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Aspects of change in New York City English short-a

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ABSTRACT

This article focuses on change in the "short-a system" of New York City English (NYCE). Recent results suggest that a complex set of tensing rules traditionally described for NYCE are being replaced by several simpler systems. This article reports on a study of this change using a recently developed large audio-aligned parsed speech corpus (CoNYCE). This change is similar to the simplification reported for Philadelphia by Labov et al. (2016). Unlike in the Philadelphia case, however, our results do not show evidence of a single abstract process of change. Our findings, rather, suggest at least two separate changes in the community—one affecting short-a in prenasal contexts and a second affecting pre-oral obstruent contexts. In addition, the results suggest an additional independent process of lowering and retraction affecting short-a sounds in contexts not targeted by the process of phonological reorganization, that is, "TRAP-backing."

This article focuses on change in the "short-a system" of New York City English (NYCE)[1]—the set of phonological conditions on vowel quality in words like *bag*, *hat*, and *bang*. Like most North American English dialects, NYCE has variation between "lax" (backer, shorter, and usually lower) and "tense" (fronter, longer, and usually higher) realizations of short-a, so-called because they largely descend from the short Middle English /a/. The phonological (and lexical) conditions governing tensing versus laxing, however, vary considerably across dialects (Labov, Ash, & Boberg, 2005). Recent literature on NYCE has reported evidence suggesting that this traditional system is being replaced by several simpler and less regionally specific systems (Becker, 2010; Becker & Wong, 2010; Coggshall, 2017; Newlin-Łukowicz, 2015, 2016; Newman, 2014; Shapp, 2018). This article reports on a study of this change using data recently

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produced through the CUNY Corpus of New York City English (CoNYCE) project, now the single largest speech corpus of New York City English specifically developed for linguistic analysis (Tortora, Cutler, Haddican, Newman, Santorini, & Diertani, in progress). In particular, this paper makes three main claims about this process of change.

First, unlike short-a change in Philadelphia English (PhilE) as described by Labov, Fisher, Gylfadóttir, Henderson, and Sneller (2016) and Sneller (2018), our results do not suggest a single abstract process of change from the traditional system to a nasal system, that is, system-level competition. Rather, our results suggest that change to the nasal system involves (minimally) two separate processes of change—one affecting change in pre-oral obstruent contexts, and a second affecting short-a in pre-nasal contexts.

Second, we present evidence that the set of recent results suggesting change in the short-a system cannot be exclusively attributed to parent L1 effects. Importantly, with the exception of Newlin-Łukowicz (2015, 2016), none of the recent studies suggesting change in NYCE short-a have taken into account parent L1 in sampling independent of ethnicity, despite previous evidence of parent L1 effects on short-a acquisition in different dialects (Labov, 2007; Payne, 1976, 1980). Our results suggest that, even among self-identified White participants with two NYCE-native parents, the traditional tensing rules are subject to age effects. Similarly, ethnicity effects reported in recent literature appear to be partially independent of parent L1 effects.

Third and finally, our results reveal an additional, orthogonal change affecting short-a sounds among the youngest speakers in our sample. In particular, short-a sounds in contexts not implicated in the phonological reorganization to a nasal system—for example, those preceding voiceless stops and tautosyllabic front nasals—are undergoing lowering and retraction "TRAP-backing." This process correlates across speakers with LOT backing (Kendall & Fridland, 2017). Social correlates of this change are somewhat distinct from those involved in the phonological shift to a nasal system.

The discussion is organized as follows. In the following section, we describe the traditional tensing systems and review previously reported evidence for age, class, and ethnicity effects on tensing rules. Subsequent sections describe the data reported and discuss the results of the analysis.

THE TRADITIONAL SYSTEM AND ITS INNOVATIVE COMPETITORS

The NYCE short-a system of the nineteenth and twentieth centuries has been characterized formally in two different ways. Most commonly, the system has been described as involving a phonemic difference between lax TRAP and tense BATH, in light of minimal pairs such as noun *can* (tense) versus stressed auxiliary *can* (lax), *adds* (tense) versus *adze* (lax), and *Abby* (tense) versus *abbey* (lax), as well as lexical exceptions to tensing rules including tense *ask* and *after*, (Kaye, 2012; Labov, 2001; Labov, 2007; Labov et al., 2005; Trager, 1934, 1940). Labov, Yaeger, and Steiner (1972), Halle and Mohanan (1985), and Benua (1995), on the other hand, described it as an allophonic difference in view of the fact that the distribution of the two sounds in this system is in fact largely predictable from a complex set of rules, likely related to the emergence of the split.[2]

