Istanbul Turkish (p. 154) is less striking, but appreciable contraction is undeniably present in both.

I have quantified overall spectro-durational Unstressed Vowel Shift in terms of the multivariate difference in variance between the stressed and unstressed token sets of each vowel phoneme, with regard to duration, F_1' and F_2' frequency, as measured by the Pillai statistic (Λ) of a standard one-way MANOVA. Figure 10.1 compares the Unstressed Vowel Shift scores for open vowels in the five varieties. The leftmost point on the x-axis indicates the mean Pillai score over all open vowels for each dialect. Even though scores differ widely across the varieties, there are discernible cross-linguistic trends. In all varieties apart from one, the phonetically most open vowel, [a / ɑ], exhibits the highest degree of Unstressed Vowel Shift. There is consistently less Unstressed Shift in /ɔ/, which as I suggested earlier,

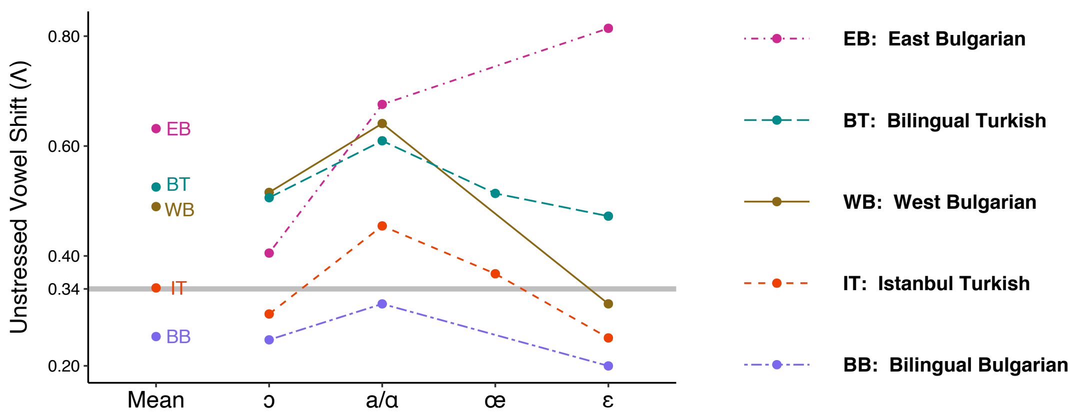


Figure 10.1: Unstressed Vowel Shift across the five varieties. Horizontal grey line at $\Lambda = 0.34$: cut-off between Zero and High Unstressed Vowel Shifts levels (§ 9.4.1, p. 255).

is probably due to the smaller amount of vertical space at the back of the mouth.[1] Istanbul Turkish, Bilingual Bulgarian and Bilingual Turkish are consistent in having Unstressed Vowel Shift scores for /ɛ/ that are only slightly lower than those for /ɔ/. The monolingual Bulgarian varieties are exceptional in this regard. East Bulgarian is the only dialect where /ɛ/ shifts more than /a/, whereas West Bulgarian is the exact opposite: the Unstressed Vowel Shift score for /ɛ/ is conspicuously low. In both Turkish varieties Unstressed Shift is somewhat stronger in /œ/ than in /ɛ/. Overall, Bilingual Turkish is closer to monolingual Bulgarian than it is to Bilingual Bulgarian or Istanbul Turkish, which are the two varieties with the lowest and second lowest Unstressed Vowel Shift scores, respectively. The trend I identified in § 9.4.1 (p. 255) for vowels with non-optimal combinations of tonality features (back unrounded and front rounded) to undergo more Unstressed Vowel Shift than their optimal counterparts (back rounded and front unrounded) is visible in Figure 10.1 as well. The grey line at $\Lambda = 0.34$ separates the Zero and High categories of Unstressed Vowel Shift, as defined by the *k*-NN outcomes. The level is High for all vowels except those of Bilingual Bulgarian and the Istanbul Turkish optimal vowels (/ɛ, ɔ/).

I performed discriminant function analysis (DFA) and used the parallel discriminant ratio coefficient (PDRC) as a measure of the relative contribution of each variate (duration, F_1' and F_2' frequency) in significant MANOVAs (§ 3.2.3.2, p. 85). Following Thomas (1992), I regard as negligible any PDRC that is less than half the mean of all absolute PDRC values in a single DFA. The contribution of F_2' frequency to Unstressed Vowel Shift has proved to be negligible in all open vowels throughout the varieties. In East and West Bulgarian, F_1' frequency is the primary, and duration the secondary Unstressed Vowel Shift discriminant. In the rest of the varieties—Bilingual Bulgarian, Bilingual Turkish, Istanbul Turkish—discriminant weights are reversed: duration is primary and F_1' frequency secondary. This

[1] F_1 frequency is correlated negatively with tongue height and positively with pharyngeal constriction: both lower tongue position and smaller pharynx volume increase F_1 frequency (Stevens 1998: 268–271; Pickett 1999: 40–42). Since lower vowels are, as a rule, articulated with a more retracted tongue root, and therefore a more constricted pharynx, than higher vowels, the two articulatory correlates often act in tandem to increase F_1 frequency. The progressive narrowing of the pharynx from high to low vowels, however, is more pronounced in back vowels, so the more limited space available for vertical tongue movement in the back of the mouth is, to some extent, acoustically compensated for by the greater pharyngeal constriction found in back open vowels.

means that both spectral and durational reduction are in place in all the varieties, the former being more prominent in monolingual Bulgarian, and the latter elsewhere.

The research question which has no doubt been the most difficult to answer is whether particular instances of Unstressed Vowel Shift are gradient or categorical. Cases of Unstressed Vowel Shift that result in strong neutralisation, where high contrast levels in stressed position are matched by low unstressed contrastiveness, are as a rule trivial instances of categorical Unstressed Vowel Shift. The Pearson product-moment correlation coefficient is a useful measure of gradience within stress-dependent allophones. However, correlation analysis should not be performed across stress conditions, because stressed and unstressed distributions often do not overlap in duration, and even when they do, probability densities are very low at the tails. I have therefore adopted another method in attempting to identify categorical Unstressed Vowel Shift that does not lead to contrast neutralisation. I have used Lindblom's (1963) widely cited study of spectral undershoot—which is based on production data from a small number of Swedish speakers—in order to calculate unstressed $\hat{F}_1$ frequencies that would be predicted from observed unstressed vowel durations and corresponding stressed vowel F_1' frequencies. I then compared the predicted $\hat{F}_1$ values with the actual mean $\bar{F}_1'$ frequencies in my data, and speculated that a separate unstressed target is likely to be in place whenever observed $\bar{F}_1'$ frequency fell below predicted $\hat{F}_1$ frequency. More production data, controlled and varied across duration and stress conditions, would be needed to ascertain whether such calculations can be used as reliable predictors of categorical difference, and what adjustments might be necessary. The mathematical results I have reported indicate that there are likely to be separate unstressed targets for West Bulgarian /ɛ, a, ɔ/, East Bulgarian /ɛ, a/, Bilingual Turkish /ɛ, œ/. In addition to these, I have accepted categorical Unstressed Vowel Shift to be present in East Bulgarian and Bilingual Turkish /ɔ/ on account of the high levels of /u–ɔ/ neutralisation. Differences between predicted and observed first formant frequencies were particularly small for West Bulgarian /ɛ/ and /a/, which prompted me to consider inter-speaker variation. This proved to be fruitful, as for both phonemes I identified two roughly equal subgroups of speakers who have considerably higher and lower unstressed $\bar{F}_1'$ frequencies than predicted.

10.2 Neutralisation

The Unstressed Vowel Shift of an open vowel may, but does not have to, result in contrast neutralisation. To quantify height contrast—or differences between open and close vowels, in both stressed and unstressed position—I have once again used the Pillai statistic (Λ). The Pillai score can be thought of as the proportion of symmetric difference, or the non-overlapping area, between token sets A and B ($\Lambda = \frac{A \, \Delta \, B}{A \cup B}$). If the total area occupied by A and B, i.e. their union, $A \cup B$, expressed as a proportion is 1 ($\frac{A \cup B}{A \cup B} = 1$), then the Pillai score also equals the whole, 1, less the proportion of intersection of the two, η: $\Lambda = 1 - \eta$. This is diagrammed in Figure 10.2. The proportion of intersection, or overlap,

$$\Lambda(A,B) \quad = \quad \frac{A \, \Delta \, B}{A \cup B} \quad = \quad 1 - \eta(A,B)$$

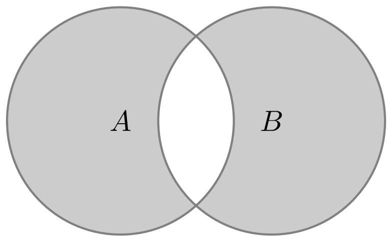


Figure 10.2: The Pillai score (Λ), used here as a measure of both **Unstressed Vowel Shift** and **contrast**, represented as the proportion of symmetric difference (Δ) of sets A and B (shaded).

of the two sets, η, is then the complement of the Pillai score, i.e. $\eta = 1 - \Lambda$ (Figure 10.3). While it is tempting to represent and quantify vowel merger as the proportion of overlap η, I have argued that this is not an optimal metric, because any two adjacent vowel phonemes, even in their unreduced realisations, will have some degree of overlap, and that it is the relative *increase* in overlap from a more contrastive (stressed) to a less contrastive (unstressed) position that is a more reliable measure of neutralisation. In order to factor in overlap that is tolerated between stressed realisations, I have quantified neutralisation as the proportion of contrast which is lost in unstressed position: neutralisation $= \frac{\acute{\Lambda} - \breve{\Lambda}}{\acute{\Lambda}}$.

$$\eta(A,B) = \frac{A \cap B}{A \cup B} = 1 - \Lambda(A,B)$$

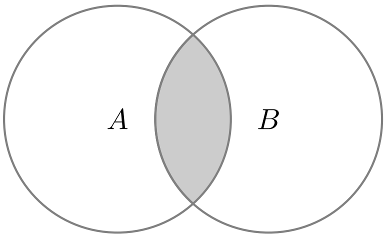


Figure 10.3: Phoneme overlap as proportion of intersection of sets A and B (shaded).

Neutralisation ratios for open–close vowel pairs in each variety are summarised in Figure 10.4. The five varieties are once more very different from one another, but again there are discernible trends in the graph. In four of the dialects, the highest degree of open–close neutralisation is found in the pair /u–ɔ/, followed by /ə–a/ or /ɯ–ɑ/, and then the front vowels. The front rounded pair /y–œ/ neutralises least of all pairs in Istanbul Turkish, whereas in Bilingual Turkish it neutralises slightly more than /i–ɛ/.

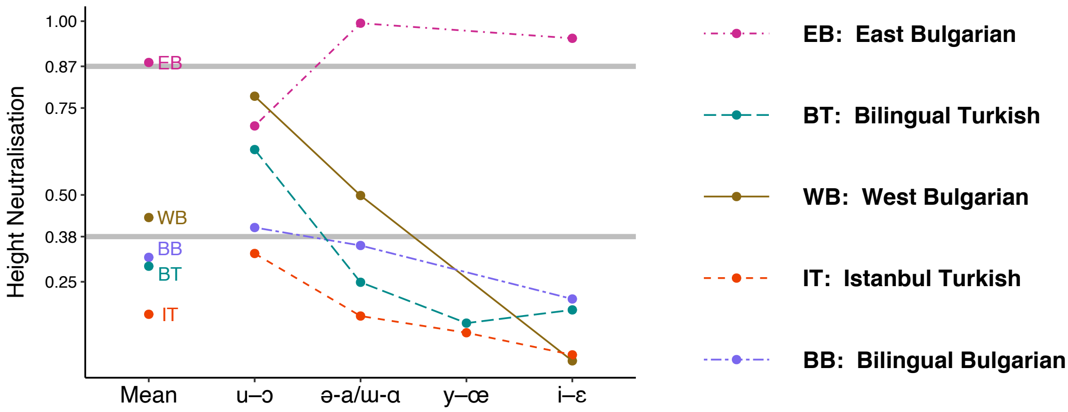


Figure 10.4: Contrast neutralisation across the five varieties. Horizontal grey lines at $\Lambda = 0.38$ and 0.87: cut-offs for Low–High and High–Total contrast levels, respectively (§ 9.4.3, p. 263).

It is not surprising that the strongest neutralisation is found in back rounded vowels, since their contrast scores in unstressed position are systematically low. East Bulgarian exhibits exceptionally strong neutralisation in /i–ɛ/ and /ə–ɑ/, while its ratio for /u–ɔ/ is lower, though still high: at a level that places it very close to West Bulgarian and Bilingual Turkish. In these three dialects, the neutralisation ratio for /u–ɔ/ is to some extent brought down by the fronting of unstressed /u/. In all varieties apart from East Bulgarian, neutralisation of /i–ɛ/ is low; this is particularly conspicuous in West Bulgarian because of the vast difference from the other pairs. The fact that the back vowels /u–ɔ/ are most susceptible, while the front /i–ɛ/ are most resistant to neutralisation is, in all probability, largely due to phonetic factors relating to the amount of articulatory space available to maintain height contrasts, but it is also likely that functional load—which in Bulgarian and Turkish is low for the back and high for the front pair—has reinforced their divergent neutralisation ratios. Strong /i–ɛ/ neutralisation is exceptional and is found in East Bulgarian only, which confirms that, once phonologised, a merger ceases to be sensitive to any deterrents that may have previously been in place.

An important incidental finding of this study is a process of /u/-fronting that has been revealed in all Bulgarian dialects, as well as Bilingual Turkish. Four distinct patterns are observed and they suggest that the process originated in Bulgarian, where it first affected only unstressed /u/, probably as a strategy to avoid merging unstressed /u–ɔ/. In the monolingual varieties the process has been generalised to stressed /u/, and in West Bulgarian the fronting has even become more pronounced in stressed than in unstressed position. In all Bulgarian dialects, about a third of relevant /u/ tokens are fronted and come from a subgroup of roughly a third of the speakers in each dialect, who are predominantly male and most of whose /u/ tokens are fronted. In East and Bilingual Bulgarian, but not in West Bulgarian, the fronting is accompanied by lowering. In addition, a third of Bilingual Turkish unstressed /u/ tokens are fronted and lowered as well, but at the same time their distribution in the sample is rather different: they are scattered across more than half of the talkers but do not predominate in the speech of any single individual. Some of the Bilingual Turkish fronters front in Bulgarian as well, but others do not. Bilingual Turkish /u/-fronting, therefore, could only be the result of transfer from the speakers' ambient Bulgarian. Since there are contrastive front rounded vowels in Turkish, Bilingual Turkish /u/-fronting results in a certain degree of neutralisation; the partial merger, however, is with Bilingual Turkish /œ/ rather than /y/, since fronting is accompanied by parallel lowering. The discovery of /u/-fronting has been instrumental in uncovering the incomplete nature /u–ɔ/ neutralisation in East and West Bulgarian, which would have remained unacknowledged if the second formant frequency had not been part of the height neutralisation model (as in Andreeva et al. 2013), or if the sample had not included data from /u/-fronters (e.g. no male speakers, as in Sabev 2015).

The spectral side of the findings outlined above is summarised schematically in Figure 10.5 for Bulgarian and Figure 10.6 for Turkish. In all varieties, unstressed open vowels are to a greater or lesser extent raised from their stressed realisations. Dotted circles indicate that the raising is from gradient undershoot, while unstressed open vowels in solid circles represent categorically different targets. Categorical Unstressed Vowel Shift is inferred from either or both of the following conditions: (*a*) observed F_1' frequency reduction exceeds predicted undershoot (West Bulgarian [ɛ̆, ɔ̆], East Bulgarian [ɛ̆, ă], Bilingual Turkish [ɛ̆, œ̆]), or (*b*) unstressed open and close vowels have a low contrast score (West Bulgarian [a, ɔ̆], East Bulgarian [ɛ̆, ă, ɔ̆], Bilingual Turkish [ɔ̆]).

