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The relationship between the coarticulatory source and effect in sound change: Evidence from Italo-Romance metaphony in the Lausberg area

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In ongoing sound changes, a coarticulatory effect is often enhanced as the coarticulatory source that gives rise to it wanes. But quite how phonologisation and these reciprocal coarticulatory changes are connected is still poorly understood. The present study addresses this issue through an acoustic analysis of metaphony, which like umlaut has its phonetic origins in VCV coarticulation, and which was analysed in three geographically proximal varieties spoken in the so-called Lausberg area in Southern Italy. The corpus was of 35 speakers producing mostly disyllabic words with phonetically mid stem vowels and suffix vowels that varied in phonetic height. The results of functional principal components analysis applied to the stem vowels' first two formant frequencies showed a progressively greater enhancement to the vowel stem across the three regions that was characterised by raising, diphthongisation, and then further raising and monophthongisation. Suffix erosion was quantified by counting deletions and the degree of vowel centralisation. The analysis showed a reciprocal relationship between stem enhancement and suffix erosion across, but not within, the three dialects. Overall, the results suggest that a trade-off of cues between suffix and stem vowel has progressed to different degrees between the three varieties.

1. Introduction

The focus of the present study is on metaphony in an Italo-Romance dialect region of Southern Italy known as the Lausberg area that extends across the border between Basilicata and Calabria (Lausberg, 1939; see also Conte, 2014; Martino, 1991; Romito, Galatà, Lio & Stillo, 2006; Trumper, 1979, 1997 for more recent studies). Metaphony is widespread in Romance languages, extending from Portuguese to Romanian (Loporcaro, 2016). Like umlaut in German (Iverson & Salmons, 2003; Kiparsky, 2015; Penzl, 1949; Twaddell, 1938), metaphony has its phonetic origins in trans-consonantal vowel-to-vowel coarticulation (Recasens, 2014), in which synchronically a vowel is influenced by a following vowel across one or more intervening consonants (Cole, Lindebaugh, Munson & McMurray, 2010; Hoole & Pouplier, 2017; Öhman, 1966). In metaphony, the suffix has an anticipatory influence on vowels in the preceding stem, typically in the direction of a vowel raising (Lausberg, 1939; Maiden & Savoia, 1997; Rohlfs, 1966; Schürr, 1936; Torres-Tamarit, Linke & Oostendorp, 2016). In most Southern Italian dialects, metaphony affects primarily stems containing phonetically mid vowels (Lausberg, 1939; Rensch, 1964; Rohlfs, 1966). The vowel system of dialects in the Lausberg area contrasts two mid stem vowels, /e, o/, and there is a three-way height contrast between high, mid, and low vowels (but none between mid-high and mid-low). In fact, most dialects in the area follow the so-called Sardinian vowel system (five vowels: /i, e, a, o, u/), in which Latin vowel qualities have been retained but vowel length neutralised (i.e. Lat. Ē, Ĕ > /e/, Lat. Ō, Ŏ > /o/) (Lausberg, 1939; Rohlfs, 1966; Savoia, 1997). The trigger for metaphony is typically one of two high vowels, /i, u/, in a word-final, unstressed, inflectional suffix that provides information about gender and number in nouns, and person, number, and tense in verbs. Examples of vowels preceding an /i/-suffix that are subject to metaphony are /mesi/ (‘months’), /morti/ (‘dead’, masc. pl.); and preceding a /u/-suffix /ossu/ (‘bone’), potentially leading to fully metaphonised forms in the stem such as /mis, murt, uss/, respectively.

Metaphony can be manifested, however, not only by mid-stem vowel raising, but also by diphthongisation (Lausberg, 1939; Rensch, 1964; Rohlfs, 1966). For instance, while the word ‘beautiful’, feminine singular, is /bella/, its masculine singular counterpart can be produced in some varieties as /ˈb[iə]llu/ or /ˈb[jɛ]llu/. Similarly, the masculine plural form of the word ‘good’ may be realised as /ˈb[uə]ni/ or /ˈb[wɔ]ni/, in contrast to the feminine plural counterpart /bone/. In both cases mentioned above, we can observe the presence of opening diphthongisation of the mid stem vowels /e, o/ triggered by the word-final high suffixes /i, u/. Based on a detailed analysis of raising and diphthongisation in Romance languages, Loporcaro (2016) argues firstly that the two processes are independent, and secondly that in Southern Italo-Romance “metaphonic raising occurred first, to then yield to metaphonic diphthongisation in a substantial subset of the dialects of Southern Italy.” (p. 83). In line with Loporcaro (2016), both Lausberg (1939, p. 40) and Rensch (1964, p. 30) suggested that metaphony by raising historically preceded the merger of Proto-Romance mid-high and mid-low vowels (which derived from long and short Latin vowels respectively) into the two mid-vowel categories, /e, o/, of the Lausberg dialects, while diphthongisation was an innovation that mainly affected etymologically mid-low vowels and that for most varieties came after the establishment of the Sardinian vowel system. They also pointed out, however, that some etymologically mid-high vowels might possibly show metaphonic diphthongisation in some words but not in other ones, depending both on whether the affected syllable is open or closed – the latter being a preferential target for diphthongisation (Lausberg, 1939) – and on the chronological point at which the establishment of the merger between mid-low and mid-high vowels and of diphthongisation came into being in each dialect (Rensch, 1964, p. 31). Given that there is no transparent phonetic reason why stem vowels should diphthongise as a consequence of anticipatory coarticulatory influences from the suffix, Loporcaro (2016) further suggests that diphthongisation occurs at a stage in the life-cycle of metaphony when it comes under increasingly phonological control and is therefore far less subject to phonetic conditioning (Bermúdez-Otero, 2015; Bermúdez-Otero & Trousdale, 2012; Kiparsky, 2015; Ramsammy, 2015). For the present sound change, this would mean that stem vowel changes could develop phonetic innovations (such as diphthongisation) that are not caused by the time-varying anticipatory coarticulatory influence of the suffix on the stem vowel.

Both metaphony and umlaut have in common with other types of sound changes that a coarticulatory effect becomes contrastive as the source or origin of the coarticulation is weakened or even completely eliminated (Walker, 2005). Thus, the historical development of contrastive nasalisation in French (e.g. *main*, /mɛ̃/ < Latin *manus*, 'hand') must have derived from a vowel that was originally non-contrastively nasalised followed by the loss of the following nasal consonant. In tonogenesis (Hagège & Haudricourt, 1978; Hombert, Ohala & Ewan, 1979), intrinsic pitch differences caused by an initial voicing contrast of a stop contrast developed into contrastive tones on the vowel combined with neutralisation of stop voicing (see also e.g. Coetzee, Beddor, Shedden, Styler & Wissing, 2018; Kirby & Ladd, 2015, 2016 for related studies).

The last two decades have seen some progress in understanding how during the progression of a sound change a coarticulatory effect could be maintained or even enhanced as its coarticulatory source is diminished. Some studies (Beddor, 2009; Beddor, Coetzee, Styler, McGowan & Boland, 2018; Cronenberg, Gubian, Harrington & Ruch, 2020; Harrington, 2012) suggest that a trading relationship (Haggard, Summerfield & Roberts, 1981; Repp, 1982) governs a sound change's transition from phonetically based coarticulation towards the development of a new phonological contrast. The physiological basis of a trading relationship between coarticulatory effect and its source is that autonomous, gestures of constant articulatory duration can be variably phased (Browman & Goldstein, 1992; Fowler, 2005; Fowler & Smith, 1986). Thus, if the velum lowering gesture in VN sequences is anticipated earlier in the vowel, and if this gesture's duration is fixed, then the duration of the nasal closure must be correspondingly less. Such a model has been shown to work quite well for explaining how in American English VN sequences, the primary cue for nasalisation can incrementally shift from the nasal consonant to the preceding vowel (Beddor, 2009; Beddor et al., 2018; Beddor, McGowan, Boland, Coetzee & Brasher, 2013). A more recent physiological study by Carignan et al. (2021) on nasalisation in German shows, however, that the trading relationship cannot just be explained by rephasing. Their evidence suggests that the path to sound change may involve no change in the temporal extent of nasalisation in the vowel, but rather a decrease in the magnitude of velum lowering in the nasal consonant. The conclusion from these separate studies on American English and German is nevertheless similar: In contexts in which vowel nasalisation and nasal loss are most likely (e.g., either in American English *sent* vs *send*, or German *Senta* vs *senden*), there is a proportional increase in the degree of nasalisation in the vowel (whether in time or magnitude) relative to the following nasal consonant. Such findings lend support to the idea that the enhancement of the coarticulatory effect and attrition of the coarticulatory source are inversely related.

How might a trade-off be manifested in Italo-Romance metaphony? Here the prediction is clear enough: The expectation is that cues to the inflectional suffix should be reciprocally distributed between the stem and suffix vowels. That is, there might on the one hand be speakers who cue the distinction between the singular and plural of 'months' predominantly in the suffix as do speakers of Standard Italian (i.e. /mese, mesi/). By contrast, speakers with the most advanced forms of metaphony will make the distinction entirely in the stem (i.e. /mes, mis/) and delete the suffix, while other speakers might be between these extremes and distribute the cues to morphological inflection in different reciprocal strengths between the stem and suffix. Certainly, final unstressed vowel neutralisation and deletion are common in varieties of Southern Italy (Bucci, Perrier, Gerber & Schwartz, 2019; Delucchi, Cangemi & Loporcaro, 2012; Lausberg, 1939; Rohlfs, 1966; Romano, 2020; Russo & Barry, 2004, among others). But whether such trade-off relationship between stem enhancement and attrition of the suffix exists for a population of speakers in dialect areas characterised by metaphony has not so far been investigated.

Various auditory phonetic studies have been carried out of the Lausberg area beginning with the author after which the region is named (Lausberg, 1939) and extended by other detailed follow-up analyses (Conte, 2014; Rensch, 1964; Romito et al., 2006; Trumper, 1997). There is some consistency across these studies that regions within the Lausberg area do indeed differ in whether metaphony is manifested primarily as raising or as diphthongisation or, possibly, even both. The map and analyses by Rensch (1964) (**Figure 1**) show, for example, that diphthongisation predominates in and around a large area of the west coast of the Lausberg area (sometimes referred to as the *Zwischenzone*, see Lausberg, 1939) but that within this area there are some perhaps more isolated villages such as Mormanno and Rotonda (Martino, 1991, p. 46; Savoia, 1997, p. 371; Savoia, 2015, p. 209) that have not undergone metaphonic diphthongisation – although Rensch (1964), comments that diphthongisation may sometimes occur synchronically alongside non-diphthongised forms in Mormanno. On the east coast (in a region sometimes known as the *Mittelzone*; see Lausberg, 1939) by contrast, there is a cluster of villages that Rensch (1964,

p. 20) characterises as “reduzierende Orte” (‘reducing villages’). Rensch’s categorisation of these villages as “reduzierend” means that metaphony may well once have been diphthongal in this region, but that the diphthongal quality has since been ironed out, leading to a monophthongal variant that is nevertheless different from that found in Mormanno (as pointed out by Martino, 1991, and Savoia, 1997, 2015) in being further raised. Trumper (1997, p. 361) is more explicit in this regard in commenting “many dialects in the (…) ‘Middle Zone’ have monophthongised all metaphonic diphthongs as phonetically long high vowels [iː], [uː] (*[ˈbɛllu] > *[ˈbiellu] > [ˈbiːllə], *[ˈkɔktu] > *[ˈkuottu] > [ˈkuːttə])”.

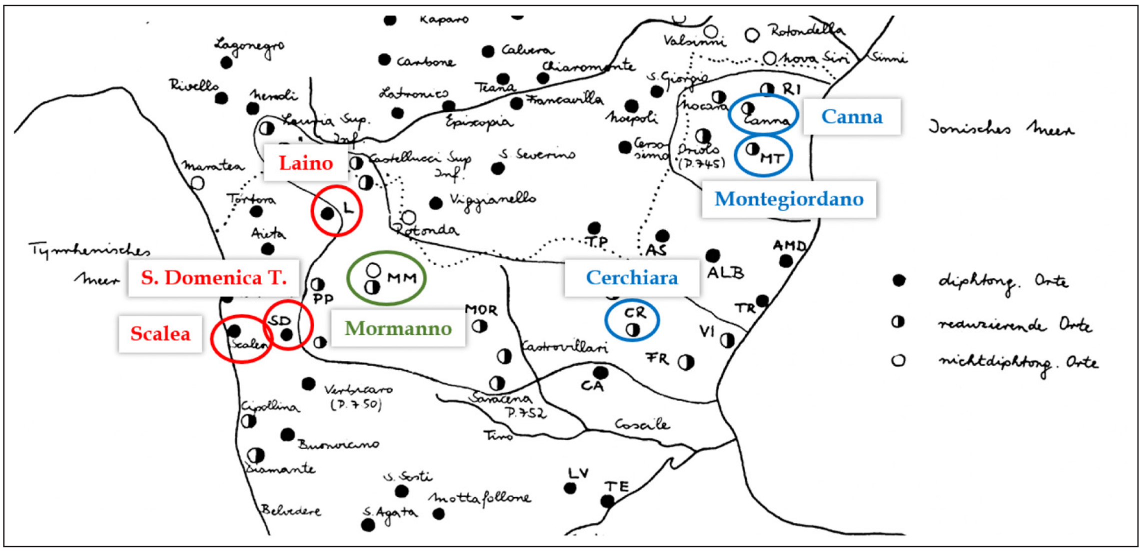

Figure 1: The classification of villages of the Lausberg area by Rensch (1964, p. 21) into diphthongising (filled circle), non-diphthongising (open circle), and reducing. The villages from which recordings were made in the present study are highlighted in colour: green for Mormanno (MM), red for the Zwischenzone (West), blue for the Mittelzone (East).

Two predictions are tested in this study based on the auditory phonetic analyses and models of sound change discussed above. The first is that information about the inflectional suffix in the stem follows the progression (where “<” means is less informative): MM (Mormanno) < West (Zwischenzone) < East (Mittelzone), where the ‘West’ includes villages exhibiting diphthongal metaphony on the west coast and where the ‘East’ includes villages characterised by the ‘reducing’ (and further raising) form of metaphony on the east coast (see **Figure 1**). The second prediction is that the degree of suffix erosion is MM < West < East. The basis for this prediction is the trade-off outlined earlier, in which the cues to coarticulatory effect and source – and, in this case, to inflectional morphology as well – are reciprocally distributed between the stem and suffix: Thus, the greater the available information in the stem, the weaker the information in the suffix, and vice-versa.

The first prediction was tested in Section 2 by analysing the influence of region and suffix vowel context on the shape trajectories of stem vowel formants. The second prediction was tested in Section 3, by analysing suffix vowel deletion (Section 3.1.1) and degree of centralisation (Section 3.1.2). Finally, a test was made of the relationship between suffix erosion and stem enhancement within each region and within the individual (Section 3.1.3).

2. Acoustic analysis of stem vowels

The aim of this part of the study was to determine whether the influence of the suffix on the stem vowels differed between the three regions. For this purpose, the shape of the first two formant frequencies in the stem vowel were quantified using functional principal components analysis, henceforth FPCA (Gubian, Torreira & Boves, 2015; Ramsay & Silverman, 2010). The output of FPCA is a set of principal components (PCs), which parameterise the shapes of F1 and F2 together, and an associated set of PC scores or weights that model how these shapes are connected to the individual stem vowel tokens.

The PCs were predicted to encode phonetic height and diphthongisation, given that these are two of the main features that are reported to occur in stem vowel metaphony. This prediction is tested in Section 2.1. The PC scores were predicted to show region-specific differences: That is greater diphthongisation in the West than in the other two regions; and a wider variation in phonetic height in the East compared with the West compared with MM. These predictions were tested in Section 2.2.

2.1. Formant trajectory shapes in the stem

As discussed above, the main aim in this section was to determine the extent to which the principal components applied to F1 and F2 trajectories together encoded phonetic height and diphthongal variation within stem-/e/ and within stem-/o/ vowels.

