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AGENT-BASED MODELING OF DIALECT CHANGE AND STABILITY IN GHEG ALBANIAN

1. Introduction

The work of Prof. Bardhyl Demiraj within Albanology has been wide ranging, far reaching, and influential for many colleagues and students, including ourselves. In preparation for this article, we took inspiration from his view that linguistic change may arise from structural factors, contact between individuals and communities, or a combination of both (e.g. Demiraj 1986; 1989a; 1989b; 1990; 1993; 1994; 1997; 1998; 2004; 2006; 2010; 2014). The summative impact of these contributions has laid the foundation for a better understanding not just of how change in the Albanian language (sound, meaning) has occurred over time and space, but also in figuring out change in language systems in general, by expounding arguments at the level of the language structure itself and that of linguistic contact. We commemorate Prof. Demiraj's work here and materialize his ideas in the form of a study wherein an agent-based computational model (hereafter, ABM) was used to simulate spoken interactions between urban and rural Gheg speakers in order to test the interplay of structural and social factors in explaining the origin and spread of sound change. The output of the computational model largely reflects patterns observed in the real speech community, thereby confirming Prof. Demiraj's arguments about the interwoven influences of structural factors and social interactions on linguistic stability and change. Before delving further into this cutting-edge methodology applied for the first time to Albanian language, we will outline some principles of sound change underpinning the architecture of the ABM (1.1), how it functions (1.2), and which Gheg speech features were selected for this study (1.3).

1.1. Interactions and phonetic bias lead to sound change

Sound change is defined here as the process through which the sounds of a language, dialect or variety are modified over time, thereby excluding style shifting and other types of linguistic changes, e.g. lexical ones. Explaining the origin and spread of sound change remains one of the greatest challenges faced by linguists to this day (e.g. Labov 2006). In the interactive-phonetic model (henceforth, IP-model; Harrington et al. 2018), which provides the general theoretical framework for this contribution, a core postulate is that sound change emerges out of interactions between speakers. This ties up with a myriad of studies which have attributed change to contact between individuals or communities (Britain 2018; Demiraj 2010; 2014; Dodsworth 2017; Kerswill & Williams 2000; Labov 1963; Trudgill 1986; 2008; Yao & Chang 2016; inter alia). It is also in line with exemplar-based models of language more generally, wherein speakers' cognitive representations of sounds, from which they draw to produce speech, are continuously updated to integrate new memorized exemplars, including those coming from their interlocutors (e.g. Bybee & Beckner 2010; Drager & Kirtley 2016; Foulkes & Docherty 2006; Johnson 1997; Pierrehumbert 2016). Imitation between interlocutors is another well-known tendency suggesting that interactions play a role in sound change (e.g. Babel 2012; Chartrand & Bargh 1999; Coles-Harris 2017; Nielsen 2014).

The IP-model starts from the premise that sound change originates from phonetic variation (Ohala 1989) and capitalizes on the directionality of this variation (Garrett & Johnson 2013; see Kirby & Sonderegger in press for a review). Directionality – also called bias, skewness or asymmetry – in phonetic variation is attributed to universal constraints on perception and/or production which make certain types of sound changes more likely or frequent than others. For example, physiological difficulties in keeping vocal folds vibrating when the subglottic air pressure is lower make final obstruent devoicing a more probable sound change than the other way around (Ohala 1983). High back vowel fronting, both fairly common cross-linguistically and much more frequent than high front vowel backing, has been related to the greater articulatory cost of maintaining peripherality in back vowels (Harrington et al. 2011). In the IP-model, sound change occurs when repeated interactions between speakers reinforce such biases in phonetic variation (Harrington et al. 2018). Conceptually, change is thus more gradual than abrupt, both phonetically and over time; technically, it is driven by properties of acoustic cue distribution.

