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Diffusion of Phonetic Updates within Phonological Neighborhoods

ABSTRACT

Phonological neighborhood density is known to influence lexical access, speech production and perception processes. Lexical competition is considered the central concept from which the neighborhood effect emanates: highly competitive neighborhoods are characterized by large degrees of phonemic co-activation, which can delay speech recognition and facilitate speech production. The study investigates phonetic learning in English as a foreign language in relation to phonological neighborhood density and onset density to see if dense or sparse neighborhoods are more conducive to the incorporation of novel phonetic detail. Also, the effect of voice-contrasted minimal pairs is explored. The results indicate that sparser neighborhoods with weaker lexical competition provide the most optimal phonological environment for phonetic learning. Moreover, novel phonetic details are incorporated faster in neighborhoods without minimal pairs. The results indicate that lexical competition plays a role in the dissemination of phonetic updates in the lexicon of foreign language learners.

Keywords: aspiration, Austrian German, Czech, English as a foreign language, lexical competition, minimal pair, phonetic learning, phonological neighborhood

Širjenje fonetičnih novosti znotraj fonoloških soseščin

POVZETEK

Gostota fonološke soseščine vpliva na dostop do leksike, govorno produkcijo in procese zaznavanja. Leksikalno tekmovanje naj bi bilo osrednji koncept, iz katerega izhaja učinek soseščine: za zelo tekmovalne soseščine je značilna velika stopnja fonemske koaktivacije, ki lahko upočasni prepoznavanje govora in olajša govorno produkcijo. Študija raziskuje fonetično učenje v angleščini kot tujem jeziku v povezavi z gostoto fonološke soseščine in gostoto začetka, da bi ugotovili, ali so za vključevanje novih fonetičnih podrobnosti bolj ugodne goste ali redke soseščine. Raziskava ugotavlja tudi učinek minimalnih parov z zvenečnostnim kontrastom. Rezultati kažejo, da redkejše soseščine s šibkejšim leksikalnim tekmovanjem zagotavljajo najbolj optimalno fonološko okolje za fonetično učenje. Poleg tega se nove fonetične podrobnosti hitreje vključijo v soseščinah brez minimalnih parov. Pokaže se, da ima pri učenju tujega jezika leksikalno tekmovanje pomembno vlogo pri širjenju fonetičnih novosti v besedišču.

Ključne besede: pridihnjenost, avstrijska nemščina, češčina, angleščina kot tuji jezik, leksikalno tekmovanje, minimalni par, fonetično učenje, fonološka soseščina

1 Introduction

Word-initial plosive aspiration, being a feature of the majority of English varieties (e.g., Watt and Yurkova 2007; Berry and Moyle 2011; Docherty et al. 2011; Chodroff et al. 2015; Sonderegger 2015; Morris 2018), can represent a phonetic challenge for learners of English whose first language is non-aspirating, such as Austrian German and Czech (Moosmüller, Schmid, and Brandstätter 2015; Skarnitzl and Rumlová 2019). From an articulatory viewpoint, aspiration is the period between an initial burst of frication and the start of voicing (Klatt 1975; Abramson and Whalen 2017), which is commonly measured as voice-onset time (or VOT). The length of VOT – and thus aspiration – can vary significantly between languages and may or may not have a contrastive function (Cho, Whalen, and Docherty 2019).

In English, German, and Czech plosives are commonly classified as "fortis" – in the case of longer VOTs – and "lenis", which are characterized by shorter or negative VOTs (Klatt 1975; Skarnitzl 2011; Chodroff et al. 2015; Luef 2020). Definitions of long-lag VOT (or fortis) differ between the three languages. The average range of fortis VOT in varieties of English spoken in North America is between 65 and 120 ms (Berry and Moyle 2011); aspiration is slightly less pronounced in British speakers and VOTs range between 45 and 100 ms (Docherty et al. 2011; Przedlacka 2012; Sonderegger 2015). From a cross-linguistic universalist viewpoint, VOTs starting at approximately 50 ms are classified as slightly aspirated, values above 90 ms are considered moderately aspirated, and values above 120 ms fall into the category of highly aspirated (Cho and Ladefoged 1999). This puts English fortis VOTs in the low to medium aspiration categories. By contrast, Austrian German (hereinafter referred to as "Austrian") and Czech fortis VOTs range well below the English ones, with Austrian fortis plosives being characterized by VOTs of 26.1–66 ms (Luef 2020; Moosmüller and Ringen 2004). As opposed to Standard Middle/Northern German with moderate degrees of word-initial aspiration (Jessen and Ringen 2002), Austrian German is generally classified as non-aspirated or weakly aspirated in the majority of phonological and stylistic contexts (Bürkle 1995; Muhr 2007; Wiesinger 2009). Czech VOTs are typically in the short-lag VOT domain of approximately 14–32 ms (Skarnitzl 2011; Kaňok and Novotný 2019). The lack of aspiration in word-initial plosives in Austrian and Czech learners of English results in the typical low-aspirated foreign language (L2) English varieties encountered in speakers from Austria and the Czech Republic. This is especially prominent in learners at lower and medium proficiency stages, but may persist even in highly proficient learners of English (Pospíšilová 2011; Ambrožová 2014; Skarnitzl and Rumlová 2019; Kong-Insam 2021).

