**[Insert Journal Name] manuscript No.**
(will be inserted by the editor)

# Naturalness, grounding, and generalisation in Turkish vowel-height rules

**Deepthi Gopal · Stephen Nichols**

Received: date / Accepted: date

**Abstract** The precise operation of the mechanism by which incipient phonological rules extend their domain of application from an initial phonetic trigger remains underexplored. Although many phonological patterns involve classes of sounds that are both phonetically-natural and have a clear 'precursor' relationship to the output, the existence of alternations failing either or both of these criteria motivates at least a partial decoupling of phonological representations and phonetic factors in our understanding of phonologisation. The current work investigates an alternation in Turkish in which the mid vowels /e ø/ are lowered to [æ∼a œ] in syllables closed by coda /r m n l(ʲ) (z)/. This pattern has not previously been reported in the phonological literature or investigated instrumentally; this paper presents the results of a detailed acoustic study of thirteen speakers. The acoustic reality (F1–F2) and phonological categoricity of the phenomenon is statistically verified; the alternation in /e/ is consistently stable and categorical for all speakers, with the pattern in /ø/ lagging behind. It is found that the degree of lowering is not predicted by the strength of the phonetic cue provided by the triggering segment, especially for strongly palatalised laterals; it is therefore proposed that the case in Turkish requires class formation and *rule generalisation* to proceed on the basis of ultimately phonological, rather than phonetic information.

**Keywords** phonology · sound change · phonological change · Turkic languages

### Statements and declarations

The authors declare that they have no conflict of interest.

D. Gopal **(corresponding)**
Uppsala universitet
E-mail: deepthi.gopal@lingfil.uu.se

S. Nichols
University of Essex
E-mail: stephen.nichols@essex.ac.uk

## 1 Introduction

Typologically-aware conceptions of phonological change must contend with the following tension: phonological processes tend to have transparently phonetically NATURAL origins, but, at the same time, can arrive in states that seem to bear little relationship to any potential phonetic precursor. A successful theory must therefore account for the preponderance of phonetically-grounded processes, while permitting patterns whose synchronic state is poorly phonetically-motivated (at one extreme, the so-called *crazy rules*, as e.g. Bach and Harms 1972; Scheer 2015), and delineating the set of possible diachronic pathways by which the latter can emerge from the former.

The commonness of phonetically-natural phonology raises a wide range of issues for synchronic phonology and its relationship to phonetic substance, but constitutes an explanandum in itself. A wide range of current views on the diachronic emergence of categorical phonological processes (e.g. in the hypo- and hyper-correction of Ohala 1981, Evolutionary Phonology as Blevins 2004, the (early) life-cycle in Bermúdez-Otero 2007) situate this empirical fact in the assumption that new patterns appear in the phonology via the reanalysis of the output of (the incremental accretion of) gradient phonetic tendencies, and therefore recapitulate their phonetic underpinnings. The implication of all such approaches is that the role of diachrony is paramount in the explanation of both the prevalence of natural phonological patterns and the existence of more problematic ones (Bach and Harms, 1972; Hyman, 1976, 2001, 2008; Blevins, 2004; Bermúdez-Otero, 2007). Recurrent 'natural' phonological patterns emerge because phonological change is constrained by phonetics, which is ultimately physical (physiological), *but* less natural rules may be generated in the further operation of diachronic processes over this initial output, as in e.g. 'rule telescoping' (Wang, 1968) or 'rule inversion' (Vennemann, 1972); in broader terms, rules distance themselves from their phonetic origins during a GENERALISATION step.

The presumed phonetic underpinnings of phonological patterning are involved in all consideration of class formation and phonological activity; what makes natural classes natural? In an elementary sense, the idea that some sets of segments are united by both phonetic similarity and typological 'preferredness' underlies all proposals for innate representational structure (Chomsky and Halle, 1968); but approaches arguing for partial or total emergence of phonological representations (Flemming, 2005; Mielke, 2008) must then locate any non-randomness in the distribution of class structures elsewhere. In the latter case, a consequence must be the existence of a non-trivial relationship between the *age* of a pattern and its *closeness to its phonetic precursors*. At the very earliest moment in the life of a new phonological process, we essentially expect it to 'look phonetic'; the longer it lasts, the higher the probability that change, in the form of generalisation, serves to distance it from this origin. The implication of this understanding regarding the emergence of phonologisation is that evidence for the internal structure of 'rule generalisation' should emerge from phonological phenomena which satisfy two conditions: i. being relatively young, identifiably-recent innovations; ii. containing some *mismatch* between the phonetic and phonological viability of the phenomenon itself. This paper identifies and investigates a previously-unstudied phenomenon of this type, mid-vowel lowering in Turkish triggered by [+sonorant] codas, and argues that this pattern, together with the micro-typology of patterns in related varieties, provides essential evidence for diachronic structuring which is sensitive to phonological information in the early history of phonological rules. This paper therefore fills a gap in both synchronic natural class typology and in the typology of the conditioning of sound change.

The major subsidiary goal of this paper is incremental empirical progress with respect to the phonology of modern Turkish. Although the basic details of the vowel harmony system and anomalous stress patterns in the language are familiar to almost all phonologists, relatively little attestation of the pattern we report here is to be found in the descriptive literature on Turkish, and none at all in the prior phonological literature.

This paper is organised as follows. In section 2, we introduce the innovation in Turkish on which the rest of this paper focuses; section 5.1 discusses the similar but non-identical patterns that arise in non-standard varieties of Turkish, and section 2.2 provides the broader context of the typology of closed-syllable height effects. Section 3 contains a straightforward overview of the set-up, methodology, and sampling of the study on which the remainder of the paper is based. The acoustic data are addressed throughout section 4. Section 4.1 deals with the overall distribution of results and the categoricity of the Turkish pattern, section 4.2 considers the details of the behaviour of individual segments, and section 4.3 discusses the potential effect of duration. We treat the various classes of exceptions to the alternation in section 4.4, provide the overall perspective from the point of view of the hypothesised diachrony in section 5, and discuss examples further afield in section 5.2.2. Section 6 concludes.

## 2 Pre-sonorant mid vowel lowering in Turkish

The pattern under investigation is described in section 2.1, with broader typological context given in section 2.2; section 2.3 briefly motivates the experimental work whose set-up and methodology appear in section 3. Detailed experimental results then follow in section 4.

### 2.1 The case

#### *2.1.1 Coda-conditioned lowering in Turkish*

The front mid vowels /e/ and /ø/ undergo alternations conditioned by the following coda, summarised (with reference to the results and descriptive discussion that follow in section 4) in examples 1–4 below. /e/ and /ø/ are systematically low in a syllable closed by a sonorant[1], and /e/ is (subject to inter-speaker variation; section 5.2.3) slightly raised relative to the non-sonorant mean in either pre-obstruent contexts, or in contexts in which the coarticulatory effect of high vowels is particularly significant. In the context of the vowel system in the language, this then looks like the right-hand diagram in figure 1: pre-sonorant realisations of /e/ and /ø/ *fill a gap* along the front diagonal of the vowel space.

*Example 1* /e/ and /ø/ surface as [æ ∼ a] and [œ] respectively in sonorant-closed syllables:

| | | |
|---|---|---|
| /erdem/ | [ær.dæm] | ‘virtue’ |
| /hejkel/ | [hej.kæl] | ‘statue’ |
| /biber/ | [bi.bær] | ‘pepper’ |
| /gøl/ | [gœl] | ‘lake’ |
| /gøm-mek/ | [gœm.mek] | ‘bury-INF’ |

*Example 2* And, for some speakers, in syllables closed with /z/:

[1] The glide /j/ patterns with the obstruents throughout the phonology (Canalis et al., 2021); we group it together with obstruents in our data. Where son+C coda clusters are typically tolerated ([hɑlk] ‘people’, [reŋk] ‘colour’), recent loans containing glide+C clusters invariably undergo high vowel epenthesis <teyp> [tejip], <feyk> [fejik]. An optional, but pervasive pattern of coda /h/-deletion – <fihrist> ‘index’ [fihrist ∼ fiːrist], <tehlike> ‘danger’ [tehlike ∼ teːlike] – also fails to apply: <Yahya> (name) *[jɑːjɑ], <kahya> ‘butler’ *[kɑːjɑ].

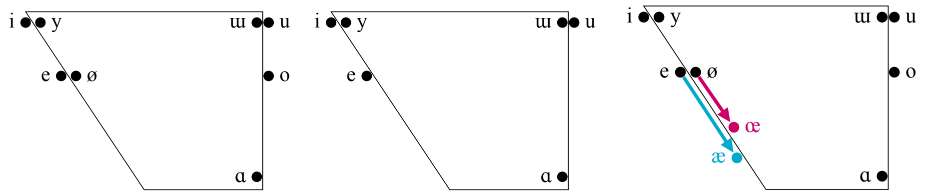



**Fig. 1** Turkish vowels in initial syllables (left) and in non-initial syllables (center); sonorant-conditioned alternations shown in the Turkish vowel space (right).

| | | |
|---|---|---|
| /pekmez/ | [pek.mæz] | ‘molasses’ |
| /merkez/ | [mær.kez] > [mær.kæz] | ‘centre’ |
| /gel-mez/ | [gæl.mæz] | ‘does not come’ |

*Example 3* Affixation destroys the environment for lowering (figure 2):

| | | |
|---|---|---|
| /erdem-i/ | [ær.de.mi] | ‘virtue-ACC’ |
| /hejkel-im/ | [hej.ke.lim] | ‘statue-1SG.POSS’ |
| /gizem-in/ | [gi.ze.min] | ‘mystery-GEN’ |
| /biber-in/ | [bi.be.rin] | ‘pepper-GEN’ |
| /gøl-i/ | [gø.ly] | ‘lake-ACC’ |
| /gøm-er/ | [gø.mær] | ‘bury-3SG.P’ |

*Example 4* No lowering in other environments; some speakers show pre-obstruent /e/-raising:

| | | |
|---|---|---|
| /dede/ | [de.de] | ‘grandfather’ |
| /bebek/ | [be.bek] ∼ [be.be̞k] | ‘baby’ |
| /herkes/ | [hær.kes] ∼ [hær.ke̞s] | ‘everybody’ |
| /taze/ | [tɑ.ze] | ‘fresh’ |

*Example 5* Unstressed open syllables preceding high vowels /i, y/: /e/ raised (section 4.1.2).

| | | |
|---|---|---|
| /deniz/ | [dɪ.niz] | ‘sea’ |
| /kedi/ | [kɪ.di] | ‘cat’ |
| /be-nim/ | [bɪ.nim] | ‘my’ |

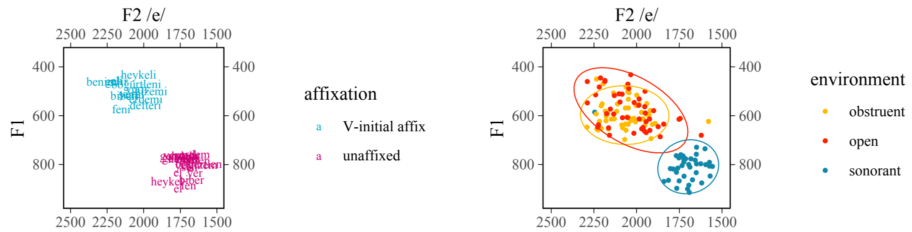



**Fig. 2** F09: F1/F2 space (Hz) for alternating /e/. Let, pre-son. unaffixed *ben, biber, böğürtlen, defter, el, erdem, fen, gizem, heykel, sen, yer* & C-initial suffixed *vermek, gelmek* vs. pre-vocalic *benim, biberi, böğürtleni, defteri, eli, erdemi, feni, gelir, gizemi, heykeli, senin, verir, yeri*. Right, all measurements coded by environment, 95% confidence ellipses.

Example 3 is illustrated in figure 2 with data from the study in section 4 for *one* representative (F09; female, b. 1980 Ankara) speaker; this shows data only for /e/, which is more frequent in the lexicon and displays more clearly phonetically discontinuous behaviour. Pre-sonorant /e/ in un-affixed forms has F1 in the range 750–900 Hz; the corresponding alternant /e/ post-resyllabification has F1 400–600 Hz.

We are not aware of any reference to this set of alternations in the formal phonological literature. Several general descriptions of the language are available, and vary in their characterisations of the system, in a manner consistent with the suggestion that the pattern under consideration is a relatively recent development in Turkish. Lewis's (1967, 14) reference grammar emphasises raising in unstressed open syllables most strongly: 'a closer pronunciation, verging on the sound of **i**, especially in the first syllables of […] **gece** 'night' ', but mentions no lower allophone and no pre-consonantal effects of any kind. Kornfilt (1997, 512), 30 years later, claims that an 'alternation phenomenon affects the front, non-high vowel [e] and [ø], which are lowered before sonorants in closed syllables'; she transcribes the lower allophone of /e/ as [ɛ], although it is unclear to what extent this decision is an impressionistic one. Göksel and Kerslake (2005) give the distribution of /e/ as [æ] before sonorants, [ɛ] in stressed open syllables, and [e] elsewhere. The earliest descriptions are not concerned with the state of final (i.e. stressed) open syllables, but Zimmer and Orgun (1999) claim that /i, y, u, e, ø/ (but not /o, ɑ/) lower to [ɪ, ʏ, ʊ, ɛ, œ] in the "final open syllable of a phrase", and Göksel and Kerslake (2005) claim that this occurs word-finally. We argue that none of these characterisations adequately represents the state of the system as we find it in current data, with the note that the disparity in descriptions corresponds to a significant time-separation and is concordant with further discussion of the diachrony of this pattern. In section 4, we present the production-study results that support the characterisation we propose in examples 1–5.

### *2.1.2 Brief notes on the phonology of Turkish*

Turkish is generally understood in the phonological literature to have eight contrastive vowels (Hulst and Weijer 1991, Kabak 2011), whose phonological behaviour is well-established (see e.g. Clements and Sezer 1982; Kabak 2011 for overviews): processes of backness and rounding harmony operate left-to-right across roots and suffixes, under the systematic constraint that rounding may only spread to high vowels in non-initial syllables. Although all eight vowels in the system are paired for backness and roundness, it is therefore the case that a gap arises in the non-initial syllables (figure 1) – the rounded mid vowels do not appear in these positions, save in loanwords. /e/ is therefore the only non-high front vowel that may appear in any position in the word, and the only vowel outside initial syllables that we can see as having 'room' to vary freely in height—/i/, /y/, /ɯ/, /u/, and /ɑ/ are all constrained in one direction by the ceiling or the floor of the vowel space.

The majority of the Turkic languages share similar systems of backness harmony, and most extend this to an allophonic distribution of *consonantal* segments[2]. Clements and Sezer (1982) describe the Turkish velars /k, g/ and the lateral /l/ as being typically [+back] in the context of [+back] vowels and [-back] in the context of [-back] vowels, although subject to various blocking effects and lexicalised exceptions. We consider (though not in exhaustive depth) the state of phonetic data on the backness of the lateral /l/ in section 4.2.1 below, with respect of the potential for degree of palatalisation to affect the lateral's suitability as a

[2] Most strikingly in Karaim, in which the typical system of [back]-spreading appears to have been lost for the vowels, and retained instead as long-distance consonant harmony (Nevins and Vaux, 2003).

phonetic precursor to vowel-lowering; the experimental data conform well to the characterisation here. The remainder of the sonorants are not, as far as the literature is aware, subject to alternations of this particular type.

## 2.2 The typology of coda-triggered height effects

The descriptive case(s) in Turkish that constitutes the majority of this paper can be placed at the intersection of two larger typologies of phonetically well-motivated phenomena: one of vowel quality effects conditioned by syllable structure, and the other of height effects triggered, irrespective of syllabic considerations, by the various sonorant segments. The pattern in Turkish is, however, not a straightforward member of either of these classes: while closed-syllable vowel laxing is well-established, it is rarely predicated on the manner of articulation of the coda involved; and while rhotic-triggered height effects are common, they are rarely extended to the set of all sonorants and rarely dependent on syllable structure.