2.1.1. Method

2.1.1.1. Speakers and villages

Recordings were made in quiet conditions in the homes of 35 participants (18 females and 17 males) from eight villages in the Lausberg area. These were chosen because, following previous impressionistic studies (Lausberg, 1939; Martino, 1991; Rensch, 1964; Savoia, 1997, see Section 1.), they are expected to present the three different types of metaphony attested in the area, i.e. raising from mid to mid-high vowels (Mormanno), raising from mid to high vowels (East), and diphthongisation of stem vowels (West). The participants were recruited from personal contacts of the first author (a native speaker of this region) and on social media. They were paid a small amount of money for their participation. Before carrying out the recordings, all participants answered some questions related to their age, degree of education, and use of dialect in everyday life. Only participants who spoke the local variety frequently and proficiently were recruited. The mean age of the subjects was 48.9 years. **Figure 2** shows the villages and regions involved and the number of speakers recorded in Mormanno (MM) and from the villages of the West ('Zwischenzone' in Lausberg, 1939) and from the the East ('Mittelzone'). A further summary of some of the speaker attributes and numbers per village is shown in Appendix A, Table 7.

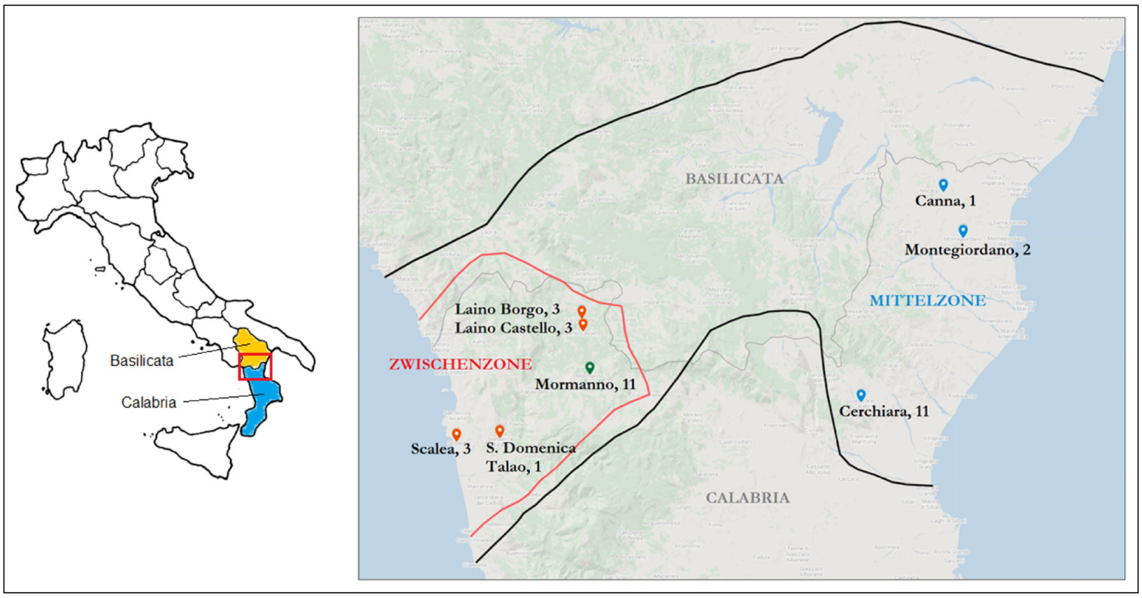

Figure 2: The Lausberg area (Map data ©2021 Google) and its main internal subdivisions (based on Pellegrini, 1977, and Trumper & Maddalon, 1988), including villages and numbers of speakers per village involved.

2.1.1.2. Materials and data elicitation

The lexical items containing the analysed stem and suffix vowels were elicited through a picture-naming task. The recordings were made using a laptop and a headset with integrated microphone (Sennheiser SC 60). The picture-naming task was carried out using the computer software SpeechRecorder (version 3.28.0) (Draxler, 2011) with one picture per inflected form of each lexical item. The order of appearance of these pictures was randomised differently for each speaker. Inflected adjectives were elicited in combination with a noun. The nouns and adjectives were first produced in isolation, and subsequently within the carrier sentence "I say … two times" ([(jɛ) ˈdiku … dui ˈvotə]), in the dialect. Verbs could not be elicited in isolation but within a sentence that was described by a picture, so the same sentence containing the target verb had to be repeated twice (see Appendix B for some examples of eliciting stimuli).

The target words were primarily selected on the basis of their stem vowel phoneme, which in most cases corresponded to the stem vowel in the Latin etymon (the dialects analysed in this study all share the so-called Sardinian vowel system, in which the vowel qualities of Latin are preserved, see Section 1.). Also, the word list aimed to represent all possible stem vowel/suffix vowel combinations. Because of the elicitation method chosen, the word choice had to be based on picturable items only, thus excluding function words or words referring to abstract concepts.

All target words analysed in this paper had primary stressed /e, o/ stem vowels combined with word-final, lexically unstressed suffix /i, e, a, u/ vowels. Most word types (n = 85) were disyllabic, while there were some words (n = 30) that were trisyllabic and in which the stem and suffix vowels were either adjacent (e.g. /niˈpote/, 'grandchild') or separated by one syllable (e.g. /ˈtenisi/, '(you) have'); see Appendix C, Table 8). The relationship between morphological inflection and suffix vowels is shown in **Table 1**.

Suffixes	Inflectional meaning	Examples	
		Stem-/e/	Stem-/o/
/a/	Feminine singular (adjectives and nouns)	bella *'beautiful'*	bona *'good'*
	Feminine plural (irregular; nouns)	–	ossa *'bones'*
	Present indicative, 3rd pers. sg. (1st-conjugation verbs)	pensa *'(s)he thinks'*	trova *'(s)he finds'*
/e/	(Mostly masculine) singular (adjectives and nouns)	verme *'worm'*	niˈpote *'grandchild'*
	Present indicative, 3rd pers. sg. (2nd-conjugation verbs)	tene *'(s)he has'*	more *'(s)he dies'*
	Feminine plural (adjectives and nouns)	mele *'apples'*	bone *'good'*
/i/	(Mostly masculine) plural (adjectives and nouns)	vermi *'worms'*	niˈpoti *'grandchildren'*
	Present indicative, 2nd pers. sg. (verbs)	ˈtenisi *'you have'*	ˈmorisi *'you die'*
/u/	Masculine singular (nouns)	bellu *'beautiful'*	bonu *'good'*
	Present indicative, 1st pers. sg. (verbs)	tengu *'I have'*	moru *'I die'*

Table 1: The suffix vowels and their inflectional meaning, with examples of words (phonemic transcription) for both stem vowels.

A total of 118 words were elicited that included 28 lexical items with stem-/e/ and 27 with stem-/o/ (Appendix C, Table 8). The total number of potentially available vowels for analysis for stem-/e/ was: 60 words (stem and suffix combinations) × 2 repetitions × 35 speakers = 4200 tokens; and for stem-/o/: 58 words × 2 repetitions × 35 speakers = 4060 tokens. However, some productions had to be removed because they had either been misarticulated, or produced in Standard Italian, or did not correspond to the target word: this left 2752 stem-/e/ and 2620 stem-/o/ vowels for the analysis. The final count of the produced words is shown in **Table 2**.

Along these words carrying mid stem vowels, other words (see Appendix D) were elicited that carried high and low /i, a, u/ stressed stem vowels (i.e. the three corner vowels of the vowel systems of the dialects analysed). These words were not analysed in this study, but only used to extract the F1 and F2 values of their stem vowels that were necessary for the Lobanov-normalisation of the /e, o/ stem vowel formants (see Section 2.1.1.3.).

Stem vowel		**/e/**				**/o/**			
Suffix vowel		/a/	/e/	/i/	/u/	/a/	/e/	/i/	/u/
Metaphonic context				✓	✓			✓	✓
Region	MM	186	244	319	274	257	178	235	292
	West	97	125	160	122	132	85	122	145
	East	222	284	373	346	317	181	299	377
	All regions	505	653	852	742	706	444	656	814

Table 2: Count of the stem vowels that were analysed in this study by suffix vowel and region.

2.1.1.3. Data pre-processing

The speech signals were semi-automatically segmented and labelled using the MAUS (*Munich Automatic Segmentation System*) forced alignment system (Kisler, Reichel & Schiel, 2017), which is integrated in the `emuR` package (version 1.1.2) (Winkelmann, Harrington & Jänsch, 2017) available in the R programming environment. The first two formant frequencies (F1, F2) of stem and suffix vowels were calculated using the Praat formant tracker included in the `PraatR` package (version 2.4) (Albin, 2014) in R with a 25 ms window and a 5 ms frame shift. Around 40% of the data were manually corrected for misplaced segment boundaries or mistracked formants.

All formant trajectories were linearly time-normalised into 11 equally-spaced time points between the acoustic onset and offset of the stem vowel. A speaker-normalisation procedure based on Lobanov (1971) was applied with (1):

$$F^{*}_{i,j,k}(t) = \frac{F_{i,j,k}(t) - \text{mean}(F)_{i,j}}{\text{sd}(F)_{i,j}} \tag{1}$$

in which $F^{*}_{i,j,k}(t)$ and $F_{i,j,k}(t)$ are, respectively, the time-normalised and raw formant frequency values of formant number j ($j = 1, 2$) produced by speaker i in utterance k at time-point t, and where mean $(F)_{i,j}$ and sd$(F)_{i,j}$ are the mean and the standard deviation of all formant values between the acoustic onset and offset for formant number j (in our case for each F1 and F2) with respect to the speaker's /a/, /i/, and /u/ stem vowels contained in the words listed in Appendix D.

2.1.1.4. Functional principal component analysis (FPCA)

The time-normalised sampled formant track pairs (F1, F2) were interpolated by means of standard smoothing techniques using B-splines, which are sequences of polynomial functions that, when multiplied by coefficients and summed, reproduce a sampled data contour by approximation to the original shape (Gubian et al., 2015). As a result, each vowel token of /e/ or /o/ was represented by a pair of continuous functions $F1_i(t)$ and $F2_i(t)$, in which i is the token index and t is the continuous, normalised time variable. This set of function pairs was the input to FPCA, which produced a parameterisation of the form:

$$F1_i(t) \approx \mu_{F1}(t) + \sum_{k=1}^{K} s_{k,i} \cdot PCk_{F1}(t) \tag{2a}$$

$$F2_i(t) \approx \mu_{F2}(t) + \sum_{k=1}^{K} s_{k,i} \cdot PCk_{F2}(t) \tag{2b}$$

in which $\mu_{F1}(t)$ and $\mu_{F2}(t)$ are the mean formant tracks, $PCk_{F1}(t)$ and $PCk_{F2}(t)$ are K pairs of Principal Component curves (PCs, $k = 1, \cdots, K$), which are fixed and depend on the entire data set, and $s_{k,i}$ are *scores*, which are weights on the PC*k*s (with one vector of weights per stem vowel token). The formant track pair of any individual vowel stem token can be reconstructed from (2): Essentially, the greater the number of PCs, the closer the approximation to the token's raw F1 and F2 trajectories.

FPCA was applied separately to the 2752 stem-/e/ tokens and to the 2620 stem-/o/ tokens. In both cases, the first $K = 3$ PCs were considered, which in combination explained around 95% and 93% of the FPCA variance for the stem-/e/ and stem-/o/ data respectively. The reason why FPCA was applied separately to /e/ and /o/ is because the extensive formant frequency differences between /e, o/ would otherwise have masked the much smaller differences caused by the influence of the suffix on the stem vowel.

2.1.2. Results

Figures 3 and **4** illustrate the type of shape variation is captured by each PC for the FPCA based on stem-/e/ and stem-/o/ vowels respectively. Each panel isolates the effect of one PC, say PCk, by displaying several colour-coded curves, each one obtained by substituting a different value of the corresponding score s_k into equations (2a) and (2b), setting all other scores to zero. For example, the top mid panel in **Figure 3** shows curves of the form $\mu_{F2}(t) + s_2 \cdot PC2_{F2}(t)$. The values used for scores s_k are equally spaced ranging between – 1 (blue) and + 1(red) standard deviations ($-1 \le \frac{s_k}{\sigma_k} \le 1$). The value $s_k = 0$ corresponds to the mean curve across the entire data for that vowel (thick black lines), and is therefore the same across panels of the same stem vowel and formant.

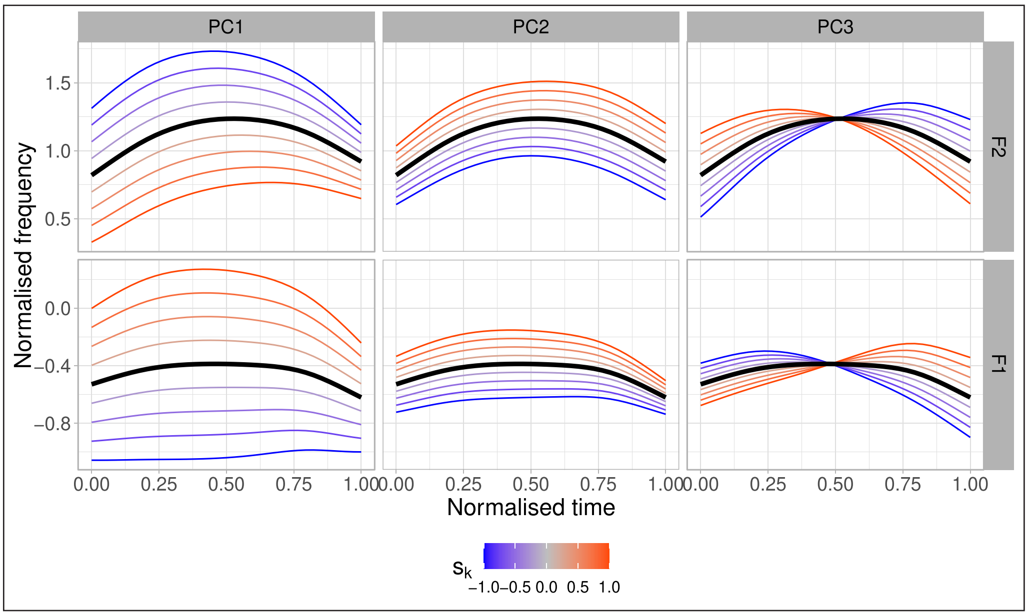

Figure 3: First three PCs for stem-/e/ vowels between their acoustic onset and offset for normalised F2 (upper row) and F1 (lower row) pooled across speakers and word tokens containing /e/ stems.

Turning firstly to /e/, as far as PC1 is concerned (**Figure 3**, left panels), decreasing and increasing s_1 caused F1 and F2 to shift further apart (blue) or to come closer together (red) respectively. Thus, the s_1 modulation of PC1 brought about a type of variation that is consistent with both a phonetic raising and simultaneous fronting, i.e. the change between the extreme blue/red trajectories for PC1 in the left panels of **Figure 3** is likely to correspond to a shift from a (peripheral) phonetically high front [i] vowel (blue trajectories, in which F1 and F2 are maximally far apart) in the direction of phonetic centralisation and lowering, possibly in the direction of [e] or [ɛ]. The s_2 modulation of PC2 (central panels in **Figure 3**) caused both formants either to decrease in frequency (blue trajectories) or to increase together (red trajectories). The phonetic interpretation of PC2 is less transparent than the one for PC1: It might, on the one hand, act to constrain the variation in PC1, but it could also be associated with a shift from a less (red trajectories) to a more (blue trajectories) rounded vowel, given that vocal tract lengthening due to lip rounding causes a decrease in formant frequencies (especially in F2, see e.g. Lindblom & Sundberg, 1971, and Figure 2 in Vaissière, 2009, p. 24). The changes to the formant shapes caused by s_3 modulations of PC3 were from (i) to (ii):

(i) Blue trajectories: In the first part of the vowel, F1 is above the mean curve and F2 is below the mean curve. Since the mean curve refers in this case to the /e/ stem vowel, then this quality corresponds to a tongue lowered [e̞] or to [ɛ]. In the second part of the vowel, F1 is below the mean and F2 above the mean. This is typical of a quality such as a tongue raised [e̝] or [i]. Consequently, the blue line from the vowel onset to the offset represents a range of phonetically closing diphthongs such as [e̞e̝] or [ɛi].