1.1 What Influences VOT Duration?

The duration of VOT can be influenced by a variety of factors in a given language, including idiosyncratic variation (Allen, Miller, and DeSteno 2003; Ladd and Schmid 2018), sociolinguistic factors (e.g., age and gender, see Swartz 1992; Bóna 2014), biological factors (menstrual cyclicity, see Whiteside, Hanson, and Cowell 2004), as well as lexical or segment frequency in foreign language learners (Luef and Resnik, in press). In addition, studies have consistently shown that one systematic influence on word-initial VOT duration is the density of the phonological neighborhood of a target word (e.g., Baese-Berk and Goldrick 2009; Peramunage et al. 2011; Schertz 2013; Buz, Tanenhaus, and Jaeger 2016; Nelson and Wedel 2017). A phonological neighborhood is the sum of all words that differ by one phonological segment via addition, deletion, or substitution (the Levenshtein distance, see Levenshtein 1966), and these neighborhoods constitute a crucial feature of the structure and organization of the mental lexicon (Aitchison 1987; Vitevitch 2002b). See Figure 1 for a schematization of the phonological neighborhood of the target word "ache" in foreign language learners of English (EFL) at the A2 proficiency level.

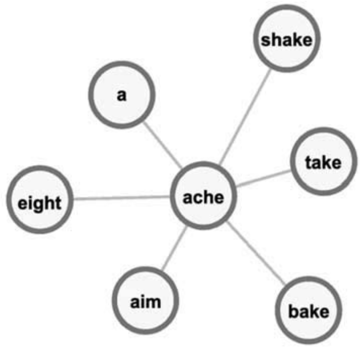

Figure 1. Exemplary phonological neighborhood of "ache" in EFL learners of English at the A2 level. Neighbors differ by one segment.

Phonological neighbors are known to impact the speed and efficiency of lexical access in speech production and perception (see Vitevitch and Luce 2016 for a review). Upon activation of a word in a phonological neighborhood, activation spreads along shared segments to neighbors of the activated word, and this activation spreading is highly competitive (see the Neighborhood Activation Model or NAM, Luce and Pisoni 1998). Lexical competitor words (i.e., the neighbors) receive co-activation from the target word and compete for activation until the target is eventually selected (Marslen-Wilson 1990; Luce et al. 2000; Haigh and Jared 2007; Friedrich et al. 2013). Psycholinguistic theory predicts that in dense neighborhoods co-activation of shared segments leads to facilitated word production processes (Goldinger, Luce, and Pisoni 1989; Gahl and Strand 2016; Karimi and Diaz 2020) that result from the strengthening of phonemic representations through repeated co-activation (Vitevitch 2002b). In speech perception, on the other hand, dense phonological neighborhoods cause retrieval delays and impede speech recognition, since target words become more difficult to identify within the cloud of activated neighbors (Vitevitch and Luce 2016). The phonological locus of neighbor formation – in other words the specific segment that differs between two neighbors – is also a matter of interest (Yiu and Watson 2015). Words overlapping in the onset phoneme ("onset neighbors") show especially strong activation sharing (Marslen-Wilson and Zwitserlood 1989; Vitevitch 2002a; Vitevitch, Armbrüster, and Chu 2004). According to some speech recognition models (TRACE, Shortlist), this is caused by inhibitory connections between words at the lexical level (McClelland and Elman 1986; Norris and McQueen 2008).

Lexical competition in phonological neighborhoods has been suggested to be an important driver of variation in fortis VOT (Nelson and Wedel 2017). Numerous studies have found fortis VOT to become hyperarticulated (i.e., lengthened) in dense phonological neighborhoods (Baese-Berk and Goldrick 2009; Goldrick, Vaughn, and Murphy 2013; Nelson and Wedel 2017). It is assumed that lexical competition leads to an enhancement of acoustical features as speakers try to compensate for speech recognition difficulties caused by dense neighborhoods (Munson and Solomon 2004; Wright 2004). Specifically, higher levels of co-activation shared by the members of a neighborhood as well as slower lexical retrieval speed of words embedded in denser neighborhoods may contribute to VOT hyperarticulation (Baese-Berk and Goldrick 2009). The presence of a minimal pair with a word-initial voicing contrast in a neighborhood – i.e., words that differ only by the word-initial voicing feature like *bat-pat* (henceforth referred to as "minimal pairs") – can lead to even more extreme hyperarticulation as competition is sensitive toward phonetic contrasts (Schertz 2013; Buz, Tanenhaus, and Jaeger 2016; Nelson and Wedel 2017). However, dense neighborhoods may not always lead to hyperarticulation, and contradictory findings have been presented by Gahl and colleagues (2012, 2016) for English, and Valentina and Staszkiewicz Garcia (2019) for Italian. Their research demonstrated that phonetic reduction affects words in denser neighborhoods more strongly. Higher degrees of co-activation from a higher number of neighbors renders the acoustic profile of words more automatized, similar to lexical frequency effects (e.g., Bybee 2002). In this framework of phonological neighborhood effects, words do not adopt unique phonetic features to outcompete neighbors, but neighborhood pressures keep phonetic patterns homogenous across all words (i.e., phonetically reduced in denser neighborhoods).