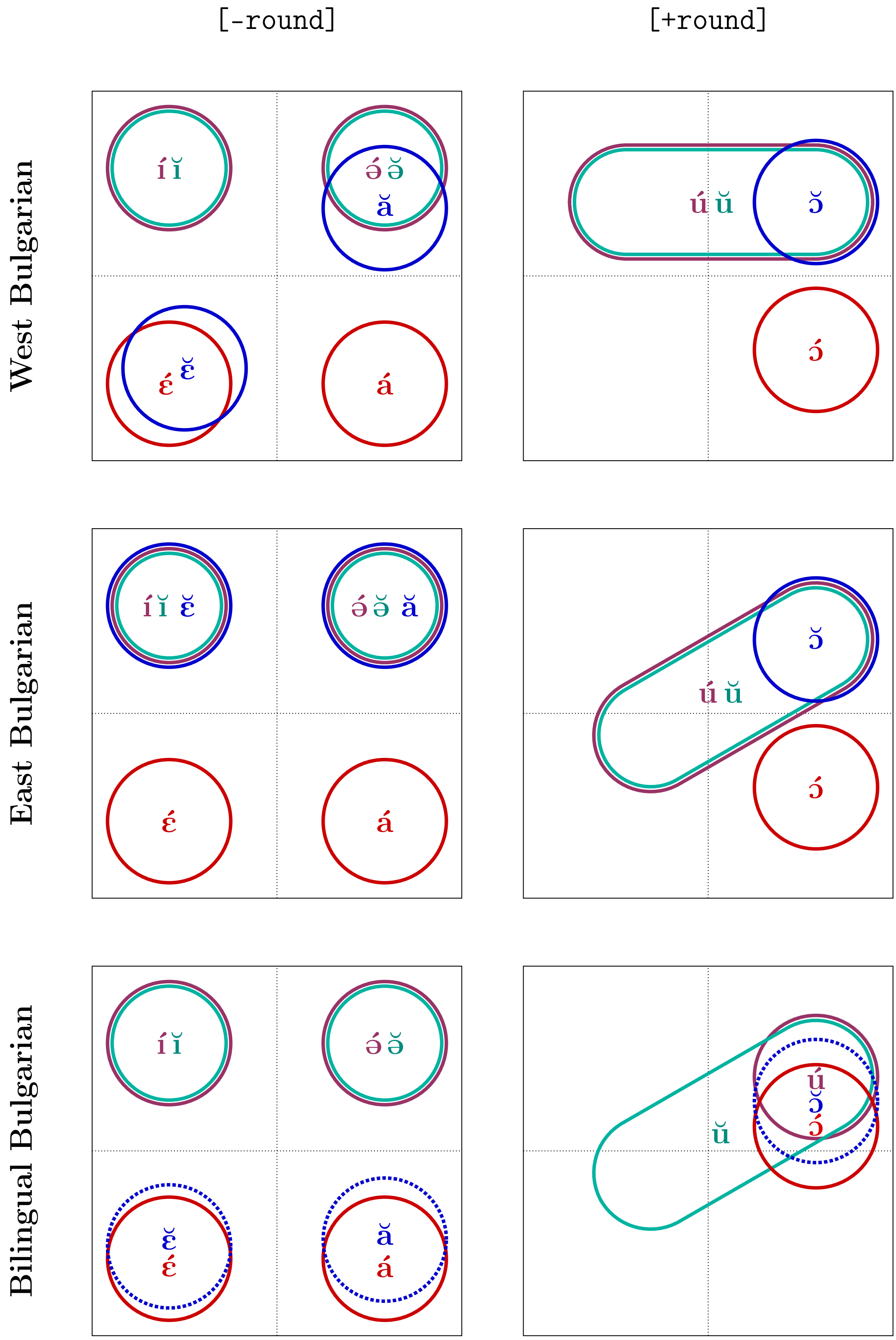


Figure 10.5: Reduction patterns in Bulgarian. Dotted circles: gradient Unstressed Vowel Shift.

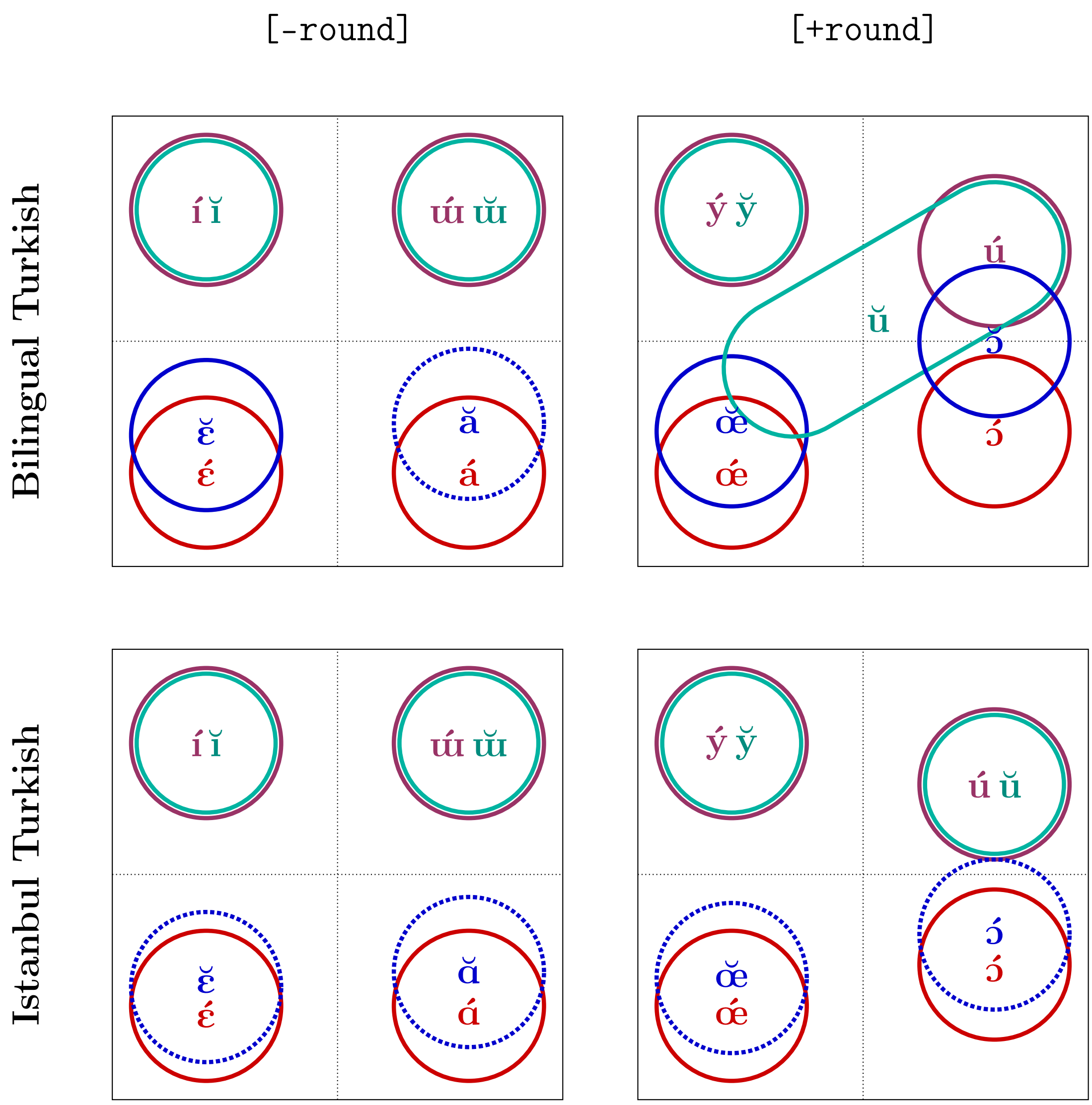


Figure 10.6: Reduction patterns in Turkish. Dotted circles: gradient Unstressed Vowel Shift.

10.3 Phonologisation

In a traditional phonological model with segments defined as bundles of universal binary features, the vowels of Bulgarian and Turkish would be specified as in Table 10.1, assuming two phonological heights, identified as `[-high]` and `[+high]`. Unstressed Vowel Shift can then be formalised as a structural change expressed as '→ `[+high]`'. Since all `[-high]` vowels have corresponding `[+high]` counterparts, the change '→ `[+high]`' must be reserved for cases of merger, i.e. substantial contrast neutralisation; it cannot be used to derive non-merging allophones. The complete rules for the four varieties that exhibit neutralising Unstressed Vowel Shift are spelt out in Figure 10.7. Bilingual Bulgarian lacks a conditioning

	ɛ	**i**	**a/ɑ**	**ə/ɯ**	**ɔ**	**u**	**œ**	**y**
[high]	−	+	−	+	−	+	−	+
[back]	−	−	+	+	+	+	−	−
[round]	−	−	−	−	+	+	+	+
[syllabic]	+	+	+	+	+	+	+	+

Table 10.1: Universal binary features for Bulgarian and Turkish vowels.

environment because /u–ɔ/ merger is unconditioned there: while not complete, it is prevalent in both unstressed and stressed position.

From the rules in Figure 10.7 it appears that Unstressed Vowel Shift targets different random combinations of features across the varieties; as a result, common underlying tendencies are not easily discernible. A phonological model that does not necessarily require that phonetically similar sounds have the same featural specifications across languages

$$[\texttt{+syllabic}] \rightarrow [\texttt{+high}] \;/\; \overset{\breve{\sigma}}{\underset{\_\_}{|}} \qquad \text{(East Bulgarian)}$$

$$\begin{bmatrix}\texttt{+syllabic}\\ \texttt{+back}\end{bmatrix} \rightarrow [\texttt{+high}] \;/\; \overset{\breve{\sigma}}{\underset{\_\_}{|}} \qquad \text{(West Bulgarian)}$$

$$\begin{bmatrix}\texttt{+syllabic}\\ \texttt{+back}\\ \texttt{+round}\end{bmatrix} \rightarrow [\texttt{+high}] \;/\; \overset{\breve{\sigma}}{\underset{\_\_}{|}} \qquad \text{(Bilingual Turkish)}$$

$$\begin{bmatrix}\texttt{+syllabic}\\ (\texttt{+back})\\ \texttt{+round}\end{bmatrix} \rightarrow [\texttt{+high}] \qquad \text{(Bilingual Bulgarian)}$$

Figure 10.7: Unstressed Vowel Shift in East Bulgarian, West Bulgarian, Bilingual Turkish and Bilingual Bulgarian expressed with universal features.

may be better suited to capture both the unity of Unstressed Vowel Shift processes and the variation that is observed within and across the varieties. This can be achieved with Mielke's (2008) emergent feature theory, in which distinctive features are not innate and universal, but emerge in a speaker's phonology through abstraction from patterns and similarity-driven generalisations. Mielke argues that:

> the natural classes and distinctive features found in human languages can be accounted for as the result of factors such as phonetically based sound change and generalization, which can be described without reference to a feature system. A feature system can be constructed (by a language learner or a linguist) on the basis of the results, but the feature system critically does not need to be a driving force behind sound patterns.
>
> (Mielke 2008: 4)

Phonological patterns are first shaped by phonetic factors, and then internalised in terms of features which are not predefined, but emerge through general cognitive processes and social biases. Segments that pattern together form a 'phonologically active class'. This term is introduced to distinguish it from two related, yet different notions: a (phonological) natural class and a phonetically natural class. A traditional natural class is a set of segments that share one or more pre-existing and theory-dependent distinctive features, while a phonetically natural class is a set of segments that share certain phonetic properties (Mielke 2008: 7–15). A phonologically active class may come into being through two scenarios. In the first, several segments that share a phonetic property (i.e. a phonetically natural class) frequently engage in similar phonetic behaviour that is subsequently phonologised into a pattern. In the second scenario, a single segment's frequent phonetic (gradient) behaviour is phonologised first, and then the resulting phonological (categorical) behaviour spreads to other segments by analogical extension based on a certain phonetic or non-phonetic similarity, which—if phonetic—may or may not be the same as the phonetic property that gave rise to the original segment's frequent phonetic behaviour that was phonologised first. Features emerge from patterns: they are abstract cognitive and descriptive tags assigned to each member of a phonologically active class involved in a pattern. They are the consequence, not the cause, of a pattern. While phonological patterns ultimately arise from frequent phonetic behaviour or generalisation, once phonologised, they are no longer directly associated with the phonetic properties that gave rise to them. The connection between a phonological pattern and the phonetic factors that led to it is only historical; it is not present in a speaker's grammar (ibid., 85–100).

Since features in this model emerge from phonological patterns, features and phonologically active classes are 'potentially isomorphic': 'No feature needs to be learned that is not motivated by the presence of a phonologically active class' (Mielke 2008: 99). A central argument for innate distinctive features has been that a model in which lexical contrast hinges on a small number of features would relax pressure on memory, compared to models in which the atomic units of contrast are segments, morphemes or words. However, human memory capacity has been demonstrated not to be as scarce a resource as was earlier believed (Goldinger 1996, 1998). It is therefore plausible to think that while abstract features may emerge from phonological patterns, lexical contrasts that do not happen to be involved in patterns can be maintained on a segment-to-segment or even morpheme-to-morpheme basis, with no further abstraction or reduction (Mielke 2008: 100).

With this selective and interpretive summary in mind, which is an oversimplification of Mielke's (2008) emergent feature model, I return to the neutralising Unstressed Vowel Shift patterns I have identified. In both Bulgarian and Turkish there is a phonetically natural class of open vowels (*ε (œ) a/ɑ ɔ*) and a class of closer vowels (*i (y) ə/ɯ u*). In East Bulgarian, all three open vowels undergo categorical and neutralising raising in unstressed position, as shown in (10.1).

$$\begin{array}{ccc} \varepsilon & \rightarrow & i \\ a & \rightarrow & \text{ə} \\ \text{ɔ} & \rightarrow & u \end{array} \Big/ \quad \begin{array}{c} \breve{\sigma} \\ | \\ \mathrm{N} \\ | \\ \_\_ \end{array} \qquad (10.1)$$

The phonetically natural class of open vowels has been phonologised into a phonologically active class, whose members undergo the same phonological process: each open vowel raises and merges with its close counterpart in the same environment (unstressed syllables). A distinctive feature has therefore emerged which both (*a*) defines the class—let us call it `[-high]`—as a whole, and (*b*) establishes a relation between each vowel in the class and a corresponding vowel from the set of remaining vowels, ¬ `[-high]` or `[+high]`. This is shown in (10.2):

$$\begin{array}{ll} (a) & \texttt{[-high]} = \{\varepsilon,\ \text{a},\ \text{ɔ}\} \\ (b) & \texttt{[-high]} : \texttt{[+high]} \quad = \quad \varepsilon : i = a : \text{ə} = \text{ɔ} : u \end{array} \qquad (10.2)$$

East Bulgarian Unstressed Vowel Shift can now be expressed as Rule (10.3), which references the abstract feature.

$$\texttt{[-high]} \rightarrow \texttt{[+high]} \;\Big/\; \underset{\underset{\underset{\breve{\sigma}}{|}}{\text{N}}}{\_\_} \qquad (10.3)$$

Historically, the East Bulgarian phonologically active class {ɛ, a, ɔ} may have been formed by the three vowels' raising at the same time, that is, the feature that defines the class may have emerged directly from sound change (Mielke 2008: 85). Alternatively, only one open vowel may have initially undergone neutralising Unstressed Vowel Shift, and the process may subsequently have spread to other open vowels by analogical extension based on a shared phonetic property, in which case the feature will have emerged through generalisation (ibid., 86ff). My data from the five dialects suggest that generalisation is the more likely route, and that phonologisation probably started from the raising of unstressed /ɔ/. In the bilingual varieties raising occurs only in /ɔ/, in West Bulgarian in both /ɔ/ and /a/, and in East Bulgarian in all three open vowels. Moreover, even in Istanbul Turkish, where Unstressed Vowel Shift is gradient and non-neutralising, the neutralisation ratio for unstressed /u–ɔ/ (33%) is markedly higher than the contrast lost in any other close–open pair (§ 6.2.2.3, p. 152). As I pointed out earlier, this is very probably due to phonetic factors: the more restricted vertical space available for height contrasts in back vowels results both in lower overall contrastiveness, and in a stronger tendency for open back vowels to raise under temporal pressure.