1.2. Sound change via agent-based modeling

The IP-model of sound change has a computational implementation in the form of an agent-based model (ABM) (Gubian, Cronenberg & Harrington 2023). ABMs are a simulation technique where independent individual agents interact and execute certain actions according to a set of rules, the goal of which is to let population-level dynamics emerge from individual behaviors (Bankes 2002). They are used to study complex adaptive systems (Beckner et al. 2009) in fields as distant as epidemiology, politics and linguistics, where phenomena as diverse as infection spread, electoral results and sound change are simulated. In the ABM we are concerned with here, each agent represents a real speaker. The initialization dataset of these agents (i.e., before any interaction between them) is composed of acoustic measurements taken from real utterances produced by the real speakers they represent. The distribution of the acoustic measurements in each agent’s dataset reflects any inherent phonetic bias of the type mentioned above. The ABM then simulates interactions between real speakers by having agents interact and exchange acoustic information from their respective datasets. Agents either memorize or forget the acoustic data exchanged during interactions and their phonological representations (e.g. the statistical properties of a given sound), which are indeed flexible and regularly updated (see Gubian, Cronenberg & Harrington 2023 for more details on the phonological, cognitive and mathematical motivations underlying this model).

After tens of thousands of simulated interactions, the output of the computational model can be compared against real data, against what is really happening in the speech community. The ABM which we will employ here (or one of its previous versions, all developed at the Institute for Phonetics and Speech Processing at LMU Munich) has successfully predicted the outcome of several types of sound changes across world languages, e.g. /u/-fronting in British English, the near-square merger in New Zealand English (Gubian, Cronenberg & Harrington 2023), the standardization of stop closure duration in West Central Bavarian (Jochim & Kleber in press), /str/-retraction in Australian English (Stevens 2023), and new accent formation among winterers in Antarctica

(Harrington et al. 2019). It has also correctly predicted the absence of /str/-retraction in Italian (Stevens & Harrington 2022), stability being an important outcome which an ABM should be able to predict as well (Sóskuthy 2015). Our goal here was to carry out for the first time ABM simulations involving speech data from speakers of Gheg.

1.3. Change and stability in Gheg: Selected features

Two features were selected for this experiment: rounding of /a/ (otherwise known within the Albanology community as *labializimi i a-së*; Çeliku 1965; 1966; 1968) and contrastive vowel length. These have traditionally been found in Southern Gheg[1], including in the capital city Tirana (Gjinari et al. 2007). Rounding of /a/ refers to stressed /a/ being rounded into [ɔ] when preceded by a nasal consonant, whereas Tosk and standard Albanian have only one unrounded [a] variant across phonetic contexts (e.g. Çeliku 1965; 1966; 1968; 2020; Gjinari et al. 2007), as shown in example (1):

(1)	*fal* 'to forgive'	*mal* 'mountain'
Southern Gheg	[fal]	[mɔl]
Standard	[fal]	[mal]

Contrastive vowel length is a phonological feature found in Southern Gheg and in other Gheg-speaking areas more generally (even as a three-way contrast), but not in standard Albanian or in Tosk, except in a few areas of Labëria and Çamëria (e.g. Beci 1978; 1979; 1995; Çabej 1970; 1975; 1976; Çeliku 1971; Demiraj 1996; Gjinari et al. 2007; Haxhihasani 1971; Shkurtaj 1975; Topalli 2007; Totoni 1964; 1971). Vowel length is used by (Southern) Gheg speakers to distinguish between minimal pairs, as in example (2). Length is also present in the indefinite form of many singular nouns which have either lost their final schwa historically (example 3), end in an open syllable, or in a liquid.

(2)	*një plak* 'an old man'	*një plakë* 'an old woman'
(Southern) Gheg	/plak/	/plaːk/
Standard	/plak/	/plakə/
(3)	*buka* 'the bread'	*një bukë* 'a bread'
(Southern) Gheg	/buka/	/buːk/

[1] Contrastive vowel length is a feature of all Gheg varieties, but we focus here only on the Southern Gheg variety.

Standard	/buka/	/bukə/

However, because of the political, sociodemographic and linguistic changes that took place in Albania since the end of World War II (e.g. Byron 1976; Gedeshi & Jorgoni 2012; Gjonça, Elezi & Sado 2015; Halilaj 2021; Ismajli 2005; Kostallari 1984; Misja & Vejsiu 1990; Pipa 1989), there have been reports that some traditional features were disappearing from Gheg (e.g. Beci 1978). In a recent apparent-time study in which we compared Southern Gheg-speaking adults and first-grade children living in Tirana and the nearby village of Bërzhitë, we found hardly any trace of rounding of /a/ in Tirana; whereas in Bërzhitë, adults were consistently producing rounded vowels, but the children less so (Riverin-Coutlée et al. 2022). In a follow-up longitudinal study, we found that the same Bërzhitë children were producing even less rounded vowels in second grade, suggesting sound change in progress (Riverin-Coutlée et al. 2021). In sharp contrast with rounding of /a/, contrastive vowel length appeared to be completely stable: it was consistently produced by adults and children, in both the city of Tirana and the village of Bërzhitë (Riverin-Coutlée et al. 2022), and in the case of children, from first to fifth grade (Kapia et al. 2023; Riverin-Coutlée et al. 2021). Our goal here is to verify whether the ABM introduced in 1.2 will predict a similar outcome for these two features when fed real data from our Southern Gheg speakers.

