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On the role of asymmetry in prosodic change of consonant duration: Results from an agent-based model with two German varieties

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Abstract

This study investigates how an asymmetric conversational situation between two standard varieties of German can influence the speakers' consonant quantity in /V:C:/ sequences, i.e. a prosodic feature. Asymmetric conversations between German and Austrian speakers, i.e. scenarios in which one of the varieties provided the majority of speech input, were simulated using an agent-based model which adhered to principles from Exemplar Theory and the mechanistic view on sound change. The results showed that Austrian agents were more prone to prosodic change than Germans due to a higher variability and bias towards shortened consonants in their acoustic representation of /V:C:/. The findings are discussed in light of the interactive-phonetic model of sound change.

Index Terms: agent-based modelling, standard varieties, prosodic quantity change

1. Introduction

In order to better understand underresearched prosodic changes in time [1, 2] this study seeks to model computationally the lenition of fortis stops in form of durational shortening in speakers with large input from a variety without lengthened fortis stops.

1.1. National varieties of German in Germany and Austria

We focus on two standard varieties of German, namely Southern Standard German (SGG) and Standard Austrian German (SAG) which can be found in urban settings in southern Germany and Austria, respectively. Although Austria is a national center of German, there is a long history of influence from SGG on SAG [3]. This influence of SGG on SAG is still noticeable today. According to [4], Germans constituted the largest group of foreign nationals in Austria in 2020. Their variants of German are considered highly prestigious and it has been claimed that young speakers of SAG aim their pronunciation towards SGG [5]. SGG is also present in the Austrian media landscape in the form of SGG-trained newscasters and German TV programs [3]. To our knowledge there are no accounts, on the other hand, of a direct impact of SAG on SGG. That is why we assume an asymmetric communicative situation between SAG and SGG.

The extent to which SGG and SAG differ phonetically is still under discussion and contrastive studies are sparse. Here, we focus on prosodic quantity differences in VC sequences. In SGG, both vowel and consonant quantity are distinctive. Consonants are characterized as fortis or lenis depending on an interaction between closure duration, intensity of burst, and voice onset time (VOT). Closure duration and VOT are longer in fortis consonants than in lenis consonants [6, 7, 8]. Vowel duration interacts with differences in vowel quality: Short vowels are lax, while long vowels are tense [9]. In VC sequences, all four possible combination patterns are documented: long vowels + lenis consonants (henceforth /V:C/), long vowels + fortis consonants (/V:C:/), short vowels + lenis consonants (/VC/), and short vowels + fortis consonants (/VC:/).

In SAG, a longer closure duration and (in formal speech) VOT separate fortis from lenis consonants [3, 10]. Vowels in SAG are mainly differentiated into short and long, however high front vowels also differ in quality [3, 11]. Similarly to SGG, all four combinations of long/short vowels and fortis/lenis consonants occur in SAG. However, as [12] showed, SGG and SAG differ with respect to the timing of vowel and consonant combinations, especially in /V:C:/ sequences. They found that SAG speakers vary their consonant duration in /V:C:/ sequences more than SGG speakers: While the SGG consonant duration in /V:C:/ largely matches the consonant duration in /V:C/ sequences, SAG data show that the consonant duration in /V:C:/ can either match that of /V:C/ or of /VC:/. [12] conclude that SAG shows some features of a purely duration-based fortis/lenis contrast (stemming from its dialectal basis in the East Central Bavarian dialect [10, 5]), while SGG's contrast is based on the combination of durational measures (closure duration and VOT) and spectral measures (intensity of the burst).

1.2. Computational Models of Sound Change

Computational models have gained popularity as a method of investigating sound changes only in the last couple of decades. Particularly useful in this research area are so called agent-based models (ABMs). These models can be constructed to test specific theories about the emergence of new sounds and their spread within a speech community (see e.g. [13, 14, 15, 16, 17]). The ABM used in this study is based on the interactive-phonetic (IP) model of sound change [18]. The phonetic part of this model is that sound changes can occur when there is a phonetic bias that skews a phonological category in a certain direction. For example, intervocalic plosives tend to be shortened in casual speech [19]. According to Exemplar Theory, listeners store the phonetic details of such (biased) tokens in an acoustic space in their memories [20, 21]. From these two models it follows that the more biased tokens listeners encounter, the more their own phonological category will shift in the direction of the bias when they turn speakers. This prediction is based on the assumption that production and perception are generally considered to be closely aligned [22] and to share representations [23, 24].