We find further support for the generalisation scenario in West Bulgarian. For all talkers in the sample, the Unstressed Shift of /ɔ/ is categorical, while with /a/ there are roughly equal numbers of categorical and gradient reducers, which indicates that not all speakers have extended the categorical process from /ɔ/ to /a/ at this point. For those who have, the feature `[-high]` has emerged, which has the properties shown in (10.4).

$$\begin{aligned} &(a) \quad \texttt{[-high]} = \{a, ɔ\} \\ &(b) \quad \texttt{[-high]} : \texttt{[+high]} \quad = \quad a : ə = ɔ : u \end{aligned} \qquad (10.4)$$

The phonological process of West Bulgarian categorical Unstressed Vowel Shift is now the same as in East Bulgarian, given in Rule (10.3) above. What is different is the membership of the phonologically active class `[-high]`: in West Bulgarian it does not include /ɛ/. Various factors may be involved in leaving West Bulgarian /ɛ/ out: there is a sufficient amount of articulatory space for a height contrast with /i/, the contrast is auditorily enhanced by the large discriminant weight (w) and symmetrical difference (Δ) of F_2' frequency (§ 4.2.1.3, p. 106), and the phoneme pair /i–ɛ/ has a high functional load in Bulgarian (§ 9.1.3.3, p. 212), to name the most obvious. Nonetheless, it may, hypothetically, be a matter of time before these factors are outweighed by analogy and the process is generalised to target West Bulgarian /ɛ/ as well. Indeed, some four decades ago Tilkov et al. (1982: 50–51) wrote that some vowel reduction was observed even in unstressed /ɛ/ in Standard Bulgarian, albeit of a smaller degree than in other open vowels. Today, as can be seen in Figure 10.1 (p. 273) and Figure 10.4 (p. 277), West Bulgarian /ɛ/ is conspicuously resistant to Unstressed Vowel Shift and neutralisation. It is highly likely that this is linked to sociolinguistic factors, more specifically that reduction of unstressed /ɛ/ to [i] is nowadays strongly stigmatised in West (and Standard) Bulgarian.

In Bilingual Turkish, only the open vowel which is most susceptible to Unstressed Vowel Shift, /ɔ/, is raised to a substantial and probably neutralising extent. The rule for Bilingual

Turkish neutralising reduction may therefore be expressed as shown in (10.5).

$$\text{ɔ} \rightarrow u \Big/ \begin{array}{c}\breve{\sigma}\\ |\\ \text{N}\\ |\\ \_\_\end{array} \qquad (10.5)$$

The process has not been generalised to other phonetically open vowels, which means that no phonologically active class has been formed and, arguably, that no distinctive feature has emerged. Of course, one could also speculate that Bilingual Turkish /ɔ/ is the sole member of a class, `[-high]` = {ɔ}. This analysis may seem expedient, since it would render the Bilingual Turkish rule identical to Rule (10.3) for East and West Bulgarian. However, such abstraction is not a logical necessity and would not be easily verifiable. Here I adopt the view that features emerge only from phonologically active classes and not from contrast alone. Lexical contrast can be realised by segment pairs, or indeed by morpheme or lexeme pairs.

Mielke (2008) extends the traditional morphophonological concept of analogy to apply it to the phonologisation of patterns on the basis of recognised phonetic similarity. There are two types of morphophonological analogy: analogical extension, also known as proportional analogy or four-part analogy, and analogical levelling. In extension a morpheme or allomorph is generalised from one paradigm to another which did not previously employ it. For example, the Old English noun *word* 'word' had the same form for the singular and the plural (in the nominative and accusative cases), and the Modern English plural *word**s*** is the result of generalising the *s*-plural marker from another noun class, as illustrated in (10.6).

$$\text{OE}\ \frac{\texttt{[sg]}}{\texttt{[pl]}} = \frac{\textit{stān}}{\textit{stānas}} = \frac{\textit{word}}{\textit{word}} \rightsquigarrow \text{ModE}\ \frac{\texttt{[sg]}}{\texttt{[pl]}} = \frac{\textit{stone}}{\textit{stones}} = \frac{\textit{word}}{\textit{word}\boldsymbol{s}} \qquad (10.6)$$

Mielke (2008) argues that phonological proportional analogy underpins the generalisation of phonological patterns. Applied to West Bulgarian data, one can say that the relation between ɔ and *u*, which was phonologised earlier in categorical Unstressed Vowel Shift, is now being extended to the pair *a*–ə, as shown in Analogical Change (10.7).

$$\frac{\text{ɔ}}{u} \begin{array}{c}\sim\\ \sim\end{array} \begin{array}{c}a\\ \text{ə}\end{array} \rightsquigarrow \frac{\text{ɔ}}{u} = \frac{a}{\text{ə}} = \frac{\texttt{[-high]}}{\texttt{[+high]}} \qquad (10.7)$$

There is a crucial difference between morphological and phonological proportional analogy. What is generalised in morphological analogy is a morph, in this case the *s*-plural morpheme: neither the grammatical category (number), nor the opposition of its terms (singular vs plural) emerge or are in any way affected by the process. The innovation that results from phonological analogy has more far-reaching systemic consequences. Before the generalisation (to the left of the $\rightsquigarrow$ arrow), there is a phonological relation ɔ : *u*, which has arisen from a neutralisation rule like (10.5), as well as a recognisable phonetic similarity ($\sim$) between each of the vowels in the neutralising relation (ɔ : *u*) and two other vowels (a, ə). The vowels of the second pair are fully contrastive with each other and are not in an alternating relation at this stage. The ɔ : *u* relation is then generalised ($\rightsquigarrow$) to the second pair: ɔ : *u* = a : ə. The earlier similarity has become categorical identity in terms of an abstract feature that has emerged from the generalisation. One more instance of proportional analogy is necessary to account for East Bulgarian Unstressed Vowel Shift: the pattern needs to be extended to the last vowel pair, *ε–i*. What is generalised this time is—one may argue—a pre-existing feature, as shown in Analogical Change (10.8). An interesting question for further research might be whether further extension becomes more likely once a feature has already emerged.

$$\frac{\texttt{[-high]}}{\texttt{[+high]}} = \frac{\text{ɔ}}{u} = \frac{\text{a}}{\text{ə}} \begin{matrix}\sim \\ \sim\end{matrix} \begin{matrix}\varepsilon \\ i\end{matrix} \quad \rightsquigarrow \quad \frac{\texttt{[-high]}}{\texttt{[+high]}} = \frac{\text{ɔ}}{u} = \frac{\text{a}}{\text{ə}} = \frac{\varepsilon}{i} \tag{10.8}$$

Whereas analogical extension operates *across* paradigms, analogical levelling (also termed paradigm levelling) occurs *within* a single paradigm: in morphological analogy it is a process that eliminates morphophonemic alternation or suppletion by generalising one of the originally alternating forms across the paradigm. The comparative and superlative forms of the English adjectives *long* and *old* were once *lenger–lengest* and *elder–eldest*, respectively. The vowel alternation was from a historical sound change (*i*-Umlaut), but the alternating stem-forms have now been levelled to the positive stems, hence present-day English *longer–longest* and *older–oldest*.[2] A more recent case of analogical levelling involves,

[2] *Elder* and *eldest* have survived longer, and are still used by a minority of speakers, but only in a restricted context: when referring to family members, e.g. *elder sister, eldest nephew* but not **elder man*, **eldest building*. The umlauted vowel is also fossilised in the noun *elder* and the adjective *elderly*.

somewhat ironically, the derivational pair *analogy* /əˈnælədʒi/ – *analogous* /əˈnæləgəs/. Under analogical influence from the noun, some speakers have now levelled the stem and say /əˈnælə**dʒ**əs/ for the adjective.

Just like proportional analogy, the morphological concept of analogical levelling, too, may be fruitfully applied in phonology. It is well-suited to account for the peculiar case of /u–ɔ/ merger in Bilingual Bulgarian. Contrast levels are low in both unstressed and stressed syllables but nonetheless higher in the latter. Bilingual Bulgarian neutralising /ɔ/-raising most probably first occurred only in unstressed position. The process was phonologised and became categorical; an [u]-like allophone came to be associated with unstressed syllables. Just as one of the alternating allomorphs, *long-*, has been generalised to all degrees of comparison (positive, comparative and superlative), one of the alternating allophones, [u], has been generalised to all positions (stressed and unstressed).

This completes my analysis and discussion of the experimental findings and cross-varietal comparisons presented in the preceding chapters. Five linguistic varieties have been closely examined in terms of levels and patterns of Unstressed Vowel Shift and height contrast neutralisation—two phenomena that I have demonstrated to be closely yet not trivially related. In this final section I have discussed the phonological implications of Unstressed Vowel Shift across the varieties, for which I have benefited from Mielke's (2008) arguments for emergent distinctive features. Using traditional universal features to formalise Unstressed Vowel Shift patterns results in phonological rules that target disparate combinations of distinctive features which are difficult to account for. By contrast, emergent features have made possible a consistent account of the varieties under study and have enabled me to identify further systematic similarities and differences. While Unstressed Vowel Shift is clearly present in Istanbul Turkish, it is neither very strong nor neutralising, which is why Istanbul Turkish was not addressed in this phonological discussion. The rest of the varieties, however, present a wide array of phonologisation routes. For various reasons discussed earlier, I have concluded that out of all vowels that differ primarily in phonetic openness, the pair [u–ɔ] are the most susceptible to merger under temporal pressure. In Bilingual Turkish, it is precisely and only unstressed /ɔ/ that raises and merges with /u/ in unstressed position. An abstract distinctive feature is not necessary in order to describe, maintain or neutralise this contrast. In Bilingual Bulgarian, the same merger—of /u/ and /ɔ/—is additionally very strong in stressed syllables as well, though not quite as strong as in unstressed position. I have argued that this can be explained as a case of phonological analogical levelling, in which the unstressed realisation of /ɔ/, i.e. [u], has become generalised across all environments. In West Bulgarian we find categorical, neutralising Unstressed Shift of /ɔ/ as well, but for half of the speakers in the sample, this process has been extended to another open vowel, /a/. West Bulgarian /ɔ/ and /a/, therefore, are part of a pattern and have thus formed a phonologically active class from which a distinctive feature has emerged. In East Bulgarian the pattern and associated feature have been further extended to another phonetically open vowel, /ɛ/, and as a result all open vowels are in the phonologically active class of vowels that merge with their phonetically closer counterparts in unstressed position. The incremental changes from one variety to the next shed new light on how Unstressed Vowel Shift is likely to have evolved.

The patterns that were revealed in this discussion are summarised in Table 10.2.

	Unstressed Vowel Shift process	`[-high]`	**Context**	**Analogy type**
East Bulgarian	`[-high]` → `[+high]`	{ɛ, a, ɔ}	$\breve{\sigma}$	Extension
West Bulgarian	`[-high]` → `[+high]`	{a, ɔ}	$\breve{\sigma}$	Extension
Bilingual Turkish	ɔ → *u*	N/A	$\breve{\sigma}$	N/A
Bilingual Bulgarian	ɔ → *u*	N/A	N/A	Levelling
Istanbul Turkish	(*gradient raising*)	N/A	N/A	N/A

Table 10.2: Phonological patterns of Unstressed Vowel Shift. **N/A** not applicable.

11
Conclusion

In this thesis I have presented an extensive acoustic examination of a range of phonetic and phonological phenomena traditionally referred to as, or associated with, unstressed vowel reduction. Five geographically contiguous or overlapping varieties of two typologically distinct and genealogically unrelated languages, Bulgarian and Turkish, have been investigated: two standard varieties, spoken in Sofia (West Bulgarian) and Istanbul (Istanbul Turkish), and three varieties from northeast Bulgaria: monolingual Bulgarian (East Bulgarian), as well as the Bulgarian and Turkish speech of a bilingual community from the same area (Bilingual Bulgarian and Bilingual Turkish, respectively).

A received view that Standard Bulgarian high vowels undergo lowering when unstressed has been definitively disproved (previously by Andreeva et al. 2013; Sabev 2015; Dokovova et al. 2019). Another long-standing claim that has beed refuted, to the best of my knowledge for the first time, is that Bulgarian unstressed vowels are more open in immediately pretonic syllables than elsewhere: I have found *more* spectral and durational reduction there, not less. The traditional view echoes a two-level vowel reduction system standardly reported for Russian, where a penultimately stressed four-syllable word would have a sonority-sequenced, single-peak prominence profile, x X X́ x, while my findings reveal a more punctuated, low-level ‘trochaic’ pattern in Bulgarian: X x X́ X.

From the very outset (§ 1.4), I have deconstructed the traditional notion of ‘unstressed vowel reduction’ into three causally related but ontologically distinct phenomena:

i. Unstressed Vowel Shift,

ii. categorical target split (vs gradient undershoot),

iii. contrast neutralisation.

Vowels have been modelled as trivariate objects consisting of duration, F_1 and F_2 frequency, and Unstressed Vowel Shift (**i.**) has therefore been conceptualised as a multivariate difference in variance between the three-dimensional stressed and unstressed clouds of data points for each vowel phoneme in each variety. This has been measured using the Pillai statistic (Λ) of a standard one-way MANOVA test: Unstressed Vowel Shift $= \Lambda(\acute{V},\check{V})$. The Pillai score has been used increasingly frequently in phonetic and sociophonetic vowel comparisons, and it has proved highly advantageous to this study as well. I have used a number of follow-up statistical procedures to gain further insight into the workings of Unstressed Vowel Shift: discriminant function analysis has been instrumental in measuring the relative contribution of duration, F_1 and F_2 frequency. Further analysis of the individual acoustic parameters has relied on probability density estimates (PDE), and the quantification and visual assessment of PDE overlap.

The contrastiveness of close and open vowels has been quantified by the same methods as those employed to compare stressed and unstressed allophones in the analysis of Unstressed Vowel Shift: Pillai’s trace, discriminant function analysis and proportion of univariate PDE overlap. I have proposed an innovative approach to the study of vowel merger, abandoning the widespread practice of equating merger with the proportion of overlap of vowel distributions, however measured. I have demonstrated that even the canonical realisations of two adjacent vowel phonemes, as represented by the distributions of their stressed realisations, will exhibit some amount of overlap. I have further argued that such canonical overlap is to be interpreted as a tolerance threshold, as it were, which should be factored into any consideration of contrast loss, or neutralisation. I have therefore defined and measured contrast neutralisation (**iii.** above) as the proportion of contrast that is lost in unstressed position, relative to canonical (or stressed) contrastiveness: Neutralisation $= \frac{\acute{\Lambda}_h - \breve{\Lambda}_h}{\acute{\Lambda}_h}$, where Λ_h denotes the Pillai score for a height-contrasting vowel pair: $\Lambda_h = \Lambda(V_c, V_o)$. Contrast and contrast neutralisation are, however, concepts that are inextricably linked not only to speech production, but also to speech perception. This acoustic investigation will not, therefore, be complete without matching perceptual studies, which remain important avenues for future research.

The second component of my breakdown of unstressed vowel reduction, i.e. the distinction between categorical and gradient Unstressed Vowel Shift (**ii.** above), has admittedly been the most elusive to quantify. Correlation analysis of duration and F_1 frequency can be useful in establishing gradience within stress-conditioned vowel allophones. It cannot be extended across such allophones, however, as distributions will be distinctly bimodal. I have instead based my estimation of gradience on Lindblom's (1963) model of spectral undershoot and suggested that a separate unstressed target is likely to be in place whenever the mean observed F_1 frequency of an unstressed open vowel is less than the frequency predicted as a result of undershoot. More production data, varied for duration within stress conditions, however, is necessary to assess this procedure.

I have demonstrated that Unstressed Vowel Shift, categorical target split and neutralisation are distinct aspects of the traditional concept of unstressed vowel reduction: Unstressed Vowel Shift may, but does not have to, result in the phonologisation of a separate unstressed target, which in turn may, but again does not have to, merge with the target of another vowel phoneme. The three processes tend to be conflated into a single 'reduction' phenomenon because of their implicational interdependence, and therefore apparent co-occurrence, as well as the scarcity of detailed chronological data from historical change. Whenever synchronic examination is possible, however, each should be addressed in its own right.

Vowel duration and F_1 frequency have proved to be robust acoustic correlates for word stress in all five varieties. Unstressed duration is shorter for all vowels, while unstressed F_1 frequency is lower in non-close vowels. In monolingual Bulgarian speech, whether from the East or the West, spectral reduction is more prominent than durational reduction, whereas in monolingual Turkish and both bilingual varieties, duration plays a more important role in indicating stress than F_1 frequency. In terms of mean Unstressed Vowel Shift scores, the five varieties are ranked are follows: East Bulgarian > West Bulgarian , Bilingual Turkish > Istanbul Turkish > Bilingual Bulgarian. What is unexpected is that the lowest level of reduction is found in Bilingual Bulgarian—lower than in both Bilingual and Istanbul Turkish—whereas Bilingual Turkish scores higher than Istanbul Turkish. In other words, Bilingual Bulgarian exhibits under-reduction and Bilingual Turkish over-reduction compared to the monolingual varieties.