2. Research goals

In order to address the goal specified at the end of Section 1.3, we turn Gheg-speaking adults from Tirana and Bërzhitë into agents within an ABM (Gubian, Cronenberg & Harrington 2023). By doing this, we seek to verify whether this computational implementation of the IP-model of sound change (Harrington et al. 2018) correctly predicts the following outcomes after tens of thousands of interactions between Gheg-speaking agents:

1) Change where rounding of /a/ disappears from Southern Gheg
2) Stability of contrastive vowel length in this variety

3. Methods

3.1. Speakers and speech material

As mentioned in Section 1.2, the initialization dataset of each agent within the ABM is composed of acoustic measurements taken from speech produced by real Southern Gheg speakers. Since these real speakers and speech materials are the same as those published in Riverin-Coutlée et al. (2022), we only provide a brief summary here. The speakers were 28 adults with a Southern Gheg background, 14 of whom lived in Tirana and 14 in Bërzhitë. They were digitally recorded in quiet rooms while performing picture-naming and reading tasks presented to them via Speech Recorder (Draxler & Jänsch 2004), during which they produced 4 repetitions of over 50 target words. The speech signals were forced-aligned using WebMAUS General (Kisler, Reichel & Schiel 2017) and structured into a speech database using EMU-SDMS (Winkelmann, Harrington & Jänsch 2017) for manual correction of segment boundaries and calculation of formant tracks. Formants were sampled at the vowels' temporal midpoint and z-score normalized (Brand et al. 2021; Lobanov 1971).

3.2. ABM simulations

The ABM simulations were carried out in R (R Core Team 2024) using the soundChangeR package (Cronenberg et al. 2022; Cronenberg 2024). For the simulations on rounding of /a/, the input data were the first two formant frequencies (F1, F2) measured in four words with canonical /a/, and three words (traditionally) with rounded [ɔ]. For contrastive vowel length, the input data was vowel duration in 7 words with a phonologically short vowel, and 17 words with a phonologically long vowel. There were 28 agents, each representing one of the abovementioned 14 speakers from Tirana and 14 speakers from Bërzhitë, who communicated both within and between groups over the course of 50,000 interactions. Eight such simulations were carried out for each feature in order to test for the robustness of the results. Due to the small number of words in the input data, the agents' memory was expanded by a factor of 10 for the simulations on rounding of /a/, and 5 for those on contrastive vowel length, which helped stabilize computations throughout the simulations (see Cronenberg 2024). The flexible phonology module, a recent addition to the model (Gubian, Cronenberg & Harrington 2023), was activated.

4. Results

The results of the simulations will be presented separately for each feature. First, how features change over the course of 50,000 interactions will be shown. Second, data distribution before and after interactions will be compared. Third, between-agent consistency will be assessed.

4.1. Rounding of /a/

The time course of the 8 simulation runs for rounding of /a/ are displayed in Figure 1. For Bërzhitë and Tirana agents alike, the first two formants of canonical /a/ changed very little over 50,000 interactions, i.e. the gray lines are mostly flat. On the other hand, F1 and F2 of rounded [ɔ] (black lines) changed substantially. Agents from both locations converged towards each other, but larger changes are observed among Bërzhitë agents. Moreover, by the end of the 50,000 interactions, change appears close to completed for Tirana agents (lines flatten out), but still in progress for Bërzhitë agents, who would likely keep changing towards Tirana agents if interactions had continued.