While short-term phonetic imitation can be affected by social motivations such as likability of the interlocutor [25, 26], Trudgill has argued that linguistic accommodation is just as

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mechanistic as many other human behaviors in interactions [27] and is not used to satisfy e.g. the need for a common identity [28, 29]. So whereas a phonetic bias can trigger the development of a new variant, interactions between speakers are needed to propagate it (hence the 'I' in IP model).

The aim of the current study is to investigate the impact of asymmetric conversational situations on the spread and outcome of a change in consonant quantity by means of an IP-inspired ABM. The asymmetry exists in the amount of speech input that a certain group of listeners receives from speakers of another group. Such an asymmetric situation can be assumed between SGG and SAG, as described above, and allows us to test – for the first time – whether or not a change can come about without a pronounced bias towards a highly dominant language.

1.3. Aims and Hypotheses

The aim of this study was to investigate the influence of the asymmetric communicative situation between the two national varieties of German on their closure duration in /V:C:/ sequences. For this purpose, the ABM first presented by [30] was adapted such that it can simulate changes that might occur as a result of the prevalence of one of the two varieties. In general, it is expected that one variety becomes more like the other when the majority of speech input is provided by the latter. We specifically hypothesize that German agents should be more resistant to changes in closure duration given their reduced variability therein. SAG, on the other hand, shows a much broader distribution of the closure duration in /V:C:/ with a bias towards those of SGG, making this group's data more prone to change. Although this bias is most pronounced in younger Austrians we will in this paper for reasons of simplification pool both age groups and focus solely on convergence between SAG and SGG speakers.

2. Method

2.1. Participants and Material

The complete corpus consisted of 38 speakers, divided into two regional and two age groups. Younger speakers were well below the age of 45, older speakers above. The Austrian speakers were all born and grew up in Vienna, while the German speakers came from the area of Munich. Since there were only 18 speakers in the German group (6 older, 12 younger) compared to 20 Austrian speakers (9 older, 11 younger), the two Austrian speakers with the least acoustic material available were removed from the corpus to balance the regional groups. The material consisted of two word types with a long vowel and a fortis consonant in medial position: *Haken* /haːkn̩/ 'hook' and *Bieter* /b̥iːtɐ/ 'bidder'. The tokens were presented in carrier sentences with three syllables preceding, and at least one syllable following the target word. Every word was recorded five times per speaker.

2.2. Acoustic Data

The data was segmented using WebMAUS [31] and was manually corrected. The closure duration was measured from the offset of the vowel (as indicated by the visible glottal pulses) to the beginning of the burst. Only orally released tokens (i.e. where VOT was present) were included in the analysis, amounting to a total of 331 tokens across 36 speakers and two word types.

The extracted closure duration was normalized by dividing it by the corresponding word duration in order to account for possible age-dependent speech rate effects. The resulting distributions can be seen in Fig. 1 for the two age and regional groups. While there is hardly any difference between younger and older German speakers, younger Austrian speakers tend towards a shorter, more SGG-like closure duration. Older Austrian speakers, on the other hand, are more conservative in that they produce longer closures. It is visible, however, that the distribution for the older speakers is skewed towards shorter closures, i.e. there is most likely a phonetic bias that causes older Austrian speakers to sometimes produce /V:C:/ words with a shortened, i.e. lenited consonant.