### *2.2.1 Closed-syllable vowel laxing*

It is reasonably well-established that there exists a general cross-linguistic tendency towards laxer vowels in closed syllables and tenser vowels in open syllables, both in distribution and in allophonic patterning; a straightforward example is the alternation that appears in French *nous gavottons* [nu ɡa.vo.tɔ̃] 'we gavotte' and *rigolo* [ʁi.go.lo] 'funny (masc.)', but *il gavotte* [il ɡa.vɔt] 'he gavottes' and *rigolote* [ʁi.go.lɔt] 'funny (fem.)' (Dell, 1995; Féry, 2003). Storme (2017c, p. 223–226) gives a substantial typological survey of 18 languages in which some such generalisation holds; for all these cases, 'lax' is understood acoustically to imply a two-dimensional movement in the vowel space, with a lax vowel having less peripheral F1 and F2 targets than a tense counterpart. Not all attested cases are equally general; in some languages laxing applies across the board to all vowels in closed syllables, while in others further restrictions on the affected vowel[3] or the consonantal context apply (example 6). It is unclear whether apparent statistical tendencies in a survey of this size should be expected to hold more broadly or carry particular significance. If we take Storme's survey as broadly representative, we observe that the mid vowels /e o/ are slightly under-targeted[4], and that languages invoking segment-specific constraints do so particularly with respect to rhotics and dorsals[5].

*Example 6* (Uma Juman) Kayan (Austronesian, Borneo): high vowels are lowered if followed by /h, l, r, ʔ/. (Blust, 2013, p. 263)

| | | |
|---|---|---|
| /lakiʔ/ | [lakeʔ] | 'male' |
| /uruʔ/ | [uroʔ] | 'grass' |
| /hivih/ | [ˈhi.veh] | 'lower lip' |
| /duh/ | [doh] | 'female' |
| /bakul/ | [ˈba.kol] | 'basket' |
| /tumiɾ/ | [ˈtu.meɾ] | 'heel' |

3 e.g. Nordhoff (2009): Sri Lanka Malay has the five-vowel inventory /a e we o u/, but only /e o/ alternate.

4 Although available in all Storme's surveyed inventories but one, /e o/ undergo laxing in 7 of 17 languages; French (Southern), Chamorro, Indonesian, Kairiru, Paluai, Sri Lanka Malay and Kuteb. The remaining languages surveyed target exclusively the more peripheral vowels, particularly /i u/.

5 Patterns of the uneven distribution of vowel height in the context of uvulars and velars are well-known; for an overview, see Gallagher (2016, p. 103).

| | | |
|---|---|---|
| /ʔatuɾ/ | [ˈʔa.toɾ] | ‘arrange’ |

The existence of coda-conditioned effects on height and backness has been attributed in various cases (Féry, 2003; Botma and Van Oostendorp, 2012) to the existence of a close relationship between length, quality, and syllable structure; that is, contingent on the claim that vowels are shorter in closed syllables than in open syllables (see e.g. Maddieson 1985). The duration-sensitive account of closed-syllable laxing then admits a connection to those patterns in which syllabically-conditioned length alternations arise, as in example 7; but requires some form of the claim that longer vowels are tenser than shorter vowels.

*Example 7* INGUSH (Nakh-Dagestanian, Ingushetia): underlying long, but not short, vowels alternate with short vowels in closed syllables. (Nichols, 2011)

| | | |
|---|---|---|
| /duucə/ | [duːcə] | ‘narrate-INF’ |
| /duuc/ | [ducː] | ‘narrate-PRS’ |
| /niisə/ | [niːsə] | ‘straight’ |
| /niis-lu/ | [nis.lu] | ‘becomes straight’ |

One potential issue for explanations along these lines is that empirical generalisations about the relationship between quality and duration are variable, and difficult to straightforwardly align with the demands of articulation or the typology of laxing. The claim that closed-syllable laxing derives from the loss of duration in closed syllables requires that lax vowels be uniformly shorter than tense vowels; given a non-low vowel subject to laxing, we expect the lax counterpart to be lower than the tense one, and therefore must claim that higher vowels are longer than lower ones. However, it is in fact frequently the case across languages that the first formant correlates positively with duration, and that therefore height itself is inversely correlated with duration: that is, the lowest vowels (with the highest F1) are the longest vowels. Claims to this effect appear both within-category and cross-category. If all other parameters are constant, Lehiste (1970) suggests that low vowels are longer than high vowels across the board, and posits physiological reasons relating to the gestural duration of jaw-opening; similar effects have also been attributed to the closeness of the jaw position during high vowels to that expected during most consonants (Maddieson, 1997; Gussenhoven, 2007). One of the more widely-known experimental results to this effect is Lindblom's (1963) claim that the F1 of Swedish non-high vowels decreases (that is, vowel height increases) exponentially as vowel duration decreases. Similar correlations are reported in English (Peterson and Lehiste, 1960; Westbury and Keating, 1980), Hindi (Ohala and Ohala, 1992); and cf. Toivonen et al. (2015) for English and Swedish, and for a review of the literature. A portion of Storme's (2017a; 2017b; 2017c) argument for a new account rooted in the perceptually-driven enhancement of post-vocalic contrasts between consonants is predicated on the claim, as above, that the derivation of lowering and centralising effects from the loss of duration is not justified; a full treatment of this account and its relationship to the case we consider here is beyond the scope of this paper, but we investigate the relationship between duration and vowel height for our case in sections 4.1.2 and 4.3.

The essential relationship of the Turkish case to the cross-linguistic pattern is largely straightforward, although in a few respects particularly divergent; the pattern in Turkish appears to show a larger deviation in phonetic space than the typical case of closed-syllable laxing, as should become apparent from the experimental data presented below, and the class of segments targeted is a new one. We argue that the pattern in Turkish is *lowering* rather than *lowering plus centralisation*, and that any apparent centralisation arises solely due to the inherent topology of the vowel space; unlike Storme's (2017c, p. 95) case in French, for which F2 effects appear to be too large to be accounted for by height targets alone.

### 2.2.2 Sonorant-related height effects

Sonorant-triggered height effects, especially rhotic-triggered ones, are fairly well-attested cross-linguistically; both as non-contrastive differences in the contextual distribution of formant values in phonetic space, and as apparent phonotactics. What distinguishes the latter 'phonological' set from the patterns described in the previous section is the frequent absence of any restrictions relating to syllable structure; several cases of sonorant-conditioned laxing or lowering apply irrespective of the relative position of the sonorant trigger and the affected vowel. In the Austronesian language Thao (Blust, 2013, p. 264), all high vowels lower if adjacent to the alveolar flap /ɾ/ (example 8); the requirement for adjacency applies in both tautosyllabic and heterosyllabic contexts, and the flap may precede or follow the affected vowel. (A further, more general case of laxing applies in the familiar set of closed-syllable environments.)

*Example 8* Thao (Austronesian; Taiwan): high vowels lower[6] adjacent to a rhotic. (Blust, 2013)

| | | |
|---|---|---|
| /ɾima/ | [ˈɾe.ma] | 'five' |
| /ɾusaw/ | [ˈɾo.saw] | 'fish' |
| /iɾuʃ/ | [ˈi.ɾoʃ] | 'saliva' |
| /ɬmiɾ/ | [ɬmeɾ] | 'grass, weeds' |
| /tuɾu/ | [ˈto.ɾo] | 'three' |
| /hibuɾin/ | [hiʔ.bo.ɾɛn] | 'be mixed together' |

Attestation exists of significant effects in F1 conditioned by the presence of an adjacent sonorant. These vary between (what we would diagnose as) the 'phonetic' and the 'phonological' in their scope, and in which sonorants they involve. What seems broadly uncontroversial is that strong articulatory and acoustic properties of THE RHOTICS often favour the development of height effects in a pre-rhotic vowel. The most widely-cited acoustic characteristic of rhoticity as a whole is the lowered third formant (Ladefoged, 2003); but see Lindau (1985) for complications. Figure 3 shows spectra for a [ir]–[iʃ] pair in Turkish, for which there is a small but significant effect of the utterance-final rhotic on the preceding high vowel. The trill in particular (Recasens, 2002; Recasens and Pallarès, 1999; Solé, 2002) has been shown to force tongue dorsum lowering and retraction, which Proctor (2009) suggests (for Latin American Spanish) is a more general property of the whole class of coronal liquids. Bradley (2010), in a survey of Ibero-Romance, claims—unlike our case—that the effect of the post-vocalic trill on the height of the preceding vowel is strongest in the _rV context, and weaker in _rC, and attributes this to constraints on articulatory organisation.

Mid vowel lowering before a rhotic coda is attested widely: throughout Ibero-Romance (Bradley, 2010), and in the context of the French *loi de position* (Storme, 2017b); in Swedish for /ɛ/ and /ø/ (Riad, 2014), in Faroese /e/ (Árnason, 2011), and, as before, in the examples for Schaffhausen German that we give in section 5.2.1. A detailed discussion of the situation of THE LATERALS appears in section 4.2.1, and we reserve a fuller overview for those passages. We draw particular attention to accounts of disparities between the rhotics and the laterals in degree and even direction of F1-effect; West (1999) gives, for southern British English, significantly higher F1 in rhotic contexts than in lateral ones, and attendantly the prediction that lateral-triggered lowering effects should, in phonetically-controlled cases,

[6] Also if adjacent to /q/: /tuqris/ [ˈtoq.ɾes] 'noose trap', /qusaz/ [ˈqo.sað] 'rain'.

[8] This is an utterance-final token; the rhotic is quite fricated.

*bir* [biɾ̥] ‘one’ *diş* [diʃ] ‘tooth’

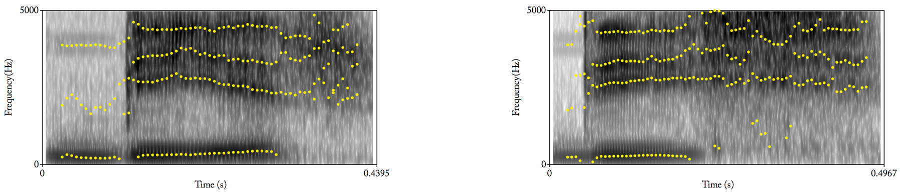



**Fig. 3** For one speaker (F01, Istanbul/1997), spectra with formants indicated for *bir* [biɾ̥] ‘one’ and *diş* [diʃ] ‘tooth’, showing formant movement driven by the presence of the rhotic.[8]

be smaller; but note that this lateral is necessarily, due to the well-known state of English phonotactics, a velarised or ‘dark’ one. Phonetically non-velarised laterals are often ignored by vowel-lowering rules, even after further generalisations and extensions (as with the case for Schaffhausen German given in section 5.2.1); we therefore consider the state of the Turkish lateral in section 4.2.1.

In European Portuguese, Vigário (2002, p. 86–88) describes a fairly similar rule; the non-high vowels /e o/ must lower in word-final, unstressed syllables closed by a sonorant[9] (the rhotic, the (velarised) lateral, or the nasals/nasal vowels), neutralising the contrast in /e o/–/ɛ ɔ/ and overriding the output of a general process that forces the raising of low vowels pre-nasal. Thus[10], *revólver* [ʁɨ.ˈvɔɫ.vɛɾ] ‘revolver’, *júnior* [ˈʒu.ni.ɔɾ] ‘junior’, *nível* [ˈni.vɛɫ] ‘level’, *álcool* [ˈaɫ.kɔɫ] ‘alcohol’, *sémen* [ˈsɛ.mɛn] *[ˈsɛ.mɨn] ‘semen’, *cólofon* [ˈkɔ.ɫu.fɔn] *[ˈkɔ.ɫu.fun] ‘colophon’. This reflects both a nice case of a similar alternation, and the (possible) phonologisation of the variable correlates of THE NASALS: although anticipatory nasalisation should drive an increase in F1 (Krakow et al., 1988), the introduction of the ‘nasal formant’ (Beddor, 1993; Beddor et al., 1986) drives a reduction in the perceptual space of the nasalised vowels, causing perceptual *raising* in low-mid and low vowels. Where the Portuguese case differs from the Turkish one is in the systematic relationship to stress and plausibly therefore to duration, which we will revisit in section 4.3.

## 2.3 This study

In the preceding sections, we have addressed the extent to which we can coerce the Turkish pattern into a broader typology of patterns with seemingly similar phonetic and phonological conditioning. With the set of potential phonetic precursors in mind, we present below the results of our experimental investigation of the status of pre-consonantal height effects in the (standard) Turkish vowels, the evidence for their categoricity, and the details of their scope and conditioning.

One of the aims of this investigation is necessarily descriptive. We are not aware of a previous systematic investigation of height effects in Turkish vowels, or any formal analysis thereof; existing descriptions combine impressionistic auditory judgements and introspection, and as such require experimental confirmation. The experimentation described in the

9 Not in non-final syllables: *revertér* [ʁɨ.viɾ.ˈteɾ] *[ʁɨ.vɛɾ.ˈteɾ] ‘to revert’; except for /l/, which can trigger neutralisation across the board: *delgádo* [dɛɫ.ˈga.du] ‘thin’, *relvínha* [ʁɛɫ.ˈvi.ɲɐ] ‘grass.DIM’.

10 Vigário (2002) gives the relevant vowel only; any errors in the remainder of the IPA rendering here are due to the authors.

following section is a first approach to the descriptive problem; our discussion of the results in section 4 is framed around the issues of cross-linguistic typology and the phonetic precursors to phonologisation that we have raised in this section and in the introduction respectively.

## 3 Methodology and sample

All analysis that follows reflects data from a production study conducted between January 2016 and June 2017 in Manchester. Thirteen native speakers of Turkish, all resident in the UK at the time of experimentation, read a list of 220 items, along with a further list of 20 sentences containing target /e/ embedded in varied phonological and morphological environments. Speakers' ages ranged from 20–39; there were eleven female speakers and three male. All speakers were raised in the place of origin within Turkey (as listed in table 1); length of time resident outside Turkish-speaking areas ranged from 0.5 to 8 years. Speakers were not made aware of the purpose of the experiment prior to recording, and were not offered compensation for their participation.

The preponderance of female speakers was an artefact of the process of speaker recruitment. As such, more data is required to determine whether sex has a statistically meaningful predictive effect on the nature of the pattern, and we cannot comment further; we exclude data points corresponding to male participants from the overall statistical analysis and modelling, but these data are included in qualitative observations where appropriate.

| ID | Year of birth | Place of origin | ID | Year of birth | Place of origin |
|---|---|---|---|---|---|
| F01 | 1997 | Istanbul | F08 | 1982 | Ankara |
| F02 | 1995 | Istanbul | F09 | 1981 | Istanbul |
| F03 | 1991 | Istanbul | F10 | 1980 | Ankara |
| F04 | 1988 | Izmir | F11 | 1978 | Ankara |
| F05 | 1987 | Istanbul | M01 | 1989 | Kayseri |
| F06 | 1985 | Fethiye | M02 | 1985 | Denizli |
| F07 | 1983 | Bursa | M03[11] | 1980 | Kars |

**Table 1** Speaker metadata (index, year of birth, region of origin) for all participants.

120 instances of /e/ appeared in the set of test items, in obstruent-closed (42), sonorant-closed (40), and open (38) syllables. 70 total were (primary-) stressed and the remainder unstressed[12]. The test set contained 32 instances of /ø/ (8 pre-obstruent and open; 16 pre-sonorant). Due to distributional restrictions on Turkish vowels, /ø/ almost never appears outside initial syllables, and is lower-frequency than /e/. The distribution of /ø/-containing tokens was therefore necessarily particularly skewed with respect to stress—the pre-obstruent and pre-sonorant categories were evenly split, but all but one of the /ø/ in open syllables were unstressed: the French loan *banliyö* 'banlieue' was included, but not all speakers found

[11] Represents a fairly clear instance of dialectal divergence and excluded from overall calculations; see figure 19 for discussion.