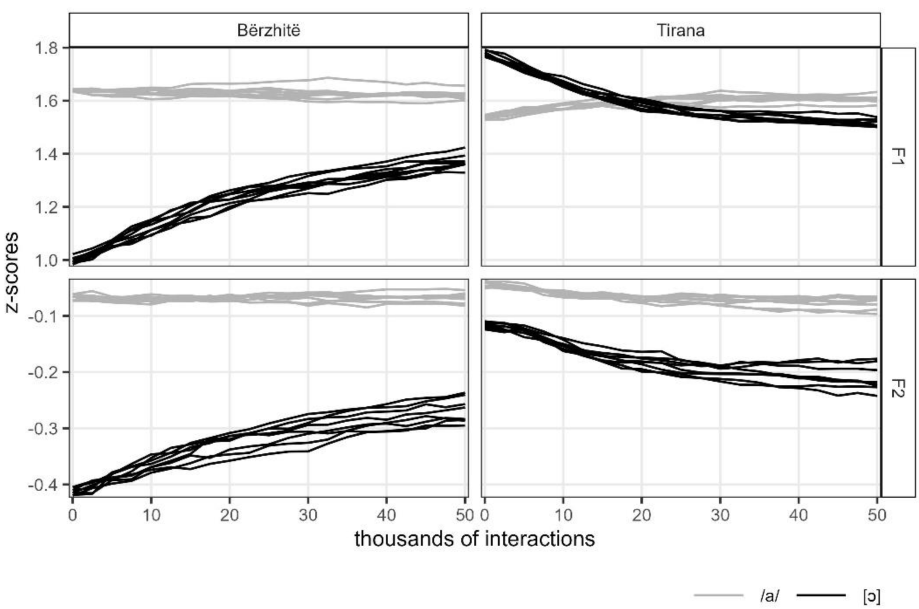

Figure 1. Mean F1 (top) and F2 (bottom) of vowels /a/ and [ɔ] over 50,000 agent interactions. Each track shows one simulation aggregated across 14 agents from Bërzhitë (left) and 14 agents from Tirana (right).

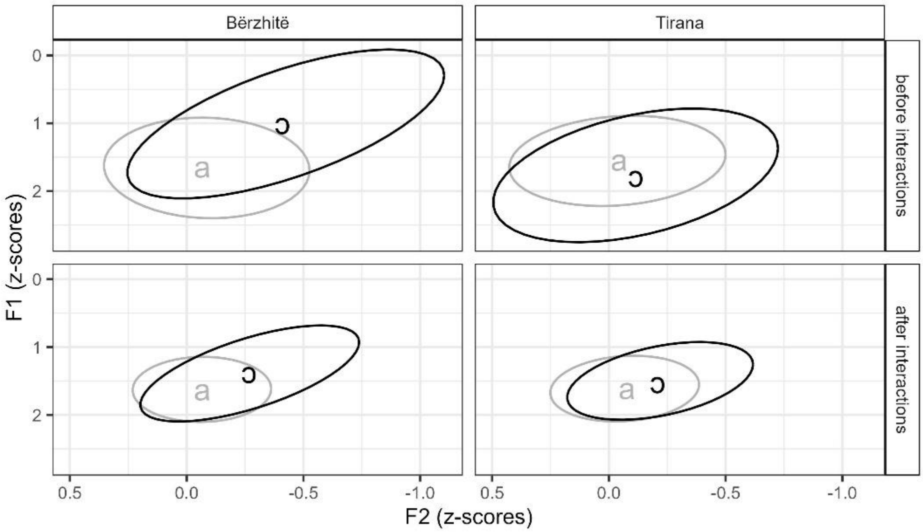

Figure 2. Centroid and distribution of /a/ and [ɔ] in F1×F2 planes before (top) and after (bottom) interactions of Bërzhitë (left) and Tirana (right) agents.