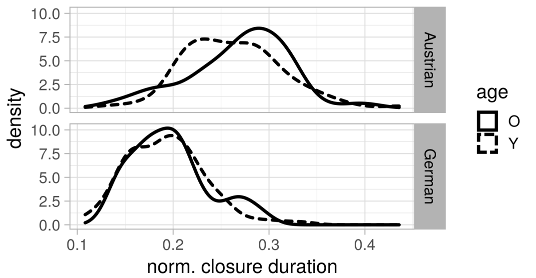

Figure 1: *Normalized closure duration for older (solid) and younger (dashed) Austrian and German speakers.*

2.3. Agent-Based Model

The ABM used in this study is an extension of [30].[1] In this model, speakers are represented by computational agents which are equipped with memories for storing as well as rules for producing and perceiving acoustic tokens. In the following simulations there are hence 18 Austrian and 18 German agents who exchange tokens of *Bieter* and *Haken*. A token consists first and foremost of phonetic information, namely the normalized closure duration, but it is also associated to a word type and a phonemic class. The latter is broadly defined as /V:C:/ for all tokens, given that both word types in this dataset are phonologically described as having a long vowel and fortis consonant (in contrast to the other possible combinations of long/short vowels and fortis/lenis consonants).

Every simulation presented here consists of 50,000 interactions. An interaction begins with the choice of an agent-speaker and an agent-listener. This choice can be influenced by means of a newly implemented option that defines the probabilities for all four combinations of group-wise interactions as demonstrated in Table 1. In this example, there is a 45% probability of an interaction between two German agents, a 5% probability of an interaction between an Austrian agent-speaker and a German agent-listener, and so forth. Overall, there is therefore a 90% (10%) probability that the agent-speaker is German (Austrian) in this example. Having determined the groups of the two agents in an interaction, the specific agents are chosen randomly from their regional groups.

We decided for this convenient parameterisation that explicitly provides the four joint probabilities $P(SPK, LIST)$ where $SPK, LIST \in \{\text{Austrian}, \text{German}\}$. The joint probability could also be parameterized by the three probabilities $P1 = P(SPK = \text{Austrian})$ where $P(SPK = \text{German}) = 1 - P1$, $P2 = P(LIST = \text{Austrian} \mid SPK = \text{Austrian})$

[1] The code basis is available at `https://github.com/IPS-LMU/ABM`.

Table 1: *Example for probabilities of group-wise interactions.*

speaker group	listener group	probability
German	German	0.45
Austrian	German	0.05
German	Austrian	0.45
Austrian	Austrian	0.05

where $P(LIST = \text{German} \mid SPK = \text{Austrian}) = 1 - P2$, and $P3 = P(LIST = \text{German} \mid SPK = \text{German})$ where $P(LIST = \text{Austrian} \mid SPK = \text{German}) = 1 - P3$. $P(SPK)$ is the probability that input was produced by a certain speaker group, and $P(LIST \mid SPK)$ is the conditional probability that the listener comes from a certain group given that the speaker comes from some group. The first probability can be estimated by the size of the speaker group, the conditional probability by the probability of contact between two groups. For the example in Table 1 the probabilities are $P1 = 0.1, P2 = 0.5, P3 = 0.5$.

The agent-speaker randomly chooses a word type, builds a Gaussian model over the closure durations of all tokens associated with that word, and finally samples a new duration value from the Gaussian model. This value, together with the word type and phonemic label, are transmitted to the agent-listener. The agent-listener's task is to decide whether or not to memorise the transmitted token. This decision is not based on word recognition, i.e. it is assumed that the word type is correctly recognized. The token is incorporated into the agent-listener's memory if its probability of belonging to the listener's corresponding phonemic class is higher than or equal to 95% according to the token's Mahalanobis distance to the phonemic class. In order to stabilize the agents' memory size, the agent-listener 'forgets' (removes from memory) a random token. We took two measures in order to control and check the robustness of the following simulations. First, every simulation was repeated five times so as to exclude the possibility that any result came about by chance. Second, artefacts due to data scarcity (there are at most five tokens per word and speaker) are prevented by enlarging the agents' memories by a factor of ten by applying SMOTE prior to the simulation [32].