[12] In practice, what this means is that these target vowels were in final and non-final syllables respectively: Turkish stress is typically word-final when regular, and although exceptionally-stressing items exist (on which Inkelas 1999; Kabak and Vogel 2001; Inkelas and Orgun 2003, inter alia) these were not tested.

it acceptable. The remaining items provided data on the non-target vowels. A full list of items tested is provided in the appendix, in the standard Turkish orthography with phonemic transcription and gloss; those expected to be exceptional have been marked.

| ENVIRONMENT | e | ø | CONTROL |
|---|---|---|---|
| no coda | i.ˈl*e* ‘with’ | b*ø*.ˈlym ‘chapter’ | d*a*.ki.ka ‘minute’ |
| coda obstruent | ʃi.ka.j*e*t ‘complaint’ | ˈtʃ*ø*p ‘garbage’ | h*a*s.ta ‘ill’ |
| coda sonorant | bi.ˈb*e*r ‘pepper’ | *ø*r.ˈnek ‘example’ | sa.ˈm*u*r ‘sable’ |

**Table 2** Example items

For each speaker, one repetition of the wordlist and sentence-list was recorded. Recordings were made in a quiet room using a Sony PCM-M10 linear PCM recorder and an Audio-Technica ATR1200 cardioid microphone, and saved sampled at 44.1 kHz. Speakers were encouraged to read at a comfortable pace, and to correct themselves if desired. (120 stimuli + 20 sentence-internal targets)$*$(13 speakers) = 1820 total instances of /e/ and 416 total instances of /ø/ were recorded, minus 13 /ø/ and 14 /e/ that occurred in lexical items that individual speakers found unacceptable. 55 /e/ tokens (3%) were removed due to the diagnosis of systematic and conditioned exceptionality, and treated independently. 10 /e/ (0.55%) and 19 /ø/ (4.6%) of these were excluded due to deletion or devoicing, mispronunciation/production errors, segmentation difficulties, interference from non-modal voicing, and post-palatalisation coarticulation, leaving 1746 instances of /e/ and 383 instances of /ø/ for analysis. 2511 tokens were measured for the remaining 6 underlying vowels as comparison; since these were non-target vowels, no attempt was made to balance their distribution (/ɑ/ 843, /ɯ/ 258, /o/ 234, /i/ 560, /y/ 366, /u/ 250).

A further set of exploratory data were collected to test systematic patterns of exceptionality, representing a further 300 tokens of /e/. These were excluded from the overall statistical analysis, and were not distributed evenly among speakers: the state of this extra dataset is discussed in detail in subsection 4.4.

All segmentation and acoustic analysis were carried out in `Praat` (Boersma and Weenink, 2017); target vowels were extracted from the produced tokens, with boundaries inserted manually based on visual inspection of the waveform and spectrogram. In pre-/post- obstruent and pre-pausal contexts, the beginning and end of the target vowel was established with a reasonable degree of confidence by the presence of low-frequency periodic noise and clearly-visible formant structure. For vowels post-sonorant, the initial boundary was placed at the onset of the formant steady-state. Pre-nasal, the appearance of the high-amplitude formants associated with a nasal release was abrupt enough to provide a high-confidence end boundary, but for laterals and rhotics the cues to the transition (formant values, intensity) are typically more gradual; for our data, pre-pausal /r/ showed significant frication which distinguished it unambiguously from the target, and the final boundary pre-lateral was placed where significant changes in formant trajectory and in intensity coincided.

F1 and F2 (in hertz) were measured at 3 points (25%, 50%, and 75% of inter-boundary duration) and averaged, and duration (in milliseconds) was automatically exported by a `Praat` script. All statistical analysis was done in R (R Core Team, 2017). Formant data were then normalised to formant-extrinsic $z$-scores (Lobanov-normalised; Lobanov 1971; Adank et al. 2004) for comparison across speakers, using the R `phonR` package (McCloy, 2016).

## 4 Data

In this section, we present the acoustic data relating to coda-conditioned height effects in Turkish. This begins (section 4.1) with a demonstration of the pattern's robustness and apparent phonological categoricity; section 4.3 deals with the patterning and condition of vowel duration. Details of lexical exceptions and blocking environments appear in section 4.4, individual triggering segments in section 4.2, and the (incipient) generalisation to some voiced obstruents is considered in section 4.5.

Since the focus in this discussion is on the comparative state of the system rather than specific physical-acoustic properties for which a rescaling to a hertz-like value might be of interest, we have presented the Lobanov-normalised/*z*-score measure directly, throughout. For /e/, the range of non-normalised F1 values is $[346.98, 1178.94]$ (Hz), and of F2 values $[1136.88, 2828.44]$; for /ø/, the F1 range is $[334.02, 851.42]$, and the F2 range is $[1062.01, 2329.58]$.

### 4.1 Distribution and categoricity

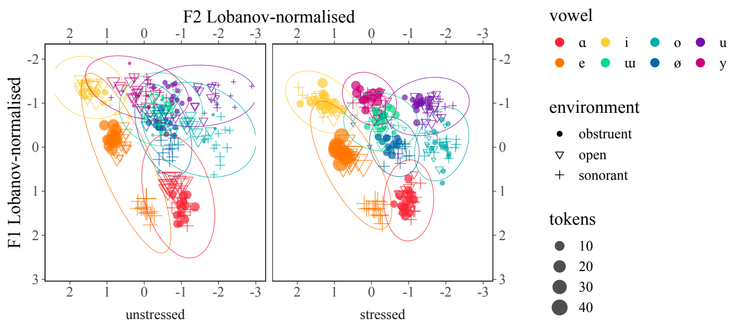



**Fig. 4** F2×F1 space, by vowel category and following environment: each point represents the mean measurement for a single speaker's productions of a particular vowel in the indicated environment; the size of a point denotes the number of tokens represented. 95% confidence ellipses indicate the overall spread of the *token-by-token* data for a particular vowel.

Figure 4 shows the Lobanov-normalised F2×F1 space for all 11 female speakers, averaged over all tokens across the 8 underlying vowel categories and separated by stress[13]. In figures 5 and 6, F2×F1 space for /e/ and /ø/ are shown individually, both token-by-token and averaged over the speakers in the sample. It is clear here that realisations of /e/ in pre-sonorant contexts diverge strongly and unambiguously from those in other contexts, subject to very little variation; realisations of /ø/ in pre-sonorant contexts also diverge from those in other environments, but the effect appears to be much smaller, and admits more variation between speakers. A further observation from figure 4 is the prevalence of strong height effects for open vowels across categories in non-final (that is, unstressed) syllables; the tendency of vowels in unstressed open syllables to be higher (have lower F1) is weak only for /e/.

[13] For all figures in this paper, 'environment' refers to the following segment, and 'unstressed' and 'stressed' may safely also be read as 'non-final' and 'final' respectively.

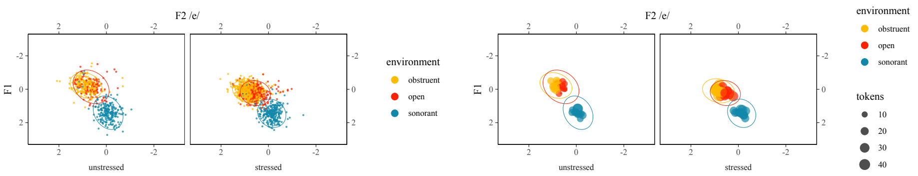



**Fig. 5** F2×F1 space for /e/, by following environment. Top: each point corresponds to a single token. Bottom: each point corresponds to the mean measurement for a single speaker's productions, with size corresponding to number of tokens. Ellipses indicate regions of 95% confidence for the token-by-token data in both plots.

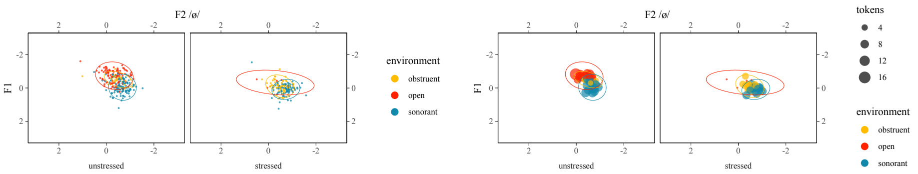



**Fig. 6** F2×F1 space for /ø/, by following environment. Top: each point corresponds to a single token. Bottom: each point corresponds to the mean measurement for a single speaker's productions, with size corresponding to number of tokens. Ellipses indicate regions of 95% confidence.

Figures 4–6 give rise to a set of preliminary generalisations. Tokens corresponding to pre-sonorant /e/ have essentially no overlap with those corresponding to /e/ in an unclosed or obstruent-closed syllable; the majority of the apparent effect is in F1, with a smaller apparent effect in F2 corresponding roughly to movement along the front diagonal of the vowel space, which we may ascribe entirely to height rather than backness. The relative relationships of the pre-obstruent and open-syllable realisations of /e/ have some dependence on stress; the overlap is near-complete for unstressed tokens, but stressed pre-obstruent /e/ appears to correspond to slightly increased F2 and slightly reduced F1. The data for /ø/ indicate that some relationship exists between environment and F1; the main contrasts relative to the state of /e/ lie in the lack of distributional discontinuity (although pre-sonorant realisations have the largest F1 values, there is overlap between their range and the ranges for the other environments), and in ordering: for /ø/, realisations in unstressed *open* syllables are consistently the most close (have the lowest value for F1). In figure 7, averaged F1 measurement is visualised, by *speaker* and environment, for both the mid vowels /e ø/. For both /e/ and /ø/, speakers vary particularly in the relationship between pre-obstruent tokens and tokens in open syllables; we revisit the question of individual systems in section 5.2.3.

### *4.1.1 Significance and effect size*

The previous sub-section offers a broad overview of the environment-mediated patterns visible in the experimental dataset. In the discussion that follows, we explore this in detail. To begin with, we consider the statistical relationship of vowel height to the various possible predictors. We fit standard linear mixed-effects models[14] to subsets of the data for /e/ and /ø/ (using R: `lme4`, Bates et al. 2015), with F1 as the dependent variable, and the following

[14] The choice of mixed-effects models is informed by the possibility of idiosyncrasy. There is no a priori reason to expect that individual speakers respond identically to environment or stress; nor is there any reason to expect that all lexical items are treated unexceptionally.

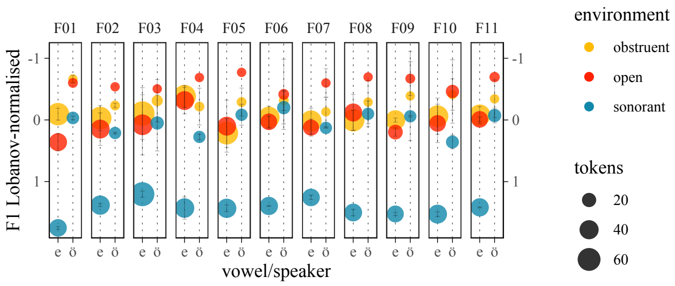



**Fig. 7** Normalised F1 by individual speaker, for /e/ and /ø/, averaged over stressed and unstressed contexts. Error bars show one standard deviation.

environment ('obstruent', 'sonorant', or 'open'), stress ('stressed' or 'unstressed'), and their interaction as categorical fixed effects. Potential contributions from individual speaker and lexical item were treated as random effects: models include a random slope of environment and stress by speaker, and of stress[15] by word. (Another linear mixed-effects model was fitted to investigate the effect of individual sonorant segments (m, n, l, r); for the presentation and discussion of these latter results, see section 4.2.) The discussion in following sections, unless otherwise specified, drops the male speakers from the sample.

Summaries of these models are presented below in tables 3–6[16]. The 'base' levels assumed by the model are 'obstruent' and 'unstressed': the estimate for the mean ($z$-score) F1 in unstressed, pre-obstruent contexts is given by the intercept. In tables corresponding to fixed effects, estimates for further terms predict the difference between these levels and the relevant 'base' ones. 95% confidence intervals[17] are given for each fixed term in the model, calculated via semi-parametric bootstrap estimation. Parameters whose value is statistically significant by this measure (that is, non-inclusive of the null) have been marked *. As a guideline, $t$-values greater than 2 should be considered significant. In tables corresponding to random effects, 'variance' and 'SD' (standard deviation) are, as in their usual definition, to be interpreted as measures of the spread corresponding to each parameter. Correlations represent the extent to which a given fixed effect is invariant for a given random variable.

It is evident from tables 3 and 5 that the predicted difference between tokens in sonorant-coda *unstressed* syllables and all other unstressed tokens is large and statistically significant for both /e/ and /ø/, as expected; the interaction with stress is substantial. The presence of (primary) stress reduces F1 in pre-sonorant /e/, but does not remove the large context separation; since, however, this is difficult to clearly adduce from the coefficients presented, as not every possible ordered pair of two-factor interactions is compared by the model[18], table 7 gives the relevant terms and estimates of significance from another mixed-effects model fitted for the *stressed* subset of /e/-tokens alone, with random effects retained as above and the single

[15] Not for /ø/, due to the unbalanced nature of the test set; instances of stressed /ø/ were so infrequent that models incorporating a random slope here *do not converge*.

[16] We're aesthetically indebted to Fruehwald (2016) in tabulating density plots for the bootstrapped parameter estimates alongside the model results.

[17] Cf. Bates et al. (2015): in complex models involving e.g. partially-crossed designs, the null distributions of parameter estimates are not $t$-distributed for finite samples, but computing a $p$-value based on the degrees of freedom for a $t$-distribution makes such asymptotic assumptions and is thus undesirable. The alternative is the calculation of confidence intervals via bootstrap estimation, with the null hypothesis rejected if it falls strictly outside the interval for a given parameter.

[18] That is, no coefficient directly compares e.g. {open, stressed} and {sonorant, stressed}

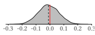
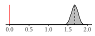
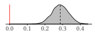
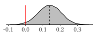
| Parameter | Estimate | 95% confidence | Bootstrap | $t$-value |
|---|---|---|---|---|
| Intercept: obstruent | −0.21436 | [−0.3086, −0.1086] |  | −4.267 |
| Environment: open | −0.03109 | [−0.1550, 0.1330] |  | −0.505 |
| Environment: sonorant* | 1.61723 | [1.510, 1.837] |  | 18.716 |
| Stress: stressed* | 0.30500 | [0.1938, 0.3791] |  | 8.435 |
| open × stressed* | 0.15163 | [0.0077, 0.2663] |  | 2.464 |
| sonorant × stressed* | −0.37112 | [−0.5173, −0.2404] |  | −5.205 |

**Table 3** Estimated means and derived confidence intervals for fixed effects in the model `F1` ∼ `environment` × `stress + (1 + environment + stress|speaker) + (1 + stress|word)` for /e/. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates (R: `bootMer` from `lme4`), for which density plots are shown in the final column.

| Group | | Variance | SD | Correlation | | |
|---|---|---|---|---|---|---|
| *Word* | Intercept | 0.119126 | 0.34515 | | | |
| | Stress: stressed | 0.150095 | 0.38742 | −1.00 | | |
| *Speaker* | Intercept: obstruent | 0.010646 | 0.10318 | | | |
| | Environment: open | 0.021631 | 0.14707 | −0.18 | | |
| | Environment: sonorant | 0.036538 | 0.19115 | −0.52 | 0.51 | |
| | Stress: yes | 0.007788 | 0.08825 | 0.33 | −0.23 | −0.93 |
| *Residual* | | 0.105680 | 0.32508 | | | |

**Table 4** Random effect standard deviations and correlations, model `F1` ∼ `environment` × `stress + (1 + environment + stress|speaker) + (1+stress|word)` (table 3), /e/.

fixed effect of environment. Modelling predicts no difference between pre-obstruent /e/ and /e/ in open syllables if both are unstressed; table 7 confirms that in stressed contexts, these differ, with $\mathrm{F1}_{\text{OBSTRUENT}} < \mathrm{F1}_{\text{OPEN}}$. We argue that there is a reasonably robust cross-linguistic basis for the claim that stressed and unstressed contexts might differ in the phonology, and that there *is* an overall significant effect of stress itself on vowel quality; in sections 4.1.2 and 4.3, we find that there is indeed a larger interaction with stress-conditioned height and duration effects.

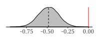
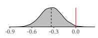
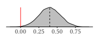
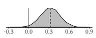
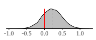
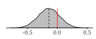
| Parameter | Estimate | 95% confidence | Bootstrap | $t$-value |
|---|---|---|---|---|
| Intercept: obstruent* | −0.4835 | [−0.7332, −0.2475] |  | −3.410 |
| Environment: open* | −0.3351 | [−0.6154, −0.0483] |  | −2.482 |
| Environment: sonorant* | 0.3986 | [0.1083, 0.6958] |  | 2.479 |
| Stress: stressed* | 0.3201 | [0.0419, 0.6169] |  | 2.140 |
| open × stressed[19] | 0.2117 | [−0.3531, 0.7609] |  | 0.822 |
| sonorant × stressed | −0.1411 | [−0.4973, 0.2118] |  | −0.872 |

**Table 5** Estimated means and derived confidence intervals for fixed effects in the model `F1` ∼ `environment` × `stress + (1 + environment + stress|speaker) + (1|word)` for /ø/. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates, for which density plots are shown in the final column.

| Group | | Variance | SD | Correlation | | |
|---|---|---|---|---|---|---|
| *Word* | Intercept | 0.04007 | 0.2002 | | | |
| *Speaker* | Intercept: obstruent | 0.01806 | 0.1344 | | | |
| | Environment: open | 0.02618 | 0.1618 | −0.95 | | |
| | Environment: sonorant | 0.02657 | 0.1630 | −0.16 | 0.46 | |
| | Stress: yes | 0.02133 | 0.1461 | −0.49 | 0.29 | −0.38 |
| *Residual* | | 0.07373 | 0.2715 | | | |

**Table 6** Random effect standard deviations and correlations, model `F1` $\sim$ `environment` $\times$ `stress + (1 + environment + stress|speaker) + (1|word)` (table 5), /ø/.