These findings can be understood in terms of competition theories as known from ecology and economics, where competition can favor but also limit innovation in populations (Pigot and Tobias 2012; Wilson 2014). Strong competition can standardize behaviors of constituents as they vie for a particular resource. In order to gain access, certain behaviors become favored and disseminated in a population. This can resemble a type of niche development or specialization effect (Pearman et al. 2008). In alternative scenarios of competition, constituents may try to reduce the effects of competition by diversifying their behaviors and exploring alternative ways to obtain a resource (Svanbäck and Bolnick 2006). This has the effect of increasing the variance of possible behaviors. Lexical competition in dense phonological neighborhoods may be subject to similar competition pressures, where VOT phonetics are either forced into homogenous acoustic patterns or become diversified in order for individual words to accrue activation and excel over their lexical competitors. The exact factors stipulating phonetic homogenization or diversification remain to be explored.

One crucial piece of information that is highly relevant for a discussion of different competition effects in lexical neighborhoods is the type of speech under investigation. In general, experimentally elicited laboratory speech is known to be more clearly and slowly articulated, and hyperarticulation can be more extreme than in spontaneously occurring speech (de Jong, Beckman, and Edwards 1993; see Smiljanić and Bradlow 2008, for results on conversational speech elicited in laboratory settings). For instance, voiceless VOTs are generally hyperarticulated in clear laboratory speech (as opposed to conversational laboratory speech, see Smiljanić and Bradlow 2008). Research by Gahl and colleagues (2012) suggests that high phonological neighborhood density elicits hyperarticulation only in laboratory speech but not in natural, spontaneous speech, where hyperarticulation is more prevalent in sparser neighborhoods (Gahl, Yao, and Johnson 2012). It is possible that competition effects are different in the two types of speech, possibly due to articulatory differences, such as more constant speech rates in read laboratory speech (Kello and Plaut 2003) and a faster speech rate in spontaneous conversational speech (Bard and Aylett 2005; Adda-Decker and Lamel 2018). In addition, the attention being paid to each token and segment is higher in experimentally elicited isolated utterances than in spontaneous connected speech (Gahl, Yao, and Johnson 2012). Faster and more reduced spontaneous speech may experience weaker competitive pressures, leading to the competition-induced phonetic diversification in sparser neighborhoods (hence hyperarticulation) as described by Gahl and colleagues. The slower and more articulate laboratory speech could raise phonological awareness in speakers, and thus lead to stronger competition effects in denser neighborhoods.

A question that has not been explored so far is the role of lexical competition in phonetic learning. As suggested by the hyperarticulation hypothesis (e.g., Nelson and Wedel 2017), a word with an innovative VOT variant has a competitive advantage by virtue of standing out in a field of competitor words lacking the innovation. The innovative word can accrue the majority of its activation, whilst leaving little co-activation to be spread to its neighbors. Through this, lexical access, recognition, and retrieval of the innovative target word become faster and more efficient. Based on the two prevailing competition theories (see above), there are two scenarios of how phonetic learning could be impacted by neighborhood density / lexical competition. First, strong competitive forces can have the effect of standardizing phonetic patterns in a phonological neighborhood, thereby reducing the chances of an innovative variant becoming introduced and spread. The conservative phonetic standard of the neighborhood is repeatedly reinforced through co-activation, keeping segmental acoustics trapped in its present state and bound to the acoustics of the neighbors. A VOT innovation is less likely to gain a foothold under such circumstances, and we may see a higher likelihood of phonetic novelty in sparser neighborhoods with weaker competition. Second, competition may increase phonetic variance in words because competitors phonetically diverge from one another in order to lessen the effects of competition and carve out a phonetic space for themselves where they can accrue activation. Here, phonetic variation can be seen as a tool to outcompete competitor words and gain an advantage over them with a unique acoustic profile. Eventually the target word refines its acoustic profile and (gradually) moves away from the neighborhood acoustic standard.

The majority of research on phonological neighborhood effects assumes that competition is rather abstract in the sense that any possible segmental difference similarly affects it (e.g., Luce and Pisoni 1998; Vitevitch and Luce 1998: Storkel 2002, Vitevitch and Luce 2016). According to this account, competition acts before the initiation of phonetic encoding – the mapping of an utterance onto speech motor programs for articulation (see, e.g., Laganaro 2019). In this theoretical framework, the words *bat* and *cat* compete with one another and spread co-activation among the shared segments. Alternative theoretical accounts of lexical competition accommodate the serial encoding of segments and posit that competition acts chronologically on a segment-by-segment basis (Marslen-Wilson and Zwitserlood 1989; Fricke 2013). Competition arises and is resolved at the segmental level, with *bat* and *ban* competing with each other for the duration of the first two segments but *bat* and *cat* not being competitors. Phonetic similarity in phonological neighborhoods adds another layer of complexity, as phonetic relationships become part of the competition equation. A common way to test how phonetics impact lexical competition is the analysis of voice-contrasted minimal pairs. Competition may cause hyperarticulation in the minimal pairs in order to increase their discriminability ("contrast-driven hyperarticulation", Baese-Berk and Goldrick 2009; Peramunage et al. 2011; Kirov and Wilson 2012; Schertz 2013; Buz, Tanenhaus, and Jaeger 2016; Nelson and Wedel 2017). Thus, the exact phonological locus of lexical competition is a crucial criterion for theoretical accounts of how competition unfolds in a phonological neighborhood.