I have argued that these peculiar reduction levels found in the bilingual varieties are due to intricate transfer patterns. Bilingual Turkish stressed vowel quality bears a striking resemblance to that of East Bulgarian vowels: spectral properties are practically identical, which is indicative of transfer from the monolingual variety. Bilingual Bulgarian vowel qualities are close enough to those in Bilingual Turkish to assume identical stressed targets in the bilinguals' phonologies. Bilingual Bulgarian reduction, however, is very weak, which points to a powerful Turkish substratum, a vestige of a once Turkish-dominated phonology, which has now been obliterated by cross-*linguistic* transfer, hence the approximation of Bilingual Turkish to East Bulgarian, but has resisted cross-*dialectal* influence, as evidenced in the clear differentiation between Bilingual Bulgarian and East Bulgarian. Resistance to external influence from ambient monolingual Bulgarian may be construed as an identity preservation strategy, which appears to be effective within a language, that is, resistance is in place with regard to transfer from ambient to own Bulgarian. There is little resistance, however, to transfer from ambient Bulgarian to own Turkish. This situation has important wider implications: it points to a considerably stronger intralinguistic (i.e. cross-varietal) than cross-linguistic sensitivity to variation. In other words, differences that are readily detected across closely related linguistic varieties are more elusive across cognitively more remote varieties.

We are thus not dealing with wholesale borrowing, but rather with two layers of cross-linguistic transfer. In the first, segmental properties (vowel quality) have been borrowed from ambient East Bulgarian into the bilingual varieties. In addition, East Bulgarian also affects Bilingual Turkish prosodically, which is evidenced in intensified vowel reduction. The second layer is that of a Turkish prosodic substrate which exerts influence on Bilingual Bulgarian. As a result, Bilingual Bulgarian has vowel targets that are very close to those of East Bulgarian, to which, however, Bilingual Bulgarian phonology applies its own form of unstressed vowel reduction.

Insights from language contact have often challenged received typological views and this study is no exception. It has been claimed, for example, that unstressed vowel reduction is incompatible with pitch accent, 'syllable-timing' and vowel harmony. Turkish has been associated with all of these features, and yet the dialect spoken by the Turkish community of Bulgaria exhibits considerable unstressed vowel reduction. For the majority of this thesis, I have treated Unstressed Vowel Shift and neutralisation as gradient properties. My findings further suggest that typological distinctions, too, may be more efficient if construed as scalar variables. The study of the bilingual varieties has yielded insights into the typological significance of vowel reduction that would have been overlooked had the investigation been based on monolingual varieties alone. Strict typological boundaries are eroded in bilingualism, as any linguistic feature can be transferred from any language to any other language, given a sufficient intensity of language contact (Thomason and Kaufman 1988).

In recent experimental work it has been argued that Bulgarian unstressed /ɔ/ and /u/ have undergone complete merger (Andreeva et al. 2013; Sabev 2015). This has been challenged by my discovery of certain patterns of unstressed /u/-fronting in the Bulgarian dialects. If a process targets unstressed /u/ but not /ɔ/, then the merger cannot have been complete. The fronting may in fact be the result of a push chain triggered precisely to avoid unstressed /u–ɔ/ merger. Further research into the matter is likely to shed more light on this particular type of near-merger, which may appear to be acoustically complete, unless and until a subsequent change reveals that the contrast was not completely lost in the first place.

Finally, the variation within and across the varieties I have studied provides ample support for a theory of emergent phonological features, such as that proposed by Mielke (2008). It is natural to expect that the same phonological rule (e.g. `[-high]` → `[+high]`) is active in all Bulgarian dialects. That would mean, however, that the rule targets different sets of segments across the varieties, to the exclusion of other segments, shown in brackets in (11.1):

Bilingual Bulgarian	ɔ	(ɛ a)	
West Bulgarian	a ɔ	(ɛ)	(11.1)
East Bulgarian	ɛ a ɔ	( )	

This is an indication that there is a problem with either (*a*) postulating the same rule, or (*b*) assuming that matching segments are underlyingly represented as the same feature bundles in all three varieties. Traditional feature theories would forgo having a unified rule, and would have no choice but to posit separate rules for each variety. The rules would have different feature combinations for the input, so that the right segment sets can be targeted. However, I have demonstrated that the same processes are in operation in all varieties: phonetically non-close vowels will raise when unstressed, although not all raised realisations are phonologised. The issue can be resolved by abandoning the assumption stated in (*b*) and accepting that a feature such as `[±high]` will only emerge in a phonology when and if it is needed to generalise over a set of segments that are identically involved in a phonological process. The Bilingual Bulgarian phonological rule will then be ɔ → *u*. This is indeed a raising process, but since it phonologically affects only one target vowel, /ɔ/, no abstract feature is necessary at this stage, for—despite earlier assumptions to the contrary—human memory has enough capacity to handle contrast on a phoneme-to-phoneme or even morpheme-to-morpheme scale. Bilingual Bulgarian /ɛ, a, ɔ/ do not form a natural class by virtue of sharing a feature like `[-high]`, as they are not uniformly targeted by the reduction rule. In West Bulgarian, on the other hand, the raising process affects both /ɔ/ and /a/ in the same way, which means that, in that dialect, abstraction in the form of a shared distinctive feature, such as `[-high]`, is required in order for the vowels to be targeted by a single rule. In East Bulgarian the class defined by `[-high]` is extended to include /ɛ/ as well, and thus the same rule targets all three open vowels. I have argued that it is likely that Bilingual, West and East Bulgarian represent three stages in the development of the same phonological rule: it started with the phonologisation of a separate unstressed target for /ɔ/, as a result of regular gradient Unstressed Vowel Shift; this new unstressed target eventually merged with the target for /u/. The rule was then extended by analogy based on phonetic similarity to East and West Bulgarian /a/, and then also to East Bulgarian /ɛ/.

This study has answered many questions, some of which were not originally asked, but it has also fallen short of finding conclusive solutions to certain problems, and has raised a host of new questions that are yet to be addressed in future research. The approach to contrast neutralisation I have adopted here needs to be complemented by perceptual data, so that perceptual thresholds are identified across varieties and compared with acoustic contrast scores and neutralisation ratios. Distinguishing between gradient and categorical unstressed vowel reduction remains a challenge; more insight is likely to come from closer examinations of how acoustic vowel parameters interact with speech rate. Eastern and western Bulgarian dialects are part of a wider South Slavonic dialect continuum on which vowel reduction is believed to increase from West to East. Extending this study to more westerly Slavonic varieties would, therefore, be a promising source of further insight. The most acute need for further research, however, is into the bilingual Turkish and Bulgarian varieties. Linguistic change is particularly fast-paced in them, and at present there are spectacular intergenerational differences to be recorded. The study of vowel reduction in the context of language contact, both in general and specifically in the Balkan Sprachbund, would benefit further from examining the speech of other bilingual communities, such as the those of bilingual or multilingual speakers of any of the South Slavonic languages, Romanian, Greek, Albanian, Romani and Turkish. In addition to all these and many other worthwhile paths for future research, there are variables that I have left out of this study which are no less central to unstressed vowel reduction, the most obvious being other acoustic correlates of linguistic stress, such as intensity and the fundamental frequency.

I have presented a detailed and multifaceted acoustic investigation of the spectral and durational properties of stressed and unstressed vowels in five linguistic varieties. The study provides an up-to-date account of unstressed vowel reduction in present-day Bulgarian and Turkish. A number of established claims and assumptions have been disproved and numerous new discoveries have been made. I have developed a methodology to examine separately three distinct processes that are frequently conflated as 'vowel reduction': unstressed vowel shift, unstressed target phonologisation and contrast neutralisation. A new approach to vowel merger has been applied, which takes into account the amount of phoneme overlap already present in stressed position. I have also demonstrated that the continuous output variables which quantify reduction and merger can be fruitfully discretised into linguistically meaningful categories by assessing the accuracy of a classification algorithm that uses the same input variables as the continuous metrics. The methods applied in this thesis are transferrable to any study of vowel reduction and merger, as they have proved efficient both in detecting fine variation and in identifying general patterns. The bilingual varieties of Turkish and Bulgarian are severely understudied, and this comprehensive acoustic investigation of their vowel systems fills an important gap in the literature. Intricate multi-layered patterns of cross-linguistic transfer have been revealed in Bilingual Turkish and Bulgarian, which have implications for both contact linguistics and language typology. It has once again been demonstrated that intense language contact can readily obscure typological boundaries. Considerable variation has been observed both within and across the five varieties, and yet overarching principles that underlie vowel reduction in all of them have been identified. Variation and invariant properties are notoriously difficult to reconcile in a framework of universal distinctive features, and my observations and analyses have lent support to emergent features, which, rather than giving rise to phonological processes, are abstracted from them. My findings have also shed new light on the long-standing issue of whether distinctive features are endowed with absolute or with relational invariance (the Chomskyan and the Jakobsonian views). The reduction patterns I have observed—in all of which lower vowels are raised regardless of their precise phonetic height, while higher vowels are unaffected even when not phonetically high—argue strongly in favour of a more relativistic approach to distinctive features.

Appendices

A
Target words

Contents

The target items used in each experiment are listed below, in phonemic IPA transcription. The sections on East Bulgarian, Bilingual Bulgarian, Istanbul Turkish and Bilingual Turkish (A.2–A.4), where both real and nonsense words were elicited, also provide comparisons of F_1' frequencies of vowels in the two types of target items.

A.1 West Bulgarian

Nonsense words

Basic set (4 elicitations per word)

pipiˈpipip
pɛpɛˈpɛpɛp
pəpəˈpəpəp
papaˈpapap
pupuˈpupup
pɔpɔˈpɔpɔp

Subsidiary sets (2 elicitations per word)

a. C_1 & C_5 = ∅	***b.*** C = /b/	***c.*** C = /f/	***d.*** C = /t/	***e.*** C = /k/
ipiˈpipi	bibiˈbibib	fifiˈfifif	titiˈtitit	kikiˈkikik
ɛpɛˈpɛpɛ	bɛbɛˈbɛbɛb	fɛfɛˈfɛfɛf	tɛtɛˈtɛtɛt	kɛkɛˈkɛkɛk
əpəˈpəpə	bəbəˈbəbəb	fəfəˈfəfəf	tətəˈtətət	kəkəˈkəkək
apaˈpapa	babaˈbabab	fafaˈfafaf	tataˈtatat	kakaˈkakak
upuˈpupu	bubuˈbubub	fufuˈfufuf	tutuˈtutut	kukuˈkukuk
ɔpɔˈpɔpɔ	bɔbɔˈbɔbɔb	fɔfɔˈfɔfɔf	tɔtɔˈtɔtɔt	kɔkɔˈkɔkɔk

A.2 East Bulgarian and Bilingual Bulgarian

6 elicitations per word, for all words.

Nonsense words

pipiˈpipip
pɛpɛˈpɛpɛp
pəpəˈpəpəp
papaˈpapap
pupuˈpupup
pɔpɔˈpɔpɔp

Real words

Stressed		**Pretonic**		**Post-tonic**	
ˈp**i**k	*peak*	b**i**ˈdɔn	*canister*	ˈkrɛd**i**t	*credit*
ˈp**ɛ**k	*heat*	b**ɛ**ˈtɔn	*concrete*	ˈdɛv**ɛ**t	*nine*
ˈp**ə**k	*but*	v**ə**ˈrjə	*to walk*	ˈsvɛk**ə**r	*father-in-law*
ˈp**a**k	*again*	v**a**ˈrjə	*to boil*	ˈdɛk**a**r	*decare*
ˈp**u**kəm	*to pop*	d**u**ˈʃa	*soul*	ˈstat**u**s	*status*
ˈp**ɔ**kriv	*roof*	d**ɔ**ˈʃtja	*to fancy*-AOR	ˈljat**ɔ**s	*in the summer*

Real–nonsense word comparisons

East Bulgarian

	Stressed σ		ℝ:pretonic – ℕ:σ_1		ℝ:pretonic – ℕ:σ_2		Final unstressed σ	
	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.1369	n.s.	0.4216	n.s.	0.2763	n.s.	0.5193	n.s.
/ɛ/	0.4089	n.s.	0.6191	n.s.	0.3132	n.s.	0.1332	n.s.
/ə/	0.4781	n.s.	0.4313	n.s.	0.0172	*	0.1197	n.s.
/a/	0.4663	n.s.	0.0541	n.s.	0.0049	**	0.0734	n.s.
/u/	0.5796	n.s.	0.2774	n.s.	0.0450	*	0.2906	n.s.
/ɔ/	0.0618	n.s.	0.0713	n.s.	0.0778	n.s.	0.3111	n.s.

Table A.1: Comparison of F_1' in East Bulgarian real (ℝ) and nonsense (ℕ) word vowels (dependent t-tests).
σ syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

Bilingual Bulgarian

	Stressed σ		ℝ:pretonic – ℕ:σ_1		ℝ:pretonic – ℕ:σ_2		Final unstressed σ	
	p	sig.	p	sig.	p	sig.	p	sig.
/i/	0.1334	n.s.	0.6290	n.s.	0.3567	n.s.	0.4736	n.s.
/ɛ/	0.1025	n.s.	0.4743	n.s.	0.0536	n.s.	0.2128	n.s.
/ə/	0.2363	n.s.	0.2248	n.s.	0.0428	*	0.0615	n.s.
/a/	0.0416	*	0.6029	n.s.	0.0309	*	0.1134	n.s.
/u/	0.0604	n.s.	0.5976	n.s.	0.1418	n.s.	0.2931	n.s.
/ɔ/	0.5146	n.s.	0.0457	*	0.2236	n.s.	0.1996	n.s.

Table A.2: Comparison of F_1' in Bilingual Bulgarian real (ℝ) and nonsense (ℕ) word vowels (dependent t-tests).
σ syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

A.3 Istanbul Turkish

Nonsense words

Basic set (2 elicitations per word)

pipiˈpiplɛ
pɛpɛˈpɛplɛ
pypyˈpyplɛ
pœpœˈpœplɛ
pɯpɯˈpɯplɑ
pɑpɑˈpɑplɑ
pupuˈpuplɑ
pɔpɔˈpɔplɑ

Subsidiary sets (1 elicitation per word)

a. $C_1 = \varnothing$	***b.*** C = /b/	***c.*** C = /f/	***d.*** C = /t/	***e.*** C = /k/
ipiˈpiplɛ	bibiˈbiblɛ	fifiˈfiflɛ	titiˈtitlɛ	kikiˈkiklɛ
ɛpɛˈpɛplɛ	bɛbɛˈbɛblɛ	fɛfɛˈfɛflɛ	tɛtɛˈtɛtlɛ	kɛkɛˈkɛklɛ
ypyˈpyplɛ	bybyˈbyblɛ	fyfyˈfyflɛ	tytyˈtytlɛ	kykyˈkyklɛ
œpœˈpœplɛ	bœbœˈbœblɛ	fœfœˈfœflɛ	tœtœˈtœtlɛ	kœkœˈkœklɛ
ɯpɯˈpɯplɑ	bɯbɯˈbɯblɑ	fɯfɯˈfɯflɑ	tɯtɯˈtɯtlɑ	kɯkɯˈkɯklɑ
ɑpɑˈpɑplɑ	bɑbɑˈbɑblɑ	fɑfɑˈfɑflɑ	tɑtɑˈtɑtlɑ	kɑkɑˈkɑklɑ
upuˈpuplɑ	bubuˈbublɑ	fufuˈfuflɑ	tutuˈtutlɑ	kukuˈkuklɑ
ɔpɔˈpɔplɑ	bɔbɔˈbɔblɑ	fɔfɔˈfɔflɑ	tɔtɔˈtɔtlɑ	kɔkɔˈkɔklɑ

Real words (2 elicitations per word)

Stressed		**Unstressed**	
ˈs**i**s	*fog*	s**i**slɛˈɾinlɛ	(*fog*-PL-POSS.2.SG-INST) 'with your fogs'
ˈs**ɛ**s	*sound*	s**ɛ**slɛˈɾinlɛ	(as above) 'with your sounds'
ˈg**y**l	*rose*	g**y**llɛˈɾinlɛ	
ˈg**œ**l	*lake*	g**œ**llɛˈɾinlɛ	
ˈk**ɯ**z	*girl*	k**ɯ**zlɑˈɾɯnlɑ	
ˈk**ɑ**z	*goose*	k**ɑ**zlɑˈɾɯnlɑ	
ˈt**u**z	*salt*	t**u**zlɑˈɾɯnlɑ	
ˈt**ɔ**z	*powder*	t**ɔ**zlɑˈɾɯnlɑ	

Real–nonsense word comparisons

	Stressed σ		Unstressed σ	
	p	sig.	*p*	sig.
/i/	0.1952	n.s.	0.0672	n.s.
/ɛ/	0.0487	*	0.0773	n.s.
/y/	0.2536	n.s.	0.2295	n.s.
/œ/	0.1366	n.s.	0.1908	n.s.
/ɯ/	0.03181	*	0.2301	n.s.
/ɑ/	0.0183	*	0.0880	n.s.
/u/	0.2283	n.s.	0.0483	*
/ɔ/	0.0863	n.s.	0.3421	n.s.