(ii) Red trajectories: These are more or less the mirror image on the time axis of the blue ones. Thus, the red trajectories from the vowel onset to the offset represent a range of phonetically opening diphthongs such as [e̝e̞], [ie] or [jɛ].

Thus, the shift from (i) to (ii) corresponds to the variation between a closing and opening diphthong.

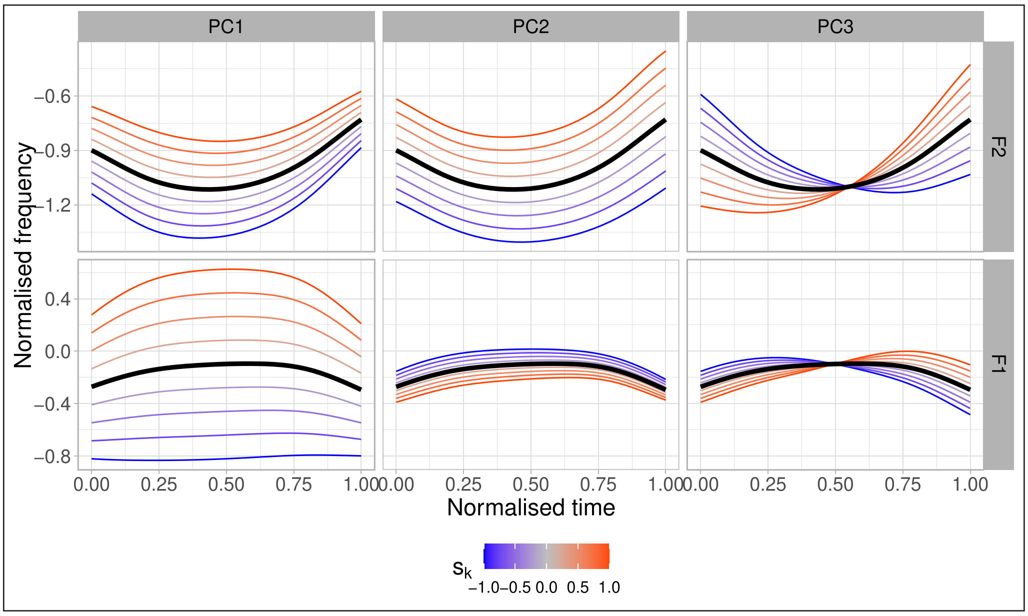

Figure 4: First three PCs for stem-/o/ vowels between their acoustic onset and offset for normalised F2 (upper row) and F1 (lower row) pooled across speakers and word tokens containing /o/ stems.

The type of variation associated with the PCs for stem /o/ in **Figure 4** bears a striking similarity to that of stem /e/. As far as PC1 is concerned (**Figure 4**, left panels), decreasing s_1 caused a lowering of both formants: That is, the change from negative (blue trajectories) to positive (red trajectories) s_1 values corresponds to a shift from a phonetically high vowel, in this case [u], towards a lower and more central vowel such as [ɔ] or [o]. The type of variation in PC2 is similar to that of PC1 except that, for PC2, F1 changes minimally: Thus, the transition from blue to red trajectories in PC2 might correspond phonetically to an increase in vowel frontness or backness, but without much change in phonetic height. The s_3-induced variation in PC3 brings about a change in diphthongal quality from (i) to (ii):

(i) Blue trajectories: In the first part of the vowel, both formants are above their respective means. Since the mean refers in this case to stem /o/, this quality possibly corresponds to a tongue lowered [o̞] or [ɔ]. In the second part of the vowel, both formants are below their respective means. This is typical of a quality in which the tongue is raised as for tongue raised [o̝] or [u]. Consequently, the blue line from the vowel onset to the offset represents a range of phonetically closing diphthongs such as [o̞o̝] or [ɔu].

(ii) Red trajectories: These are more or less the mirror image on the time axis of the blue ones. Thus, the red trajectories from the vowel onset to the offset represent a range of phonetically opening diphthongs such as [o̝o̞], [uo] or [wɔ].

Thus, as for stem /e/, the change from (i) to (ii) represents a shift from a phonetically closing to an opening diphthong.

2.1.3. Discussion

The separate application of FPCA to the formant trajectories of /e/ and of /o/ resulted in a set of *k* PCs such that each one encoded different aspects of the variation in the formant trajectories across speakers and words. PC1 is likely to be associated with simultaneous variations in phonetic height and frontness/backness either between high front and low-mid front in the case of /e/, or between high back and low-mid back in the case of /o/. The phonetic interpretation of PC2, instead, might be related to a variation in lip rounding for /e/ and in phonetic backness for /o/. PC3 for both /e/ and /o/ encode variations between phonetically closing and opening diphthongs.

The issue to be considered next is the extent to which these variations in the formant trajectories were connected to the metaphonic influence of V_2 on V_1 and with the differences between the three regions. For this purpose, the analyses in the following sections were based on PC1 and PC3 and relative scores, given the evidence so far that metaphony is mainly associated with variations in phonetic peripherality (modulated by s_1) and diphthongisation (modulated by s_3) in the stem vowel.

2.2. Regional variation

The more specific hypotheses to be tested were that (i) the influence of the suffix on the stem was greatest for the East, intermediate for the West, and least for MM and (ii) that the West was differentiated from the other two regions by diphthongisation.

2.2.1. Method

The PC-scores s_1 and s_3 were modelled by linear mixed-effects regression models which were applied with the `lmerTest` package in R. The mixed models were of the form (R notation):

$$s \sim \text{Suffix vowel} * \text{Region} + (\text{Region} \,|\, \text{Stem}) + (1 \,|\, \text{Speaker}) \tag{3}$$

in which the response s was one of two PC-scores and in which there were fixed factors suffix (four levels: /i, e, a, u/) and region (three levels: MM, West, East) and their interaction. Stem was a unique identifier for the lexical stem of the word independently of its suffix (e.g. the stem representation for the different inflected forms of 'months' was /mes/). The random factors originally included intercepts and all logically possible slopes to measure the interaction between the fixed and random factors. These were dropped if they were non-significant, resulting in the final model shown in (3) that was applied separately to the stem-/e/ and stem-/o/ data. Post-hoc tests were computed using the `emmeans` package in R whenever the two fixed factors interacted. Finally, expected F1 and F2 trajectories were obtained by first computing estimated marginal means of s_1 and s_3 for each combination of the fixed factors from the LMER models in (3), and then by substituting those values into Eq. (2) (setting the other scores to zero).

2.2.2. Results

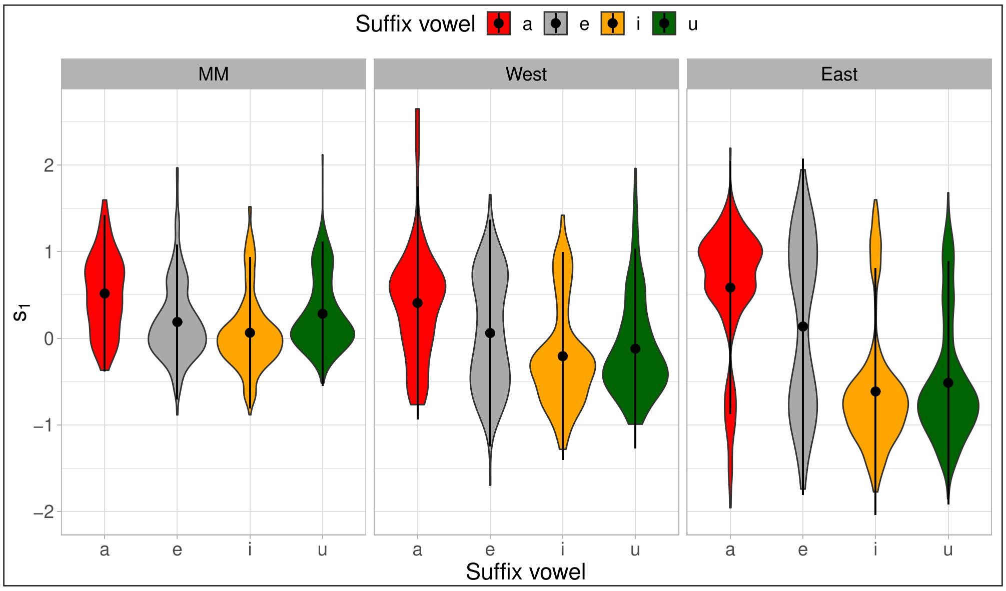

Figure 5: Violin plots of the s_1 PC-scores for the stem vowel /e/ shown separately by region and suffix vowel. The mean for each distribution is indicated by a black dot.

2.2.2.1. Stem-/e/

Consistently with the analysis in Section 2.1, **Figure 5** shows that s_1 varied with the phonetic height of the suffix vowel. This is most evident in the East's data in which the lowest s_1 scores were in the context of suffix-/i, u/ (thus suggesting that the stem vowels are phonetically highest in these contexts – see the right panel of **Figure 3**) followed by stems vowels in the /e, a/ contexts respectively. **Figure 5** also suggests that s_1 varied by region: Where > denotes 'the suffix vowel had a greater influence on the stem vowel' then East > West > MM. This is evident from **Figure 5** (e.g., the s_1 separation between /a/ vs /e/ vs /i, u/ was greatest for the East, intermediate for the West, and least for MM).

The results of the mixed model in (3) showed a significant influence on s_1 of the suffix vowel ($F_{3,\ 2493.6} = 122.1$ $p < 0.001$), of region ($F_{2,\ 49.1} = 9.7$, $p < 0.001$) and a significant interaction between these factors ($F_{6,\ 1120.7} = 35.3$, $p < 0.001$). The post-hoc tests showed significant differences between all pairs of regions for suffix-/i/ (MM vs West: $p = 0.001$; MM vs East: $p < 0.001$; West vs East: $p < 0.01$) and for suffix-/u/ (MM vs West: $p = 0.001$; MM vs East: $p < 0.001$; West vs East: $p < 0.01$), but no differences between the regions for suffix-/a/ and only one pairwise difference (MM vs West: $p < 0.05$) for suffix-/e/ (see **Table 3** for details).

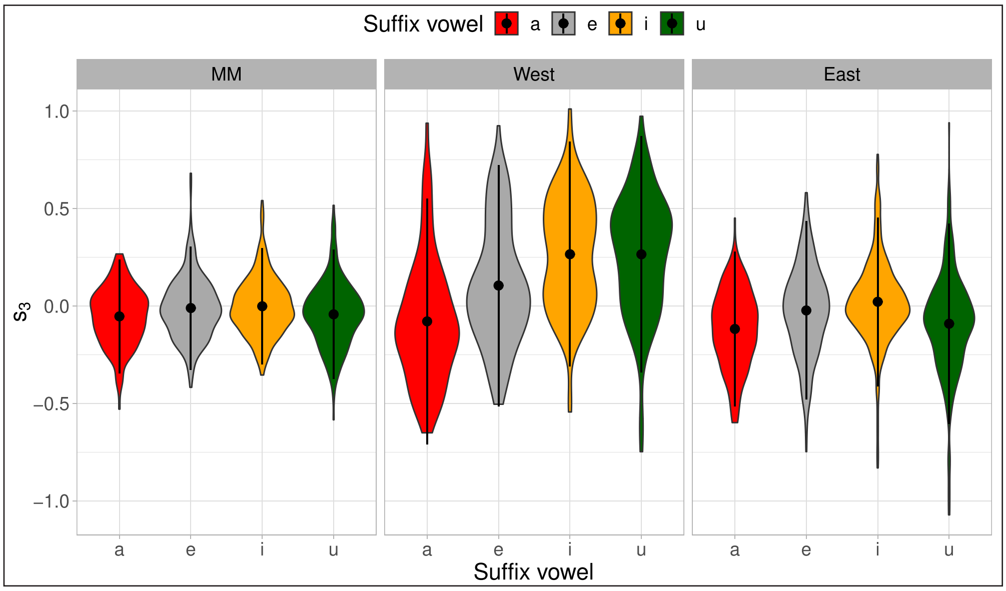

Figure 6: Violin plots of the s_3 PC-scores for stem /e/ vowels shown separately by region and suffix vowel. The mean for each distribution is indicated by a black dot.

As far as s_3 is concerned, which as shown in Section 2.1 is indicative of stem vowel diphthongisation, **Figure 6** suggests higher scores (and hence greater opening diphthongisation) for the West compared with the other two regions, especially in the context of suffix-/i, u/. The results of the mixed model (3) with s_3 as the dependent variable showed a significant influence of suffix ($F_{3,\ 2632.7}$ = 11.9, $p < 0.001$), a not quite significant influence of region ($F_{2,\ 48.8}$ = 3.1, $p = 0.5$), and a significant interaction between these factors ($F_{6,\ 2068.1}$ = 14.7, $p < 0.001$). The post-hoc tests showed a significant difference between the West and the other two regions for suffix-/i/ (MM vs West: $p < 0.05$; West vs East: $p < 0.01$) and for suffix-/u/ (MM vs West: $p < 0.001$; West vs East: $p < 0.001$). There were no significant differences between any of the regions for suffixes-/e, a/ (see **Table 3** for details).

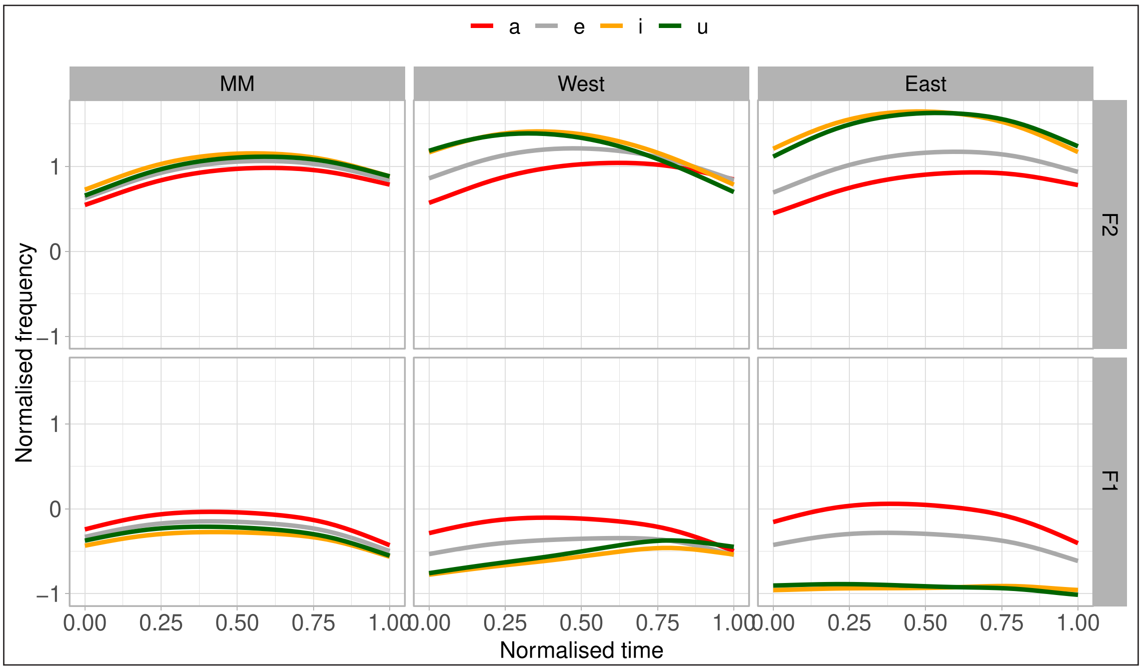

Figure 7: Reconstructed formant trajectories from the estimated marginal means of s_1 and s_3 for stem-/e/in the context of the four suffix vowels shown separately by region.

The reconstructed formants from the estimated marginal means of s_1 and s_3 (see Section 2.2.1.) in **Figure 7** shows trends that are entirely consistent with the above analyses. In particular, **Figure 7** shows a greater influence of the suffix on F1 and F2 in the East than in the West than in MM; and also that there was a greater degree of diphthongisation in the West than in the other two regions (see also Appendix E, Figure 19, for some lexical examples with spectrograms).