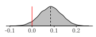
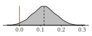
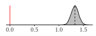
| Parameter | Estimate | 95% confidence | Bootstrap | *t*-value |
|---|---|---|---|---|
| Intercept: obstruent | 0.08364 | [−0.0154, 0.1801] |  | 1.663 |
| Environment: open* | 0.11841 | [0.0093, 0.2248] |  | 2.147 |
| Environment: sonorant* | 1.32594 | [1.183, 1.472] |  | 17.674 |

**Table 7** Estimated means and derived confidence intervals for fixed effects in the model `F1` $\sim$ `environment + (1 + environment|speaker) + (1|word)` for *stressed* /e/ only. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates (R: `bootMer` from `lme4`), for which density plots are shown in the final column.

| Group | | Variance | SD | Correlation | |
|---|---|---|---|---|---|
| *Word* | Intercept | 0.02551 | 0.1597 | | |
| *Speaker* | Intercept: obstruent | 0.02285 | 0.1512 | | |
| | Environment: open | 0.01548 | 0.1244 | −0.20 | |
| | Environment: sonorant | 0.04737 | 0.2176 | −0.83 | 0.40 |
| *Residual* | | 0.09305 | 0.3050 | | |

**Table 8** Random effect standard deviations and correlations, model `F1` $\sim$ `environment` $\times$ `stress + (1 + environment + stress|speaker) + (1|word)` (table 7), stressed /e/.

Effects are given in $z$-score measures throughout, which scale the whole dataset to a normal distribution with mean 0 and standard deviation 1; each linear-model estimate can then be understood to correspond to a number of standard deviations across the whole vowel space. As an index of comparison, one standard deviation in F1 across the raw (non-normalised) dataset is 164 Hz. Cross-linguistic work on formant-frequency discrimination (Kewley-Port and Watson, 1994; Kewley-Port et al., 2005) suggests that the baseline ΔF1 required for reliable perceptual discrimination is in the region of 20 Hz, so effects greater than around $z$ $\pm 0.12$ over our whole dataset are plausibly perceptually meaningful.

#### *4.1.2 /i/-triggered height effects*

Recall from tables 3 and 7 that there were statistically-significant estimates distinguishing /e/-realisations in *stressed* and *unstressed* open syllables, and in *stressed* syllables for each of

[19] Recall that only four data points went into this estimate.

the three environment types, but that we could not reject the zero-difference hypothesis for ‘obstruent’ and ‘open’ in unstressed syllables: $F1_{\text{OBSTRUENT}} \sim F1_{\text{OPEN}} < F1_{\text{SONORANT}}$ in unstressed syllables, but $F1_{\text{OBSTRUENT}} < F1_{\text{OPEN}} < F1_{\text{SONORANT}}$ in unstressed syllables. Both cases for /e/ are distinct from the case for unstressed /o/, for which $F1_{\text{OPEN}} < F1_{\text{OBSTRUENT}} < F1_{\text{SONORANT}}$. One possibility is that the state of unstressed /e/ is in fact a *superposition* of an /o/-like case (open < obstruent < sonorant) and a stressed-/e/-like case (obstruent < open < sonorant).

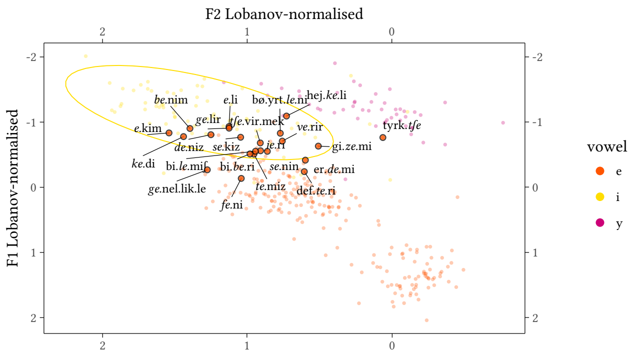



**Fig. 8** F2×F1 space for /e/, with the high vowels /i/ and /y/. Ellipse: 95% confidence region for tokens of **/i/**. One point corresponds to the *mean* across all tokens of a single word.

Consider the F2×F1 space depicted in figure 8 above. All items of the form /(C)e.Ci/ are highlighted and transcribed; /e/-realisations in these contexts fall within the bounds of tolerance for high /i/, and skew the overall F1-distribution for /e/ in open syllables.

## 4.2 Triggering segments

In section 2.2.2, we considered the extent to which the individual sonorants constitute robust PHONETIC PRECURSORS to vowel lowering. The answer is not entirely conclusive; but the strength of the precursor in each environment does not seem to be constant, and the cross-linguistic evidence is variable. Further phonetic discussion of the case of the Turkish lateral appears in section 4.2.1 below; we argue therein that the lateral in Turkish does not represent a strong acoustic-articulatory trigger for vowel lowering. In this section, we test for the presence or absence of effects distinguishing the individual triggering segments from one another.

The F2×F1 scatterplots given in figure 9 represent all tokens followed by coda /r/, /l/, /m/, /n/ only. Each point represents a single pre-sonorant token of /e/ (left) and /ø/ (right), with 95% confidence ellipses indicating the spread of realisations. Inspection suggests that there is no substantial discontinuity and certainly no further categorical allophony; there is a slight predominance of pre-*rhotic* /e/ tokens at higher F1 values (lower, more open realisations). Examining the F2×F1 landscape after averaging and weighting by speaker (figure 10) suggests that the majority of this pre-rhotic effect can be attributed to productions from two speakers, F01 (Istanbul, b. 1997) and F04 (Izmir, b. 1988). F01 shows a generally higher F1 across contexts than other speakers, but all cross-context variation is well within confidence intervals and cannot be attributed to a ‘real’ effect. The separation between pre-rhotic tokens and other pre-sonorant tokens for F04 appears genuinely significant, and may represent an individual idiosyncrasy in production.

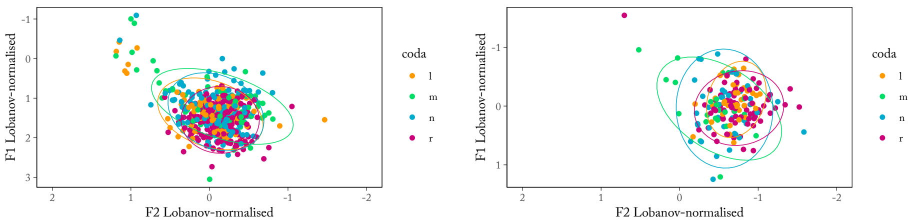



**Fig. 9** F2×F1 space for pre-sonorant /e/ (left) and /ø/ (right), by individual coda segment. Each point corresponds to one vowel produced by a single speaker.

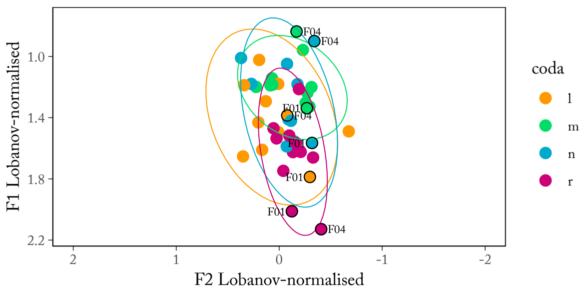



**Fig. 10** F2×F1 space for pre-sonorant /e/, by individual coda segment. Each point corresponds to the *mean* of all corresponding tokens for a single speaker. Speakers F01 and F04, both of whom show particularly high F1 values in pre-rhotic contexts, are highlighted.

Recall (section 2.1) that resyllabification under affixation blocks lowering, as in [gi.zæm] 'mystery' but /gizem-i/ [gi.ze.mi] 'mystery-DAT'; in open syllables preceding an onset sonorant, we do not predict the existence of any systematic, grammatically-controlled lowering of the type investigated here. The scatterplot given in figure 11, represents all tokens of /e/ in *unstressed open syllables* immediately followed by an onset sonorant across the syllable boundary. Although the number of tokens is not large, there is some evidence to suggest that there is a meaningful effect of the rhotic on a vowel that precedes it *across* a syllable boundary. Vowels in open syllables are very susceptible to other height effects, and in particular *raising* triggered by the presence of a subsequent high vowel (sections 4.1.2 and 4.3); but such effects are absent here.

We fit two further mixed-effects models—for /e/ and /ø/ respectively—to a subset of the data consisting solely of those tokens with a coda sonorant in the right-hand environment, with F1 as dependent variable, coda (m, n, l, r) and stress ('stressed' or 'unstressed') as categorical fixed effects. Summaries of these results are presented in tables 9 and 10, including confidence intervals calculated via semi-parametric bootstrap estimation; the base levels assumed by the model are 'coda /l/' and 'unstressed'.

The model in table 9 does not support a claim that a significant difference exists between *pre-lateral* /e/ and *pre-rhotic* /e/. Realisations preceding *nasals* are generally higher (lower

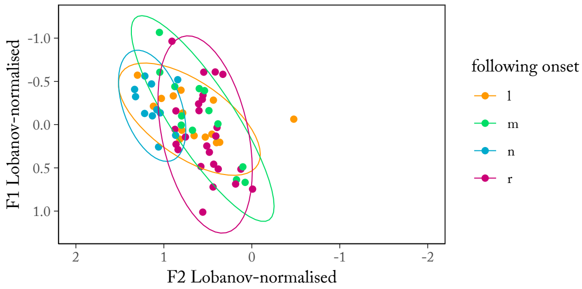



**Fig. 11** F2×F1 space for /e/ in *open syllables*, by the content of the immediately following syllable onset. Each point corresponds to one vowel produced by a single speaker.

values of F1); what cannot be diagnosed from this analysis is whether this represents a systematic property of the phonologically-conditioned environments, or a ‘top-level’ effect of nasalisation in pre-nasal vowels (driven by the presence of nasal anti-formants).

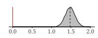
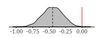
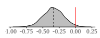
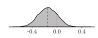
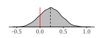
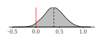
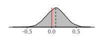
| PARAMETER | ESTIMATE | 95% CONFIDENCE | BOOTSTRAP |
|---|---|---|---|
| Intercept: coda /l/ | 1.47751 | [1.230, 1.726] |  |
| Coda: /m/* | −0.44463 | [−0.7648, −0.1452] |  |
| Coda: /n/* | −0.33914 | [−0.6501, −0.0239] |  |
| Coda: /r/ | 0.08575 | [−0.1924, 0.3616] |  |
| Stress: stressed* | −0.14399 | [−0.4413, 0.1428] |  |
| coda /m/ × stressed | 0.21697 | [−0.2289, 0.6633] |  |
| coda /n/ × stressed | 0.37876 | [−0.0244, 0.7911] |  |
| coda /r/ × stressed | 0.08133 | [−0.2982, 0.4731] |  |

**Table 9** Estimated means and derived confidence intervals for fixed effects in the model `F1 ~ coda × stress + (1 + coda + stress|speaker) + (1|word)` for /e/. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates (R: `bootMer` from `lme4`), for which density plots are shown in the final column.

### *4.2.1 The lateral*

This section considers in greater detail the status of the lateral. In section 2.2, we discussed possible motivations, phonetic and structural, for anticipatory F1-lowering. In section 1, we suggested that the analysis of the ‘naturalness’ of active classes in phonological change should take into account the individual likelihood that each segment in that class constitutes a plausible phonetic precursor to the change in question, rather than the overall structure of the class alone. We reference in section 2.1.2 the descriptive claim that the Turkish /l/ has an allophonic distribution conditioned by the backness of the surrounding vowel. The expected status of the lateral as a phonetic precursor to height effects then has a necessary dependence on its status as plain, velarised, or palatalised; these impressionistic categories correspond to a significant degree of acoustic variation (Proctor 2009 for an overview).

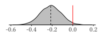
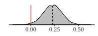
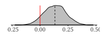
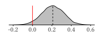
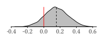
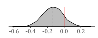
| Parameter | Estimate | 95% confidence | Bootstrap |
|---|---|---|---|
| Intercept: coda /l/ | −0.21494 | [−0.4132, −0.0175] |  |
| Coda: /m/ | 0.22929 | [−0.0273, 0.4198] |  |
| Coda: /n/ | 0.13411 | [−0.0567, 0.3241] |  |
| Coda: /r/* | 0.20231 | [0.0249, 0.3791] |  |
| Stress: stressed | 0.20982 | [−0.0164, 0.4321] |  |
| coda /m/ × stressed | *no tokens, dropped from model* | | |
| coda /n/ × stressed | 0.14977 | [−0.1268, 0.4321] |  |
| coda /r/ × stressed | −0.13339 | [−0.3727, 0.1141] |  |

**Table 10** Estimated means and derived confidence intervals for fixed effects in the model `F1 ~ coda × stress + (1 + coda + stress|speaker) + (1|word)` for /ø/. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates (R: `bootMer` from `lme4`), for which density plots are shown in the final column.

Cross-linguistic acoustic work on laterals suggests a correspondence between the first two formants and the degree of ‘darkness’, with a larger F2×F1 difference corresponding to a ‘lighter’ (and thus further fronted) [l] (Sproat and Fujimura, 1993; Carter, 2002; Recasens and Espinosa, 2005; Turton, 2014). The locus of this difference is largely in F2 variation, with F1 relatively invariant throughout even in dynamic analysis (Strycharczuk and Scobbie, 2016), but due to the non-independence of F1 and F2 a correspondence is expected between backing (decrease) in F2 and openness (increase) in F1; Sproat and Fujimura (1993); Carter and Local (2007) give increased F1 as a secondary correlate of /l/-darkness, If anticipatory coarticulation with a lateral affects the quality of the vowel immediately prior, we may then hypothesise that the major effect of a *velarised* lateral on a front vowel, corresponding in gestural terms to predorsum lowering and postdorsum retraction (Recasens, 2012), would be reflected in a F2 decrease from the V target towards the lower /l/-target. It is less clear that a fronted lateral should cause an increase in F1 as an anticipatory coarticulatory effect, since the predicted transition into such a lateral from a mid vowel involves a drop in F1 and a sharp increase in F2; indeed, the tongue-tip gesture corresponding to alveolarity corresponds rather to predicted raising, and thus F1-decrease. Recasens (2014) gives /e/-lowering to [a] post-palatal lateral in Catalan as a possible progressive dissimilatory process in a very small handful of cases, but gives pre-lateral raising as far more frequent.

The remarks in this section constitute a very preliminary study of the acoustic properties of the Turkish lateral; is the transition in /el/ a favourable or unfavourable phonetic environment for the pattern under consideration? All instances of /l/ were extracted from the production data collected in this stud; across 11 (female) speakers, this yielded 627 tokens for analysis; of these, 53 were discarded due to regressive manner assimilations (to coronals s, z, n) or due to phrase-final devoicing and frication leading to unreliable formant measurements. For the remaining 574 datapoints, F1 and F2 were measured at the midpoint, to give a rough indicator of the ‘frontness’ of the lateral. A summary visualisation appears in figure 12; in the left figure, tokens were coded ‘front’, ‘back’, and ‘disharmonic’ by adjacent vowel (respectively: exclusively i, y, e, ø; exclusively ɯ, u, a, o; one vowel from both sets).

The distribution of the Turkish laterals in F2×F1 space is thus discontinuous and categorical, conditioned by the adjacent vowels and with no particular dependence on syllabic position; all post-/e/ and post-/ø/ laterals, which trigger the alternation under discussion, have

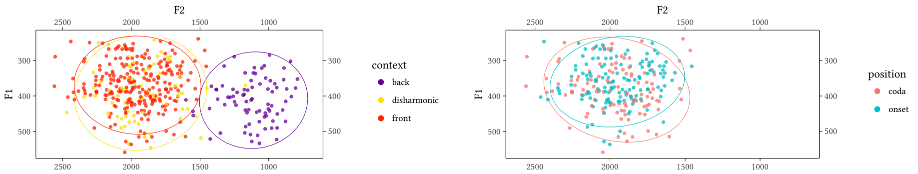


**Fig. 12** F2×F1 space for the lateral /l/, measured at midpoint, by vocalic environment (**left**) and by syllabic position (**right**): 'disharmonic' tokens are adjacent in the string to both a front vowel (i, e ∼ æ, y, ø ∼ œ) and a back vowel (ɯ, u, o, ɑ), within a single syllable or across the syllable boundary.

categorically raised F2. Other plausible predictors (vowel quality, stress) had no statistically meaningful effect. The implication for our analysis of class formation, which we will revisit in later sections, is as follows: in a language like English, in which the distribution of the plain lateral and the heavily velarised lateral is strictly conditioned by position in the syllable, the velarised coda lateral becomes a natural and well-motivated phonetic trigger for vocalic effects of the type seen here. In any of the contexts in which we are interested in the Turkish lateral, however, no such well-motivated trigger exists.