The present study was designed to shed light on the relationship between lexical competition and the learning of aspiration in a foreign language. Specifically, we focus on phonological neighborhood density and the advancement of aspiration acquisition in two learner groups of English as a foreign language: laboratory speech of Austrian and natural spontaneous speech of Czech learners of English. The results of this study can help understand how new phonetic variants are disseminated in a learner's lexicon and inform about phonological neighborhood characteristics that are most conducive to learning. The following research questions are posed:

1. Which neighborhoods (dense, sparse) show the most advanced rate of aspiration production by learners?
2. What is the effect of onset neighbors on the production of aspiration?
3. What is the effect of minimal pairs on the production of aspiration?
4. Do neighborhood effects hold across different EFL speaker groups and type of speech?

2 Methods

2.1 Participants

We recruited 21 Austrian students of English at the University of Vienna during the academic year 2018/19 for a reading task in their foreign language English. The Austrian data was experimentally elicited (= laboratory speech). Data from Czech students of English Studies at Charles University in Prague (during the academic years 2012, 2013, and 2014) were obtained from the Czech Lindsei Corpus ("LINDSEI_CZ", see Gráf 2017). Speech was elicited in the form of semi-structured interviews and is regarded as natural conversational speech (= spontaneous speech). English proficiency levels of all participants were B2 or higher (with C1 representing the majority), according to the Common European Framework of Reference for Languages (Council of Europe 2018). The Czech Lindsei Corpus includes information on the proficiency levels of the speakers; the Austrian students self-assessed themselves based on previous proficiency tests they had taken at their university. All participants were between 19 and 27 years of age. They gave written consent to have their data used for linguistic experimentation.

2.2 Data Collection

2.2.1 Austrian Laboratory Speech

A total of 12 fortis-initial nouns were selected from a larger dataset of laboratory speech that focused on English word-initial plosive consonants produced by Austrian speakers (see Luef and Resnik, in press, for details). Data were elicited in a sentence reading task consisting of over 80 short English sentences and phrases, read once at a comfortable speed and in the same order by each participant. The target words selected for the present study were fortis-initial monosyllabic nouns, placed in sentence-initial position (and preceded by a pause) in their carrier sentences (e.g., *Cats are active at night*). All three places of articulation were included (bilabial, alveolar, velar), and plosive combinations with three vowel types were possible: high vowels ([i, ɪ]), mid vowels ([e, ɛ, æ, ʌ]), and low vowels ([a, ɑ, ɒ]). Consecutive sentences did not contain target words starting with the same plosive. In order to minimize habituation effects of the plosives and their acoustic patterns, participants rated the level of difficulty of each sentence in their first language as easy, medium, or difficult (German: *leicht, mittel, schwer*). See Table A1 in the appendix for an overview of the carrier sentences. A ZoomH4n digital audio recorder and a Sennheiser ME67 microphone were used for the recordings, and speech was sampled at a rate of 44.1 kHz and 16-bit depth. The sample size for the Austrian models was 251 tokens, involving 12 types, and 21 speakers.

2.2.2 Czech Spontaneous Speech

A total of 47 fortis-initial mono-syllabic nouns of all three places of articulation were cut from the spontaneous speech of 34 participants in the corpus data. In order to achieve a comparative sample size to the Austrian data, we had to include a larger number of types. Due to the rarity of nouns in sentence-initial or phrase-initial position in the corpus (whole sentences are rare in spontaneous speech), target nouns could appear in any sentence position. Target words started with bilabial, alveolar, and velar word-initial plosives, followed by either high vowels ([i, ɪ]), mid vowels ([e, ɛ, æ, ʌ]), or low vowels ([a, ɑ, ɒ]). Words appearing in obstruent clashes were removed (e.g., "best type", "his teeth"), and high-frequency phrases, such as "kind of", were also excluded from the sample as they can show extreme phonetic reduction in connected speech. The sample size for the Czech models was 155 tokens, 47 types, and 34 speakers.

2.3 Procedure

Target words were manually cut from the audio files and further processed with the Praat acoustic software (Boersma and Weenink 2019). Two annotation tiers were established: one for overall word duration and one for VOT of the word initial plosive. Durations (in seconds) were extracted with an automated script. The burst of the stop was identified as the start of VOT and overall word duration (Abramson and Whalen 2017). The onset of glottal pulsing, indicated by visible pitch on the spectrogram (pitch settings: 100–600 Hz for women, 75–300 Hz for men; see Vogel et al. 2009), was treated as the end of VOT. The end of overall word duration was marked when the waveform cycle had ceased and the sound was completely faded (see Figure 2).