2.2.2.2. Stem-/o/

For stem-/o/, **Figure 8** shows that the extent of influence of the region on s_1 was East > West > MM. The results of the statistical model in (3) applied to these data showed a significant influence on s_1 of the suffix vowel ($F_{3,\ 1995.6}$ = 253.6, $p < 0.001$), of region ($F_{2,\ 44.2}$ = 6.3,

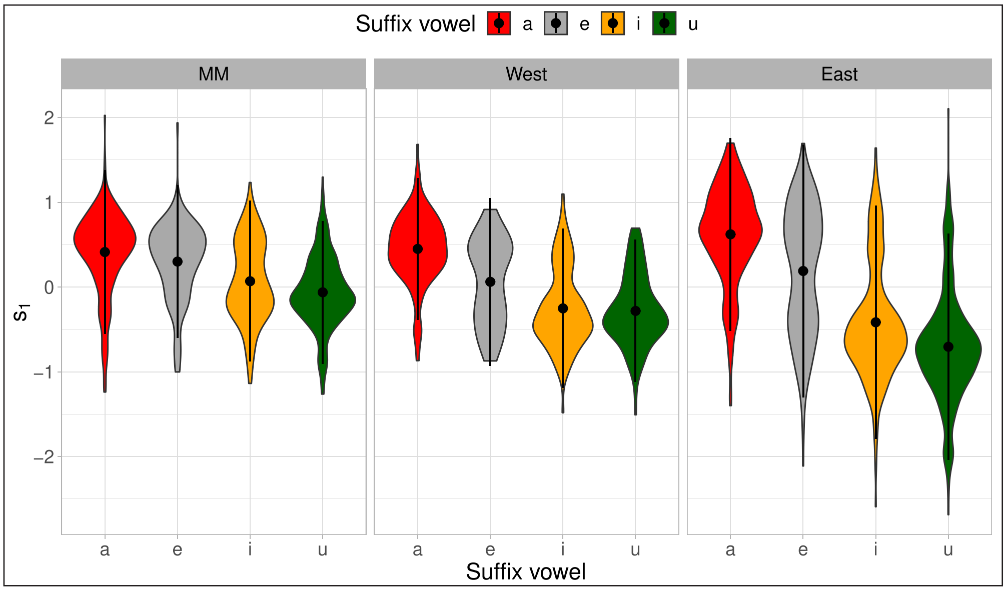

Figure 8: Violin plots of the s_1 PC-scores for the stem vowel /o/ shown separately by region and suffix vowel. The mean for each distribution is indicated by a black dot.

$p < 0.01$) and that there was a significant interaction between these factors ($F_{6,\ 889.0} = 37.7$, $p < 0.001$). The results of the post-hoc tests showed a significant difference between MM and the East in the context of all four suffix vowels (/i/: $p < 0.001$; /u/: $p < 0.001$; /e/: $p < 0.01$; /a/: $p < 0.05$). There were significant differences between MM and the West in three suffix vowel contexts (/i/: $p = 0.001$; /u/: $p < 0.05$; /e/: $p < 0.01$) but not in /a/. There were differences between the West and the East in the context of suffix-/u/ ($p < 0.01$) and suffix-/a/ ($p < 0.05$) but not in the context of the other two suffix vowels (see **Table 3** for details).

Concerning s_3, **Figure 9** shows higher s_3 values – and therefore greater opening diphthongisation – for the West than for the other two regions. The application of the statistical model in (3) to these data showed a significant influence on s_3 of suffix vowel ($F_{3,\ 2504.7} = 17.9$, $p < 0.001$), of region ($F_{2,\ 42.7} = 5.0$, $p = 0.01$) and a significant interaction between these factors ($F_{6,\ 465.6} = 17.7$, $p < 0.001$). The results of the post-hoc tests showed significant differences between the West and the other two regions in the context of suffix-/i/ (West vs East: $p < 0.001$; MM vs West: $p < 0.01$) and suffix-/u/ (West vs East: $p < 0.001$; MM vs West: $p < 0.001$) but not for the other two suffix vowel contexts (see **Table 3** for details). There were no significant differences between MM and the West in any contexts. Compatibly with these results, the reconstructed formants from the estimated marginal means in **Figure 10** show firstly that the influence of the suffix was greatest for the East followed by the West followed by MM, and that there was a greater degree of diphthongisation for the West than for the other two regions (see also Appendix E, Figure 20, for some lexical examples with spectrograms).

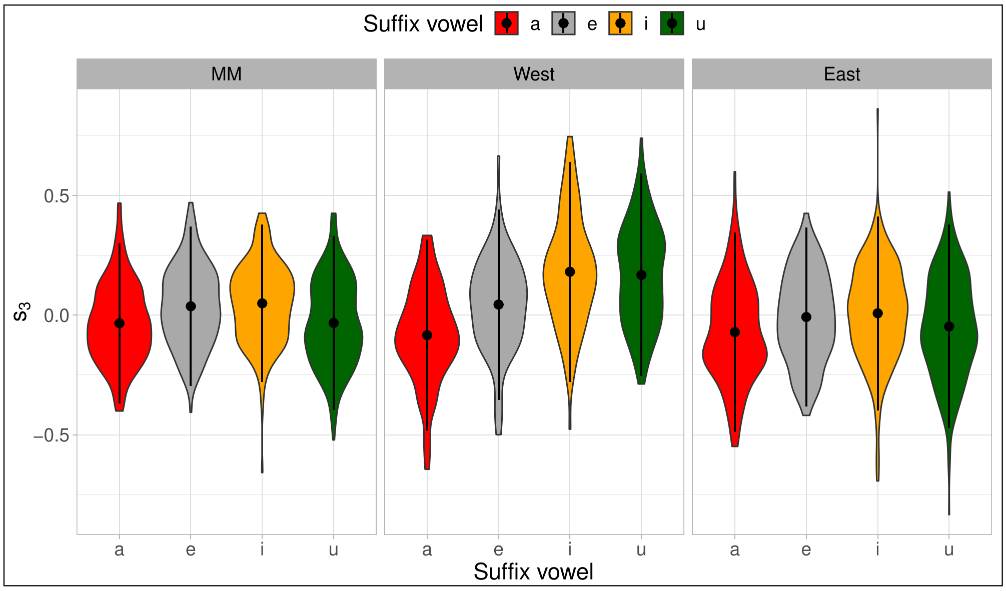

Figure 9: Violin plots of the s_3 PC-scores for stem /o/ vowels shown separately by region and suffix vowel. The mean for each distribution is indicated by a black dot.

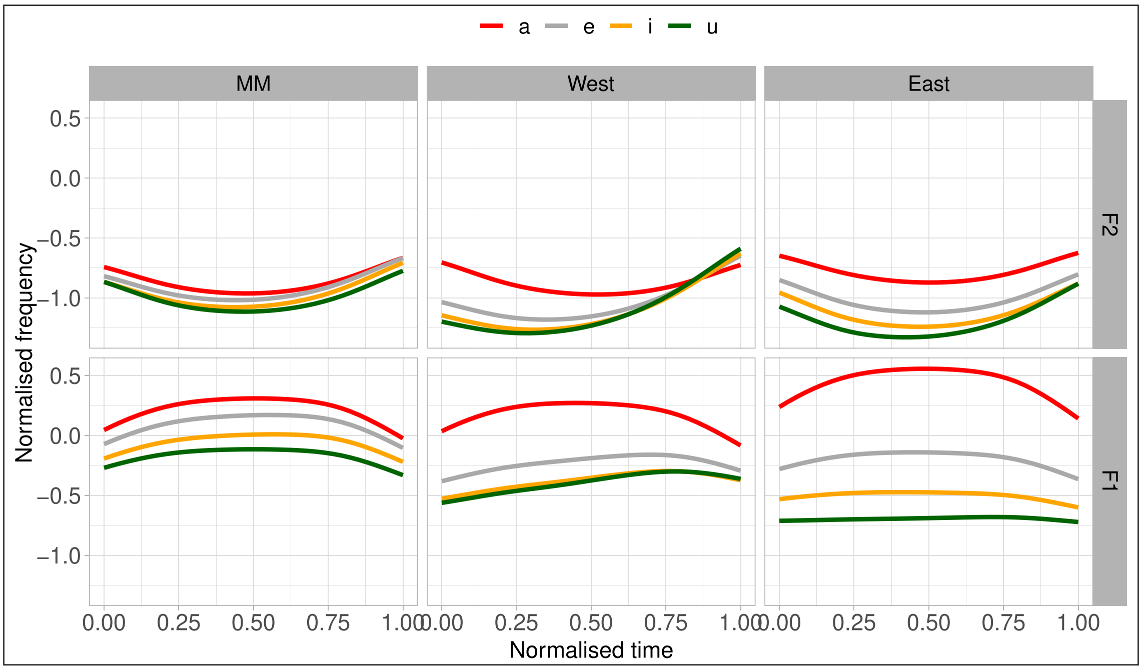

Figure 10: Reconstructed formant trajectories from the estimated marginal means of s_1 and s_3 for stem-/o/ in the context of the four suffix vowels shown separately by region.

2.2.3. Discussion

These results show that suffix vowels influenced the phonetic height of stem vowels. This effect is most clearly seen in the reconstructed formant plots for F1 in MM and the East in **Figures 7** and **10**, in which the stem vowels – especially for the East[1] – had a progressively higher F1 in the context of suffix vowels /a/ vs /e/ vs /i, u/. A new finding in this regard is that the stem vowel change occurs not just for high suffix vowels as most of the literature on Italo-Romance metaphony suggests (Calabrese, 1998; Maiden & Savoia, 1997; Rohlfs, 1966; Torres-Tamarit et al., 2016), but also in the context of suffix-/a/. In all three regions stem vowels were found to be lowered in the context of suffix vowel /a/ and increasingly so from MM to West to East. If there were no effect of suffix-/a/ on the stem vowels, then there should have been no difference between the quality of the stem vowels before suffix /e, a/, but this was not the case: As **Figures 7** and **10** show, F1 in the context of suffix-/a/ within any region is typically higher (thus signalling a vowel lowering) compared with F1 in the context of suffix-/e/.

The extent of the influence of the suffix vowel on the phonetic height in the stem varied between regions. The influence of the suffix vowel was most marked in the East and least in MM. These MM–East differences are once again apparent in the reconstructed formants, in which, especially for stem-/o/, the F1-separation due the suffix vowel was considerably greater in the East than in MM. For the West, the influence of the suffix vowel on stem vowel height was more marked than in MM but not as marked as for the East. This is also shown by the reconstructed formant plots in **Figures 7** and **10**, for which the F1-separation in the suffix vowel contexts is intermediate between that for MM and for the East.

In the West, but not in the other two regions, the influence of the suffix vowel was associated with diphthongisation in the stem vowel. Compatibly, the reconstructed formant trajectories in **Figures 7** and **10** show a diphthongal quality to the West's stem vowels and a greater suffix-dependent formant separation in the initial compared with the final part of the formant trajectories.

The concern of the next section is to consider whether the phonetic information for the suffix vowel is reciprocally distributed between the stem and the suffix, such that the more information that there is in the former the less there is in the latter, and vice-versa.[2]

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[1] See also Appendix F for a comparison of formant values between high and metaphonically raised stem vowels in the East.

[2] In this study, the relationship between metaphony and suffix erosion was analysed in terms of reciprocal changes in vowel quality between stems and suffixes. In addition to this analysis, we also explored in Appendix G the potential presence of a trading relationship between stem and suffix vowel durations.

Regions	Stem vowel	PC-score	Suffix vowel	*m*	*SE*	*df*	*t*	Sig.
MM – East	/e/	s_1	/i/	0.75	0.11	53.0	6.7	***
			/u/	0.79	0.11	55.0	7.0	***
	/o/	s_3	/a/	–0.24	0.10	65.2	–2.4	*
			/e/	0.30	0.11	86.0	2.8	**
			/i/	0.47	0.10	68.7	4.6	***
			/u/	0.56	0.09	61.2	5.7	***
MM – West	/e/	s_1	/e/	0.23	0.09	78.1	2.4	*
			/i/	0.34	0.09	66.1	3.7	***
			/u/	0.34	0.09	76.3	3.6	***
		s_3	/i/	–0.17	0.06	63.7	–2.8	*
			/u/	–0.24	0.06	67.2	–3.8	***
	/o/	s_1	/e/	0.35	0.10	65.5	3.4	**
			/i/	0.35	0.09	54.7	3.7	***
			/u/	0.26	0.09	50.8	2.8	*
		s_3	/i/	–0.10	0.03	82.4	–3.5	**
			/u/	–0.16	0.03	74.3	–5.7	***
West – East	/e/	s_1	/i/	0.41	0.13	52.4	3.2	**
			/u/	0.46	0.13	56.5	3.5	**
		s_3	/i/	0.18	0.06	63.8	3.1	**
			/u/	0.29	0.06	67.0	4.8	***
	/o/	s_1	/a/	–0.28	0.10	71.4	–2.7	*
			/u/	0.31	0.10	67.1	3.0	**
		s_3	/e/	0.11	0.04	82.1	2.9	**
			/i/	0.15	0.03	63.3	4.2	***
			/u/	0.15	0.03	56.7	4.3	***

Table 3: The estimated mean (*m*) and standard error (*SE*) of the statistically significant s_1 and s_3 contrasts between regions, separately for stem vowel and suffix vowel, and the associated post-hoc *t*-statistics (final three columns; *** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$).

3. Analysis of suffix erosion

The prediction was tested that MM < West < East, where '<' denotes the extent of suffix erosion. The erosion of the suffix was quantified by analysing separately the extent of suffix deletion (Section 3.1.1) and suffix centralisation (Section 3.1.2).

3.1. Method

The lexical items were the same as those for the stem vowel analysis. **Table 4** shows the number of suffix vowel tokens analysed (also including the number of deleted ones), separately by region, stem vowel of the lexical items to which the suffixes in question were attached, and suffix vowel type.

For the statistical models described in the following sections, all possible interactions between the fixed factors were tested, while the random factors originally included intercepts and all possible slopes to measure the interaction between the fixed and random factors; these were dropped if they were detected as non-significant by using the function `step` of the package `lmerTest` (version 3.1.3) in the R environment.

Stem vowel	Region	Suffix vowel	N. of tokens	
			Deleted	Realised
/e/	MM	/a/	6	180
		/e/	8	236
		/i/	14	305
		/u/	17	257
	West	/a/	4	93
		/e/	6	119
		/i/	15	145
		/u/	11	111
	East	/a/	62	160
		/e/	56	228
		/i/	78	295
		/u/	76	270

(Contd.)

Stem vowel	Region	Suffix vowel	N. of tokens	
			Deleted	Realised
/o/	MM	/a/	6	251
		/e/	7	171
		/i/	13	222
		/u/	12	280
	West	/a/	8	124
		/e/	11	74
		/i/	24	98
		/u/	23	122
	East	/a/	66	251
		/e/	36	145
		/i/	64	235
		/u/	73	304

Table 4: Count of the suffix vowels that were analysed by region, stem vowel, and suffix vowel type.

3.1.1. Suffix vowel deletion

A suffix was considered to be deleted if, upon audiovisual inspection of the spectrogram, there was neither a visibly detectable formant structure nor an acoustically perceivable word-final suffix vowel at the end of the uttered word. Voiceless vowels were considered for this analysis as phonetically realised suffixes. Suffix deletion occurred in 696 out of 5372, i.e. 13% of tokens (**Table 4**).