## 4.3 Duration

One possible origin for the vowel-lowering alternations that what we see is in coda-conditioned loss or gain of duration, as discussed in section 2.2.1. If this is the case, we might expect some systematic pattern to appear in the sample, both in the duration–F1 correlation, and in the predicted duration for each phonologically-active set of environments (pre-obstruent; pre-sonorant; open).

### *4.3.1 The duration–height connection*

In section 2.2.1, we devoted some attention to the relationship between duration and vowel quality, which is cross-linguistically well established. What we did not address in full was the debate as to whether this relationship has a purely mechanical aetiology, rooted solely in facts of articulation and low-level phonetics, or instead arises from the variable phonologisation of durational targets.

The mechanical explanation makes several testable predictions. If low vowels are longer due to the length of the jaw-opening gesture (Lehiste, 1970) then the 'extra' length must be particularly visible in the onset and offset formant movements towards the low vowel (Lisker, 1974); if instead the steady-state is the locus of increased duration, this argues for a phonological explanation. If durational effects are purely mechanical, they should remain constant across speech rates; Solé and Ohala (2010) find that this is indeed the case in Japanese, but is not the case in Catalan or English, and argue therefore that the correlation between F1 and duration is phonologically-controlled in the latter languages but phonetically-controlled in the former. The lowest and highest vowels are inherently constrained, and therefore there should be durational 'ceilings' at the extremes of these categories; duration itself cannot approach 0 very closely, or approach arbitrarily large values. This fact predicts non-linearity at both the extremes of the vowel space and the extremes of duration.

Two further predictions have been shown not to hold in all cases. First, that a positive correlation between F1 and duration should hold both across categories and within categories (the highest instances of any individual vowel should be shorter than the lowest instances); Toivonen et al. (2015) find, for English and Swedish, that although there is a cross-category correlation between height and duration (tokens of phonemically high vowels /ɪ/ are longer than tokens of phonemically low vowels /æ a/) this does not always persist within categories (higher and lower realisations of [ɪ] show no systematic patterning in duration). Second, and most centrally, that if realisations of an individual vowel systematically shift in height as the result of phonological change, we should expect an attendant pattern in duration; Tauberer and Evanini (2009) show, for various sound changes in North American English, that the distributions of dialectal variation in F1 and in duration appear independent.

The alternate explanation for any apparent positive correlation between duration and F1 is then a phonologically-controlled one: each vowel (category) has an independent phonologised duration target, and it happens to be the case that these targets are shorter for high vowels than they are for low vowels. In one sense, a solution of this type just moves the problem to a slightly different tier of analysis: why should this separation in durational targets arise and phonologise? Solé and Ohala (2010) propose that phonologisation 'overrides' what is presumed to be the original mechanical bias: the use of duration as a marker of phonological identity is ultimately phonologised from an uncontrolled phonetic preference for long low vowels, and short high ones.

From the point of view of the alternation under consideration, three questions arise. Given that we have a systematic difference in mid-vowel height constrained by environment, do we see an attendant distribution of duration across these environments? If not, how do we interpret the mismatch? Thirdly, what is the direction of the causal relationship between the first formant and duration; do changes in F1 drive responses in duration, or vice versa?

In this subsection, we take a filtered dataset corresponding to all 'reasonable' measurements of duration: points more than 3 standard deviations (39.75 ms) away from the dataset mean of 99.04 ms were dropped, giving an adjusted range of [12, 219] ms. (This corresponded to a loss of a little under 5% of the data, 214 points of 4747 total; this can essentially be attributed to automated measurement errors.) We plot per-category duration in figure 13, list the results of a linear mixed-effects model for per-category duration of /e/ in tables 11 and 12, and consider the potential for individual variation in figure 14.

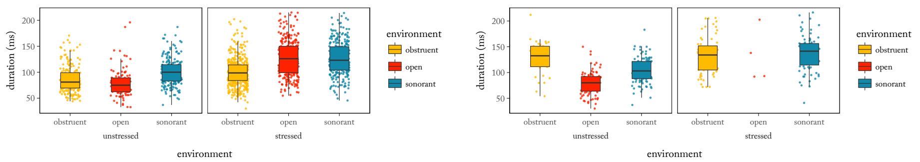



**Fig. 13** Box-plot of duration, by conditioning coda environment and split by stress, for all tokens of /e/ (**left**) and /ø/ (**right**) in the sample.

As before, a linear mixed-effects model was chosen in order to mitigate some of the effect of inter-speaker variation and idiosyncrasy on the result. Although the state of the within-category linearity between F1 and duration is inconsistent (figure 13), it is reasonable to posit that the overall distribution of duration is categorically predictable: it is the case that overall, vowels *are* shorter in unstressed open syllables, but it is not necessarily the case that a predictive relationship holds between the within-category variation in vowel length and the within-category in height. The effect of category on the duration of /ø/ is particularly striking; the effect on the duration of /e/ is not as large in absolute units of time, but statistical modelling suggests that it is significant, and that there is an inversion of the expected cross-category duration between /e/ and /ø/ (section 4.3.1).

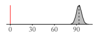
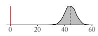
| Parameter | Estimate | 95% confidence | Bootstrap |
|---|---|---|---|
| Intercept: obstruent* | 93.452 | [86.22, 100.52] |  |
| Environment: open* | −10.945 | [−20.94, −0.25] |  |
| Environment: sonorant* | 13.134 | [3.78, 22.48] |  |
| Stress: stressed | 6.582 | [−1.45, 14.85] |  |
| open × stressed* | 44.144 | [36.00, 52.02] |  |
| sonorant × stressed* | 14.887 | [6.45, 23.69] |  |

**Table 11** Estimated means and derived confidence intervals for fixed effects in the model `duration` ∼ `environment` × `stress + (1 + environment + stress|speaker) + (1|word)` for /e/. 95% confidence intervals are calculated on 6,000 semi-parametric bootstrap estimates (R: `bootMer` from `lme4`), for which density plots are shown in the final column.

| Group | | SD | Correlation | | |
|---|---|---|---|---|---|
| *Word* | Intercept: obstruent | 16.000 | | | |
| | Environment: open | 16.208 | −0.85 | | |
| | Environment: sonorant | 20.439 | −0.72 | 0.94 | |
| *Speaker* | Intercept: obstruent | 7.521 | | | |
| | Environment: open | 12.406 | 0.31 | | |
| | Environment: sonorant | 9.262 | 0.07 | −0.60 | |
| | Stress: yes | 10.906 | 0.51 | 0.55 | 0.03 |
| *Residual* | | 20.694 | | | |

**Table 12** Random effect standard deviations and correlations, model `duration` ∼ `environment` × `stress + (1 + environment + stress|speaker) + (1|word)` (table 11), /e/.

We can then ask whether this relationship continues to hold across individual speakers. The distributions of duration for each of the 11 female speakers in the sample are visualised in figure 14 for /e/ and /ø/ respectively.

Qualitatively, there is no strong differential in the pattern visible across speakers for unstressed /e/, which is broadly concordant with the overall statement we give in section 4.3.1. The pattern in stressed /e/ is more variable, in the sense that there is an apparent reversal of the broad hierarchy of environments; for *older* speakers, like F08, F09, F10, and F11, the ordering of predicted durations of stressed /e/ runs sonorant > open > obstruent, which is counter to the behaviour of *younger* speakers for whom the prediction is instead open > sonorant > obstruent. As an indicative illustration we plot the relationship between year of birth and /e/-duration in figure 15. The pattern in /ø/ is more generally constant; there is no evidence for conditioning by age that meets statistical qualifications for significance, nor a particularly strong qualitative pattern, unless the youngest speaker's reversal of the typical ordering in unstressed syllables (F01) is to be taken as representative of a genuinely distinct system. Does the variable but constrained patterning in duration reflect some artefact of the end-product of sound change in Turkish, or is it coincidental? One possible argument here is that the existence of patterning in duration is a reflection of the original conditions of phonologisation; for speakers who are behind in the change, a few traces of the original environment for phonologisation are seen, and these traces disappear for speakers who are further ahead. Due to the lack of age variation in the sample, this is difficult to comment upon further, but is a productive direction for an expansion of this work.

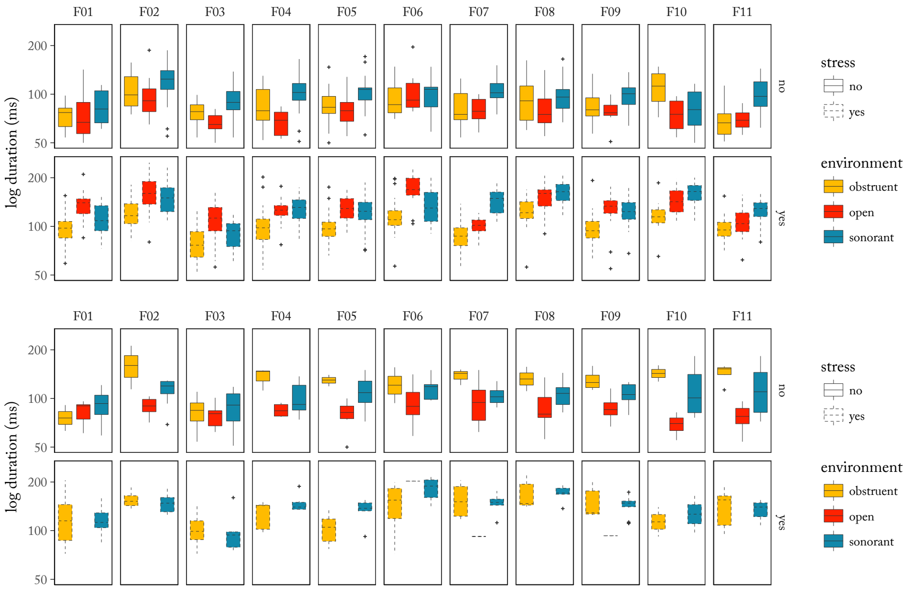



**Fig. 14** Duration in milliseconds, by individual speaker and split by stress, for (**top**) /e/ and (**bottom**) /ø/.

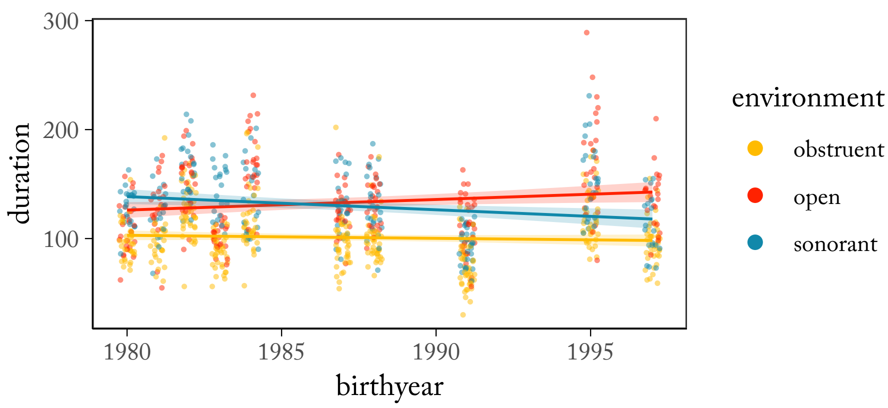



**Fig. 15** Duration in milliseconds, by speaker’s year of birth, for stressed /e/.

| VOWEL | STRESS | DURATION BY ENVIRONMENT |
|---|---|---|
| /e/ | unstressed | sonorant > obstruent > open |
| /ø/ | unstressed | obstruent > sonorant > open |
| /e/ | stressed | open > sonorant > obstruent |
| /ø/ | stressed | sonorant ∼ obstruent |

**Table 13** Summary description: conditioning environments, stress, and duration.

## 4.4 Exceptionality and the voiced fricatives

Two broad classes of exceptions to mid-vowel lowering occur; the first set consists of pre-sonorant non-undergoers of /e/-lowering, and the second of pre-obstruent *undergoers*; the latter is given in our sample largely by tokens of the aorist negative /-mAz/[20], although it appears to apply more generally. These are presented in sections 4.4.1 and 4.5 below, with brief commentary.

### *4.4.1 Pre-sonorant exceptionality*

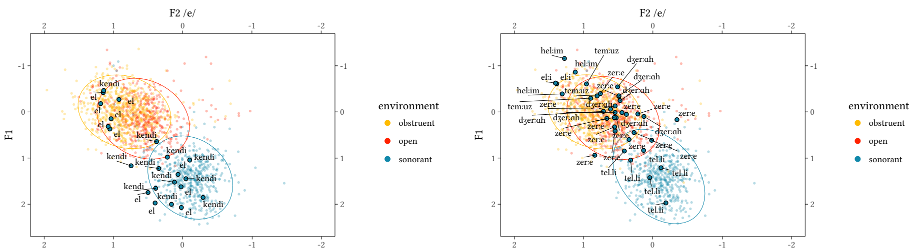



**Fig. 16** F2×F1 space for all tokens of /e/, with variability highlighted. **Left:** *el* [el ∼ æl] 'hand', and *kendi* [ken.di ∼ kæn.di] 'self'. **Right:** Exceptional 'true geminates', along with /tel-lI/ [tæl.li] 'wired' for comparison. One point represents one speaker's production.

Although all speakers show /e/-lowering across the board, occasional lexically-conditioned exceptionality arises: figure 16 (left) shows, for *el* [el ∼ æl] 'hand', and *kendi* [ken.di ∼ kæn.di] 'self', a general instance of variability in relatively high-frequency items. Several further examples of exceptionality that seem to be more explicitly grammatical follow in figure 16 (right) and figure 17; we present these only minimally here as our experimentation did not test systematically for conditioning. The first, in figure 16 (right), represents an arguably 'false' case of exceptionality. What appears initially to be unexplained opacity seems instead to arise from apparent 'true' geminates, syllabified as onsets rather than as coda–onset clusters; the lexical items involved have in common a status as comparatively-unadapted loans. This can be contrasted with /tel-lI/ [tæl.li] 'wired', also shown, which presents a

[20] /A/ here indicates an underspecified affix vowel, and thus in [back] harmony with the final vowel of the root either [ɑ] or [e∼æ] on the surface.

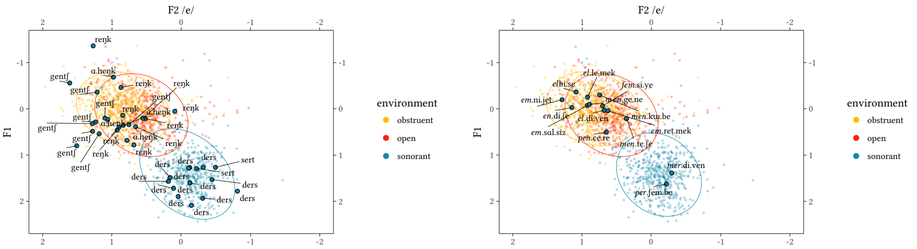



**Fig. 17** F2×F1 space for all tokens of /e/, **Left:** coda N+C clusters and coda R+C clusters are highlighted and labelled. **Right:** Exceptionally-behaving initial syllables are marked, along with similar-seeming items whose patterning shows no corresponding exceptionality. Data in the right-hand figure are *averaged* for readability.

morphologically-doubled sonorant on the surface, but in which /e/-lowering does apply. Secondly, pre-sonorant lowering appears to be blocked for N+C clusters but not for R+C clusters, as figure 17 (left). A final, particularly intractable exception appears in a poorly-characterised set of word-initial (and thus unstressed) sonorant-coda syllables, as figure 17 (right). There is no *general* constraint against lowering in a word-initial syllable: /erdem/ [ær.dæm] ‘virtue’, [kæn.di.mi.ze] ‘REFL-1PL-DAT’, and non-resyllabifying affixation does not induce exceptionality in an undergoer-root.