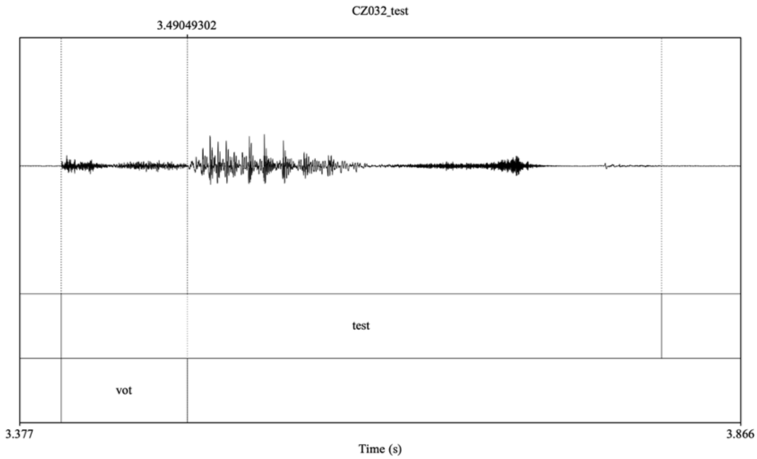

Figure 2. Example annotation of the target word "test" as produced by a Czech speaker.

Two coders compared annotation judgements of 5% of the data and they agreed at a level of Pearson's r = 0.99 (root mean square error / RMSE = 0.02) for word durations and r = 0.71 (RMSE=0.01) for VOT onset. In order to normalize word durations and VOTs for speech rate, an individual speech rate per syllable was calculated for each participant. To do this, three text / speech-medial sentences (that were filler sentences in the Austrian sample and not in close proximity to the target words in the Czech sample) were measured in terms of their durations (sum of all word durations) and divided by the total number of syllables per sentence (see Jacewicz et al. 2009). This speech rate value was then multiplied with all word durations and VOT measurements per participant and later converted to milli-seconds by multiplying it by 1,000. The Austrian part of the study was approved by the Internal Review Board of the first author's former university (Seoul National University) under IRB No. 1710/002-002.

a. Variables

Neighborhood density measures were based on the database of L2-English phonological neighborhood data previously compiled by Luef (2022). The C1 level was selected for the present study and all phonological neighbors of target words at that proficiency level were extracted. Onset density was obtained by manually sorting the phonological neighbors and counting the ones sharing the word-initial plosive within a given neighborhood. Similarly, the presence of a minimal pair word differing in the word-initial plosive voicing contrast (e.g., *ghost – coast*) was checked manually.

English lexical frequency rates (token frequency) and plosive frequency rates were calculated with *Clearpond for English* (Marian et al. 2012) and subsequently z-scored before analysis. Vowels were categorized according to their articulatory position as high, mid, or low (Ladefoged 2001).

b. Statistical Models

Linear mixed models are extensions of linear regression models containing both fixed effects and random effects (Bates et al. 2014). They have become an increasingly popular method of analyzing data in which participants respond to multiple items (Brown 2021).

Different linear mixed models were run to test the influence of the independent variables – (a) phonological neighborhood density, (b) onset density, and (c) minimal pair presence – on the (normalized) VOT duration in word-initial plosives. The following control variables that have been documented to have an effect on VOT were included: lexical frequency rate, (onset) plosive frequency, word duration (in ms), and type of vowel that immediately follows the onset plosive. As random effects, the identity of the participant ("ID") and "word" were included. To keep type I error at the nominal level of 0.05, we further included random slopes of all fixed effects for "ID" and "word" (Schielzeth and Forstmeier 2009; Barr et al. 2013). As an overall test of the influence of the fixed effects, a likelihood ratio test was conducted (Dobson 2002; Forstmeier and Schielzeth 2011), and the full model was compared with a respective null model that lacked a specific fixed effect but was otherwise identical to the full model. The significance of individual fixed effects was tested by comparing the full model with a respective reduced model lacking the effect to be tested. Collinearity was not an issue, with maximum generalized variance inflation factors below 3 in the Austrian sample and below 2.3 in the Czech sample (Fox and Monette 1992; Field 2005). Different models were calculated with the Austrian laboratory data and the Czech spontaneous speech data. All models were implemented in R (RStudio Team 2020) using the function *lmer* of the package *lme4* (Bates et al. 2014). Collinearity diagnostics were obtained with the package *car*; R-squared values for all models were obtained with the package *MuMIn*.

3 Results

In both laboratory Austrian and spontaneous Czech speech, the duration of fortis VOT increased from bilabial to alveolar to velar plosives. Aspiration was most advanced in velar plosives, and spontaneous Czech speakers produced bilabial and alveolar fortis plosives with more aspiration than laboratory Austrian speakers (see Figure 3).

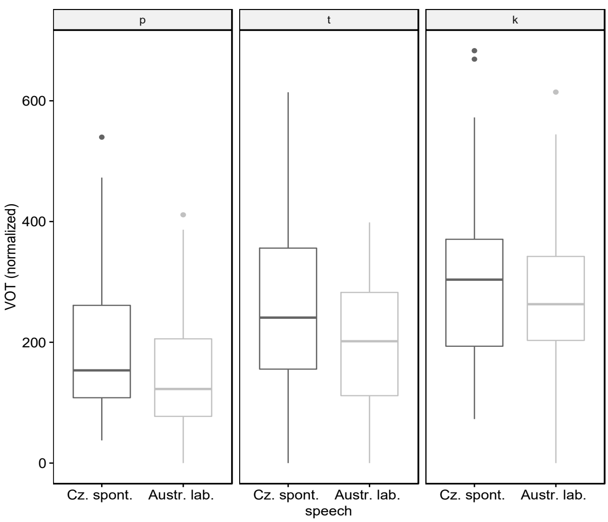

Figure 3. Bilabial plosives show the shortest, velar plosives the longest VOTs. Czech spontaneous speech was characterized by higher aspiration values.