Deletion of the suffix vowel was modelled with a logistic generalised linear mixed model (GLMM), in which the response variable was the (logit transformed) proportion of deletions. *Region* had three levels (MM, West, and East), *Stem vowel* had two levels (/e, o/), and *Suffix vowel* had four levels (/a, e, i, u/). The random factors were *Stem*[3] (the same 55 lexical stems analysed

[3] The terms (1|Stem) + (0 + Region | Stem) indicate together that the random intercept and the slope of *Stem* by *Region* were estimated, but not their correlation.

in Section 2.1.1.4) and *Speaker* (35 speakers). The analysis was based on (4), which shows the final model that converged after all non-significant terms were removed.

$$\begin{aligned}&\text{Deletion} \sim \text{Region} + \text{Suffix vowel} + \text{Stem vowel} + \\ &\text{Region} : \text{Suffix vowel} + \text{Region} : \text{Stem vowel} + \\ &(1 \mid \text{Stem}) + (0 + \text{Region} \mid \text{Stem}) + (1 \mid \text{Speaker})\end{aligned} \tag{4}$$

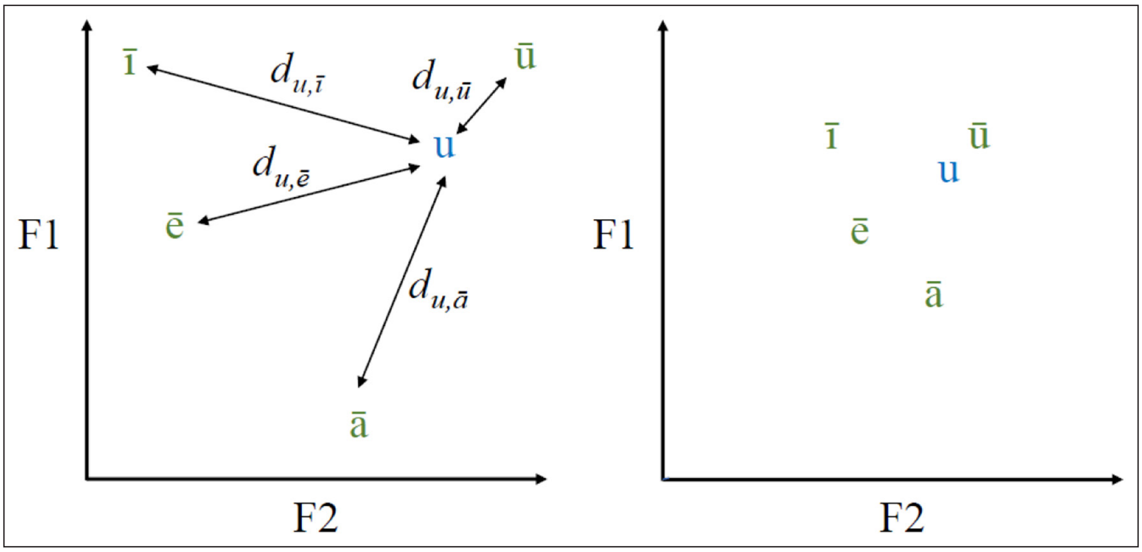

Figure 11: A schematic outline in the (*F*1*, F*2) space of a hypothetical expanded (left) vs centralised (right) vowel space, showing a single vowel token [u] (in blue) and its distances (left) to the mean positions of four suffix vowels (in green, with a macron) produced by the same speaker.

3.1.2. Suffix vowel centralisation

The degree of suffix vowel centralisation was quantified by comparing the distance of a suffix vowel token to its own class centroid in relation to the distances to other class centroids. The basis for this algorithm is schematically outlined in **Figure 11**, which shows a hypothetical vowel token [u] in the (F1, F2) space and the centroids (mean positions) of the four suffix vowels for the same speaker.

If the suffix vowel space is expanded (**Figure 11**, left) then the distance of the vowel token to its own centroid is small in relation to its distance to the other vowel centroids. By contrast, the ratio of these two distances is greater if the vowel space is centralised (**Figure 11**, right). The degree of centralisation was quantified using the centralisation index in (5):

$$c_{s,j} = \log\left(d_{s,j,\bar{j}} \middle/ \frac{1}{(n-1)} \sum\nolimits_{\bar{j} \neq \bar{k}} d_{s,\bar{j},\bar{k}} \right) \tag{5}$$

in which n is the number of different vowel categories, $c_{s,j}$ is the degree of centralisation of vowel suffix token j produced by speaker s, and in which $d_{s,j,\bar{j}}$ and $d_{s,\bar{j},\bar{k}}$ are its distances in the normalised ($F1,F2$) space to the same and other suffix vowel centroids respectively produced by the same speaker. Thus, in the example on the left of **Figure 11**, the centralisation index is given by $log(d_{u,\bar{u}} / (1/3(d_{u,\bar{i}} + d_{u,\bar{e}} + d_{u,\bar{a}})))$. The calculations in the normalised formant space were in all cases made using F1 and F2 values aggregated across all time points between acoustic onset and offset of suffix vowels.

After all non-significant terms had been removed, the statistical modelling of the centralisation index c was carried out as in (6) using the same independent variables as in (4):

$$c \sim \text{Region} * \text{Suffix vowel} * \text{Stem vowel} + (1 \mid \text{Stem}) + (1 \mid \text{Speaker}) \qquad (6)$$

3.1.3. Relationship between suffix reduction and stem vowel enhancement

Euclidean distances in an (s_1,s_3) space were calculated between stem vowels in different suffix contexts. The idea behind the calculation was that, if a trade-off of cues between stem and suffix takes place *within* the individual, we can expect a large influence of the suffix on the stem vowel (i.e., the inter-Euclidean distances between the stem vowels in e.g. *bone, boni, bona* should be high). Conversely, the stem vowels should be similarly positioned in the (s_1,s_3) space, if the suffix vowel's influence on the stem is negligible. These calculations were carried out for those lexical items in which (i) the suffix had not been deleted; and (ii) for which there was, by speaker and by lexical stem, at least one combination between metaphonic (i.e. high) and non-metaphonic suffixes (so word pairs such as e.g. *lettu, letti* were not taken into account), thus leaving, for this analysis only, 3197 tokens (stem-/e/ words: n = 1499; stem-/o/ words: n = 1698). Also, the suffixes /i, u/ were pooled because of low numbers of suffix-/e/ – suffix-/u/ combinations. Accordingly, only the influence of suffix vowel height (i.e. distances between stem vowels in suffix vowel contexts /i, u/ vs /e/ vs/ /a/) was taken into account for this purpose.

The quantification of these distances was done separately by speaker and stem from (7):

$$d_{s,w,j,k} = \log\left(\sqrt{(x_{s,w,j} - \bar{x}_{s,w,k})^2 + (y_{s,w,j} - \bar{y}_{s,w,k})^2}\right) \qquad (7)$$
$$j,k \in \{/\text{i},\text{u}/,/\text{e}/,/\text{a}/\};\ j \neq k$$

in which $d_{s,w,j,k}$ is the logarithm of the Euclidean distance from a vowel token produced by speaker s in stem w in the context of suffix-vowel j to aggregated vowels produced by the same speaker in the same stem in the context of suffix-vowel k. The variables x and y in (7) are in this case s_1 and s_3 respectively ($\bar{x}$ and $\bar{y}$ are corresponding aggregates). Thus, informally, the calculation by (7) was the Euclidean distance in an (s_1,s_3) space (henceforth d_{stem}) from a stem vowel token of, for example, *boni* token to stem vowel aggregates in *bone* or in *bona* (but not in *boni*) produced by the same speaker.

The same distance metric was applied to suffix vowels in which *x* and *y* of (7) were respectively F1 and F2 (extracted as explained in Section 3.1.2). Thus, the Euclidean distance was obtained from (7) in an ($F1$,$F2$) space (henceforth d_{suffix}) from a suffix vowel token of, for example, *boni* to suffix vowel aggregates in *bone* or in *bona* (but not in *boni*) produced by the same speaker. Following this reasoning, high/low acoustic differentiation between the suffix vowels should be manifested as high/low values on $d_{s,w,j}$ in (7). Thus, a trade-off of cues between stem and suffix *within* the individual is likely to take place when d_{stem} and d_{suffix} are inversely related.

The test of the relationship between stem vowel enhancement and suffix vowel erosion was analysed in (8) and separately for stem-/e/ and stem-/o/ vowels:

$$d_{stem} \sim d_{suffix} * \text{Region} * \text{Vowel pair} + (d_{suffix} \mid \text{Stem}) + (d_{suffix} \mid \text{Speaker}) \quad (8)$$

in which d_{stem} and d_{suffix} are Euclidean distances calculated with (7) in the (s_1,s_3) (for stem vowels) and ($F1$,$F2$) spaces (for suffix vowels) respectively, and *Vowel pair* is a fixed factor denoting contrasts between suffix vowel height levels between which distances were calculated. The levels for this factor were *High* (pooled /i, u/ suffix vowels), *Mid* (/e/-suffixes) and *Low* (/a/-suffixes). For *Vowel pair* /e, a/, for example, d_{stem} is the Euclidean distance between stem vowels preceding suffix-/e/ and suffix-/a/; and d_{suffix} the Euclidean distance between suffix vowels /e, a/. *Region*, *Stem*, and *Speaker* had the same definition as in (4) and (6).

3.2. Results

3.2.1. Suffix vowel deletion

Figure 12 shows that the extent of suffix deletion was greater in the East, least for MM, and with the West between the two. The GLMM analysis confirmed that the degree of suffix deletion was significantly influenced by both region ($F = 6.5$, $p = 0.001$) and suffix vowel type ($F = 4.2$, $p = 0.005$). The post-hoc tests showed that MM–East contrasts were significant for all stem-suffix vowel combinations ($p < .05$ in all cases, see **Table 5** for details). Conversely, contrasts between either MM and the West or the West and the East were only sporadically significant ($p < .05$ in all cases, see **Table 5** for details). Within any region, there were no significant differences in the deletion rate between any vowel pairs, except for the West, which showed a greater deletion for /i, u/ than for /a/ suffix vowels (/a – i/: $z = 3.0$, $p = 0.01$; /a – u/: $z = 2.9$, $p = 0.01$).

3.2.2. Suffix vowel centralisation

Figure 13 provides evidence across the stem-suffix vowel combinations for MM < West < East, in which '<' denotes less suffix vowel centralisation as measured by the centralisation index *c* calculated in (5). Compatibly, the results of the mixed model showed significant influences on the centralisation index of the region ($F_{2, 32.3} = 20.9$, $p < 0.001$) and of the suffix vowel ($F_{3, 3124.1} = 28.0$, $p < 0.001$). There was also a significant interaction between these two fixed factors ($F_{6, 4590.5} = 10.7$, $p < 0.001$) and between region, stem and suffix vowel ($F_{6, 4590.6} = 5.4$, $p < 0.001$).

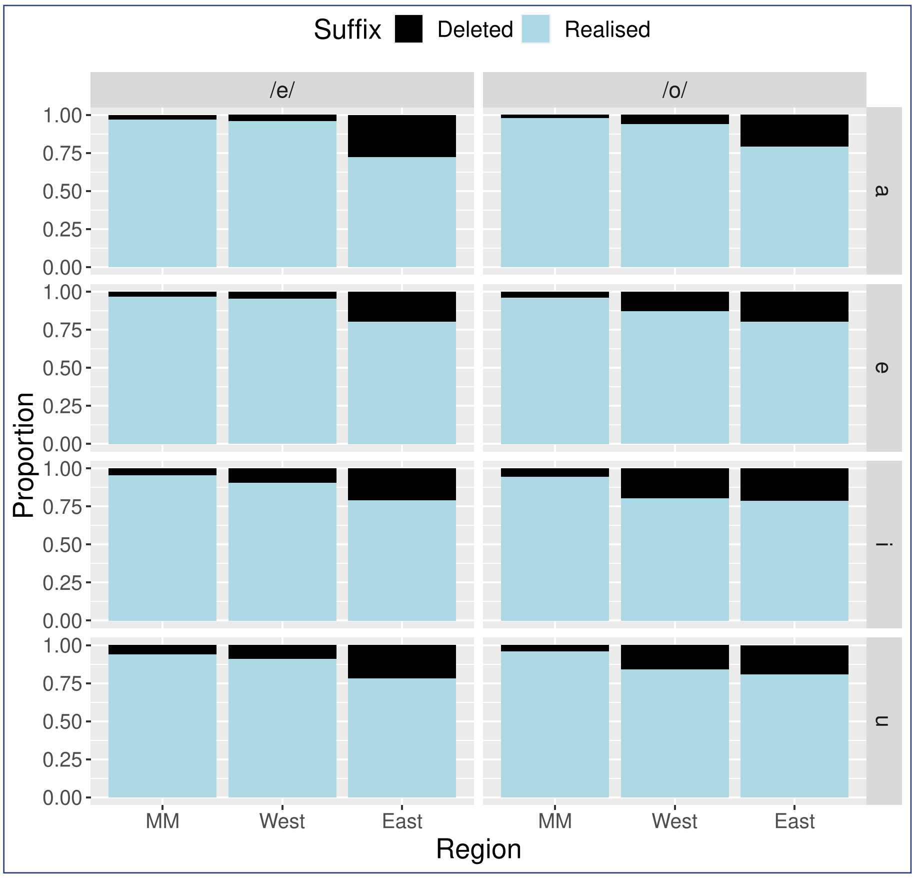

Figure 12: Proportion of deleted vs phonetically realised vowel suffixes, shown separately for the three regions, for stem vowel and for suffix vowel type.

Regions	Stem vowel	Suffix vowel	*m*	*SE*	*z*	Sig.
MM – East	/e/	/a/	3.03	0.77	3.9	***
		/e/	2.43	0.74	3.3	**
		/i/	2.19	0.71	3.1	**
		/u/	2.14	0.72	2.9	**
	/o/	/a/	2.80	0.75	3.7	***
		/e/	2.20	0.75	2.9	**
		/i/	1.96	0.71	2.7	*
		/u/	1.91	0.71	2.7	*

(Contd.)

Regions	Stem vowel	Suffix vowel	*m*	*SE*	*z*	Sig.
MM – West	/o/	/e/	1.85	0.79	2.3	*
		/i/	1.88	0.74	2.5	*
		/u/	1.91	0.75	2.6	*
West – East	/e/	/a/	2.48	0.78	3.2	**

Table 5: The estimated mean (*m*, expressed in log odds) and standard error (*SE*) of statistically significant contrasts related to the amount of suffix vowel deletion between regions, and the associated post-hoc *z*-statistics (final three columns; *** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$).

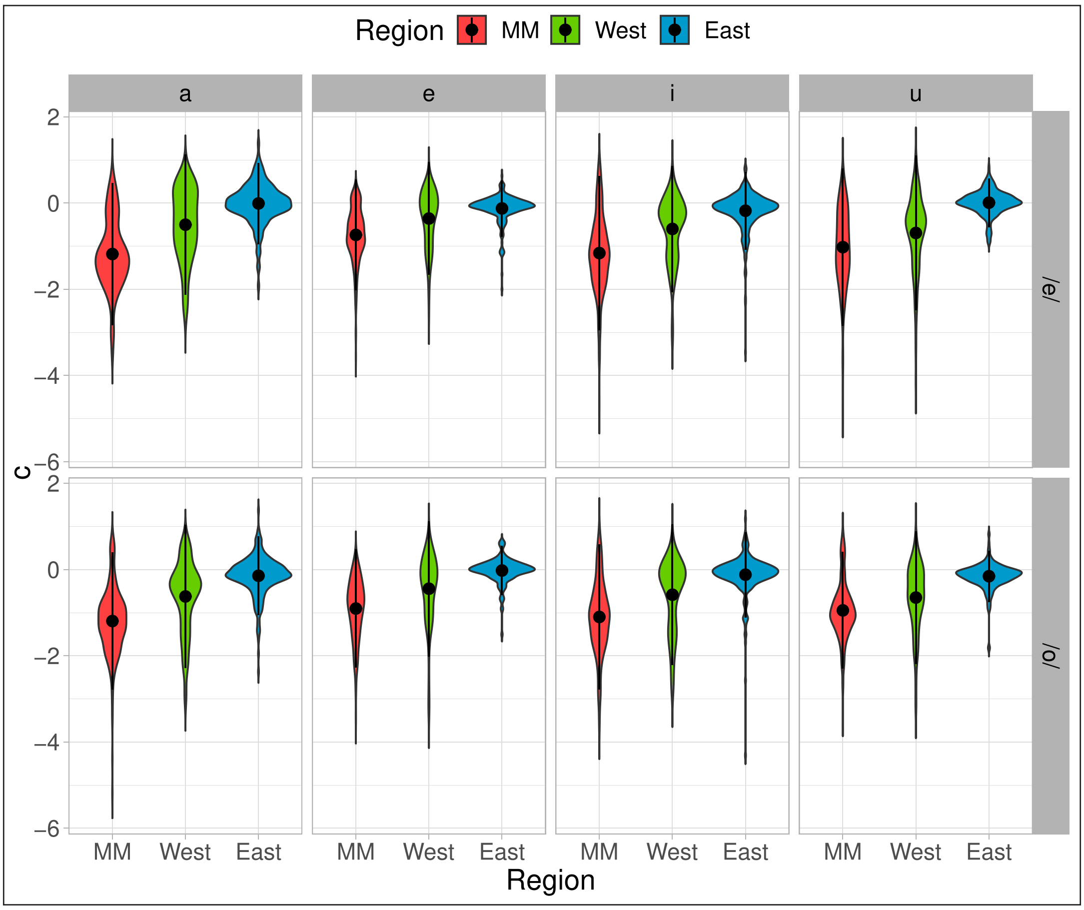

Figure 13: Centralisation index (*c*) of phonetically realised suffix vowels, shown separately for the three regions, stem vowel (rows) and suffix vowel type (columns), with the mean indicated by a black dot. Higher values are indicative of greater centralisation.