Four scenarios were constructed for which the probability of one regional group providing the agent-speaker in an interaction was varied in 10%-steps between 60% and 90%. Table 1, for instance, contains the settings for the scenario in which there is a 90% probability of having agent-speakers from the German group. That means that approx. 90% of all input to any agent-listener comes from German agent-speakers and only approx. 10% of input comes from Austrian agent-speakers in this scenario. In the following simulations there is, therefore, an asymmetry regarding the amount of input that agent-listeners receive from the two national varieties. There was an additional control simulation in which the agents only conversed with agents from their own regional group. This simulation should yield only marginal and random changes.

3. Results

Fig. 2 shows the results of a simulation in which the agents conversed only with agents from their own regional group, i.e. there was no contact between Austrian and German agents. There are five (almost indistinguishable) lines per panel, one for each repetition of this simulation. The plot shows that there was no change in the closure duration of Austrian agents over 50,000 interactions. The slight reduction in closure duration for German agents was marginal. These results are very robust across repetitions.

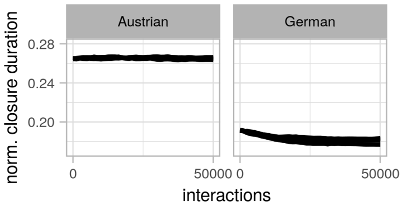

Figure 2: *Normalized closure duration over simulation time, aggregated by the regional groups.*

Fig. 3 summarizes the results for the remaining eight simulations: the four asymmetry scenarios with majority input from German agents in the top and the other four scenarios in the bottom row. The specific probability of input is indicated by the color-coding and there is again one line for each of the five repetitions per scenario. Just like Fig. 2, Fig. 3 shows the normalized closure duration over the number of interactions aggregated by regional group. The first observation is that Austrian agents always adapted their closure duration to German agents when the majority of input came from German agents (top row). The amount of input did not make a difference with regard to the outcome of the simulation. In these scenarios, German agents changed their acoustic representation of /V:C:/ words only marginally: the more German input there was, the more they decreased their closure duration.

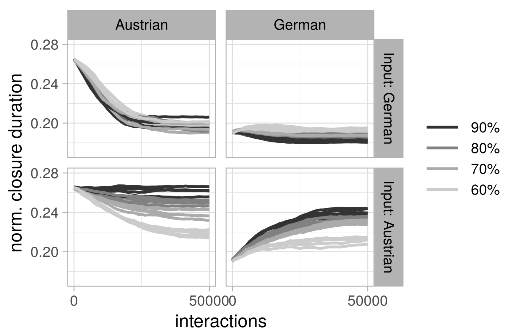

Figure 3: *Normalized closure duration over simulation time, aggregated by the regional groups (columns) and the asymmetry scenario (rows and colors). Top (bottom) row: majority of interactions had German (Austrian) agent-speakers.*

When Austrian agents provided the majority of input (bottom row), on the other hand, the amount of input influenced the outcome of the simulated sound change: At 90% Austrian input, German agents clearly adopted a longer closure duration (but they never reached SAG-like values), while Austrian agents did not change. With decreasing amount of input from Austrian agents, there was less change from German towards Austrian agents and more change vice versa. When there was 60% Austrian input (and, hence, 40% German input), there was more change from Austrian in the direction of German closure durations than the other way around. These results are again very robust across repetitions.

4. Discussion

Several insights arise from this study: (1) prosodic quantity changes in this ABM come about as a result of interactions between heterogeneous speakers some of which have a more innovative variant of the observed phoneme than others; (2) the higher variability in the acoustic data of Austrian speakers due to a phonetic bias towards shortened consonants makes them less resistant to this particular prosodic change compared to German speakers even when SAG is the dominant input variety; (3) considerable lengthening in the SGG group only emerges when Austrian agents provided 90% of all input and even then German agents never completely adapted to Austrian closure duration. The last two findings are insofar of interest as they further support the importance of a phonetic bias in change as predicted by the IP-model [18], while also showing that asymmetric input can nonetheless cause change in an initially non-biased distribution (if only to a lesser extent, as the lengthening in SGG agents suggests), underlining the significance of input and interaction in change.