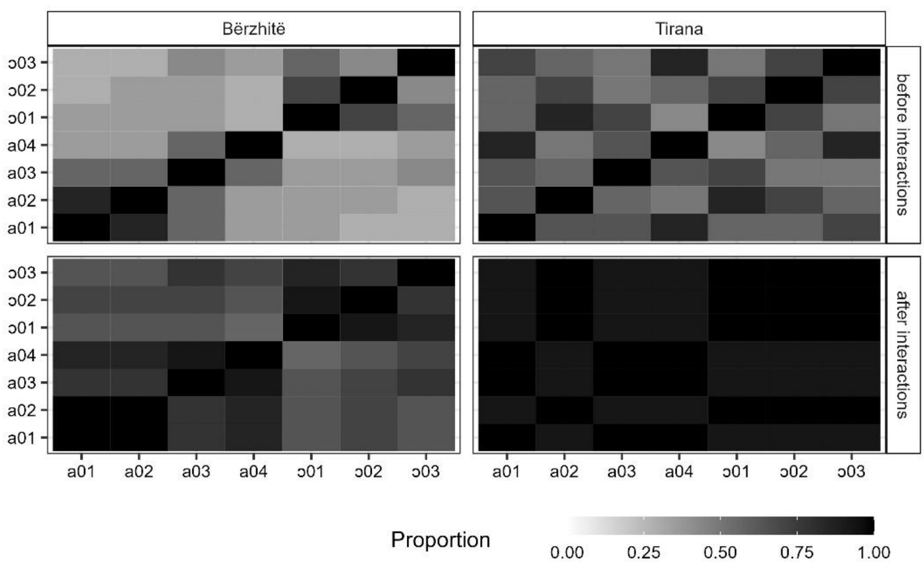

Figure 3. Proportion of Bërzhite (left) and Tirana (right) agents who grouped together words with /a/ or [ɔ] before (top) and after (bottom) interactions in one stimulation. A darker color indicates a larger proportion of agents who grouped a given pair of words together.

Further information on the changes that occurred over the course of the simulated interactions is provided by Figure 2, which shows the location and spread of /a/ and [ɔ] in F1×F2 planes before and after interactions. For Bërzhitë agents, the spread of [ɔ] is reduced and its centroid becomes closer to that of /a/. For Tirana agents, change is mostly a matter of spread reduction, while /a/ and [ɔ] remain very similar before and after simulations.

Figure 3 addresses between-agent consistency in the form of similarity matrices. A darker tile within a matrix indicates that a large proportion of agents agree that the two words intersecting at this tile have similar acoustic properties. Matrices are expected to exhibit a black diagonal from bottom left to top right; that is, all agents agree that a01 (word 01 with canonical /a/) is similar to a01, a02 to a02, and so on. These matrices also allow to observe how agents group words into categories before and after interactions. For example, the top left panel of Figure 3 shows that before interactions, Bërzhitë agents tended to group the three words with [ɔ] together, as indicated by the 3×3 darker zone in the top right corner of the matrix. Few agents found [ɔ] words similar to /a/ words, as indicated by the light gray zones in the top left and bottom right corners. This suggests that before interactions, the Bërzhitë agents distinguished words with [ɔ] from those with /a/. There is no such clear word grouping among Tirana agents before interactions, suggesting that they did not differentiate between the acoustic properties of /a/ and [ɔ] from the very beginning. The very dark after-interaction matrices of both Bërzhitë and Tirana agents indicate that they all find the acoustic properties of all words to be similar, i.e. [ɔ] and /a/ have merged.

In sum, the ABM simulations predict a sound change where rounding of /a/ disappears from Southern Gheg. The Tirana agents already merged canonical /a/ and rounded [ɔ] at simulation onset, and only changed towards less acoustic variability. The Bërzhitë agents substantially reduced the difference between canonical /a/ and rounded [ɔ], and overall, converged towards their Tirana interlocutors.

4.2. Contrastive vowel length

The 8 simulation runs for contrastive vowel length are represented in Figure 4. For Tirana agents (right panels), the duration of short and long vowels stays similar over the 50,000 interactions of the simulations. At simulation onset, Bërzhitë agents' vowels were overall longer, but became closer in duration to those of Tirana agents over the course of the simulations, with a slight decrease of both short and long vowels' duration. Strikingly, however, short and long vowels remain well separated in both groups of agents, i.e. they are stably distinguished and the phonological contrast is preserved.