The results of the post-hoc tests showed that there was significantly greater centralisation in the suffix vowel for the East than MM for all stem-suffix vowel combinations (see **Table 6**). There was also greater suffix vowel centralisation for the West than MM for /i, a/-suffixes and for /e/-suffixes preceded by /o/-stems ($p < 0.05$ for all significant contrasts). The extent of suffix vowel centralisation was also greater for the East than the West for /i, u, a/-suffixes ($p < 0.05$ in all cases, see **Table 6** for details).

Across the three regions, suffix-/e/ was more centralised[4] than /a/ ($t_{3328} = 7.0$, $p < 0.001$), /i/ ($t_{3764} = 8.5$, $p < 0.001$) and /u/ suffixes ($t_{2573} = 7.0$, $p < 0.001$).

Regions	**Stem vowel**	**Suffix vowel**	***m***	***SE***	***df***	***t***	**Sig.**
MM – East	/e/	/a/	–1.10	0.15	44.4	–7.4	***
		/e/	–0.54	0.15	40.4	–3.7	**
		/i/	–0.93	0.14	37.9	–6.5	***
		/u/	–1.03	0.14	39.0	–7.1	***
	/o/	/a/	–0.98	0.14	39.3	–6.8	***
		/e/	–0.82	0.15	45.8	–5.4	***
		/i/	–0.92	0.14	40.5	–6.3	***
		/u/	–0.72	0.14	38.0	–5.0	***
MM – West	/e/	/a/	–0.59	0.16	47.3	–3.6	**
		/i/	–0.52	0.16	40.5	–3.3	**
	/o/	/a/	–0.51	0.16	42.7	–3.2	**
		/e/	–0.44	0.17	51.0	–2.6	*
		/i/	–0.45	0.16	45.6	–2.8	*

(Contd.)

[4] That a vowel like /e/ tends to be more reduced than other vowels in an unstressed position is, however, cross-linguistically common (see e.g. Delforge, 2008) due to its articulatory proximity to the vowel sound [ə].

Regions	Stem vowel	Suffix vowel	*m*	*SE*	*df*	*t*	Sig.
West – East	/e/	/a/	–0.52	0.16	50.1	–3.3	**
		/i/	–0.41	0.15	42.0	–2.7	*
		/u/	–0.75	0.15	45.0	–4.9	***
	/o/	/a/	–0.47	0.15	44.2	–3.1	**
		/i/	–0.47	0.16	47.1	–3.0	*
		/u/	–0.52	0.15	43.6	–3.4	**

Table 6: The estimated mean (*m*) and standard error (*SE*) of statistically significant contrasts between regions for the suffix centralisation index *c*, and the associated post-hoc *t*-statistics (final three columns; *** $p \leq .001$; ** $p \leq .01$; * $p \leq .05$).

3.2.3. Relationship between metaphony and suffix erosion

The concern here is to consider whether there was a predictable relationship between suffix erosion and the degree of a suffix's influence on the stem vowel using (7) as described in Section 3.1.3.

Figure 14 shows that the distance between vowel stems in the (s_1,s_3) space was progressively greater under the influence of different suffix vowel contexts. Consistently with Section 2.2.2, this shows therefore that the acoustic information about the suffix in the stem was increasingly stronger from MM to the West to the East. **Figure 14**, lower row, also shows a progressive decrease in acoustic distance in the (*F*1,*F*2) space between different suffix vowel types: That is, consistently with 3.2.2, the suffix vowels were increasingly centralised from MM to the West to the East. The test of whether these two parameters were correlated using model (8) showed a non-significant influence of d_{suffix} (**Figure 14**, lower row) on d_{stem} (**Figure 14**, upper row) for both stem-/e/ and stem-/o/: That is, there was no significant correlation between the two parameters. The output of (8) additionally showed a significant interaction between d_{suffix}, *Region* and *Vowel Pair* ($F_{4,\ 800.6} = 4.1, p < 0.01$) for stem-/e/, and a not quite significant interaction on these same variables for stem-/o/ ($F_{4,\ 1368.9} = 2.0, p = 0.09$).

The post-hoc tests showed a significant association between d_{stem} and d_{suffix} only for the MM region and only for distances between stems in the context of suffix vowels /i, e/. However, the association (**Figure 15**) between d_{stem} and d_{suffix} for both the stem/e/ and stem-/o/ data was significantly *positive*. This means that, for MM speakers, a phonetically greater difference between the suffix vowels is associated with a greater difference in the stem (i.e. there is an anticipatory coarticulatory influence of the suffix on the stem vowel). Other than this, the suffix

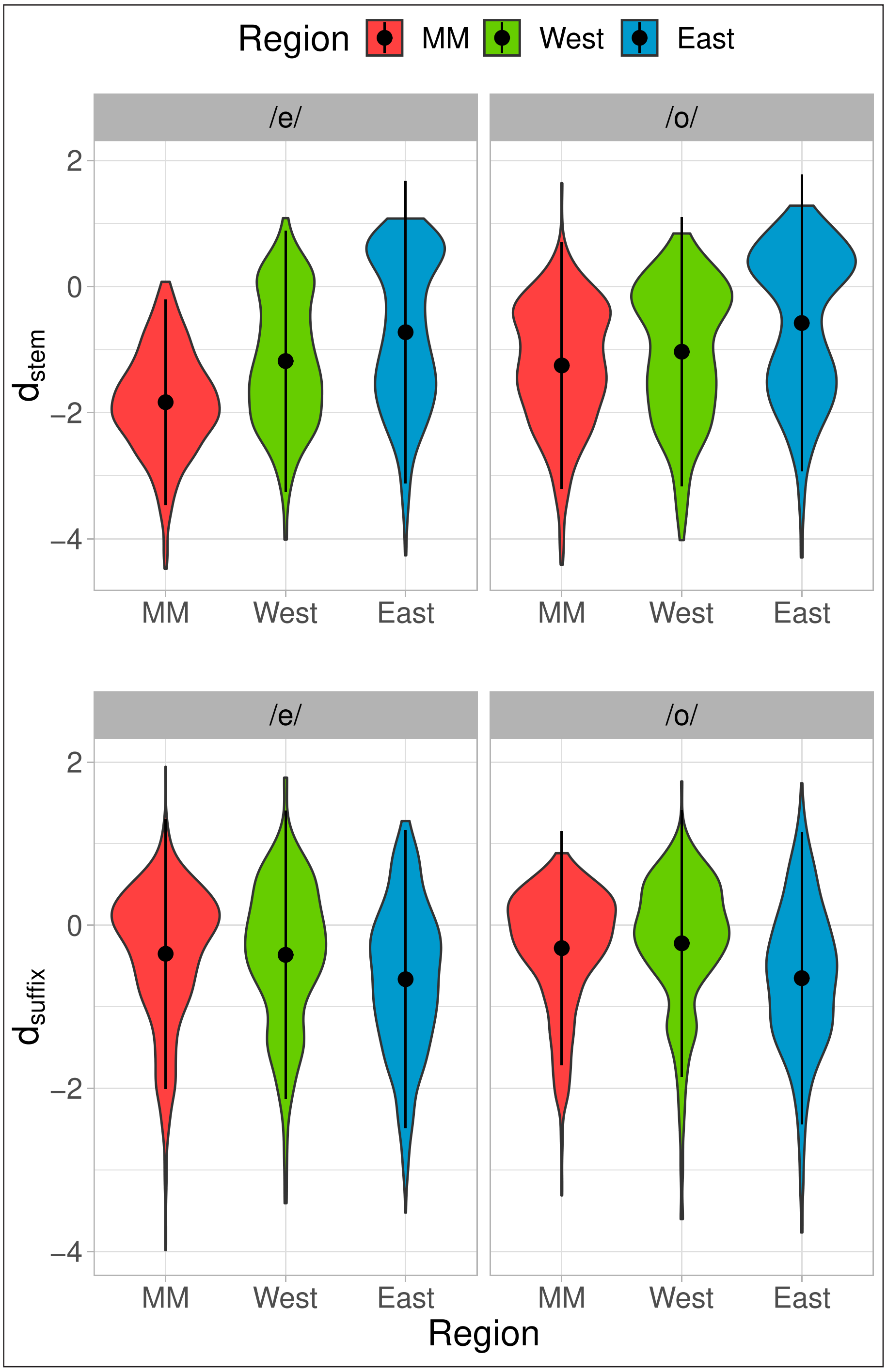

Figure 14: Euclidean distances obtained with (7) between stem vowels in the context of different suffix pairs (d_{stem}, upper row), and between suffixes (d_{suffix}, lower row), shown separately by stem vowel and region. The mean is indicated by a black dot. In both cases, higher values indicate greater distances.

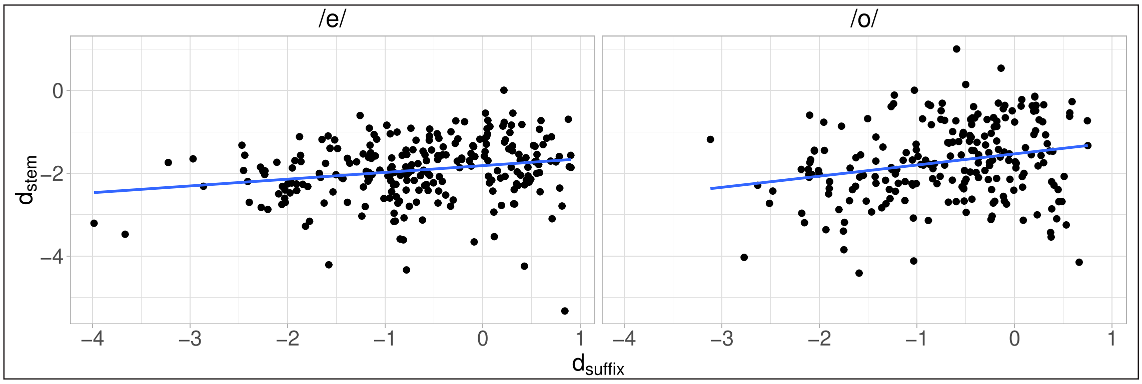

Figure 15: Euclidean distances obtained with (7) for MM between /e/-stem vowels (left) and between /o/-stem vowels (right) in the context of suffix pairs /i, e/, including regression line between d_{stem} (*y*-axis) and d_{suffix} (*x*-axis), and relative confidence interval. Higher values indicate greater distances.

had no significant influence on the stem within any of the three regions. Taken together, these results show that, within any region, it was not the case that speakers who produced more stem vowel raising/diphthongisation also produced more suffix centralisation.

4. General discussion

The focus of the present study has been on the cues available in mid stem vowels to morphological, inflectional suffixes in the Italo-Romance varieties of the Lausberg area, and whether such cues are predictably related to the phonetic erosion (centralisation, deletion) of the suffix. The present results are consistent with other analyses that stem vowel metaphony and suffix vowel reduction are connected in various Italo-Romance languages (Bucci et al., 2019; Delucchi et al., 2012; Lausberg, 1939; Rohlfs, 1966; Romano, 2020; Russo & Barry, 2004).

In the first part of the study, the influence of the suffix vowel on the stem was analysed using a data-driven technique that parameterised the stem's time-varying shape of the first two formants together. Compatibly with earlier auditory analyses for the Lausberg area (Conte, 2014; Lausberg, 1939; Rensch, 1964; Trumper, 1997), the results showed the presence of cues in the stem vowel principally to suffix vowel height, and to a lesser extent to suffix vowel fronting. These cues were evident in all three regions examined but to different strengths: Most prominent in the 'Mittelzone' region on the east coast, least prominent in the inland village of Mormanno, and intermediate between the two in three villages analysed on the west coast. In both MM and the East, the stem vowels in which suffix vowels were cued to different strengths were monophthongal. In the West by contrast, the trajectories were diphthongal. The second part of the study showed an inverse relationship between presence of the cues to the suffix vowel in the stem and suffix vowel erosion: That is, the degree of erosion was greatest in the East, least in MM, and intermediate in the West.

The findings in this study are consistent with others demonstrating a trade-off between coarticulatory source and effect in sound changes in the course of phonologisation (Carignan et al., 2021; Kuang & Cui, 2018), such as the development of contrastive nasalisation (Beddor, 2009; Beddor et al., 2018) and tonogenesis (Beckman, Li, Kong & Edwards, 2014; Hombert et al., 1979; Kang, 2014; Kirby, 2014). This type of trade-off may be especially likely in southern Italian varieties in which the reduction of unstressed, word-final vowels is very common (Russo & Barry, 2004). On the other hand, some rare counterexamples of absence of cue-trading between stem and suffix vowel in metaphony have been reported in auditory studies (Calabrese, 1988; Gaglia, 2011). Further acoustic analyses on these and other varieties presenting metaphony would be needed in order to confirm whether a trade-off between stem and suffix vowel actually takes place in all (or most) Romance metaphony types.

Although the trade-off between stem and suffix vowel was demonstrated between the regions of the Lausberg area, there was no evidence for a trade-off of this kind within any of the three regions. Thus, within any region, it was not the case that individuals who centralised suffixes also tended to augment their stem vowels with cues to the suffix vowel: In an individual's speech production, there was just no observable trade-off connection between the two sets of cues. This, in turn, suggests that the trade-off is not situated within the cognitive mechanism that converts words and their phonological code into an acoustic signal in speech production. The trade-off could instead be acquired by mobile individuals who have been exposed to talkers from all these regions, following ideas from exemplar theories (Johnson, 1997; Pierrehumbert, 2003, 2006) that experienced speech signals are stored in memory. For such individuals, the trade-off would then form part of their knowledge about the differences between these three varieties that need not carry over into their own speech production. A further investigation comparing mobile and non-mobile individuals in the Lausberg area would, however, be necessary to substantiate this view.

This conclusion about the cognitive location of the trade-off is broadly the same as the one suggested by Cronenberg et al. (2020) in their analysis of a sound change in progress by which pre-aspiration is evolving into post-aspiration in underlying /sC/ clusters in Andalusian Spanish. The study by Cronenberg et al. (2020) supported the idea from Parrell (2012) that a trade-off exists between these cues depending on whether a glottal closure was timed late (leading to pre-aspiration) or early (leading to post-aspiration) during a voiceless interval. However, the trade-off was only found to exist through a comparison between different groups of speakers (young vs old; East vs West Andalusian). Just as in the present study, there was no evidence within any of these groups of within any individual that pre- and post-aspiration were connected through a trade-off.

Compatibly with suggestions in the Italo-Romance literature (Maiden, 1991; Krämer, 2009, p. 123; Torres-Tamarit & Linke, 2016), the present study finds evidence of phonetic enhancement (Barzilai & Riestenberg, 2021; Hall, 2011; Keyser & Stevens, 2006), which comes about when a non-contrastive phonetic cue is magnified: In this case, the enhancement is that the effect of the suffix vowel on the stem is much greater than would be predicted by anticipatory vowel coarticulation alone. Enhancement has been variously documented for sound changes (Cohn, 2007; Garrett & Johnson, 2013; Hyman, 2013; Kiparsky, 2016; Kirby, 2013): For instance, the differences in vowel length as a cue to a post-vocalic stop voicing contrast (e.g. English *feet*, *feed*) are much greater than would be expected from purely coarticulation-based adjustments to vowel length induced by the following stop closure (Solé, 2007). The stem vowels in the Eastern region show enhancement, given that the influence of phonetic height is well beyond that of MM, as the reconstructed formant trajectories (**Figures 7, 10**) show. The stem diphthongisation in the West is also a form of enhancement, because there was more information about the suffix in the West's stems than for MM.