Table A.3: Comparison of Istanbul Turkish real and nonsense word vowels (independent *t*-tests). **σ** syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

A.4 Bilingual Turkish

6 elicitations per word, for all words.

Nonsense words

pipiˈpiplɛ
pɛpɛˈpɛplɛ
pypyˈpyplɛ
pœpœˈpœplɛ
pɯpɯˈpɯplɑ
pɑpɑˈpɑplɑ
pupuˈpuplɑ
pɔpɔˈpɔplɑ

Real words

The same real words as in Istanbul Turkish (A.3 above).

Real–nonsense word comparisons

	Stressed σ		Unstressed σ	
	p	sig.	p	sig.
/i/	0.4474	n.s.	0.0988	n.s.
/ɛ/	0.1286	n.s.	0.0867	n.s.
/y/	0.7888	n.s.	0.1352	n.s.
/œ/	0.4340	n.s.	0.1063	n.s.
/ɯ/	0.6126	n.s.	0.0358	*
/ɑ/	0.8839	n.s.	0.0625	n.s.
/u/	0.0683	n.s.	0.1925	n.s.
/ɔ/	0.3859	n.s.	0.4248	n.s.

Table A.4: Comparison of F_1' in Bilingual Turkish real and nonsense word vowels (dependent t-tests).
σ syllable; **sig.** significance level: ******* $p \leq 0.001$, ****** $p \leq 0.01$, ***** $p \leq 0.05$, **n.s.** $p > 0.05$.

B

Comparisons of probability density estimates

Contents

B.1 Summary of results

Tables B.1 and B.2 list the PDE comparison results for individual acoustic parameters and the overall Pillai scores for all varieties.

B.1.1 Stressed–unstressed vowels

		Duration			F_1' frequency			F_2' frequency			**UVS**
		p	Δ	w	p	Δ	w	p	Δ	w	(Λ)
WB	/i/	0.000	0.477	1.000	0.000	0.360	0.000	0.099	0.182	0.000	0.075
	/ɛ/	0.000	0.678	0.612	0.000	0.584	0.388	0.000	0.313	0.000	0.313
	/ə/	0.000	0.515	1.000	0.000	0.256	0.000	0.173	0.157	0.000	0.138
	/a/	0.000	0.766	0.328	0.000	0.851	0.672	0.000	0.478	0.000	0.641
	/u/	0.000	0.418	0.625	0.000	0.377	0.000	0.000	0.406	0.375	0.099
	/ɔ/	0.000	0.744	0.378	0.000	0.785	0.622	0.000	0.432	0.000	0.516
EB	/i/	0.007	0.359	0.762	0.121	0.279	0.000	0.011	0.366	0.238	0.009
	/ɛ/	0.000	0.855	0.407	0.000	0.929	0.593	0.404	0.235	0.000	0.814
	/ə/	0.312	0.227	0.195	0.031	0.315	0.333	0.531	0.183	0.472	0.041
	/a/	0.000	0.834	0.211	0.000	0.841	0.789	0.000	0.642	0.000	0.676
	/u/	0.451	0.287	0.000	0.003	0.407	0.542	0.136	0.299	0.458	0.045
	/ɔ/	0.000	0.752	0.498	0.000	0.639	0.502	0.000	0.456	0.000	0.405
IT	/i/	0.002	0.307	0.797	0.263	0.203	0.203	0.597	0.152	0.000	0.057
	/ɛ/	0.000	0.611	0.787	0.000	0.403	0.213	0.055	0.286	0.000	0.251
	/y/	0.004	0.299	0.326	0.088	0.237	0.000	0.000	0.383	0.674	0.128
	/œ/	0.000	0.634	0.641	0.000	0.537	0.359	0.000	0.367	0.000	0.368
	/ɯ/	0.003	0.325	0.655	0.420	0.158	0.000	0.006	0.343	0.345	0.069
	/ɑ/	0.000	0.739	0.521	0.000	0.649	0.479	0.066	0.221	0.000	0.455
	/u/	0.000	0.375	1.000	0.572	0.163	0.000	0.000	0.365	0.000	0.076
	/ɔ/	0.000	0.613	0.705	0.000	0.431	0.295	0.444	0.173	0.000	0.294
BB	/i/	0.000	0.364	0.804	0.070	0.155	0.000	0.593	0.127	0.196	0.041
	/ɛ/	0.000	0.592	1.000	0.013	0.228	0.000	0.011	0.230	0.000	0.200
	/ə/	0.096	0.176	0.000	0.006	0.270	1.000	0.000	0.260	0.000	0.017
	/a/	0.000	0.651	0.608	0.000	0.586	0.392	0.000	0.379	0.000	0.313
	/u/	0.002	0.286	0.221	0.111	0.213	0.000	0.000	0.368	0.779	0.059
	/ɔ/	0.000	0.585	0.773	0.000	0.417	0.227	0.000	0.397	0.000	0.247
BT	/i/	0.006	0.343	0.636	0.261	0.213	0.364	0.117	0.234	0.000	0.033
	/ɛ/	0.000	0.806	0.782	0.000	0.567	0.218	0.159	0.209	0.000	0.472
	/y/	0.007	0.347	0.339	0.000	0.426	0.661	0.103	0.235	0.000	0.125
	/œ/	0.000	0.794	0.650	0.000	0.595	0.350	0.406	0.182	0.000	0.514
	/ɯ/	0.000	0.490	0.821	0.000	0.383	0.179	0.380	0.198	0.000	0.177
	/ɑ/	0.000	0.866	1.000	0.000	0.635	0.000	0.000	0.471	0.000	0.610
	/u/	0.001	0.385	0.459	0.044	0.300	0.000	0.000	0.449	0.541	0.158
	/ɔ/	0.000	0.802	1.000	0.000	0.483	0.000	0.180	0.223	0.000	0.506

Table B.1: Unstressed Vowel Shift (UVS): PDE comparisons. $\boldsymbol{\Delta}$ symmetric difference between S/U PDEs ($\Delta = 1 - \eta$); $\boldsymbol{w}$ adjusted PDRC (discriminant importance); $\boldsymbol{\Lambda}$ Pillai score.
BB Bilingual Bulgarian, **BT** Bilingual Turkish, **EB** East Bulgarian, **IT** Istanbul Turkish, **WB** West Bulgarian.

B.1.2 Open–close vowels

		Duration			F_1' frequency			F_2' frequency			**Contrast**	
		p	Δ	w	p	Δ	w	p	Δ	w	Λ	Loss
WB	í, ɛ́	0.019	0.243	0.000	0.000	0.884	0.653	0.000	0.761	0.347	0.729	
	ĭ, ɛ̆	0.000	0.186	0.000	0.000	0.834	0.480	0.000	0.846	0.520	0.713	0.022
	ə́, á	0.000	0.493	0.000	0.000	0.963	1.000	0.000	0.494	0.000	0.776	
	ə̆, ă	0.955	0.063	0.000	0.000	0.698	1.000	0.000	0.346	0.000	0.389	0.498
	ú, ɔ́	0.000	0.424	0.000	0.000	0.756	1.000	0.000	0.651	0.000	0.513	
	ŭ, ɔ̆	0.015	0.174	0.000	0.000	0.342	0.632	0.000	0.331	0.368	0.111	0.784
EB	í, ɛ́	0.000	0.683	0.327	0.000	0.953	0.673	0.023	0.371	0.000	0.858	
	ĭ, ɛ̆	0.000	0.415	0.533	0.000	0.401	0.467	0.942	0.127	0.000	0.042	0.951
	ə́, á	0.000	0.777	0.196	0.000	0.880	0.804	0.000	0.633	0.000	0.726	
	ə̆, ă	0.245	0.216	0.000	0.007	0.315	1.000	0.912	0.137	0.000	0.004	0.994
	ú, ɔ́	0.000	0.597	0.327	0.000	0.665	0.673	0.000	0.538	0.000	0.482	
	ŭ, ɔ̆	0.006	0.362	0.000	0.000	0.416	0.570	0.001	0.357	0.430	0.145	0.698
IT	í, ɛ́	0.000	0.606	0.000	0.000	0.907	0.799	0.000	0.673	0.201	0.702	
	ĭ, ɛ̆	0.000	0.317	0.000	0.000	0.886	0.826	0.000	0.641	0.174	0.674	0.040
	ý, œ́	0.000	0.641	0.000	0.000	0.857	1.000	0.000	0.522	0.000	0.621	
	y̆, œ̆	0.000	0.403	0.000	0.000	0.811	0.714	0.000	0.546	0.286	0.557	0.103
	ɯ́, á	0.000	0.706	0.000	0.000	0.954	1.000	0.001	0.376	0.000	0.773	
	ɯ̆, ă	0.000	0.465	0.000	0.000	0.888	1.000	0.134	0.202	0.000	0.656	0.151
	ú, ɔ́	0.000	0.542	0.000	0.000	0.806	1.000	0.003	0.366	0.000	0.516	
	ŭ, ɔ̆	0.000	0.373	0.000	0.000	0.648	1.000	0.004	0.280	0.000	0.345	0.331
BB	í, ɛ́	0.000	0.618	0.367	0.000	0.928	0.633	0.000	0.497	0.000	0.807	
	ĭ, ɛ̆	0.000	0.417	0.000	0.000	0.846	0.772	0.000	0.639	0.228	0.645	0.200
	ə́, á	0.000	0.712	0.191	0.000	0.938	0.809	0.000	0.568	0.000	0.715	
	ə̆, ă	0.000	0.284	0.000	0.000	0.793	1.000	0.000	0.356	0.000	0.462	0.354
	ú, ɔ́	0.000	0.601	0.590	0.000	0.562	0.410	0.000	0.499	0.000	0.355	
	ŭ, ɔ̆	0.000	0.237	0.000	0.000	0.513	0.412	0.000	0.512	0.588	0.211	0.406
BT	í, ɛ́	0.000	0.810	0.258	0.000	0.924	0.742	0.000	0.436	0.000	0.808	
	ĭ, ɛ̆	0.000	0.460	0.000	0.000	0.883	0.781	0.000	0.544	0.219	0.671	0.169
	ý, œ́	0.000	0.744	0.283	0.000	0.857	0.509	0.000	0.489	0.208	0.734	
	y̆, œ̆	0.000	0.384	0.000	0.000	0.855	0.676	0.000	0.608	0.324	0.638	0.131
	ɯ́, á	0.000	0.771	0.242	0.000	0.924	0.758	0.000	0.479	0.000	0.726	
	ɯ̆, ă	0.000	0.556	0.000	0.000	0.850	1.000	0.003	0.264	0.000	0.546	0.249
	ú, ɔ́	0.000	0.719	0.463	0.000	0.752	0.537	0.000	0.497	0.000	0.566	
	ŭ, ɔ̆	0.000	0.312	0.000	0.000	0.443	0.250	0.000	0.525	0.750	0.209	0.630
	ú, œ́	0.000	0.740	0.183	0.000	0.379	0.000	0.000	0.973	0.817	0.812	
	ŭ, œ̆	0.000	0.379	0.000	0.000	0.477	0.271	0.000	0.849	0.729	0.413	0.491

Table B.2: Contrast and Neutralisation: PDE comparisons. $\boldsymbol{\Delta}$ symmetric difference between O/C PDEs ($\Delta = 1 - \eta$); $\boldsymbol{w}$ adjusted PDRC (discriminant importance); $\boldsymbol{\Lambda}$ Pillai score; **Loss** proportion of contrast lost, i.e. Neutralisation ($= \frac{\acute{\Lambda} - \breve{\Lambda}}{\acute{\Lambda}}$).
BB Bilingual Bulgarian, **BT** Bilingual Turkish, **EB** East Bulgarian, **IT** Istanbul Turkish, **WB** West Bulgarian.

B.2 PDEs and reference bands

The diagrams below plot each two PDEs under comparison along with a superimposed reference band that is two standard errors in width and is centred at the mean density of the two curves (Bowman and Azzalini 1997: 110). The band is designed to contain both curves within its bounds whenever the two PDEs are not significantly different.

B.2.1 West Bulgarian stressed–unstressed vowels

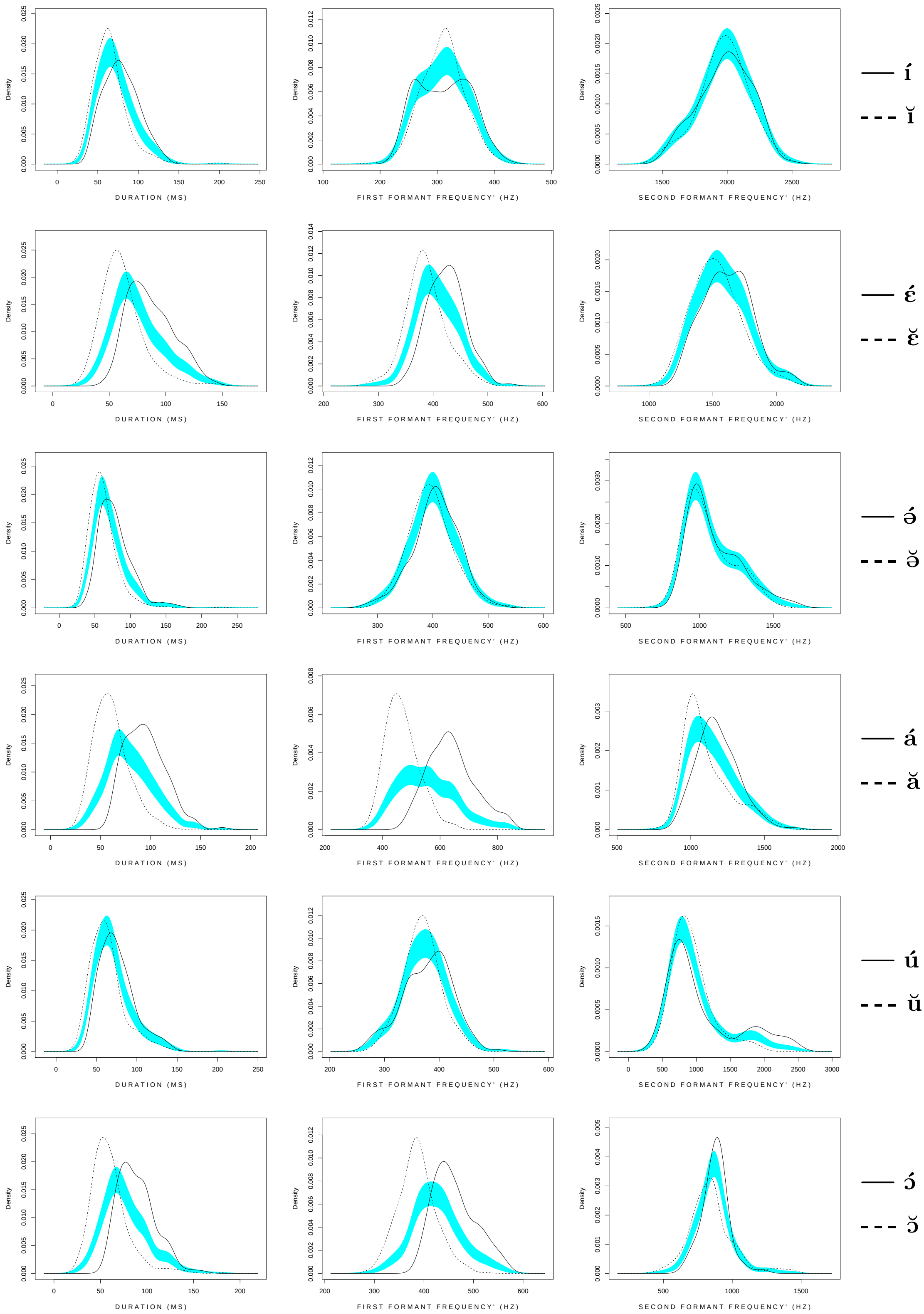


Figure B.1: PDEs and reference bands for West Bulgarian S/U vowels.