In laboratory Austrian speech, neighborhood density and minimal pair presence, but not onset density, were significant predictors of VOT duration in fortis plosives (see Table 1).

Table 1. Results of the laboratory speech (Austrian) linear mixed effects model.

Predictors	Estimate	SE	t	χ^2	p
(Intercept)	211.75	64.11	3.3		
Lexical frequency	12.95	4.77	2.7	4.44	0.035*
Plosive frequency	-77.43	21.25	-3.64	5.96	0.015*
Word duration	227.8	181.79	1.25	1.18	0.28
Vowel	-10.28	14.9	-0.69	0.52	0.47
Neighborhood density	-6.04	3.92	-1.54	9.66	0.0018**
Onset density	0.79	8.48	0.1	0.01	0.93
Minimal pair presence	74.6	31.46	2.37	3.92	0.047*

Marginal R^2=0.16, conditional R^2=0.51

Specifically, sparse neighborhoods showed longer VOT durations, and were thus indicative of improved aspiration production (see Figure 4).

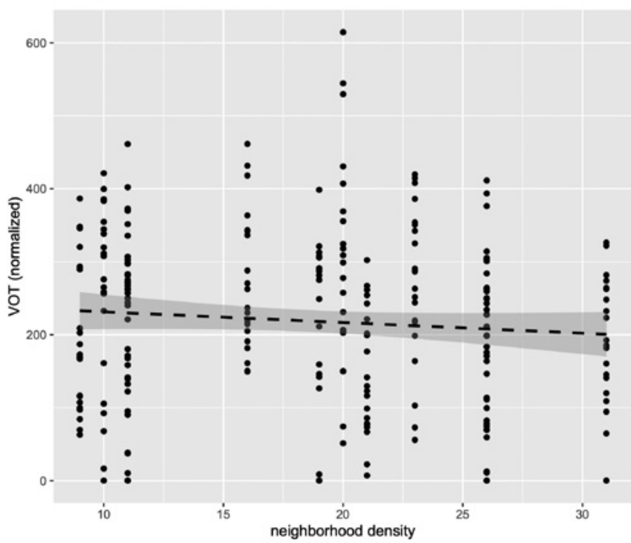

Figure 4. The dotted linear regression line (with confidence intervals) shows that aspiration was more progressed in sparser neighborhoods in laboratory Austrian speech.

Neighborhood density was not significant in the spontaneous Czech speech sample (see Table 2), but onset density and minimal pair presence had an effect on aspiration (see Figures 5 and 6).

In spontaneous Czech speech, sparser onset neighborhoods proved to be more conducive to the advancement of aspiration (see Figure 5).

Table 2. Results of the spontaneous speech (Czech) linear mixed effects model.

Predictors	Estimate	SE	T	χ^2	p
(Intercept)	176.39	54.79	3.22		
Lexical frequency	22.14	10.92	2.03	2.84	0.09
Plosive frequency	-20.27	11.89	-1.7	1.95	0.16
Word duration	72.22	16.76	4.3	9.89	0.002**
Vowel	-42.6	38.26	-1.11	2.19	0.33
Neighborhood density	5.44	2.88	1.89	2.87	0.09
Onset density	-12.75	4.95	-2.58	5.78	0.016*
Minimal pair presence	-54.59	21.1	-2.59	3.6	0.05*

Marginal R^2=0.17, conditional R^2=0.57

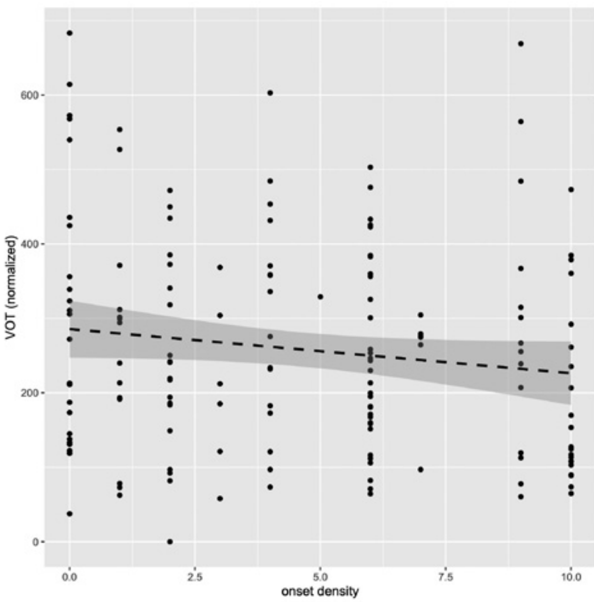

Figure 5. The dotted linear regression line (with confidence intervals) shows that aspiration was more advanced in sparse onset neighborhoods in spontaneous Czech speech.