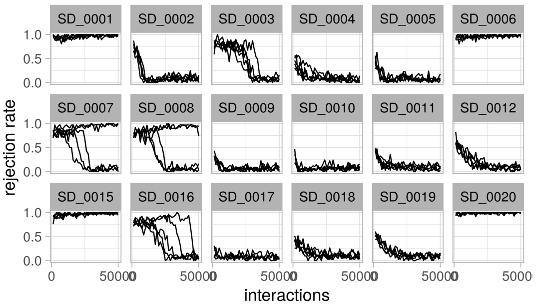

Figure 4: *Rejection rate, computed as* $1 - \frac{nr.\ accepted\ tokens}{nr.\ perceived\ tokens}$*, of German agents over 50,000 interactions for the simulation with 90% Austrian input.*

The individual German data in Fig. 4 shows that six SGG agents hardly ever (SD_0001|06|15|20) or only rarely after approx. 25k interactions (SD_0007|08) accepted any perceived tokens when the SAG input was high. These six agents, who were most resistant to change towards the SAG pronunciation, represented the German speakers who most shortened their consonants, as shown in Fig. 5. On the other hand, only two older Austrian agents (WS_0016|17), with some of the longest closure duration (see Fig. 5), rejected perceived tokens when the SGG input was high. These eight agents' relatively marginal and narrow distributions of closure duration explain why the corresponding agents rejected most perceived tokens: according to the applied memorisation criterion, i.e. Mahalanobis distance with a threshold of 95% probability, any token perceived by these agents had to be very close to their other tokens in the acoustic space, compared to agent-listeners who had a wider distribution of values.

The overall result from this study is that a prevalent variety can attract speakers from another variety towards their pronunciation norms under certain circumstances. A phonetic bias in the non-prevalent variety can facilitate the linguistic accommodation. The two national varieties of German provided the ideal state of imbalance needed to simulate such a conversational asymmetry: (1) SGG is much more present in the lives of SAG speakers than vice versa; (2) Austrian speakers showed a greater skew towards the German distribution in the input data than vice versa. Using these data, the ABM was capable of simulating both shortening and lengthening of consonants, depending on the direction of the asymmetry. The exact outcome, however, also depended on the resistance to change in individual agents whose production of /V:C:/ sequences was rather extreme. Since there were more Austrian speakers biased towards shortened consonants than there were German agents biased towards longer ones, the accommodation from Austrians towards the prosodic patterns of Germans was stronger than vice versa. The finding of an asymmetric shift towards one speaker group due to speaker interaction is in line with an observed, although reversed asymmetry in short-term imitation between dialect speakers of Bavarian from Germany and Austria [33]. By showing a distribution-dependent shift towards German the present study suggests that the reversed asymmetry in [33] may have come about due to a stronger phonetic bias (in this case in the spectral domain) in German Bavarian speakers towards patterns found in Austrian Bavarian.

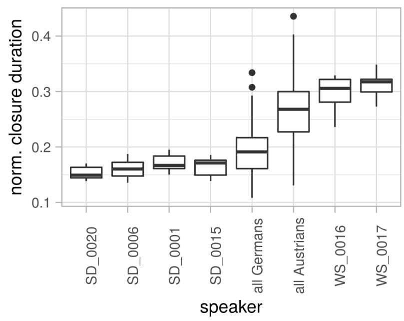

Figure 5: *Normalized closure duration for the speakers that were most resistant to change in the ABM as well as for all German and all Austrian agents.*

More generally and despite a tendency towards a greater skew towards the German distribution in younger SAG speakers we do not claim here that there is a prosodic quantity change in progress whereby SAG speakers adapt to the SGG-typical closure duration and lose the quantity distinction in consonants. The ABM used in this study necessarily abstracts from reality, e.g. it does not take into account the social dynamics that may exist between SAG and SGG speakers. It has, for instance, been reported anecdotally that there is a pull from the Viennese dialect on SAG. Future studies may examine the behavior of SGG and SAG agents when they interact with agents who represent speakers of the Viennese dialect.

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