Enhancement could be caused by the loss of other available cues to a contrast. In a computational simulation of tonogenesis and /r/-loss in the Phnom Penh dialect of Khmer, Kirby (2014) demonstrated how F0 and the difference between the first two harmonics for distinguishing between /ku, kru/ were enhanced as a third cue, the duration of /r/, reduced to zero. In the present study, the loss of information in the suffix vowel is associated with enhancement of cues in the stem. Neither study relies on a separate, independent mechanism of enhancement. This is because enhancement in Kirby (2014) is a by-product of cue loss and in the present study of cue attenuation and loss via a trade-off, according to which weaker cues in the suffix imply stronger cues in the stem.

The final issue to be considered is whether the stem vowel enhancements and suffix erosion in the three regions are representative of different stages in the progression of the same sound change. The evidence of a progressively greater trade-off between these two sets of cues from MM to the West to the East suggests that this is so. Some prior auditorily based analyses are compatible with this view (see e.g. Barbato, 2008; Lausberg, 1947; Lüdtke, 1956). For example, both Lausberg (1939) and Trumper (1997) note that regions in the south of the Mittelzone and in the villages of Cerchiara and Rocca Imperiale near the east coast of the Lausberg area, had the types of diphthongs found in the West that then became monophthongised resulting in a long, raised monophthong characteristic of the East.

At the same time, any conclusion that these are necessarily chronologically successive changes – meaning that the East's raising developed historically out of diphthongisation as in the West which developed historically out of MM raising – must be treated with caution. Firstly, there is, apart from the auditory analyses noted above, little (acoustic or historical) evidence from prior studies of the Lausberg area for such a chronological progression. Secondly, in an exemplar-type, memory-based model in which the association between phonological categories and speech signals is a stochastic generalisation across remembered speech signals (Johnson, 1997; Johnson, 2006; Pierrehumbert, 2003, 2006), phonologisation-type sound changes are themselves likely to be stochastic. This means that the type of phonetic variation that comes to be phonologised may well differ across varieties. Consider in the light of this the variable nature of anticipatory V_1CV_2 coarticulation. In some cases, VCV coarticulation has been found to extend leftwards not much beyond the temporal midpoint of V_1 (Beddor, Harnsberger & Lindemann, 2002, in an analysis of English and Shona) or of the intervening consonant (Alfonso & Baer, 1982). Other researchers report instead that coarticulation may extend up to the onset of V_1 (Magen, 1997; Rubertus & Noiray, 2018; Whalen, 1990) or may even be more extensive in first than in the second half of V_1, if coarticulation is attenuated or 'clamped' (Fowler & Brancazio, 2000) by the intervening consonant (Fowler, 2005; Recasens, 1984, 2002). Coarticulation is also highly variable (Cole et al., 2010) between speakers (Magen, 1997; van den Heuvel, Cranen & Rietveld, 1996) and languages (Beddor et al., 2002; Manuel, 1990), and affected by speaking style (Krull, 1989). For some speakers, coarticulation can be quite extensive and extend several syllables leftwards well beyond even the VCV sequence (Grosvald, 2009). A variety might therefore phonologise (and then enhance as described above) different types of anticipatory VCV variation. For example, if the 'clamping' type of VCV coarticulation is phonologised, then the outcome is likely to be diphthongisation of the kind observed in the West. The MM and the East regions might differ because they happen to have developed (and possibly fully phonologised, especially in the East's case) anticipatory VCV coarticulation of different strengths. The general point is that varieties certainly can differ in the degree to which a sound change has advanced, as others (e.g. Ramsammy, 2015) have observed. The three varieties analysed here provide evidence that this is so. But it does not necessarily follow from this that the variety that is the exponent of the most advanced sound change (East) has progressed chronologically through all the earlier stages of the sound change that might be found in other varieties (MM, West).

In conclusion, the results of this study show that the three varieties are characterised by the same sound change in which there is a trade-off between cues to the suffix vowel in the stem and suffix erosion that has progressed to different degrees. That is, the varieties differ in the strength of the trade-off, being greatest for the East, intermediate for the West, and least for MM. The changes to the stem are a form of enhancement that are brought about by suffix reduction, based on a model in which a trade-off links both sets of cues. The present study suggests that the trade-off in the Lausberg area may be represented cognitively as a consequence of storing and possibly compartmentalising remembered speech signals sampled across the three varieties. Establishing how this the cognitive knowledge of the differences and similarities between the varieties is related to the mechanisms in processing speech production and perception will, however, require further investigation.

Additional files

The data and scripts used for this study can be accessed here: https://doi.org/10.5282/ubm/data.422.

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Competing interests

The authors have no competing interests to declare.

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Appendices

A. Speakers: Sociolinguistic metadata

The first two letters of the speakers' code in **Table 7** refer to the village: CA = Canna, CC = Cerchiara, LI = Laino Borgo / Laino Castello, MG = Montegiordano, MM = Mormanno, SD = S. Domenica Talao, SC = Scalea. The column "Region" refers to the three main village groups examined: MM = Mormanno, East = Mittelzone, West = Zwischenzone. The column "Age" indicates the biological age of each speaker when recorded. The column "Education" refers to the highest level of education attained: 1 = elementary school, 2 = middle school (in Italy "scuola media"), 3 = high school ("maturità"), 4 = university.

Speaker	Region	Age	Education
CA01F	East	44	2
CC01F	East	65	4
CC01M	East	27	3
CC02F	East	13	1
CC02M	East	47	3
CC03F	East	44	3
CC03M	East	46	3
CC04F	East	51	2
CC05F	East	81	2
CC06F	East	14	2
CC07F	East	19	2
CC08F	East	44	3
LI01M	West	82	1
LI02M	West	80	1

(Contd.)

Speaker	Region	Age	Education
LI03M	West	90	1
LI04M	West	92	1
LI05M	West	67	3
LI06M	West	85	1
MG01M	East	45	4
MG02M	East	67	3
MM02F	MM	25	4
MM03F	MM	28	4
MM03M	MM	26	4
MM04F	MM	26	4
MM04M	MM	25	3
MM05F	MM	25	4
MM05M	MM	22	3
MM06F	MM	72	4
MM07F	MM	47	4
MM07M	MM	81	1
MM09M	MM	73	2
SC01F	West	44	3
SC01M	West	40	4
SC02F	West	47	3
SD01F	West	27	4

Table 7: The recorded speakers: codes, age, regions, and education level.

B. Data elicitation: examples of visual stimuli

Figures 16, **17**, and **18** show some examples of the visual stimuli used for the picture-naming task used to elicit the lexical items listed in Appendices C and D.

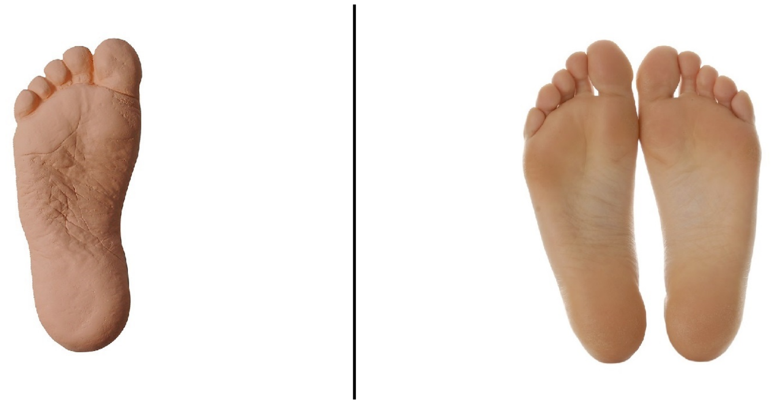

Figure 16: Picture stimulus used to elicit the word 'foot' in its singular form (/ˈpede/), on the left, vs picture stimulus to elicit the plural 'feet' (/ˈpedi/), on the right.

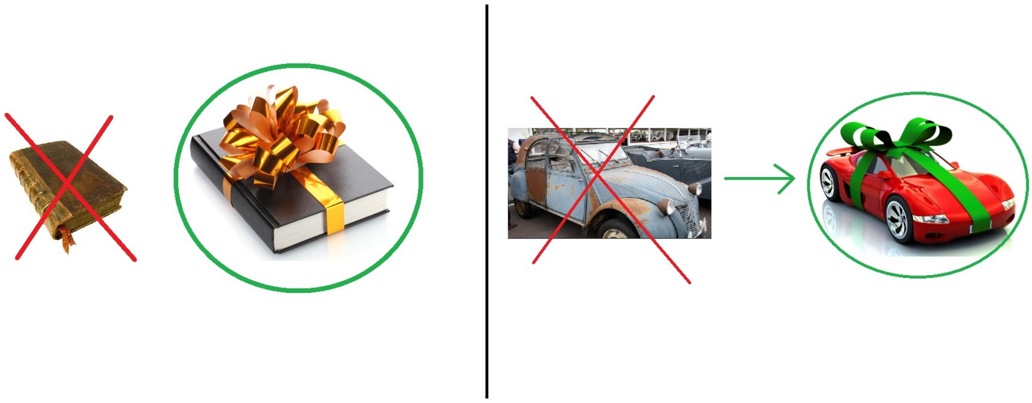

Figure 17: Picture stimulus used to elicit the word 'new', masc. sg. (/ˈnovu/), on the left, vs picture stimulus to elicit the word 'new', fem. sg. (/ˈnova/), on the right.

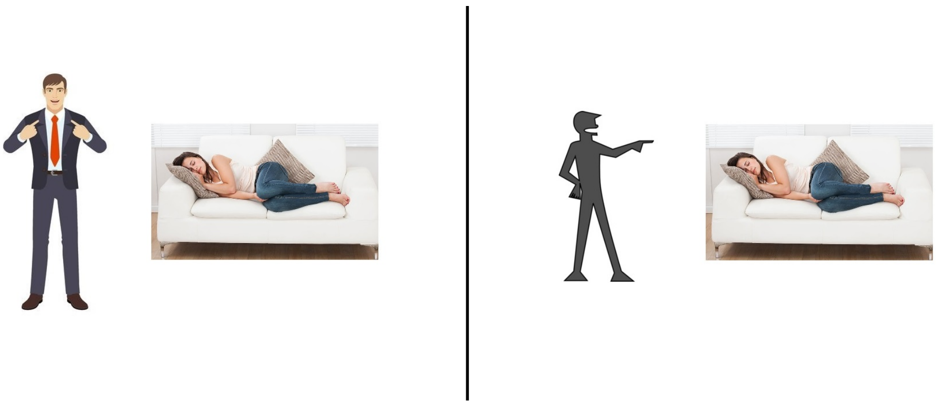

Figure 18: Picture stimulus used to elicit the word '(I) sleep', 1st pers. sg. (/ˈdormu/), on the left, vs picture stimulus used to elicit the word '(he/she) thinks', 3rd pers. sg. (/ˈdorme/), on the right.

C. Lexical items analysed

The first column of **Table 8** lists in alphabetical order the lexical items used for analysis in Standard Italian. The words' transcription indicated in the second column is a phonemic reconstruction of the dialect target form and does not take into account possible phonetic realisations. In disyllabic words, the stressed syllable is always the first one, while in other cases the stress is marked. The third column provides a translation of each item into English.

Target word	Target phonemic form	Meaning
anelli	aˈnelli	rings (masc. pl.)
anello	aˈnellu	ring (masc. sg.)
bella	bella	beautiful (fem. sg.)
bello	bellu	beautiful (masc. sg.)
buona	bona	good (fem. sg.)
buone	bone	good (fem. pl.)
buoni	boni	good (masc. pl.)
buono	bonu	good (masc. sg.)
capelli	kaˈpelli	hair (fem. pl.)
capello	kaˈpellu	hair (masc. sg.)
cappelli	kapˈpelli	hats (masc. pl.)
cappello	kapˈpellu	hat (masc. sg.)
capretta	kraˈpetta	kid (goat) (fem. sg.)
capretti	kraˈpetti	kids (goat) (masc. pl.)
capretto	kraˈpettu	kid (goat) (masc. sg.)
cervelli	tʃerˈvelli	brains (masc. pl.)
cervello	tʃerˈvellu	brain (masc. sg.)
coltelli	kurˈtelli	knifes (masc. pl.)
coltello	kurˈtellu	knife (masc. sg.)
corna	korna	horns (fem. pl.)
corno	kornu	horn (masc. sg.)
cotta	kotta	cooked (fem. sg.)
cotto	kottu	cooked (masc. sg.)

(Contd.)

Target word	Target phonemic form	Meaning
cuore	kore	heart (masc. sg.)
cuori	kori	hearts (masc. pl.)
dente	dente	tooth (masc. sg.)
denti	denti	teeth (masc. pl.)
donna	ˈfemmina	woman (fem. sg.)
donne	ˈfemmine	women (fem. pl.)
dorme	dorme	(he/she) sleeps
dormi	ˈdormisi	(you) sleep
dormo	dormu	(I) sleep
esce	esse	(he/she) goes out
esci	ˈessisi	(you) go out
esco	esku	(I) go out
ferri	ferri	irons (masc. pl.)
ferro	ferru	iron (masc. sg.)
foglia	foλλa	leaf (fem. sg.)
foglie	foλλe	leaves (fem. pl.)
fuochi	foki	fires (masc. pl.)
fuoco	foku	fire (masc. sg.)
grossa	grossa	big (fem. sg.)
grosso	grossu	big (masc. sg.)
letti	letti	beds (masc. pl.)
letto	lettu	bed (masc. sg.)
lunga	longa	long (fem. sg.)
lungo	longu	long (masc. sg.)
mela	mela	apple (fem. sg.)
mele	mele	apples (fem. pl.)
mese	mese	month (masc. sg.)
mesi	mesi	months (masc. pl.)
morta	morta	dead (fem. sg.)

(Contd.)

Target word	Target phonemic form	Meaning
morti	morti	dead (masc. pl.)
morto	mortu	dead (masc. sg.)
muoio	moru	(I) die
muori	ˈmorisi	(you) die
nipote	niˈpote	grandchild (masc. sg.)
nipoti	niˈpoti	grandchildren (masc. pl.)
nuova	nova	new (fem. sg.)
nuovo	novu	new (masc. sg.)
occhi	okki	eyes (masc. pl.)
occhio	okkju	eye (masc. sg.)
ossa	ossa	bones (fem. pl.)
osso	ossu	bone (masc. sg.)
pecora	ˈpekura	sheep (fem. sg.)
pecore	ˈpekure	sheep (fem. pl.)
pensa	pensa	(he/she) thinks
pensi	ˈpensasi	(you) think
penso	pensu	(I) think
pesca	peska	peach (fem. sg.)
pesche	peske	peaches (fem. pl.)
pettine	ˈpettine	comb (masc. sg.)
pettini	ˈpettini	combs (masc. pl.)
pezza	pettsa	piece of cloth (fem. sg.)
pezzo	pettsu	piece (generic) (masc. sg.)
piede	pede	foot (masc. sg.)
piedi	pedi	feet (masc. pl.)
pietra	petra	stone (fem. sg.)
pietre	petre	stones (fem. pl.)
ponte	ponte	bridge (masc. sg.)
ponti	ponti	bridges (masc. pl.)

(Contd.)