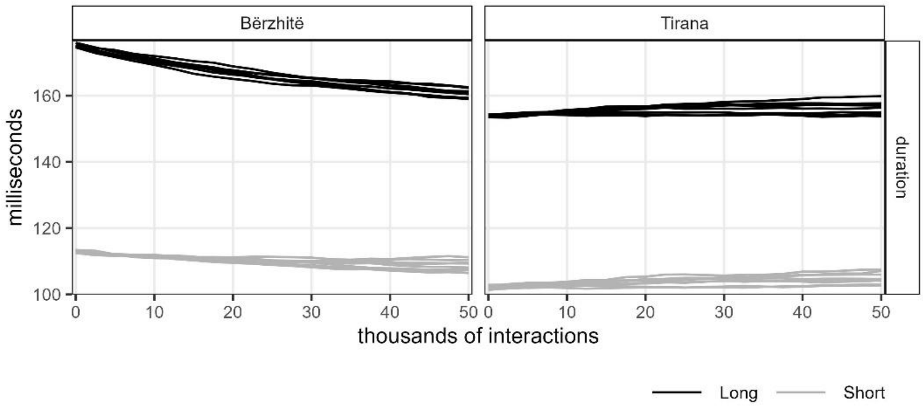

Figure 4. Mean duration of short and long vowels over 50,000 agent interactions. Each track shows one simulation aggregated across 14 agents from Bërzhitë (left) and 14 agents from Tirana (right).

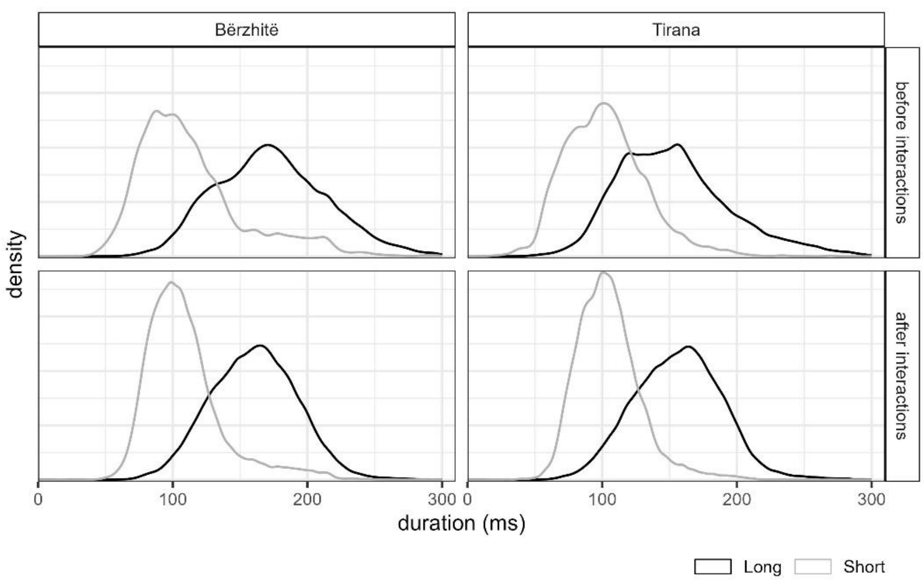

Figure 5. Density plot of short and long vowel duration before (top) and after (bottom) interactions of Bërzhitë (left) and Tirana (right) agents.

Data distribution before and after interactions is shown in Figure 5. Small differences can be observed between Bërzhitë and Tirana agents before interactions, e.g. short and long vowel distributions are more spread for Bërzhitë agents, but these are leveled out by the end of the simulations. Before and after interactions, both groups of agents display bimodal distributions suggestive of two length categories, although these categories' distributions overlap to a certain extent.