B.2.2 West Bulgarian open–close vowels

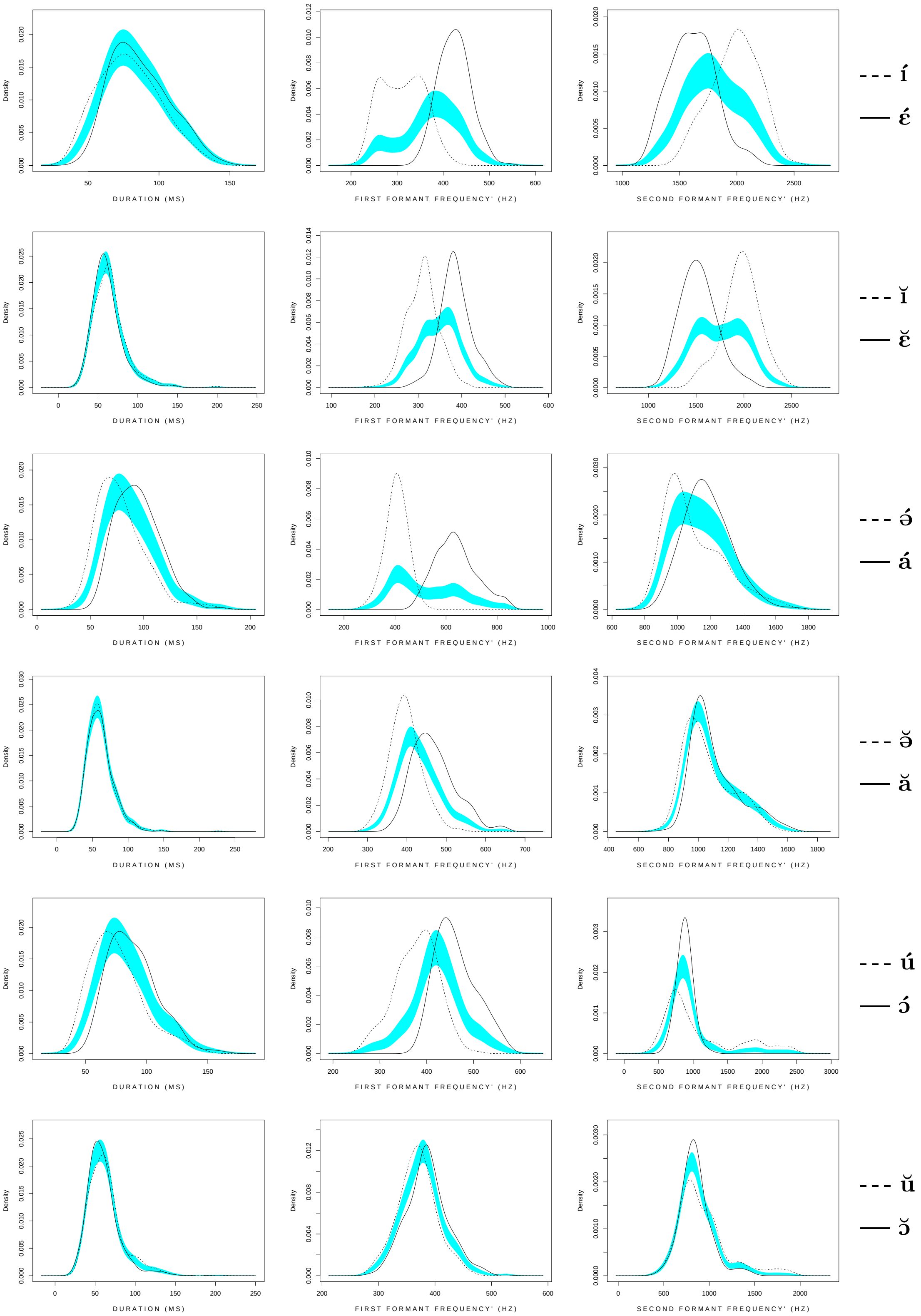


Figure B.2: PDEs and reference bands for West Bulgarian o/c vowels.

B.2.3 East Bulgarian stressed–unstressed vowels

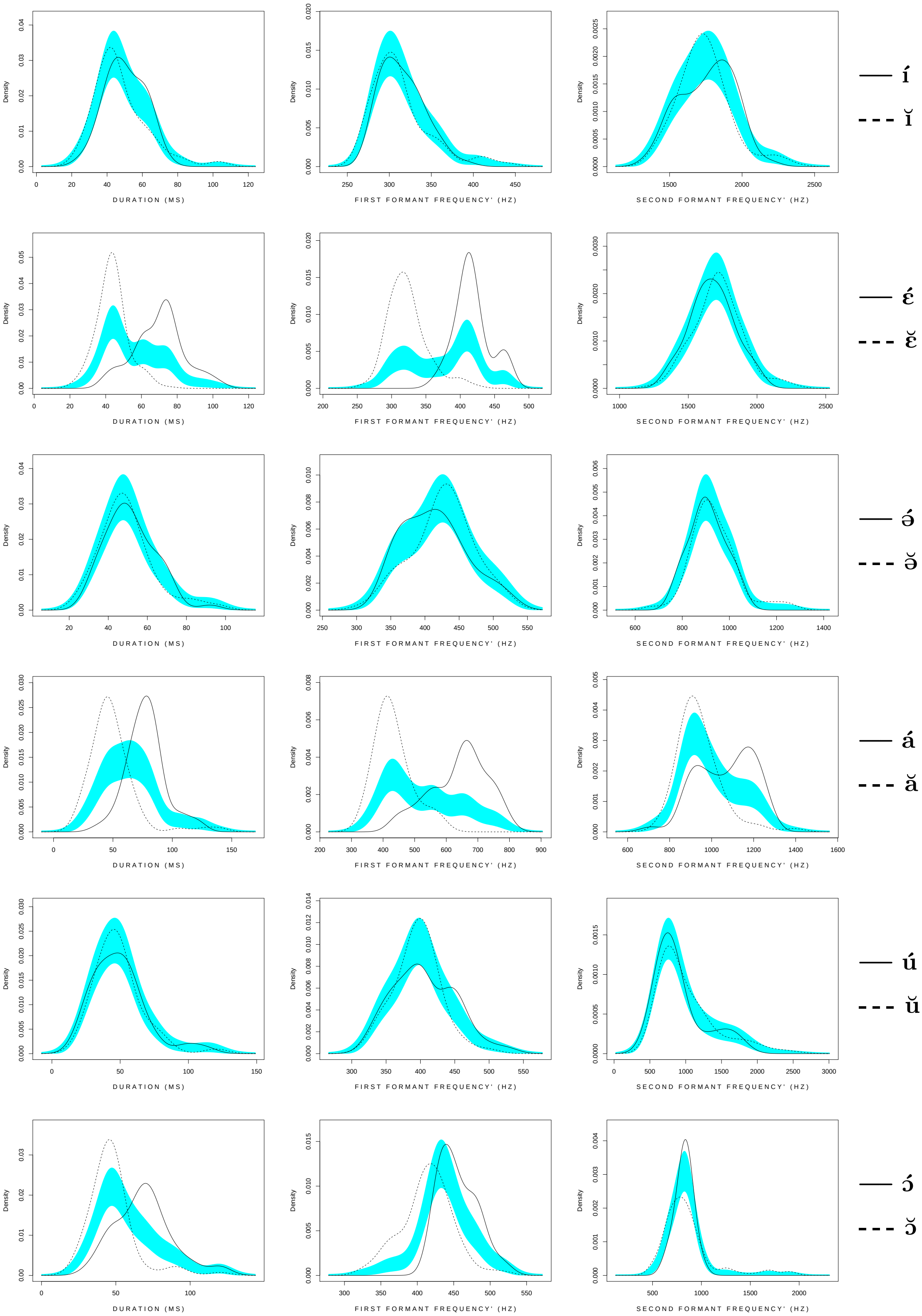


Figure B.3: PDEs and reference bands for East Bulgarian S/U vowels.

B.2.4 East Bulgarian open–close vowels

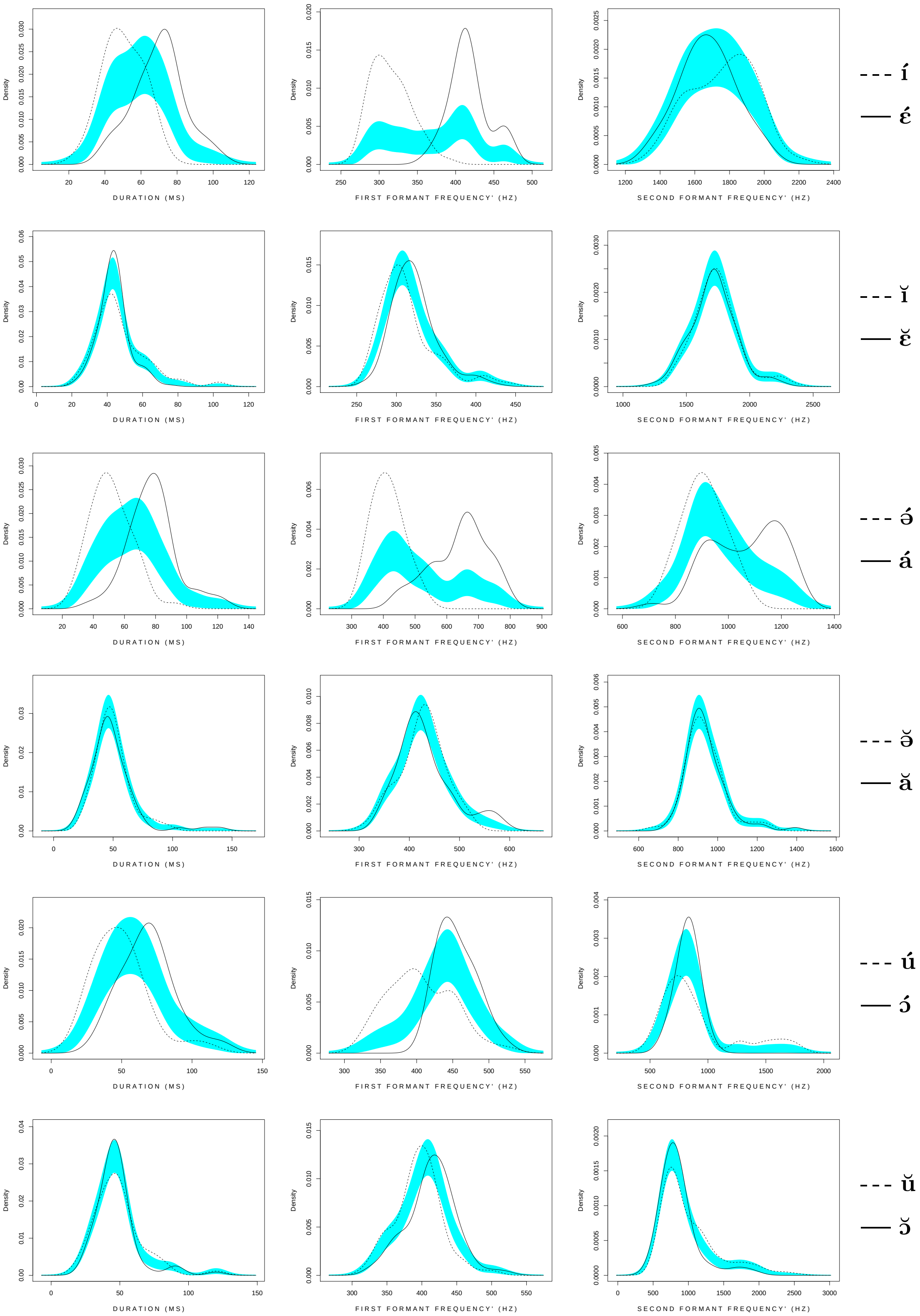


Figure B.4: PDEs and reference bands for East Bulgarian O/C vowels.

B.2.5 Istanbul Turkish stressed–unstressed vowels

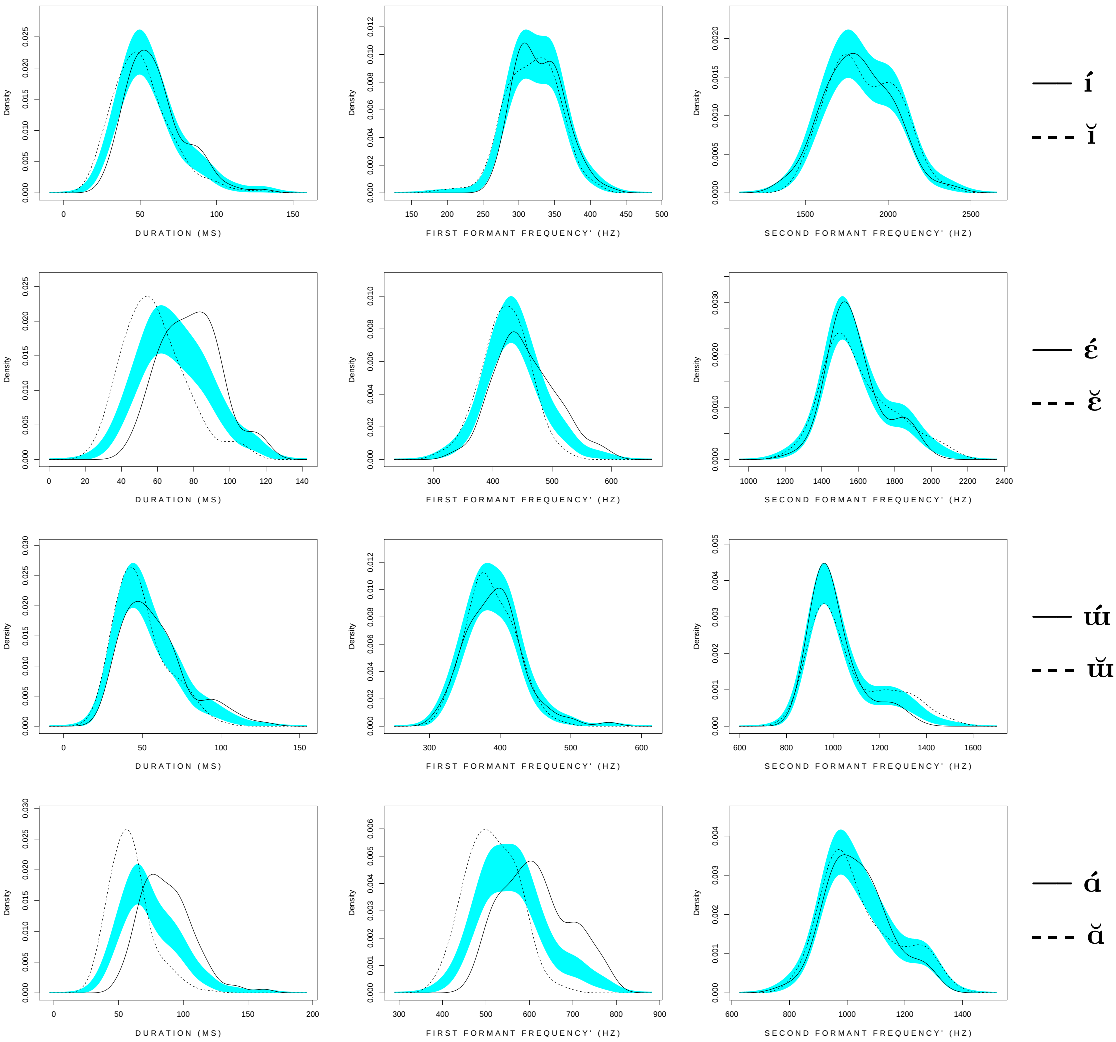


Figure B.5: PDEs and reference bands for Istanbul Turkish S/U unrounded vowels.