In both laboratory Austrian and spontaneous Czech speech, the presence of minimal pairs differing in the voicing contrast in the word-initial plosive affected the progression of aspiration, with aspiration being more advanced in neighborhoods without minimal-pair neighbors (see Figure 6).

Minimal pair presence affected laboratory Austrian speech to a larger degree: VOT in spontaneous Czech speech did not differ between minimal-pair and no-minimal-pair neighborhoods (Wilcoxon: W=4426, p=0.7), whereas laboratory Austrian speech differed significantly between the two neighborhood conditions (W=5045, p=0.0002). These findings are in agreement with the competition-induced hyperarticulation hypothesis of laboratory

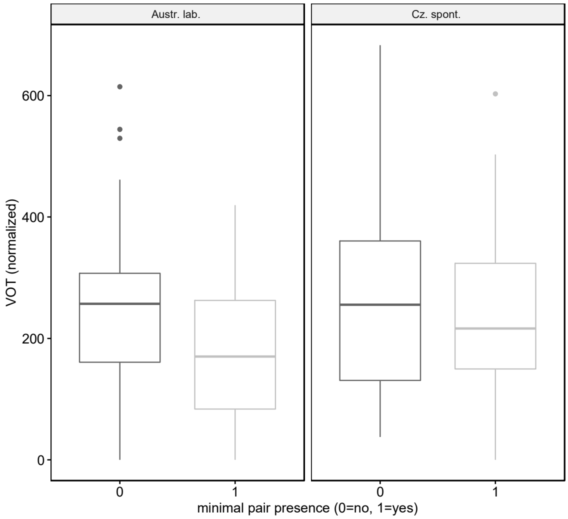

Figure 6. Aspiration was generally more advanced in neighborhoods without minimal pairs ("0") differing in the word-initial voicing contrast in Austrian laboratory and Czech spontaneous speech.

speech being more strongly affected by competition effects (e.g., Gahl, Yao, and Johnson 2012). A post-hoc analysis demonstrated that the spread of the VOT data was different for the two types of minimal pair neighborhoods (see Figure 7).

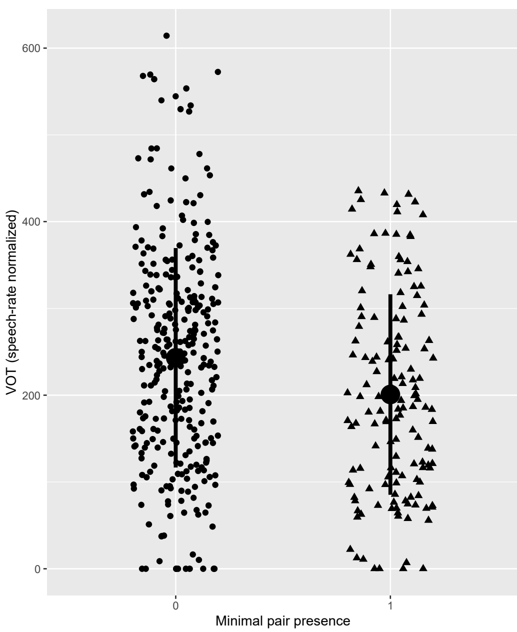

Figure 7. Spread of the VOT data in neighborhoods with ("1") and without ("0") minimal pairs (Austrian and Czech data pooled).

4 Discussion

This study investigated the effects of phonological neighborhood density on the progression of aspiration of word-initial plosives in two groups of EFL learners (speakers of Austrian German and Czech) using different types of speech (laboratory, spontaneous). It was shown that sparse (onset) neighborhoods provide a better learning environment for aspiration acquisition. The presence of a minimal pair within a neighborhood also had an effect, with minimal pairs providing a worse learning environment for the acquisition of aspiration. The results of the two study groups showed similarities, but also some differences.

The results obtained from the Austrian speakers show that a low number of phonological neighbors facilitated the advancement of aspiration in target words. It is known from previous literature that phonological neighborhood effects in speech production generally lead to the strengthening of articulation-relevant features of phonological representations (Vitevitch 2002b). As a result, phonological segments are produced faster and phonetically more accurately in denser neighborhoods (Vitevitch 2002b). One could assume that such neighborhoods facilitate phonetic learning. However, this was not reflected in our results. We hypothesize that the spreading of phonetic co-activation in denser neighborhoods creates a homogeneity bias that forces co-activated segments to a stricter adherence to the phonetic standard form that is constantly reinforced through joint activation. Phonetic deviation is less likely to become established and spread in these neighborhoods. Conversely, low-density neighborhoods are characterized by less co-activation among segments and thus novel phonetic features may more easily be introduced and disseminated. The reduced lexical competition in sparse neighborhoods could allow improved implementation of the aspiration feature.

In spontaneous Czech speech the neighborhood density effect that we observed was restricted to onset neighbors. Similar to what was found for "regular" neighborhoods in Austrian speech, low density in Czech speakers predicted better implementation of aspiration in word production. Previous literature indicates that phonological onset neighbors share more co-activation with one another (Marslen-Wilson 1987), and the activation levels in a neighborhood influence the strength of the phonological links (Vitevitch 2002a). Czech speakers seem to pay more phonological attention to onset segments and may have the phonetic variants of the onsets more deeply engrained. A consequence of this is less flexibility to incorporate new features. Words residing in low-onset-density neighborhoods receive less co-activation from the fewer onset neighbors, providing a more inclusive environment for phonetic change.