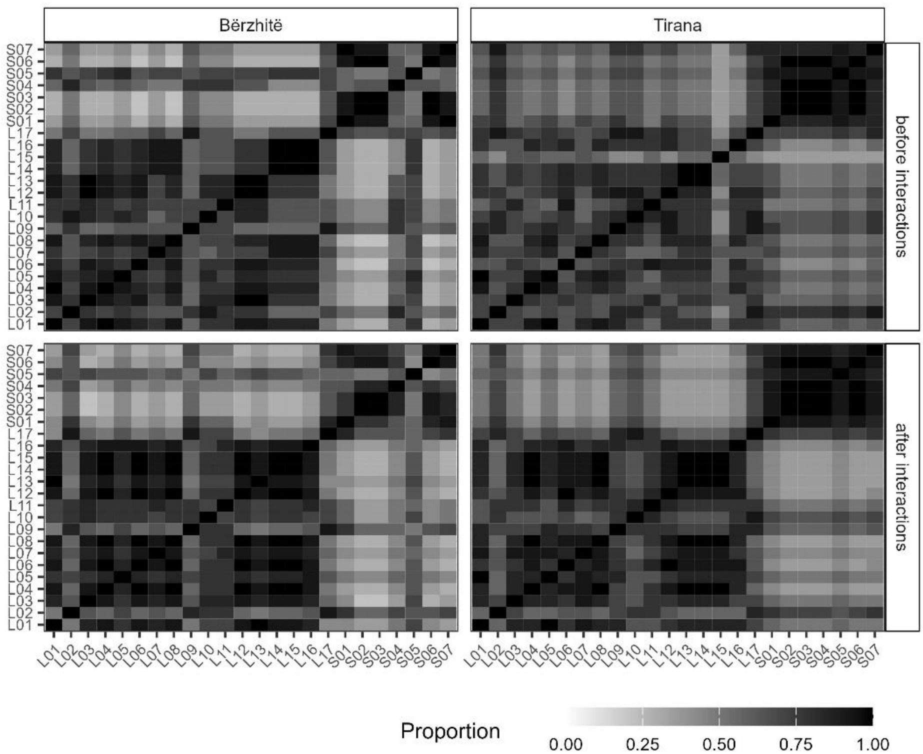

Figure 6. Proportion of Bërzhite (left) and Tirana (right) agents who grouped together words with short and long vowels before (top) and after (bottom) interactions in one stimulation. A darker color indicates a larger proportion of agents who grouped a given pair of words together.

The four similarity matrices reproduced in Figure 6 are highly comparable. Before and after interactions, the agents agreed on two main groups, which mostly comprise words with short vowels on the one hand (S01 to S07), and long vowels on the other (L01 to L17). For Tirana agents, it is interesting to note that one standalone word before interactions, L15, was grouped together with other words of the same phonological category after interactions. Such a pattern is consistent with the reduction of distribution spread resulting from interactions repeatedly observed throughout this study.

To sum up, the ABM simulations predict stability of contrastive vowel length in Southern Gheg. The duration of short and long vowels remained steadily distinct and consistently distinguished by the two groups of agents. Small changes observed among Bërzhitë agents mainly resulted in alignment with Tirana agents' vowel durations, and an overall reduction of distribution spread was observed.

5. Discussion and conclusion

The purpose of this paper was to honor Prof. Bardhyl Demiraj's important contribution in Albanology with respect to sound and language change in general. The idea that sound change is linked to both structural and social factors strongly resonates with the main views in Prof. Demiraj's work focusing on several types of sound changes over time in Albanian. The general ethos of these ideas was put at the center of this study, which aimed at verifying the predictions of an agent-based computational model relative to stability and change in Southern Gheg. Two speech features of this Albanian variety were investigated: rounding of /a/, previously found to change in a recent study of speech data from children and adults living in rural and urban Southern Gheg-speaking areas (Riverin-Coutlée et al. 2022), and contrastive vowel length, which instead continues to exhibit stability even today in these populations and areas (Kapia et al. 2023; Riverin-Coutlée et al. 2021). As detailed in Section 4, when real speech data from actual Southern Gheg-speaking subjects where inputted into our computational model of sound change, it successfully predicted both stability of contrastive vowel length and change in rounding of /a/ in these communities.

Part of these successful predictions can be attributed to the way the structural aspect of sound change has been conceptualized and implemented in the computational model utilized in this study. The ABM draws heavily on the psycholinguistic and cognitive underpinnings of exemplar theory, which proposes that exemplars exchanged between interlocutors are memorized and can influence speakers' phonological representations (e.g. Bybee & Beckner 2010; Drager & Kirtley 2016; Foulkes & Docherty 2006; Harrington et al. 2018; Johnson 1997; Pierrehumbert 2016). Concretely, in the model, the memorization of new tokens by agents changes the statistical properties of cues in the acoustic space; biases in distribution are magnified, while spread is reduced. This is well exemplified in Figure 2, where in the upper left panel representing Bërzhitë agents' vowels before interactions, the ellipse encompassing [ɔ] is spread (reflecting variation in the production of this vowel in Bërzhitë, i.e. either with an [ɔ] quality, an [a], or in-between, as noted by Çeliku 1966) and oriented towards /a/. This type of distribution is similar to that observed for other types of sound change, e.g. /u/-fronting in British English (Gubian, Cronenberg & Harrington 2023; Harrington, Kleber & Reubold 2008; Harrington & Schiel 2017). In contrast, in the upper right panel, the Tirana agents' [ɔ] distribution before interactions is more compact and overlaps almost entirely with /a/. In the ABM, distribution spread and skewness in a given group of agents is resolved through convergence towards another group's overlapping and more compact distribution; here, Bërzhitë agents' [ɔ] changes because its initial distribution is more spread and encompasses the Tirana agents' [ɔ] distribution. The ABM's correct prediction that [ɔ] is changing towards /a/ in Southern Gheg, as observed in our previous empirical study of adults and children living in urban and rural environments (Riverin-Coutlée et al. 2022), lends support to this type of conceptualization of how sound change may take place at the structural level.