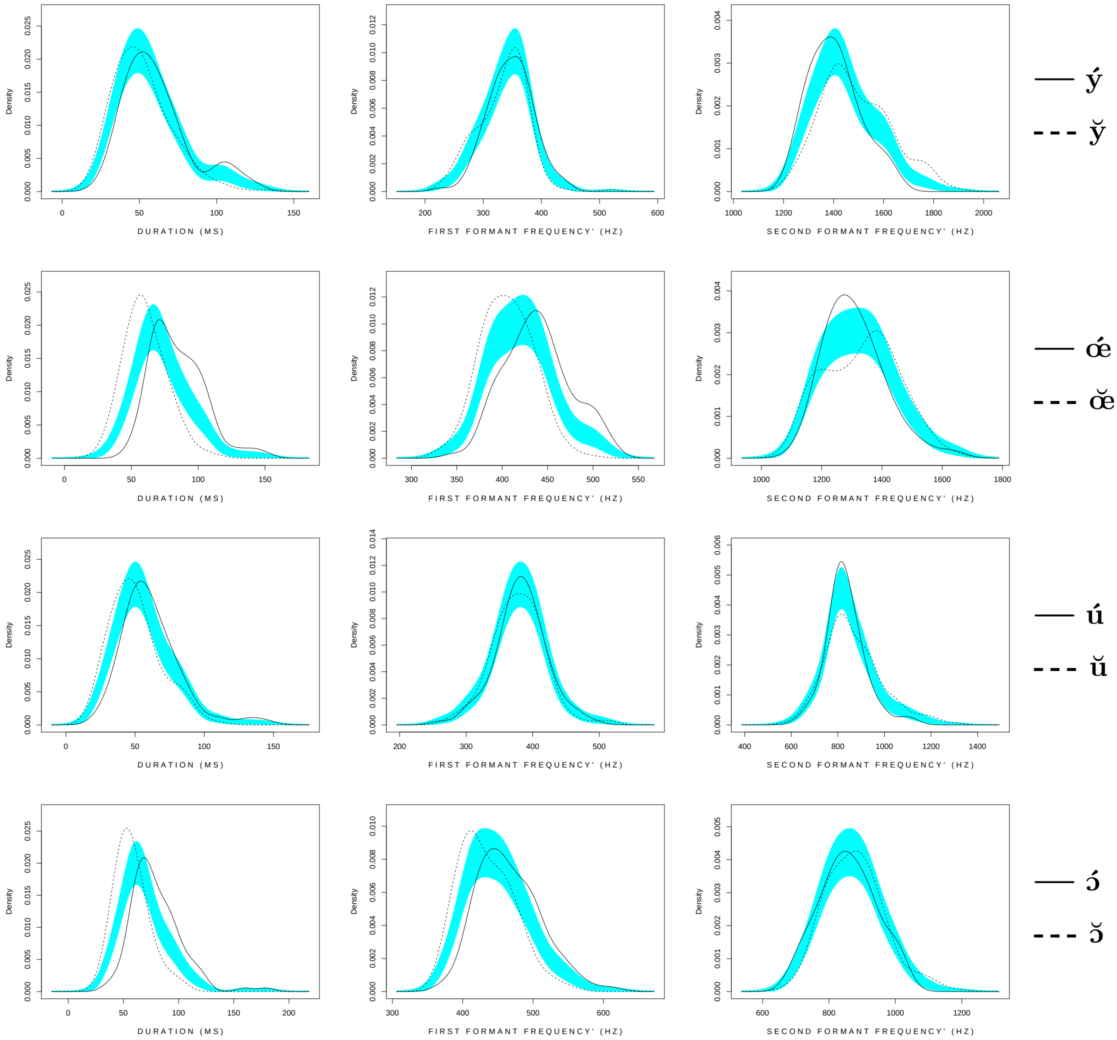


Figure B.6: PDEs and reference bands for Istanbul Turkish S/U rounded vowels.

B.2.6 Istanbul Turkish open–close vowels

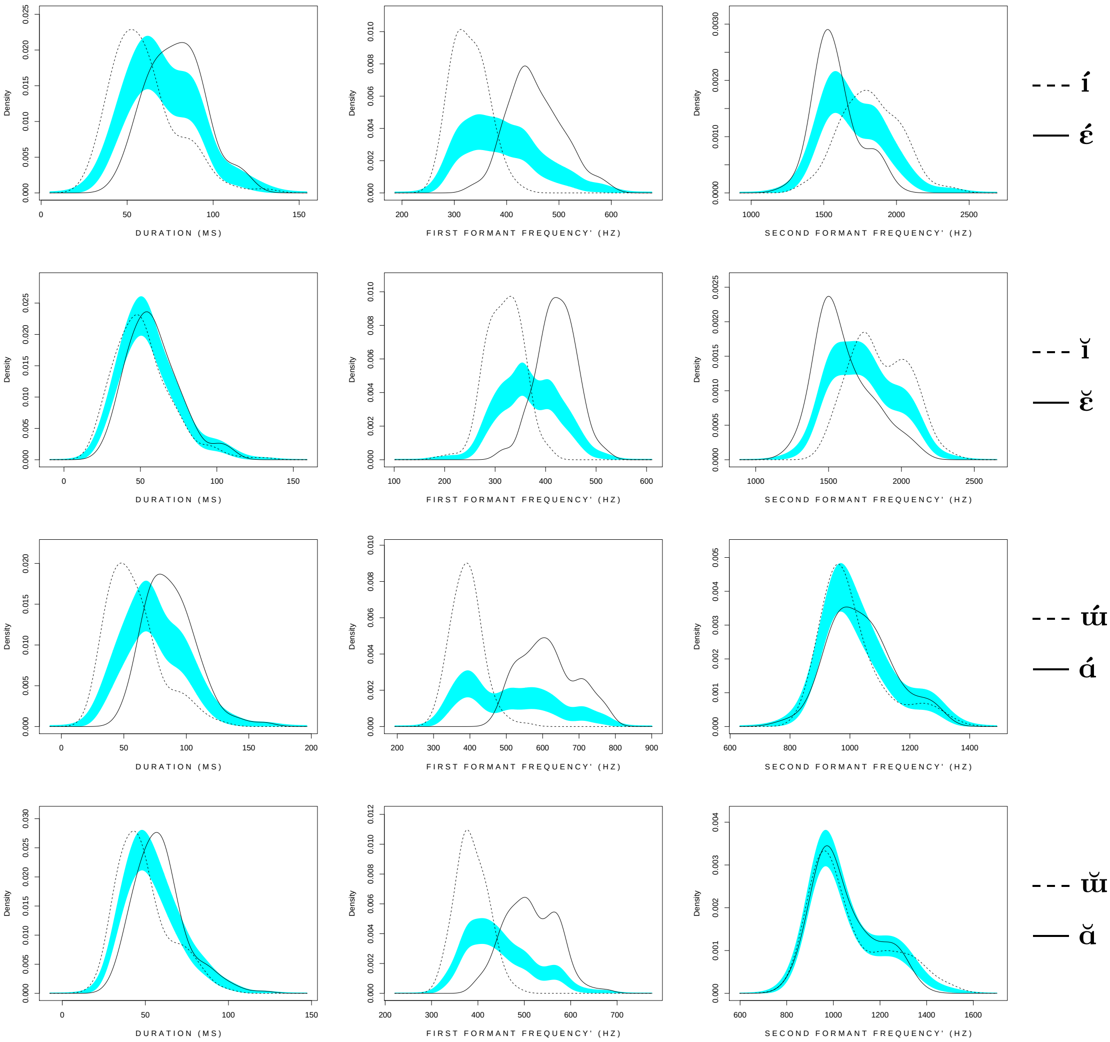


Figure B.7: PDEs and reference bands for Istanbul Turkish O/C unrounded vowels.

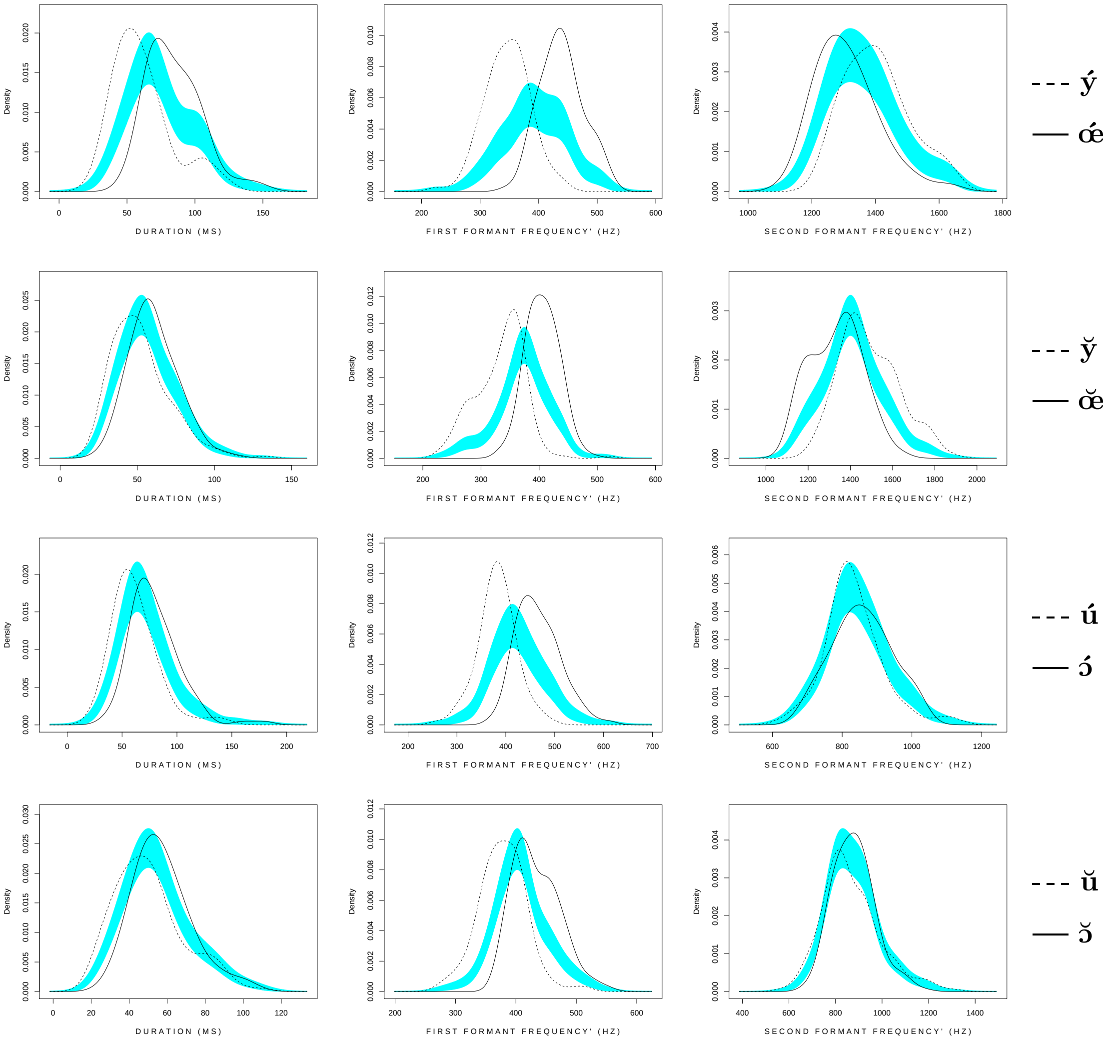


Figure B.8: PDEs and reference bands for Istanbul Turkish o/c rounded vowels.

B.2.7 Bilingual Bulgarian stressed–unstressed vowels

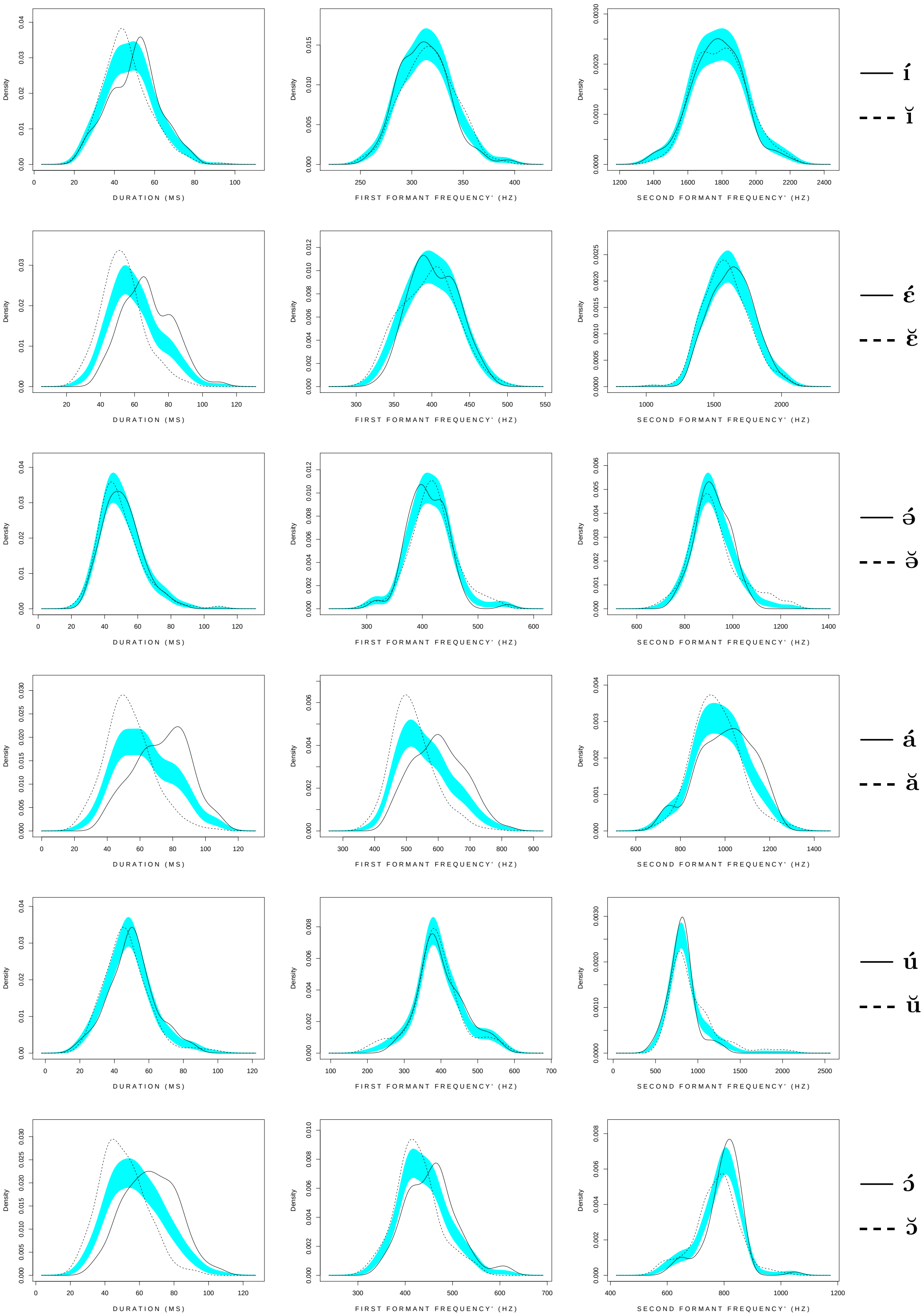


Figure B.9: PDEs and reference bands for Bilingual Bulgarian S/U vowels.

B.2.8 Bilingual Bulgarian open–close vowels

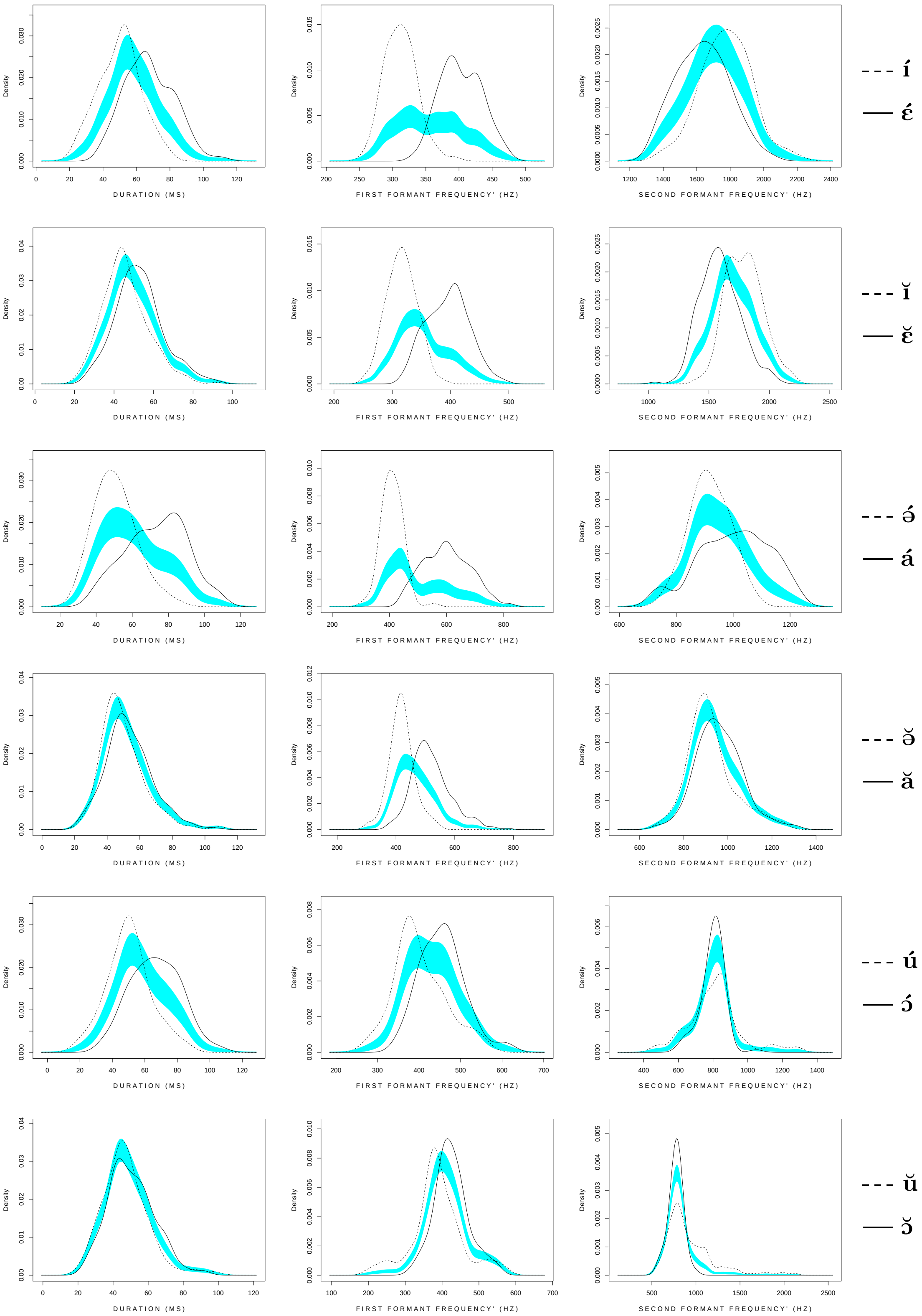


Figure B.10: PDEs and reference bands for Bilingual Bulgarian O/C vowels.