We are unable to find any evidence of exceptionality in /ø/, although due to the size of the test set and the greater variability in /ø/ across the board, we cannot claim that this is conclusive. If it is genuinely the case that there is no real exceptionality for /ø/, then this is consistent with a model in which the ‘phonological’ status of lowering in /e/ is further advanced, and thus amenable to effects violating strict phonetic conditioning (see e.g. Bermúdez-Otero 2015). If lowering generalises to /ø/ after /e/, we expect /ø/ to be behind in *stabilisation*.

### 4.5 Generalisations to the voiced fricatives

Coda voiced fricatives in Turkish are relatively infrequent, for reasons possibly ultimately related to a significant rate of pre-pausal devoicing. Instances of the negative aorist /-mAz/ make up the majority of these, and the majority of /ez/ tested. In a set of 1, 337, 898 morphologically-complex types (parsed by Bilgin 2016, derived from the corpus of Sak et al. 2008), there were 91, 798 <z>-final types, of which 2, 104 were <ez>-final; of these, only 62 did not contain the negative aorist. (One of these others is *pekmez* [pek.mæz] ‘molasses’, which did appear in the test set and unproblematically showed /e/-lowering pre-*z*.) The negative aorist /-mAz/ itself is both frequent and (perhaps optionally, although no speaker in our data showed a real exception) susceptible to the process of /e/-lowering – despite /z/’s non-membership in the natural class of [sonorant] segments to which the other triggers belong. What the existence of this piece of exceptionality then represents is a generalisation of what we have described as PRE-SONORANT LOWERING to at least one voiced obstruent. This informs the remarks that follow in section 5.

## 5 Discussion

The previous sections have established the existence of the pattern in which front mid vowels are low before a tautosyllabic sonorant; the pattern is discontinuous in phonetic space,

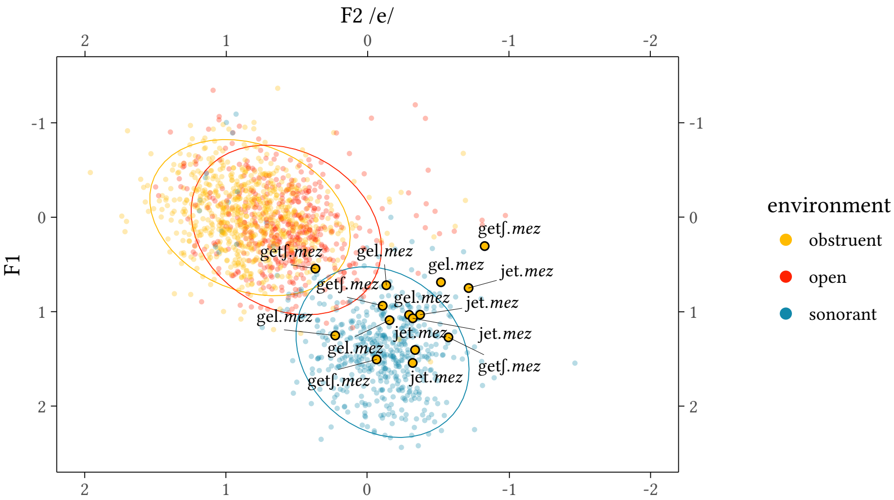



**Fig. 18** F2×F1 space for /e/, all tokens shown in background. Each highlighted point represents a single token, for a single speaker, of an item containing the negative aorist /mez/; either *gelmez* [gæl.mæz] 'not come', or *geçmez* [getʃ.mæz] 'not pass'.

persists across a large test set and across all experimental participants, and varies under re-syllabification in a manner consistent with phonologised positional restrictions. Two observations raise questions about the construction of the active class involved; the first is the phonetic mismatch between the strongly palatalised lateral and vowel-*lowering* effects, and the second is the apparent extension of the phonologically-active class of segments to /z/. The current section is therefore largely concerned with the inference of the diachronic pathway by which this alternation arose, and the consequences for a well-ordered picture of phonological change.

We note the caveat that the experimental sample considered in this paper represents a small window into the variation that exists in present-day Turkish; the range in apparent time is very narrow, and the set of participants is fairly homogeneous in dialectological terms. The construction of any account of the trajectory of change and the historical context for innovation is therefore necessarily reliant on other strands of evidence and argumentation.

## 5.1 Phonetic precursors

Several strands of evidence from the preceding discussion suggest that the pattern under discussion has an ultimate origin in phonetic effects of the coda rhotic. In section 2.2.2, we discuss the cross-linguistic evidence supporting the idea that rhotic-triggered lowering and laxing is well-attested and phonetically-grounded. In section 4.2, if speaker variability distinguished between the individual coda sonorants, the rhotic was the favoured environment; for /ø/, which can be assumed to be behind /e/ in the trajectory of change and as such closer to the presumptive phonetic origin of the pattern, pre-rhotic realisations were lower across the board. In this subsection, we will consider further evidence from dialectological sources that the pattern in Turkish generalises across the class of sonorants from a rhotic precursor.

Although we have referred generally in this paper to ‘Turkish’ without further qualification, this should be understood to refer to the standard variety, very broadly (Lewis, 1967) understood to be the speech of the upper classes of Istanbul and Ankara. This is unsurprisingly reductive; there is substantial dialectal variation, particularly in phonology, across Turkish-speaking regions. Karahan (1996) has a *relatively* recent and thorough classificatory dialectology, postulating three major dialect groups in Anatolia: western and eastern Anatolian groups separated from each other roughly by the boundary of the Euphrates, and a north-eastern group encompassing the dialects of Trabzon, Rize, and surrounding areas (for which a comprehensive phonological account in English exists, namely Brendemoen 2002).

We have access to very little conditioned experimental data for any regional varieties; conclusions drawn in sections 5.1.1 and 5.1.2 are based on what is often passing reference in the literature, and should therefore be assigned the appropriate degree of scepticism in consideration. Section 5.1.3 shows the vowel space for a single divergent speaker, M03, who was excluded from the analysis due both to gender and to a markedly distinct system; this speaker’s production suggests the presence of gradient but statistically non-negligible pre-rhotic vowel height movement, plausibly a phonetic precursor to the more fully phonologised effects seen both in the standard variety and in Trabzon Turkish.

### *5.1.1 Western Anatolian rhoticity loss*

An oft-cited minor example of compensatory lengthening triggered by syllable-final /r/-deletion (Sezer, 1986; Kavitskaya, 2002) in Western Anatolian Turkish dialects incidentally suggests that these dialects show additional rhotic-triggered vowel height effects, which persist even when the rhotic is deleted in the surface output. The data in example 9 are Sezer’s transcription of Korkmaz (1965), and the pattern itself seems to be restricted to the environment of compensatory lengthening (that is, to syllables underlyingly closed by a surface-deleted rhotic). The caveat here is that we cannot be sure that this does *not* extend beyond the environment of the rhotic alone, due to incomplete data.

*Example 9* Compensatory lengthening and mid-vowel lowering in Western Anatolian dialects. (Sezer, 1986, p. 241)

| *Standard Turkish* | *Western Anatolian* | |
|---|---|---|
| var | vaː | ‘there is’ |
| verdi | væː.di | ‘s/he gave’ |
| giderler | gi.dæː.læː | ‘they go’ |
| piʃirir | piʃiræː | ‘s/he cooks’ |
| verir | viriː | ‘s/he gives’ |

### *5.1.2 Sonorants and velars in Trabzon dialects*

In the traditional ‘East Anatolian’ dialects, the distinction between /e/ and /æ/ is a phonemic one; this is also the case in Azerbaijani, for which more description is available (Schönig, 1998; Dehghani, 2000). In the dialects of Trabzon and the neighbouring regions, in the north-east of Anatolia, Brendemoen (2002, p. 53) describes an ongoing merger between phonemic /e/ and [i], which proceeds *unless* blocked by an immediately following */r, l, ɣ, ŋ/*. There is further free variation, if /e/–[i] alternation does not apply, between [e] and [æ] in pre-sonorant and pre-velar positions */r, l, k, ɣ, ŋ, n/* (Brendemoen, 2002, p. 55). An overview, with incomplete coverage of the environments in which Brendemoen claims an effect arises, appears in examples 10 and 11[21]; a full dataset is unavailable. ‘Standard Turkish’ given below is phonemic, and does not indicate /e/ → [æ] etc.

*Example 10* /e/-raising and [i]-blocking in Trabzon dialects.

| *Standard Turkish* | *Trabzon* | |
|---|---|---|
| /erkek/ | er.kek ∼ er.kik | ‘male’ |
| /køp/[22] | kep ∼ kip | ‘many’ |
| /et/ | et ∼ it | ‘do/reach’ |
| /kel/ | kel ***kil** | ‘come’ |
| /ejer/ | ezer ***ezir** | ‘saddle’ |

*Example 11* /e/-lowering in Trabzon dialects.

| *Standard Turkish* | *Trabzon* | |
|---|---|---|
| /geldi/ | gæl.di | ‘came’ |
| /gid-er-ken/ | gidærgæn | ‘while going’ |
| /benzer/ | bænzer | ‘smilar’ |
| /ben/ | bæn | ‘I’ |
| /jemek/ | jemæk | ‘food’ |

Despite incomplete evidence, the best-guess deductions that we can make about the overall attested space of variation appear in table 14:

| Dialect | Rule type | Triggers |
|---|---|---|
| Trabzon (NE Anatolian) | /e/–[i] blocked, /e/–[æ] promoted | /r, l, ɣ, ŋ/ block; /r, l, k, ɣ, ŋ, n/ cause |
| general Eastern Anatolian | /e/, /æ/ have phonemic status | |
| Western Anatolian | /e/–[æ] | /r/ |
| **‘Standard’ Turkish** | **/e/–[æ], /ø/–[œ]** | **/r, l, m, n/** |

**Table 14** The state of mid-vowel rules across consensus Turkish dialects.

### *5.1.3 Divergent individuals and phonetic detail*

In the data we present in section 4.1, which represent in total a fairly coherent variety of the language, a relationship holds exceptionlessly between sonorant environment and vowel height. For the variant systems in the ‘non-standard’ dialects that appear immediately above, this is also the case; these systems differ from the consensus variety in the details of their phonological conditioning, but shared consistently the presence of *phonetically abrupt* mid-vowel lowering. Consider the non-normalised F2×F1 space in figure 19 below; each point represents one token produced by a single speaker (table 1: M03) from the eastern city of Kars, and the whole is indicative of a very divergent dialect.

Due to the clear difference in underlying system, and to the relative paucity of data (lexical items with which the speaker was entirely unfamiliar were omitted in recording, and thus

21 Brendemoen (2002) marks aspiration on some of these examples, but inconsistently; as it is unclear if this is contrastive, and unclear whether its absence in the text indicates true absence or simply lack of disambiguatory relevance, we have omitted this here.

22 The Trabzon dialects already have a partial /e/–/ø/ merger; additionally, /køp/ is itself an archaism/regionalism.

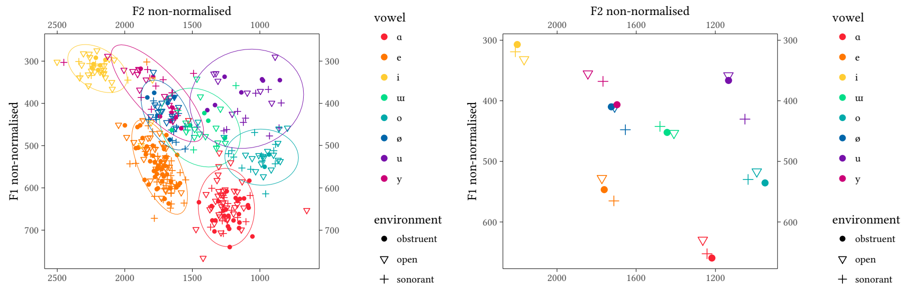



**Fig. 19** Dialectal divergence: F2×F1 space (non-normalised) for speaker M03, Kars. Left: each point corresponds to a single token, measured at the midpoint of the vowel. Right: points represent the average across all tokens for each vowel in each environment.

only 158 of 220 wordlist items were available for analysis), this speaker is not considered in combined analyses above. We may impute to this speaker's overall system, however, a status as one 'extreme' of the possible realisational space for Turkish /e/, across dialects: although some spread in possible F1 appears, with a 95% confidence range of [451, 637] Hz, this does not appear to be distributed strictly by *environment* as previously coded (as a factor with levels: obstruent, sonorant, no-coda), and simple linear models[23] suggest no statistically meaningful effect of environment. An alternative model in which F1 is a function of *rhoticity*, however, `F1 ~ rhotic`, where tokens are coded by the presence or absence of a following /r/ coda, gives a significant effect due to /r/, an F1 increase of [53.33 ± 15.68] Hz, $F(1,115) = 7.353$, $p = 0.007721$.

## 5.2 L-shaped generalisations

In this section, we consider the emergence of 'less-natural' phonological activity as a consequence of sound change, and its relevance to the pathway by which grammatical generalisations arise. If a phonological pattern originates in a speaker–listener mismatch over natural and well-grounded phonetic features, the appearance of unnaturalness must arise from some implementational change subsequent to the original phonetic effect; when can such changes arise, and what scope can they have? We might see this as involving a move from phonetically-driven to phonologically-driven (that is, more abstract) control (Kiparsky, 1995; Janda, 2003): as a rule 'dephoneticises' and is less strictly coupled to the action of phonetics, the potential for generalisation to a set of environments in which its action is less physically and perceptually well-motivated exists. If this is the case, then one suggestion is that the *craziest* (Bach and Harms, 1972) rules are the most extreme members of a broader typology of the end-products of change, and that what we should expect to see is rules in *intermediate* historical states. We illustrate this point with the two sketches that follow; in both examples, an original phonetically-grounded state can be deduced, but phonologisation has driven the emergence of what we call a 'natural class plus', in which a pattern generalises to an 'L-shaped' set of contexts. The further question we will revisit concerns the extent to

[23] Generalised linear mixed-effects models were used in previous sections to capture the effects of any possible inter-speaker or item-specific variation, modelled with random slopes. For the case of a single-speaker subset of the data, accounting for speaker-specific variation is unnecessary. The models referenced here are linear regressions with one dependent variable, F1, and the categorical predictors *environment* and *stress* (and their interaction).

which we can adduce information about the pathway of phonologisation from *non*-unnatural cases: do the regular-seeming products of phonological change carry traces of the potential for more arbitrary generalisations?

### *5.2.1 North-eastern Swiss German*

A particularly high degree of phonological variation exists in the German dialects of north-eastern Switzerland; phonological systems differ from 'one village to the next in the same sub-dialect of a single canton' (Keel, 1982). In the Swiss German varieties of the canton of Schaffhausen, an assumed historical rule lowering pre-rhotic (whether within the same syllable, or across a syllable boundary) o → ɔ has undergone generalisation into several distinct systems, summarised overall in example 13 (Keel, 1982; Janda and Joseph, 2003). All dialects show o → ɔ before *r* (example 12); variation arises when the domain of the rule is further extended. Evidence for further *synchronic* conditioning of this lowering rule comes from alternation under affixation example 15: plurals and diminutives of words with /ɔ/ have /ø/, under both the loss of sonorant-triggered lowering and a dialectally-widespread morphologically-conditioned fronting (Garrett, 2014).

*Example 12* Schaffhausen German: /o/-lowering in all dialects before /r/ (Keel, 1982):

| | |
|---|---|
| bɔrə | 'to bore' |
| hɔrn | 'horn' |
| kwɔrffə | 'thrown' |

*Example 13* Schaffhausen German: dialectal variation (Keel, 1982):

[Schaffhausen proper:] o → ɔ before *r* and *nasals*; all above, and:

| | |
|---|---|
| xɔ.məd | 'come-PL.IND.' |
| tɔnə | 'to drone' |
| frɔm | 'pious, good' |

13 of the surrounding villages: o → ɔ before *r*, *nasals*, and *coronals*; above, and:

| | |
|---|---|
| ʃtɔtsə | 'to push down' |
| rɔss | 'horse' |
| ʃnɔdərə | 'to stir' |

[17 villages:] o → ɔ before *r* and *coronal obstruents*; but *not* nasals.

[5 villages:] o → ɔ before *r*, *coronal obstruents*, and *non-coronal obstruents* except *b*.