Our findings demonstrate that lexical competition effects are similar in different groups of speakers and in different types of EFL speech. Specifically, less competition – demonstrated through sparser phonological neighborhoods – provides an advantage in terms of the acquisition of novel phonetic features. Reduced segmental co-activation puts less standardizing pressure on segments, and this could result in greater phonetic freedom for the segments, hence phonetic innovation can be introduced and spread more easily.

What could have played a role in the different neighborhood effects shown for our two study groups are various differences between laboratory and spontaneous speech. First, spelling biases exert larger influence in reading tasks (Damian and Bowers 2003; Cutler, Treiman, and van Ooijen 2010; Bauch, Friedrich, and Schild 2021), with inconsistent phoneme representation causing a recognition delay (such as in the present study /k/ being represented by <c> or <k>). In addition, articulatory planning and phonological encoding (i.e., the process of sequentially constructing the phonological form of a target token before articulatory gestures can be prepared in spoken word production) tend to work differently in read and spoken language (Castles and Coltheart 2004; Ganushchak and Chen 2016). Greater reliance on auditory cues in spoken language may put the phonological focus on the serial assembly of phonological units and thus the onset segments, hence the onset neighborhood effect in the Czech spontaneous speech sample. The differences in neighborhood effects between our two groups may, of course, also be the results of first-language transfer effects. Follow-up studies should investigate EFL speakers of other non-aspirating languages to see whether our findings can be generalized to other populations. Furthermore, comparing Austrian spontaneous speech to Czech laboratory speech may also yield interesting insights that can help further our understanding of neighborhood effects and aspiration acquisition.

Our two study groups showed striking similarities concerning aspiration in neighborhoods with a voice-contrasted minimal pair. Both Austrian laboratory and Czech spontaneous speakers showed more progressive aspiration when neighborhoods did not include a minimal pair word. As first language research has shown, competition-associated hyperarticulation is often more pronounced in minimal-pair-containing neighborhoods, since phonetic discrimination is especially important in this context (Nelson and Wedel 2017). This means that minimal pairs are subject to competition pressures that shape their features in a way that magnifies phonetic contrast. While this was not directly confirmed by the present results, it is possible that the absence of hyperarticulation-furthering pressure frees up word forms to adopt novel phonetic patterns and increase phonetic variation in a neighborhood. More variation could mean a higher likelihood of introducing a new phonetic feature. Support for this assumption stems from the fact that range and variance of VOT was higher in the neighborhoods without minimal pairs (see Figure 7). It seems that minimal-pair neighborhoods are characterized by a higher degree of phonetic homogeneity, an assumption in line with the contrast-enhancing lexical competition hypothesis outlined earlier (e.g., Baese-Berk and Goldrick 2009; Nelson and Wedel 2017).

Our findings indicate that phonetic learning of aspiration is not equally diffused among all words in a foreign language lexicon but is dependent on the characteristics of the phonological neighborhoods in which words are embedded. Lexical competition seems to play a role in phonetic dissemination, and relaxed lexical competition (i.e., sparser phonological neighborhoods) allows a greater degree of phonetic variation, which ultimately aids the learning of novel phonetic detail. The fact that our findings are largely generalizable to different speaker groups and speech types underscores the significance of lexical competition in foreign-language phonetic learning.

Future studies should focus more closely on the relationship between phonetic variation and lexical competition during the build-up of phonological neighborhoods in foreign language learners. As neighborhood densities change over the course of word learning, some neighborhoods may turn out to be more prone to the incorporation of new phonetic detail, whereas other may be more resistant. An unequal phonetic diffusion in the mental lexicon can have implications for lexical processing (recognition, retrieval, production) at various stages of language learning.

5 Conclusion

The present study demonstrated that phonological neighborhood characteristics play a role in the introduction and dissemination of novel phonetic detail in the lexicon of foreign language learners. Phonological neighborhood density, onset neighborhood density, as well as the presence of voice-contrasted minimal pairs in a neighborhood all affected the degree of aspiration production in both spontaneous Czech and laboratory Austrian EFL speech. This argues for the involvement of lexical competition effects in phonetic learning where activation competition impairs the diffusion of phonetic innovation, possibly due to stronger phonetic conformity biases exerted by denser phonological neighborhoods.

Data Availability

The data underlying the analyses can be accessed at: http://hdl.handle.net/11234/1-4915.

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Appendix

Table A1. Carrier sentences for the Austrian data. Target words are in initial position.

1.	Cans have to be recycled.
2.	Cats are active at night.
3.	Cups you can find in the upper left shelf.
4.	Kids have to go to school.
5.	Kings of England.
6.	Kiss for you, kiss for me.
7.	Pets are not allowed in the apartments.
8.	Pills are generally prescribed by your doctor.
9.	Punch contains a lot of sugar.
10.	Tests will not be written this semester.
11.	Ticks carry lots of diseases.
12.	Tins have to be recycled.