Target word	Target phonemic form	Meaning
porci/maiali	portʃi	pigs (masc. pl.)
porco/maiale	porku	pig (masc. sg.)
prete	ˈprevite	priest (masc. sg.)
preti	ˈpreviti	priests (masc. pl.)
rosa	rosa	rose (fem. sg.)
rose	rose	roses (fem. pl.)
ruota	rota	wheel (fem. sg.)
ruote	rote	wheels (fem. pl.)
sedia	seddʒa	chair (fem. sg.)
sedie	seddʒe	chairs (fem. pl.)
sole	sole	sun (masc. sg.)
sposa	sposa	bride (fem. sg.)
sposo	sposu	groom (masc. sg.)
stella	stella	star (fem. sg.)
stelle	stelle	stars (fem. pl.)
tengo	tengu	(I) have
tiene	tene	(he/she) has
tieni	ˈtenisi	(you) have
topi	ˈsoritʃi	mice (masc. pl.)
topo	ˈsoritʃe	mouse (masc. sg.)
trova	trova	(he/she) finds
trovi	ˈtrovasi	(you) find
trovo	trovu	(I) find
uomini	ˈommini	men (masc. pl.)
uomo	ˈommine	man (masc. sg.)
uova	ova	eggs (fem. pl.)
uovo	ovu	egg (masc. sg.)
vecchia	vekkja	old woman (fem. sg.)
vecchio	vekkju	old man (masc. sg.)
venti	venti	winds (masc. pl.)

(Contd.)

Target word	Target phonemic form	Meaning
vento	ventu	wind (masc. sg.)
verme	verme	worm (masc. sg.)
vermi	vermi	worms (masc. pl.)
voglio	voλλu	(I) want
vuoi	voi	(you) want
zoppa	tsoppa	lame woman (fem. sg.)
zoppo	tsoppu	lame man (masc. sg.)

Table 8: List of lexical items containing /e, o/ vowel stems, in alphabetical order.

D. Lexical items used for the Lobanov normalisation

The first column of **Table 9** lists in alphabetical order the lexical items used for analysis in Standard Italian. The words' transcription indicated in the second column is a phonemic reconstruction of the dialect target form and does not take into account possible phonetic realisations. In disyllabic words, the stressed syllable is always the first one, while in other cases the stress is marked. The third column provides a translation of each item into English.

Target word	Target phonemic form	Meaning
aghi	agi	needles (masc. pl.)
ago	agu	needle (masc. sg.)
apre	apre	(he/she) opens
apri	ˈaprisi	(you) open
apro	apru	(I) open
beve	vive	(he/she) drinks
bevi	ˈvivisi	(you) drink
bevo	vivu	(I) drink
braccia	vrattsa	arms (fem. pl.)
braccio	vrattsu	arm (masc. sg.)
cane	kane	dog (masc. sg.)
cani	kani	dogs (masc. pl.)
casa	kasa	house (fem. sg.)
case	kase	house (fem. pl.)

(Contd.)

Target word	Target phonemic form	Meaning
cenere	ˈtʃinnira	ash (fem. sg.)
corre	kurre	(he/she) runs
corri	ˈkurrisi	(you) run
corro	kurru	(I) run
corta	kurta	short (fem. sg.)
corti	kurti	short (masc. pl.)
corto	kurtu	short (masc. sg.)
croce	krutʃe	cross (masc. sg.)
croci	krutʃi	crosses (masc. pl.)
dita	ˈjidita	fingers (fem. pl.)
dito	ˈjiditu	finger (masc. sg.)
dolce	durtʃe	sweet (masc. sg.)
dolci	durtʃi	sweets (masc. pl.)
forni	furni	ovens (masc. pl.)
forno	furnu	oven (masc. sg.)
fredda	fridda	cold (fem. sg.)
freddi	friddi	cold (masc. pl.)
freddo	friddu	cold (masc. sg.)
fumo	fumu	smoke (masc. sg.)
galli	galli	roosters (masc. pl.)
gallo	gallu	rooster (masc. sg.)
gatti	gatti	cats (masc. pl.)
gatto	gattu	cat (masc. sg.)
ginocchia	jiˈnukkja	knees (fem. pl.)
ginocchio	jiˈnukkju	knee (masc. sg.)
giorni	jurni	days (masc. pl.)
giorno	jurnu	day (masc. sg.)
ladri	latru	thief (masc. sg.)
ladro	latri	thieves (masc. pl.)
latte	latte	milk (masc. sg.)

(Contd.)

Target word	Target phonemic form	Meaning
legna	liɲɲa	wood (fem. sg.)
legno	liɲɲu	piece of wood (masc. sg.)
luce	lutʃe	light (fem. sg.)
luna	luna	moon (fem. sg.)
mani	manu	hands (fem. pl.)
mano	manu	hand (fem. sg.)
mare	mare	sea (masc. sg.)
nera	ˈnivura	black (fem. sg.)
neri	ˈnivuri	black (masc. pl.)
nero	ˈnivuru	black (masc. sg.)
noce	nutʃe	walnut (fem. sg.)
noci	nutʃi	walnuts (fem. pl.)
pasta	pasta	pasta (fem. sg.)
peli	pili	body hair (masc. pl.)
pelo	pilu	body hair (masc. sg.)
pesce	piʃʃu	fish (masc. sg.)
pesci	piʃʃi	fish; fishes (masc. pl.)
rossa	russa	red (fem. sg.)
rosso	russu	red (masc. sg.)
santa	santa	saint (fem. sg.)
santi	santi	saint (masc. pl.)
santo	santu	saint (masc. sg.)
unghia	uɲɟa	nail (fem. sg.)
unghie	uɲɟe	nails (fem. pl.)
uva	uva	grapes (fem. sg.)
vacca	vakka	cow (fem. sg.)
vacche	vakke	cows (fem. pl.)
vedi	ˈvidisi	(you) see
vedo	vidu	(I) see
verde	virde	green (masc. sg.)

(Contd.)

Target word	Target phonemic form	Meaning
verdi	virdi	green (masc. pl.)
volpe	vurpe	fox (fem. sg.)
volpi	vurpi	foxes (fem. pl.)

Table 9: List of lexical items containing /i, a, u/ stem vowels (which were not further analysed in this paper), in alphabetical order.

E. Spectrogram examples of metaphonic raising and diphthongisation

The following two figures show spectrograms with superimposed F1 an F2 indicating progressively greater raising for a stem-/e/ vowel (**Figure 19**) and for a stem-/o/ vowel (**Figure 20**) across the three regions analysed in this study. The spectrograms of the changing F2 between onset and offset also show diphthongisation in the West.

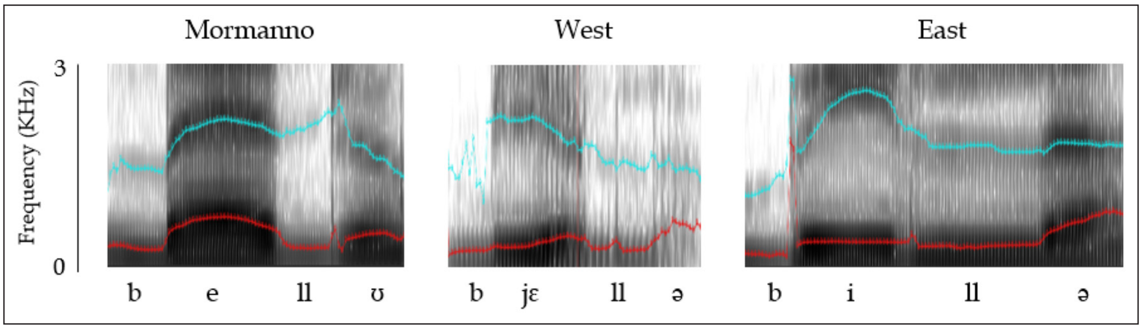

Figure 19: Annotated spectrograms of three productions of /bellu/ ('beautiful', masc. sg.) by a speaker from Mormanno (left), the West (mid), and the East (right). F1 and F2 are highlighted in red and blue respectively.

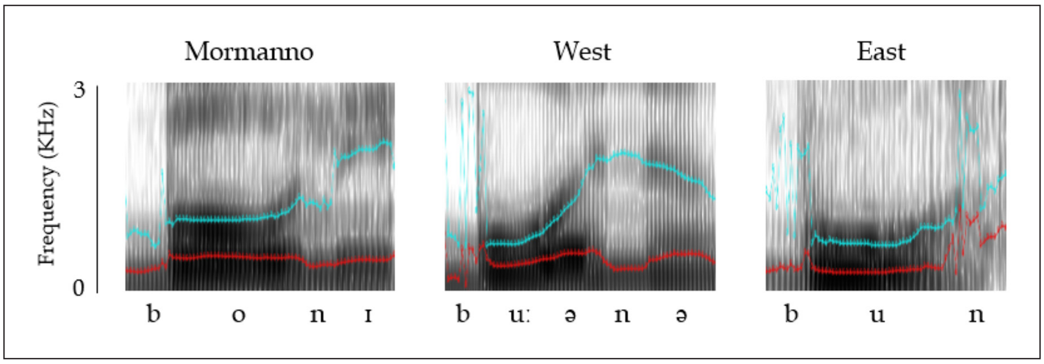

Figure 20: Annotated spectrograms of three productions of /bonu/ ('good', masc. sg.) by a speaker from Mormanno (left), the West (mid), and the East (right). F1 and F2 are highlighted in red and blue respectively.

F. Comparison between high and metaphonically raised vowels in the East

Figure 21 shows that, for the Eastern region ('Mittelzone'), in which the suffix vowel influence was the greatest, raised (metaphonic) /e/ (as in e.g. [bill] for /bellu/, 'beautiful', masc. sg.) has formant positions similar or even more extreme (i.e. indicating an even more peripheral vowel) than those in lexical /i/ (as in e.g. /linnu/, 'piece of wood'). Similarly, the metaphonically raised /o/ stems (as in e.g. [ussu] for /ossu/, 'bone') have overall formant positions that are similar to and much closer to lexical /u/ (as in e.g. /nutʃe/, 'walnut') than to corresponding non-metaphonic forms (as in e.g. /ossa/, 'bones').

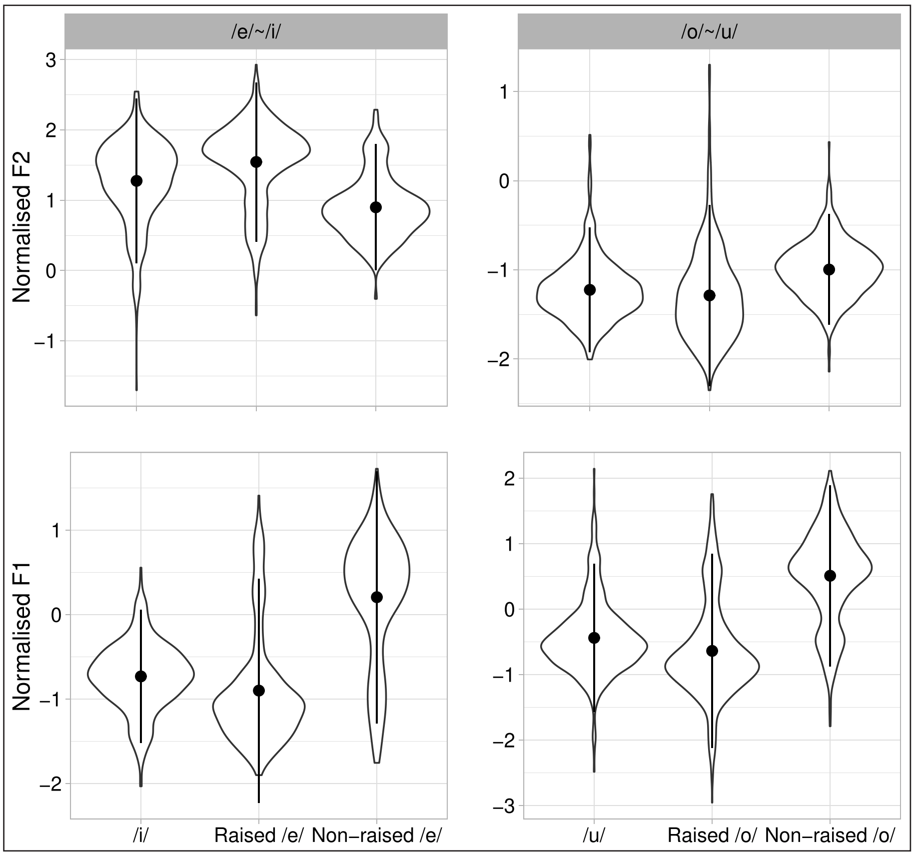

Figure 21: Normalised F1 (below) and F2 (above) for the East in lexical /i/ and /u/ and in raised (i.e. metaphonic) and non-raised mid vowels. Lobanov-normalised higher/lower F1 values correspond to increasing vowel lowering/raising, while normalised higher/lower F2 values indicate increasing vowel fronting/retraction. Formant values refer to the vowels' temporal midpoint.

G. Absence of relationship between stem vowel duration and suffix vowel duration

In this study, the relationship between metaphony and suffix erosion was analysed mainly in terms of changes in vowel quality. Nevertheless, in some sound changes a durational trade-off between source and effect has also been observed (see e.g. Beddor, 2009; Hualde, 1990). In the case of metaphony and associated suffix vowel erosion, a compensatory lengthening of the stem vowel as the suffix is eroded could potentially co-exist with the acoustic trade-off observed in the data. For instance, Beddor (2009) observed for American English that more extensively nasalised vowels co-occur with shorter nasal consonants. However, it has also been shown that greater nasalisation is not necessarily accompanied by greater vowel lengthening, given that the vowel and nasal gestures increasingly overlap in time as acoustic nasalisation increases (see also Carignan et al., 2021). **Figure 22** below shows stem and suffix vowel durations (in milliseconds) in the data analysed in this study (for those words with no suffix deletion), separately by region and suffix vowel. If suffix vowel loss were compensated by stem vowel lengthening, then the Eastern region with its high degree of reduction in suffix vowel quality and duration should have greater stem vowel duration than regions such as Mormanno: But as **Figure 22** shows, this is evidently not the case.

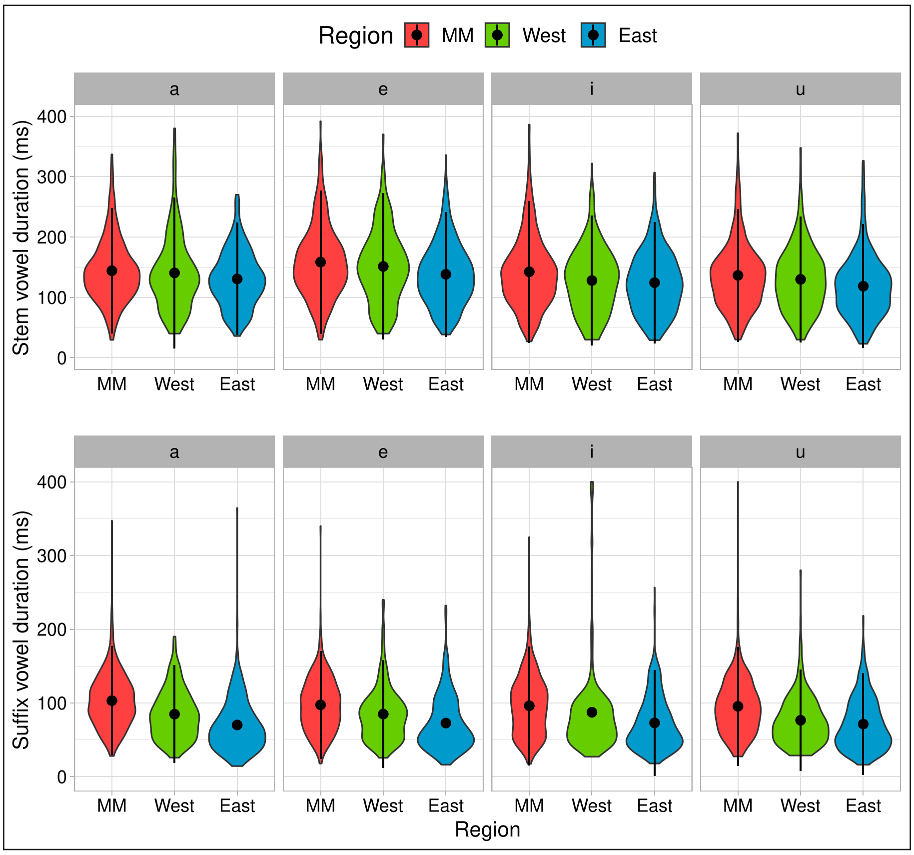

Figure 22: Stem (upper panels) and suffix (lower panels) vowel duration compared by region and suffix vowel.