*Example 14* Schaffhausen German: /o/-lowering never applies before /l/ (Keel, 1982):

| | |
|---|---|
| foll | 'full' |
| holə | 'to fetch' |
| bollə | 'bud' |

*Example 15* Schaffhausen German: morphologically-conditioned loss of [ɔ] (Garrett, 2014):

| | |
|---|---|
| /bɔdə/ → bødə | 'floor, ground'-PL |
| /lɔxxə/ → løxxli | 'hole'-DIM |

The rhotic is the only trigger for /o/-lowering that persists exceptionlessly across (sub-)dialects; this is taken by Keel (1982); Janda and Joseph (2003); Mielke (2008) to be evidence that the rhotic is the original environment in which the /o/-lowering rule was first instantiated. In Schaffhausen proper, the environment for the rule is given by part of the natural class of sonorants: the consonantal sonorants absent the lateral /l/. In 17 villages of the Schaffhausen canton, the environment for the rule is given by the set {r, coronal obstruents}, in which coronality is shared but manner differs. In 13 other villages, these generalisations are superimposed: /o/-lowering applies before both nasals and coronal obstruents.

The extensions that arise in the different varieties do not lend themselves as well-behavedly to further categorical generalisations; nor do they strictly track the set of contexts in which a vowel-lowering rule is best-motivated. Some implicational generalisations are observed—non-coronals are involved only if coronals are involved—but not all cases admit further hierarchical generalisations: obstruents and nasals seem to be involved (or not) freely, subject to no further implicational requirement. It is the case in every instantiation of the o-rule that the rhotic must be involved, due to its status as the 'original' trigger; we may further adduce from example 13 that o → ɔ applies before non-coronal obstruents iff it applies before coronal obstruents, but the coronal obstruents and nasals behave orthogonally here—either may be a triggering environment independent of the other.

Of course, the observation that the distribution of patterns in Schaffhausen German involves variable extension from a single plausible phonetic precursor is not a new one; this insight underlies the discussion of the case in Janda and Joseph (2003); Mielke (2008). Janda and Joseph use cases of this type as evidence for their 'big bang' theory of sound change; in less specific terms, what is being described here is really a conception of *phonologisation* that is EARLY and ABRUPT (see also e.g. Fruehwald 2016), rather than gradual.

*Example 16* The BIG BANG theory of sound change (Janda and Joseph, 2003), and its relationship to other accounts.

1. All sound changes begin as very 'small', very localised, **purely phonetic** effects, over a **short temporal span**; the obligatory presence of early phonetic conditioning is after e.g. Ohala (1981).
2. The future trajectory of generalisation is determined by this original 'burst'.
3. As an innovation generalises and spreads, phonetic conditions are supplanted; **phonological and/or sociolinguistic** conditions take precedence.
4. At the latest stages, reanalyses lead to new morphological or lexical conditioning; cf. Bermúdez-Otero's (2007) 'domain narrowing'.

The relationship of this schematic to examples 12, 13 and 15 is in the inherent variability of the patterns. If it must be the case that sound change has some initial phonetic trigger, in order for the different dialects to show this variety of implicationally-unrelated, phonetically-unjustified, but very different alternations, 'control' over the development of these patterns must be ceded to the phonology. What this argument does not cover, however, is why we see these generalisations in particular; if we say that the phonology drives the formation of generalisations to novel environments, what we require is a mechanism by which these novel environments are selected or ruled out.

### *5.2.2 Georgian*

In Georgian (Butskhrikidze, 2002, p. 90), the non-high vowels /ɑ/ and /e/ followed by coda {m, n, l, r, v} are deleted when -V(C) suffixes are appended;[24] it can be argued (ibid.) that

/v/ in Georgian is best analysed as a sonorant as it generally patterns with the set {m, n, l, r} across processes. The case of /o/ is more complicated. If followed by the labial /m/ or /b/, /o/ deletes; elsewhere, it alternates with /v/, as in example 17.

*Example 17* Georgian: /o/-deletion and [o∼v] alternation. (Butskhrikidze, 2002, p. 82 & 95)

| | | |
|---|---|---|
| /diɣomi-is/ | [diɣmis] | toponym-GEN |
| /sap'oni-is/ | [sap'nis] | soap-GEN |
| /mindor-is/ | [mindvris] | field-GEN |
| /p'amidor-is/ | [p'amidvris] | tomato-GEN |
| /nigoz-is/ | [nigvzis] | nut-GEN |

*Example 18* GEORGIAN: syncope in VCV(C) if intervening C is {m, n, l, r, v}. (Butskhrikidze and van de Weijer, 2001; Butskhrikidze, 2002)

| | | |
|---|---|---|
| /mertsxal-is/ | [mertsxlis] | swallow-GEN |
| /t'omara-it/ | [t'omrit] | sack-INST |
| /ʃvel-is/ | [ʃvlis] | deer-GEN |
| /bal-eb-i/ | [blebi] | cherry-PL-NOM |
| /xed-av-a/ | [xedva] | see-THEM-INF |
| /ʃe-i-p'χ'ar-ob/ | [ʃeip'χ'rob] | 'you will arrest' |
| /ga-tʃ'er-i/ | [gatʃ'ri] | 'you will cut' |
| /xar-av-a/ | [xvra][25] | gnaw-THEM-INF |

*Example 19* GEORGIAN: no syncope for non-V(C) affixes or non-sonorant finals.

| | | |
|---|---|---|
| /mertsxal-ma/ | [mertsxalma] | swallow-ERG |
| /k'amat-is/ | [k'amatis] | debate-DAT |

If we admit /v/ as a sonorant in Georgian[26], examples 18 and 19 then describe a pattern whose environment is given entirely by the feature [sonorant]: pre-sonorant vowels undergo syncope, pre-obstruent vowels do not. However, Butskhrikidze gives cases (example 20) in which this pattern optionally extends to non-high vowels followed by the voiced stop /b/:

*Example 20* GEORGIAN: syncope before /b/. (Butskhrikidze, 2002)

| | | |
|---|---|---|
| /k'ak'ab-is/ | [k'ak'bis] | partridge-GEN |
| /xoxob-is/ | [xoxbis] | pheasant-GEN |

The distinction between pre-sonorant contexts and pre-obstruent contexts is not arbitrary with respect to the pattern itself; but a potential argument for the emergence of this alternation from sonority or syllabicity is not straightforward to reconcile with the optional participation of the obstruent /b/. The parallel we want to draw between the cases in Schaffhausen German and in Georgian, and eventually extend to the novel case in Turkish, is then as follows. Both the Schaffhausen /o/-lowering and the Georgian mid-vowel syncope apply in environments

[24] Except the nominative /-i/: this is appended to consonant-final stems to satisfy constraints on well-formedness, and does not trigger any alternation.

[25] Both the vowel in /-av/ and the root vowel are deleted; this shows a further case of v-metathesis, for details of which see Butskhrikidze and van de Weijer (2001).

[26] Which is supported more generally in the phonology by its behaviour in syllabification; see Butskhrikidze and van de Weijer (2001); Butskhrikidze (2002), again.

which are supersets of some ‘sensible’ set of environments, with respect to *both* phonetic grounding and natural class behaviour. /o/-lowering generalises to various L-shaped sets that don’t constitute natural classes in themselves, but that are supersets over multiple reasonable natural-class generalisations. Lowering a mid vowel has ample phonetic motivation pre-rhotic, but it is not straightforward to deduce that there exists equal phonetic motivation in various pre-obstruent positions to which the change optionally generalises—especially given the absence of any requirement on the moraic position of the trigger segment. Mid-vowel syncope in Georgian extends to pre-/b/ mid vowels, despite the violation of natural-class boundaries; as in the previous case, this has some intuitive origin in the proximity of /b/ to a peripheral member of the class of sonorants, /v/, in representational space. Consider the inventory for Georgian given in table 15; the set of segments that are uncontroversially sonorant in Georgian is highlighted, as is the /b/.

| | | | | | | |
|---|---|---|---|---|---|---|
| p | t | t͡s | t͡ʃ | k | | |
| p’ | t’ | t͡s’ | t͡ʃ’ | k’ | | |
| | s | | ʃ | x | χ’ | h |
| b | d | d͡z | d͡ʒ | g | | |
| v | z | | ʒ | ɣ | | |
| m | n | | | | | |
| | l | | | | | |
| | r | | | | | |

**Table 15** The Georgian consonant inventory, adapted from Butskhrikidze (2002).

The ordering of rows in table 15 is somewhat (intentionally) impressionistic; the intent here is solely to present a sketch of where the syncope-triggering segments might fall in a notional ‘similarity space’. Much as in Schaffhausen German, it was difficult to claim that phonetic motivation for a change in vowel height existed in every environment, it’s here difficult to construct either a phonetic or a perceptual reason for syncope to apply before this set of segments. The nearest thing we then find to a unifying generalisation is the *similarity* of /b/ to nearby members of the more sensible set; in particular, to /v/, which itself could plausibly be understood to represent the original trigger for syncope. Butskhrikidze (2002, p. 88) claims that C+/v/ sequences are realisationally most like $C^w$, single segments with secondary labialised articulation; see also the general special status of labial segments in the phonology, as example 17. If this is the case, then of all possible C+son sequences, C+/v/ constitutes the best onset, and thus also the best possible output of V-deletion in CVC under resyllabification: despite the well-known tendency in Georgian toward large clusters, simple onsets are still preferred, where possible, throughout the phonology. It’s then plausible that syncope giving rise to C+/v/ (as in example 18: /xed-av-a/ → [xedva] or [xed$^w$a]) was preferentially phonologised on this basis, and extended to the rest of the sonorants; no such property holds for underlying /b/, however.

*5.2.3 Variation (and theme)*

The argument that remains to be made is that the Turkish case can be classed together with those immediately previously in showing a similar lack of what we might call ‘first-order’ groundedness. Cases of this type must then represent abstract generalisations, in which the role of *phonological* information is crucial; the operation of the phonological pattern shifts in scope from a domain of operation corresponding to high phonetic grounding to one that is poorly-grounded but related to the first in some representational way. Note that this does not imply development *de novo*, with no phonetic precursor at all, but rather that the leap from the domain of gradient phonetics to the domain of categorical phonology arises early in the stabilisation of a rule, allowing biases towards particular phonetic precursors to dissipate.

The system in the Turkish of Western Anatolia, as given in section 5.1.1, is a comparatively simple one in its targeting and conditioning; lowering applies to the unrounded mid vowel if it precedes a rhotic. In both the standard variety that constitutes much of the focus of this paper, and in the Trabzon Turkish considered in section 5.1.2, mid vowel lowering is subject to more complex and extensive conditioning; while in the speech of the informant from Kars presented immediately above, little is seen other than a small phonetic effect pointing in a generally similar direction. The single property that unites this disparate set of systems is the presence of an effect triggered by the rhotic. In the standard variety and plausibly in Trabzon Turkish, this effect has PHONOLOGISED; that is, there now exists an effect whose control is within the domain of the phonological computation, rather than in the domain of mechanical phonetics. We cannot make a judgement as to the phonological status of vowel height in Western Anatolian Turkish, but we can note that the pre-rhotic effect therein is at least well-documented and understood to be phonetically discontinuous; in the speech of the informant from Kars, the balance of evidence suggests that the pre-rhotic effect is not (yet) a grammatical one.

The disunity across systems is then essentially emergent from phonologisation itself; in asking the question of what happened in Turkish, we are implicitly also asking why it is that the process of phonologisation produced this particular rule, with this particular domain, in the standard variety; a different set of environments in the Trabzon variety; and did not generalise beyond the rhotic in other regions of Anatolia. In the standard variety, we can take into account the apparent presence of a pre-/z/ effect (section 4.5), and describe the operation of mid-vowel lowering as involving the active class /r l n m z/; in Trabzon, the relevant environment is instead /r l n ŋ ɣ k/, with the exclusion of the labial nasal but with the inclusion of a phonemic dorsal nasal[27] and the dorsal obstruents. Not all these environments are created equal, from the point of view of either representational unity or phonetics.

Both Standard Turkish and Trabzon Turkish show a phonologically-active class that mixes sonorants and obstruents; in the standard variety, all sonorants are involved, while Trabzon omits the labial nasal, but in both cases the phonetically-unfavourable lateral participates exceptionlessly. The conjecture that we will propose here is that this set of facts is evidence for a neat diachronic pathway. The persistence of the rhotic across varieties and across types of phenomenon (both phonetic and phonological) lends itself to the idea that the rhotic constitutes an initial phonetic precursor to the phonological change that we observe; as we proposed in section 5.1.3, it appears to have a phonetic effect in varieties of Turkish that do not in themselves show any sign of categorical /e/-effects, and . If we then posit that the phonologisation of lowering in the mid vowels in Turkish is driven by an initial, functionally-grounded and well-motivated effect of a rhotic on a preceding vowel; the subsequent decision process contained in stabilisation and generalisation of the initial rule extends over the set of mid vowel undergoers and the full consonantal inventory of the language, proceeding according to similarity to the initial trigger. The difference in resultant activity between the standard variety and the variety of Trabzon we might then attribute to differences in the consensus computation of similarity: for speakers of the Trabzon variety,

27 Marginal to the standard variety.

similarity of the rhotic precursor to the dorsal nasal and thereby to dorsal obstruents[28] takes precedence over similarity to the labial nasal. This process of generalisation is fundamentally *abstract*, in the sense that after the initial actuation it pays relatively little ‘attention’ to phonetic substance; this allows generalisation both to the lateral, and eventually to the voiced obstruent /z/.

### *5.2.4 On diachrony, again*

How did the sound system of Turkish get into this state? Recall the examples from Schaffhausen German and from Georgian given in section 5.2.1 and section 5.2.2 respectively. What these cases had in common was the L-SHAPED nature of the classes involved; recall the active class given in table 15 for Georgian, and the inventories and active classes given below in table 16 for the micro-variation across the local varieties of Schaffhausen German.

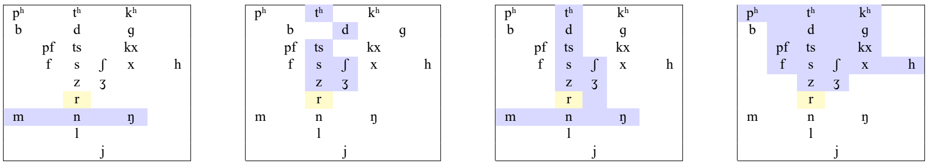


**Table 16** Consonant inventories and active classes in Schaffhausen German, adapted from Mielke (2004). The classes of alternation-triggering segments across the different varieties have been highlighted in each case.

Both the pattern in Georgian, in which deletions applied before a coherent set of sonorants and the voiced labial stop /b/, and the rather wide set of variants depicted above in table 16 are alike, in that we can think about them as containing a *core* that represents an original actuator. In Georgian, this is likely to be the /v/, triggering alternations first in the labial /o/, then generalising to the other non-high vowels and to the sonorants, and to the /b/ via shared labiality. In Schaffhausen German, this is likely to be the rhotic; the geography of variation in this case shows us that the rhotic is the only *consistent* participator across the environments in which the rule of /o/-lowering is instantiated. Extension from the rhotic then proceeds in the direction either of the ‘nearby’ sonorants, or of the coronal and then non-coronal obstruents. In both cases, then, the ultimate determiner of the set of triggers (and the set of undergoers) is the action of DIACHRONY.

Consider the description in table 17 of the case in standard Turkish that we establish in this paper, and of the variation in the Trabzon dialects given by Brendemoen (2002).

There is a clear analogy between the environment for /e/-lowering in both the standard and the Trabzon variety, the presence of phonetic pre-rhotic lowering in the speech of the informant from Kars, and the descriptions we assign to the L-shaped generalisations in Swiss German and in Georgian. In the Trabzon variety, the extension of phonetically-driven pre-rhotic lowering from its original environment to the final set takes a different path through the inventory from the case that we cover in this paper, bounded more closely by considerations of place; generalisation to coronals and dorsals is strongly preferred over generalisation to the

[28] Which are better promoters of lowering and backing than many of the other segments involved; there is then an independent question of whether a second phonetic influence is to be considered in the Trabzon variety.

| | | | | |
|---|---|---|---|---|
| f | s | ʃ | | h |
| v | z | ʒ | | |
| | r | | | |
| | l | j | | |
| m | n | | | |
| b | d | d͡ʒ | g | |
| p | t | t͡ʃ | k | |

| | | | | |
|---|---|---|---|---|
| f | s | ʃ | | h |
| v | z | ʒ | | |
| | r | | | |
| | l | j | | |
| m | n | | ŋ | |
| b | d | d͡ʒ | ɣ | |
| p | t | t͡ʃ | k | |

**Table 17** Consonant inventories and active classes promoting the rule of /e/-lowering in two varieties of Turkish; the standard Turkish of this paper (**left**), and the Trabzon dialect given by Brendemoen (2002) (**right**).

labials. The crucial property that all these cases share is that they do not straightforwardly admit expression as a more traditional featurally-based class; we cannot really establish a simple conjunction of features that does not then include unwanted segments. At the same time, they are far from being the truly ‘crazy’ rules of Bach and Harms (1972); there is a clear logic of transitivity by which they can be derived sequentially from the original actuator.