In previous studies on Southern Gheg, we also suggested that structural factors were at play, i.e. rounding of /a/ is changing because it is a phonetic feature, while contrastive vowel length is stable because it is at least partially involved in phonology (Kapia et al. 2023; Riverin-Coutlée et al. 2022). Based on the results presented here, we may hypothesize that the relative stability of phonological categories within individuals and communities, as observed in Southern Gheg and beyond (e.g. Chambers 1992; Kerswill 1996; Kwon 2018; Nielsen 2011; Sankoff 2004), could be related to regularities in their statistical distribution in the acoustic space. Under the associative account of phonetic cue use by speakers/listeners, distributional properties of cues indeed form the basis of phonological categories in a given language (see Schertz & Clare 2020 for a review).

Change in Southern Gheg also has a sociolinguistic component, as it is likely the consequence of contact between speakers of different varieties brought about by intense population movements in Albania since the end of World War II (King, Uruçi & Vullnetari 2011; Lerch 2014; Vullnetari 2014). The ABM provides further evidence that contact resulting from this type of situation may cause change (Britain 2018; Dodsworth 2017), as also argued in our previous study on Southern Gheg spoken by adults and children in urban and rural communities (Riverin-Coutlée et al. 2022). Despite this, the influence of social factors on change remains a relatively under-developed aspect of the current version of the computational model. For example, while it has been suggested that speech features carrying social stigma may be prone to change and instability (e.g. Auer 2018; Pharao in press; Riverin-Coutlée, Kapia & Gubian in press), it is currently not possible to control this parameter when carrying out ABM simulations. Personal or social attributes of a given speaker may also influence the degree to which their speech features are imitated by interlocutors during interactions (e.g. Babel 2012; Babel et al. 2014). Additionally, in this study, the agents randomly interacted with agents of the same community (in-group, e.g. Bërzhitë agents with Bërzhitë agents) and of the other community (out-group, e.g. Bërzhitë agents with Tirana agents), the two other options available being in-group interactions only, and out-group interactions only. However, the possibility to adjust the relative frequency of in-group and out-group interactions (or network structures more generally, e.g. Dodsworth 2019) would be desirable in future releases of the ABM. For example, for residents of an isolated village, even though both in-group and out-group interactions occur (e.g., Bërzhitë speakers interact with Bërzhitë and Tirana speakers), it is possible that in-group interactions are more frequent than out-group ones. This can in turn influence aspects of sound change, such as the speed at which it spreads throughout a community (e.g. Gordon 2019).

Within ABM simulations, the accumulation of interactions represents the passage of time. However, interactions between agents are not necessarily representative of daily-life encounters between real people, as they entail many simplifications relative to the complex social setting and sustained exchange of rich acoustic information which characterize real interactions. In particular, it cannot be assumed here that 50,000 interactions between agents mean 50,000 interactions between speakers as they would be in real life (for the reasons metioned above), and the amount of time for a sound change to spread and reach completion cannot be inferred from the model (Gubian, Cronenberg & Harrington 2023: 112). Using this type of methodology can provide fresh and complementary insights into sound and language change, but it cannot replace detailed diachronic studies in Albanology which put historical precision at the forefront. A good example would be Prof. Demiraj's work on how Albanian number words have evolved, wherein he has focused on how structural considerations have shaped out their evolution over time in the language; see for instance the explanations of the number word *katër* or the suffix *-të* on numeral words and other adjectives (Demiraj 1986; 1989a; 1997). In other work, he has suggested the strong role that the social context has played in how several different phenomena and words have evolved diachronically; one such notable mention would be the evolution of the words *shqiptar* and *shqa* (Demiraj 2010; 2014). Most importantly, however, we hope to have convincingly bridged here lifelong ideas sculpted within Prof. Demiraj's work with a computational model of sound change, both of which suggest that change and stability are shaped and constrained by linguistic factors as well as the social context in which speakers produce and perceive speech.

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