B.2.9 Bilingual Turkish stressed–unstressed vowels

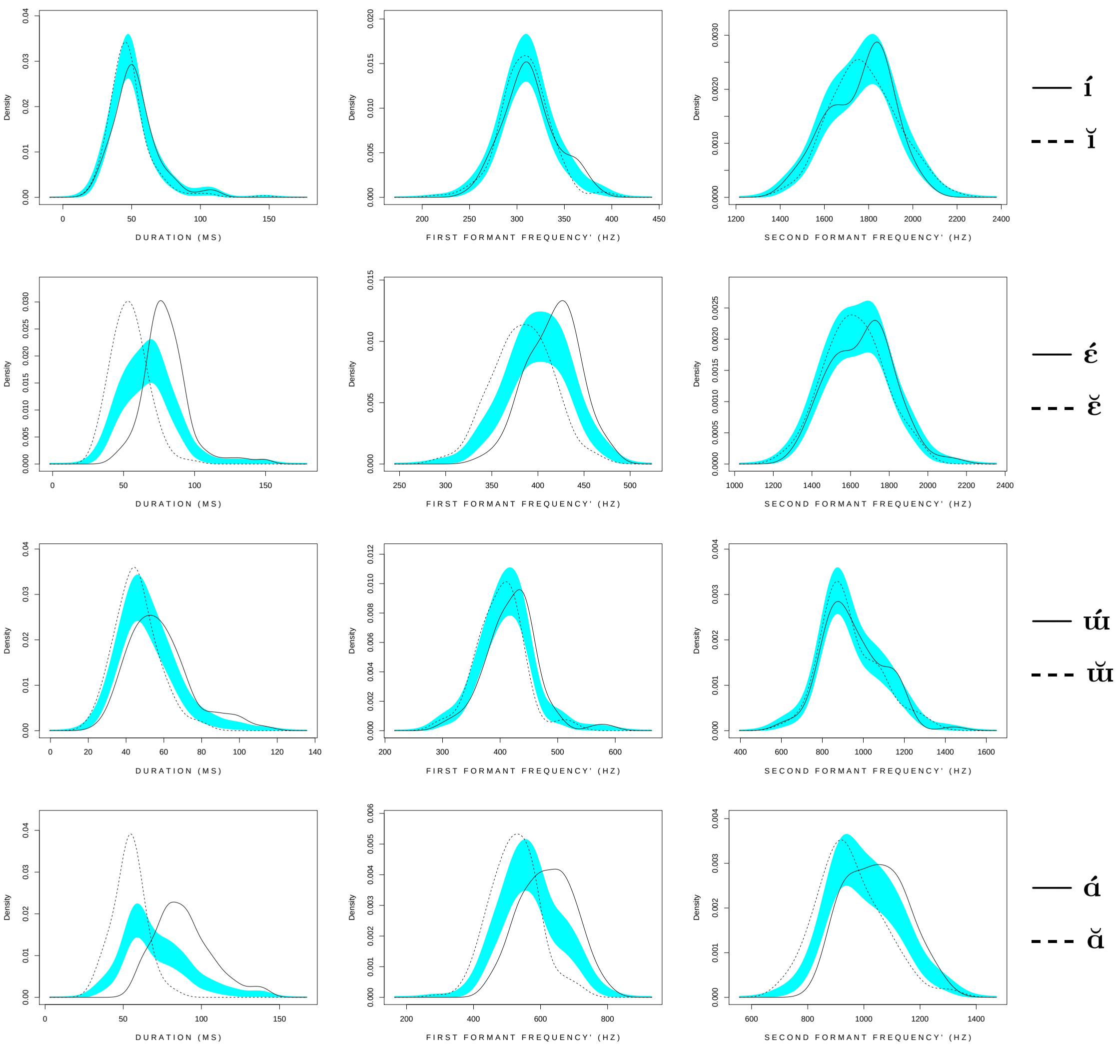


Figure B.11: PDEs and reference bands for Bilingual Turkish S/U unrounded vowels.

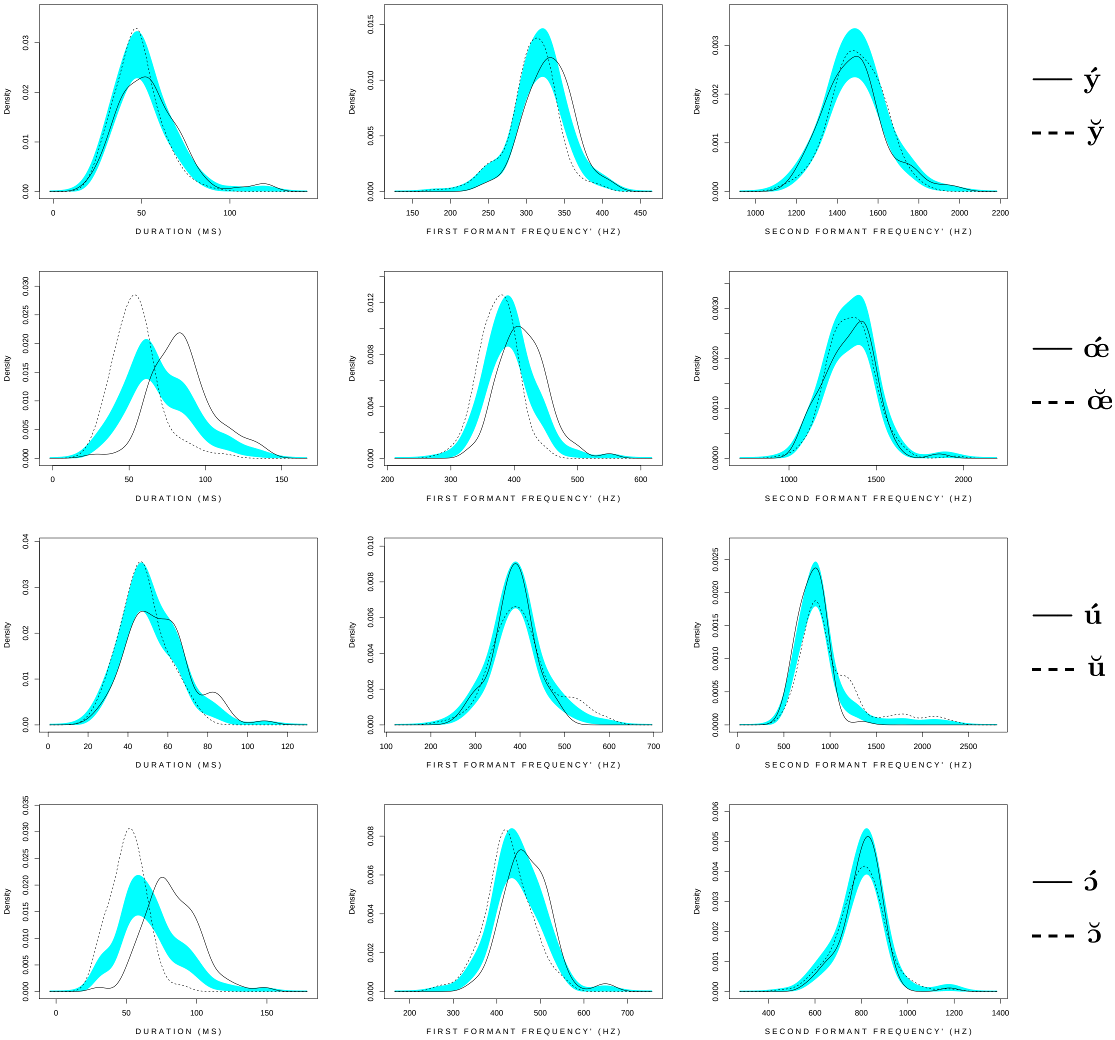


Figure B.12: PDEs and reference bands for Bilingual Turkish S/U rounded vowels.

B.2.10 Bilingual Turkish open–close vowels

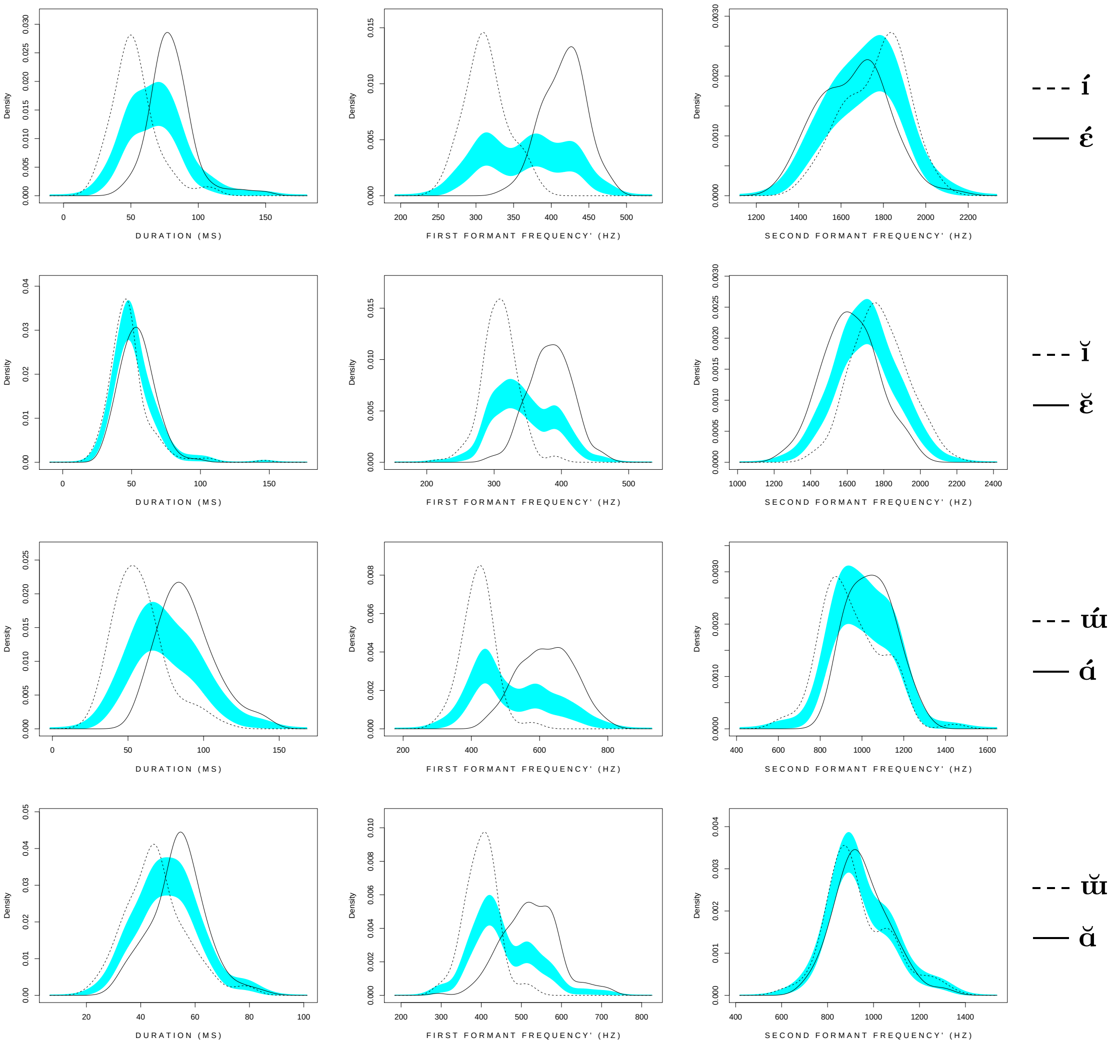


Figure B.13: PDEs and reference bands for Bilingual Turkish O/C unrounded vowels.

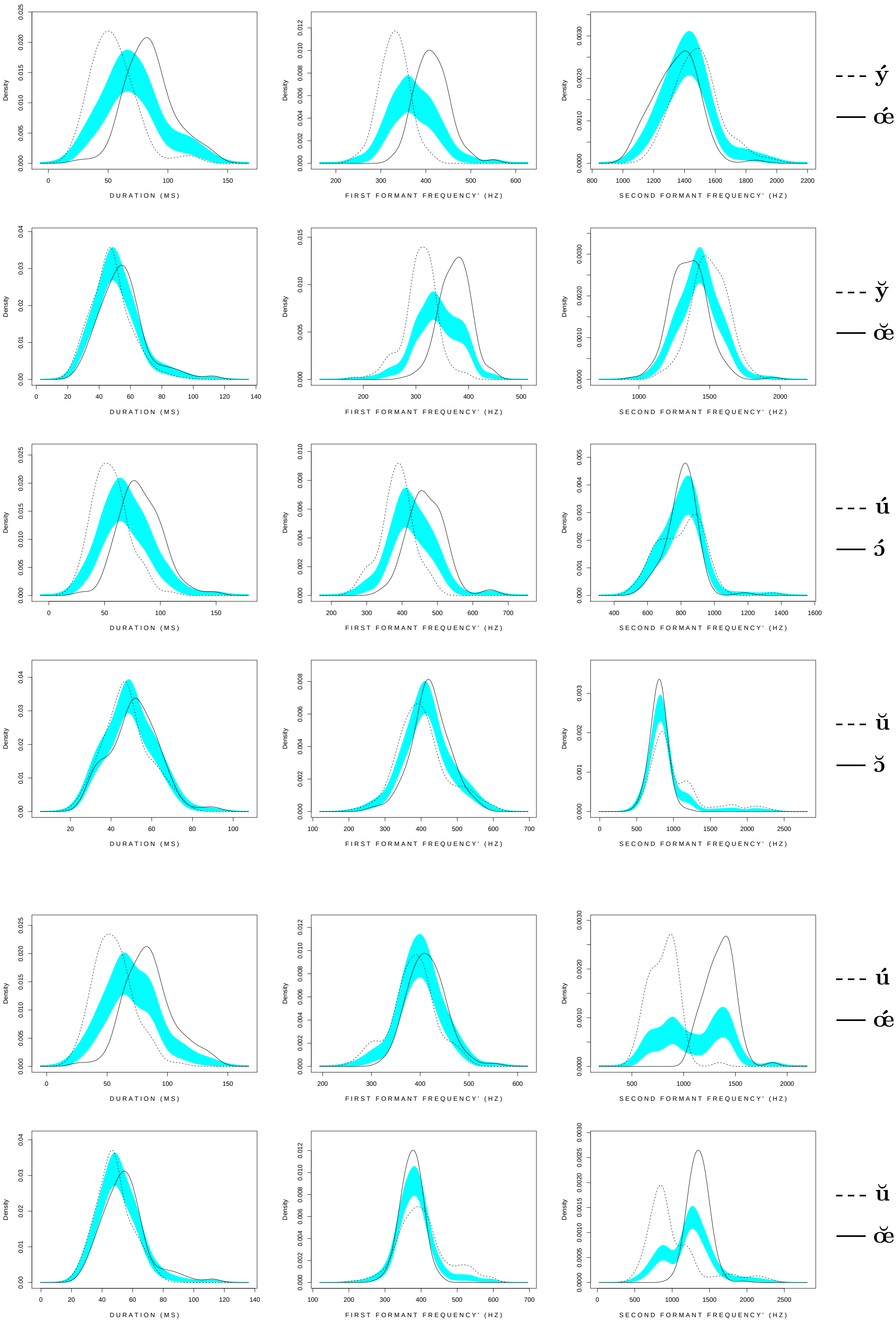


Figure B.14: PDEs and reference bands for Bilingual Turkish O/C rounded vowels and /u–œ/.

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