## 6 In sum

The first contribution of this paper is the descriptive one; the establishment of the existence, categoricity, and interest of the problem of mid-vowel lowering in Turkish. We have demonstrated throughout (section 4) that the Turkish mid vowels are subject to alternations conditioned by [±sonorant] coda and by /z/ (and sensitive explicitly to the syllable boundary and not simply the presence or absence of the segment; figure 2); that the alternation in /e/ displays a much more discontinuous and categorical-seeming distribution in the phonetic parameter space (section 4.1), is subject to a larger set of exceptions (section 4.4), and *lacks* the apparent dependence on triggering segment seen for /ø/ (section 4.2) and for dialectally-divergent speakers from whose systems phonological /e/-lowering is definitively absent (section 5.1.3). We have suggested further that the ‘initial’ state of the Turkish mid vowel system most closely resembled the synchronic state of unstressed /ø/, in which a process of raising in unstressed open syllables interacts with phonetically-driven, gradient lowering triggered by the rhotic; the most innovative state resembles the overall pattern in stressed /e/.

More central to the issues that we raise in section 1 are the following remarks. First, generalisation of /e/-lowering *at least* to the negative aorist /-mez/, outside the [sonorant] class previously characterised, is well under way, and is discontinuous rather than gradual with respect to manipulation of the phonetic parameter involved. Second, the phonetic properties of the Turkish lateral suggest that it should exert little to no coarticulatory pressure to *lower* a vowel, but there is no statistically-significant difference between pre-lateral tokens and pre-rhotic tokens, despite the rhotic’s significantly better inherent properties as a precursor to this type of sound change. From an explanatory point of view, we argue that these facts allows us to derive a well-ordered set of diachronic hypotheses, despite the poor time-depth of the experimental sample; the intent of this claim is to illustrate the potential relationship between the selection of active classes and the trajectory along which phonological change progresses. Differences in categoricity and continuity, dependence on trigger, and sensitivity to lexical and prosodic effects suggest that /ø/ is *behind* /e/ in the process of rule-generalisation; the persistence of small-scale effects in the rhotic, the relevance of the rhotic to the state of rules in non-standard varieties, and the existence of phonetic effects targeting pre-rhotic vowels in varieties that show no categorical phonological rule suggests to us a diachronic pathway involving a series of successive generalisations from a functionally-motivated rhotic precursor.

## References

Adank P, Smits R, Van Hout R (2004) A comparison of vowel normalization procedures for language variation research. J Acoustical Society of America 116(5):3099–3107
Árnason K (2011) The Phonology of Icelandic and Faroese. Oxford University Press
Bach E, Harms RT (1972) How do languages get crazy rules? In: Stockwell RP, Macaulay RKS (eds) Linguistic change and generative theory, Indiana University Press, pp 1–21
Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Statistical Software 67(1):1–48
Beddor PS (1993) The perception of nasal vowels. In: Huffman MK, Krakow RA (eds) Nasals, Nasalization, and the Velum, Phonetics and Phonology, vol 5, Academic Press, pp 171–196
Beddor PS, Krakow RA, Goldstein LM (1986) Perceptual constraints and phonological change: A study of nasal vowel height. Phonology Yearbook 3:197–217
Bermúdez-Otero R (2007) Diachronic phonology. In: de Lacy P (ed) The Cambridge Handbook of Phonology, Cambridge University Press, p 497–517
Bermúdez-Otero R (2015) Amphichronic explanation and the life cycle of phonological processes. In: Honeybone P, Salmons J (eds) The Oxford handbook of historical phonology, Oxford University Press, pp 374–399
Bilgin O (2016) Frequency effects in the processing of morphologically complex turkish words. Master's thesis, Bogaziçi University, URL `http://st2.zargan.com/public/resources/turkish/frequency_effects_in_turkish.pdf`
Blevins J (2004) Evolutionary Phonology: The emergence of sound patterns. Cambridge University Press
Blust R (2013) The Austronesian languages. Asia-Pacific Linguistics
Boersma P, Weenink D (2017) Praat: doing phonetics by computer. URL `http://www.praat.org/`
Botma B, Van Oostendorp M (2012) A propos of the Dutch vowel system 21 years on, 22 years on. In: Botma B, Noske R (eds) Phonological explorations: Empirical, theoretical and diachronic issues, Mouton de Gruyter, pp 1–16
Bradley TG (2010) Mid front vowel lowering before rhotics in Ibero-Romance. In: Herschensohn J (ed) Romance Linguistics 2010, John Benjamins, pp 63–78
Brendemoen B (2002) The Turkish dialects of Trabzon: their phonology and historical development, vol 1. Otto Harrassowitz Verlag
Butskhrikidze M (2002) The consonant phonotactics of Georgian, LOT Dissertation Series, vol 63. Lot
Butskhrikidze M, van de Weijer J (2001) On v-metathesis in Modern Georgian. In: Hume E, Smith N, van de Weijer J (eds) Surface Syllable Structure and Segment Sequencing, Holland Institute of Generative Linguistics, Leiden University, pp 91–101
Canalis S, Özdemir S, Türk U, Ümit C Tunçer (2021) When glides are obstruents, or Turkish [j], talk at the 18th OCP, 28 January
Carter P (2002) Structured variation in British English liquids. PhD thesis, U. of York
Carter P, Local J (2007) F2 variation in Newcastle and Leeds English liquid systems. J International Phonetic Association 37(02):183
Chomsky N, Halle M (1968) The Sound Pattern of English. Harper and Row

Clements GN, Sezer E (1982) Vowel and Consonant Disharmony in Turkish. In: Hulst Hvd, Smith N (eds) The Structure of Phonological Representations, Foris, pp 213–55
Dehghani Y (2000) A grammar of Iranian Azari: Including comparisons with Persian. Lincom Europa
Dell F (1995) Consonant clusters and phonological syllables in french. Lingua 95(1):5–26, DOI https://doi.org/10.1016/0024-3841(95)90099-3
Féry C (2003) Markedness, faithfulness, vowel quality and syllable structure in French. J French Language Studies 13(2):247–280
Flemming E (2005) Deriving natural classes in phonology. Lingua 115(3):287–309
Fruehwald J (2016) The early influence of phonology on a phonetic change. Language 92(2):376–410
Gallagher G (2016) Vowel height allophony and dorsal place contrasts in Cochabamba Quechua. Phonetica 73(2):101–119
Garrett A (2014) Sound change. In: Claire Bowern BE (ed) The Routledge handbook of historical linguistics, Routledge, pp 227–248
Gussenhoven C (2007) A vowel height split explained: Compensatory listening and speaker control. Papers in Laboratory Phonology 9: Change in Phonology pp 145–172
Göksel A, Kerslake C (2005) Turkish: A Comprehensive Grammar. Routledge
Hulst Hvd, Weijer Jvd (1991) Topics in Turkish Phonology. In: Boeschoten H, Verhoeven L (eds) Turkish Linguistics Today, E. J. Brill, pp 11–5
Hyman LM (1976) Phonologization. In: Juilland A (ed) Linguistic studies presented to Joseph H. Greenberg, Anna Libri, pp 407–418
Hyman LM (2001) The limits of phonetic determinism in phonology. *NC revisited. In: Hume E, Johnson K (eds) The Role of Speech Perception in Phonology, Academic Press, pp 141–185
Hyman LM (2008) Enlarging the scope of phonologization. In: UC Berkeley Phonology Lab Annual Report, pp 302–408
Inkelas S (1999) Exceptional stress-attracting suffixes in Turkish: representations versus the grammar. In: Kager R, van der Hulst H, Zonneveld W (eds) The prosody-morphology interface, Cambridge University Press, pp 134–187
Inkelas S, Orgun CO (2003) Turkish stress: a review. Phonology 20(01):139–161
Janda RD (2003) Phonologization as the start of dephoneticization–or, on sound change and its aftermath: Of extension, generalization, lexicalization, and morphologization. In: Joseph BR, Janda RD (eds) The handbook of historical linguistics, Blackwell, pp 402–422
Janda RD, Joseph BD (2003) Reconsidering the canons of sound-change: Towards a "Big Bang" theory. In: Blake BJ, Burridge K (eds) Historical Linguistics 2001: Selected Papers from the 15$^{Th}$ International Conference on Historical Linguistics, John Benjamins, pp 206–19
Kabak B (2011) Turkish Vowel Harmony. In: van Oostendorp M, Ewen CJ, Hume E, Rice K (eds) The Blackwell Companion to Phonology, Wiley-Blackwell, pp 2831–53
Kabak B, Vogel I (2001) The phonological word and stress assignment in Turkish. Phonology 18(03):315–360
Karahan L (1996) Anadolu Ağizlarının Sınıflandırılması, Türk Dil Kurumu, vol 630. Atatürk Kültür, Dil ve Tarih Yüksek Kurumu
Kavitskaya D (2002) Compensatory Lengthening: Phonetics, Phonology, Diachrony. Outstanding Dissertations in Linguistics, Routledge
Keel WD (1982) Atomic phonology and phonological variation, vol 16. Gunter Narr
Kewley-Port D, Watson CS (1994) Formant-frequency discrimination for isolated English vowels. The J Acoustical Society of America 95(1):485–496, DOI 10.1121/1.410024

Kewley-Port D, Bohn OS, Nishi K (2005) The influence of different native language systems on vowel discrimination and identification. Acoustical Society of America Journal 117:2399–2399, DOI 10.1121/1.4785992

Kiparsky P (1995) The phonological basis of sound change. In: Goldsmith J (ed) The handbook of phonological theory, Blackwell, pp 640–670

Korkmaz Z (1965) Güney-Batı Anadolu Ağızları: ses bilgisi (phonetik). Ankara Üniversitesi DTCF Yayini

Kornfilt J (1997) Turkish. Routledge

Krakow RA, Beddor PS, Goldstein LM, Fowler CA (1988) Coarticulatory influences on the perceived height of nasal vowels. J Acoust Soc Am 83(3):1146–1158

Ladefoged P (2003) Phonetic data analysis. Blackwell

Lehiste I (1970) Suprasegmentals. MIT Press

Lewis GL (1967) Turkish Grammar. Oxford University Press

Lindau M (1985) The story of /r/. In: Fromkin V (ed) Phonetic Linguistics: Essays in Honor of Peter Ladefoged, Academic Press, pp 157–168

Lindblom B (1963) Spectrographic study of vowel reduction. J Acoustical Society of America 35:1773–1781

Lisker L (1974) On “explaining” vowel duration variation, tech. Rep. SR-37/38, Haskins Laboratories, New Haven, Connecticut

Lobanov BM (1971) Classification of Russian vowels spoken by different speakers. J Acoustical Society of America 49(2b):606–608

Maddieson I (1985) Phonetic cues to syllabification. In: Fromkin V (ed) Phonetic Linguistics: Essays in Honor of Peter Ladefoged, Academic Press

Maddieson I (1997) Phonetic universals. In: Hardcastle W (ed) The Handbook of Phonetic Sciences, Blackwell, pp 190–232

McCloy DR (2016) PhonR: tools for phoneticians and phonologists. R package version 1.0-7

Mielke J (2004) The emergence of distinctive features. PhD thesis, The Ohio State University

Mielke J (2008) The emergence of distinctive features. Oxford University Press

Nevins A, Vaux B (2003) Consonant harmony in Karaim. In: Csirmaz A, Lee Y, Walter MA (eds) Proc. Workshop on Altaic in Formal Linguistics, MIT Press, pp 175–194

Nichols J (2011) Ingush Grammar, U. of California Publications in Linguistics, vol 143. U. of California Press

Nordhoff S (2009) A grammar of upcountry Sri Lanka Malay. PhD thesis, Utrecht University

Ohala JJ (1981) The listener as the source of sound change. CLS 17:178–203

Ohala M, Ohala JJ (1992) Phonetic universals and Hindi segment duration. In: Second International Conference on Spoken Language Processing

Peterson GE, Lehiste I (1960) Duration of syllable nuclei in English. J Acoustical Society of America 32(6):693–703

Proctor MI (2009) Gestural characterization of a phonological class: The liquids. PhD thesis, Yale University

R Core Team (2017) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, URL `http://www.R-project.org/`

Recasens D (2002) On the production characteristics of apico-alveolar taps and trills. J Phonetics 19:267–280

Recasens D (2012) Coarticulation in Catalan dark [ɫ] and the alveolar trill: General implications for sound change. Language and Speech 56(1):45–68

Recasens D (2014) Coarticulation and Sound Change in Romance. John Benjamins

Recasens D, Espinosa A (2005) Articulatory, positional and coarticulatory characteristics for clear /l/ and dark /l/: evidence from two Catalan dialects. J International Phonetic As-

sociation 35(1):1–25
Recasens D, Pallarès MD (1999) A study of /j/ and /r/ in the light of the "dac" coarticulation model. J Phonetics 27(2):143–169
Riad T (2014) The phonology of Swedish. Oxford University Press
Sak H, Güngör T, Saraçlar M (2008) Turkish language resources: Morphological parser, morphological disambiguator and web corpus. In: Nordström B, Ranta A (eds) Advances in Natural Language Processing, Lnai, vol 5221, pp 417–427
Scheer T (2015) How diachronic is synchronic grammar? crazy rules, regularity and naturalness. In: Honeybone P, Salmons JC (eds) The Handbook of Historical Phonology, Oxford University Press, pp 313–336
Schönig C (1998) Azerbaijanian. Routledge, pp 248–260
Sezer E (1986) An autosegmental analysis of compensatory lengthening in Turkish. In: Wetzels L, Sezer E (eds) Studies in compensatory lengthening, Foris, pp 227–250
Solé MJ (2002) Aerodynamic characteristics of trills and phonological patterning. J Phonetics 30(4):655–688
Solé MJ, Ohala J (2010) What is and what is not under the control of the speaker: Intrinsic vowel duration. Papers in Laboratory Phonology 10 pp 607–655
Sproat R, Fujimura O (1993) Allophonic variation in English /l/and its implications for phonetic implementation. J Phonetics 21(3):291–311
Storme B (2017a) Contrast enhancement motivates closed-syllable laxing and open-syllable tensing, unpublished manuscript, lingbuzz/003700
Storme B (2017b) The *loi de position* and the acoustics of French mid vowels. Glossa: a journal of general linguistics 2(1):64
Storme B (2017c) Perceptual sources for closed-syllable vowel laxing and derived environment effects. PhD thesis, Massachusetts Institute of Technology
Strycharczuk P, Scobbie JM (2016) Gradual or abrupt? the phonetic path to morphologisation. J Phonetics 59:76–91
Tauberer J, Evanini K (2009) Intrinsic vowel duration and the post-vocalic voicing effect: Some evidence from dialects of North American English. In: Proc. Interspeech 10
Toivonen I, Blumenfeld L, Gormley A, Hoiting L, Logan J, Ramlakhan N, Stone A (2015) Vowel height and duration. In: Steindl U, Borer T, Fang H, Pardo AG, Guekguezian P, Hsu B, O'Hara C, Ouyang IC (eds) Proc. 32nd WCCFL, Cascadilla Proceedings Project, pp 64–71
Turton D (2014) Variation in English /l/: Synchronic reflections of the life cycle of phonological processes. PhD thesis, U. of Manchester
Vennemann T (1972) Phonetic analogy and conceptual analogy. In: Vennemann T, Wilbur TH (eds) Schuchardt, the neogrammarians, and the transformational theory of phonological change: four essays, Linguistische Forschungen, vol 26, Athenäum Verlag, pp 181–204
Vigário M (2002) The Prosodic Word in European Portuguese. De Gruyter Mouton
Wang WSY (1968) Vowel features, paired variables, and the english vowel shift. Language 44(4):695–708, URL `http://www.jstor.org/stable/411892`
West P (1999) Perception of distributed coarticulatory properties of English /l/ and /r/. J Phonetics 27(4):405–426
Westbury JR, Keating PA (1980) Central representation of vowel duration. J Acoustical Society of America 67(S37)
Zimmer K, Orgun O (1999) Turkish. In: Handbook of the International Phonetic Association, Cambridge University Press, Cambridge, pp 154–156