The NYCE short-a pattern is one of a number of split systems found along the US East Coast from Providence to Baltimore (Labov et al., 1972), and in New Orleans (Carmichael, 2020). Durian (2012), however, argued that it was once much more widespread, encompassing Eastern varieties at least as far west as Ohio. In these outlying regions, it has now been replaced by a simple allophonic distribution where tense forms occur only and always before nasals, the so-called "nasal system." From this perspective, the NYCE split could be considered a conservative remnant of a previously widespread pattern. In any case, the US split systems appear related to the southern British and Antipodean TRAP/BATH splits. Of course, those versions, along with a remnant found in Eastern New England, show a backing of BATH instead of the tensing found in North America. This widespread cross-dialectal variation and the diachronic geographic shrinkage discussed by Durian suggests the split is relatively unstable at least in the US.

Following Coggshall (2017), we will refer to this traditional NYCE system as the "Tragerian" system, after George Trager, who provided one of the first detailed descriptions of these facts (Trager, 1930, 1934, 1940). The details of this system are complex and subject to considerable variability (see Coggshall [2017] for an extensive overview). Here, we focus on three of the main properties of the Tragerian system that will be most relevant for the analysis to follow.

Following sound and syllable structure

The most important set of conditions for our purposes concerns the interaction of following sound and syllable structure. In particular, as the system is typically characterized, tensing is triggered in closed syllables with following voiceless fricatives, voiced stops, voiced affricates, and front nasals. Elsewhere contexts including all open syllables are lax.[3] This is schematized in Figure 1, where the shading indicates the set of following consonants triggering tensing. Importantly, this set of conditions only applies to closed syllables. Short-a in open syllables is, in the general case, lax regardless of following sound, such that the stressed vowels in *cannibal*, *hammer*, and *saddle* are lax, while closed-syllable counterparts (beer) *can*, *ham*, and *sad* are tense.

Morphological boundary

Morphological operations that affect syllable structure may or may not feed the tensing rules just described. For instance, the vowel in the progressive verb form *canning* typically remains tense despite the fact that it sits in an open syllable, because the syllable is open by virtue of concatenation of *-ing*. Similarly, short-a vowels in syllables closed by truncation (*Cameron* > *Cam*) typically remain lax. Labov (2007) characterized this constraint as limited to inflectional morphological

	Labial	Interdental	Alveolar	Postalveolar	Velar
Voiceless stops/affricates	p		t	tʃ	k
Voiced stops/affricates	b		d	dʒ	g
Nasals	m		n		ŋ
Voiceless fricatives	f	θ	s	ʃ	
Voiced fricatives	v	ð	z	ʒ	
Liquids			l	r	

FIGURE 1. The effect of following sound on short-a tensing in closed syllables under the Tragerian system (adapted from Labov [2007]). Shading indicates sounds triggering tensing.

processes, though Trager (1934) described the condition as applying to "derivational or inflectional suffix[es]," and Labov (2001:335) described the effect of derivational boundaries as "variable." In our dataset, open syllables formed by derivational morphology generally pattern with monomorphemic open syllables and have been treated as such in the analyses below.

Preceding word boundary

Short-a vowels in word-initial position are lax, even in closed syllables with a following sound that otherwise triggers tensing pursuant to Figure 1, as for example lax *absolute*, *athlete*, *ash*. Lexical exceptions to this rule include high frequency *ask*, *after*, and, for many speakers, *avenue* and *answer*.

Several descriptions from the last decade of work on NYCE have reported evidence of change away from the Tragerian system (Becker, 2010; Becker & Wong, 2010; Coggshall, 2017; Newman, 2014; Shapp, 2018). In particular, Becker and Wong (2010) reported that the Tragerian system is being lost to a simplified system common in many parts of the US, where tensing applies before a following nasal, unconditioned by syllable structure, as in (1).

(1) /æ/→ tense / _____ [nasal]

We illustrate the contrast between the two systems in the F1~F2 plots in Figure 2. The left panel of this plot (a) shows tokens by context for an older White man, originally from Brooklyn. The plot shows a fairly clean distinction in acoustic space between the Tragerian tensing contexts (*ask/after* and closed syllables with a following voiceless fricatives and voiced stops/affricates) and laxing contexts (contexts preceding velar nasals and all other laxing contexts). By contrast, the right panel, showing data from a younger African American

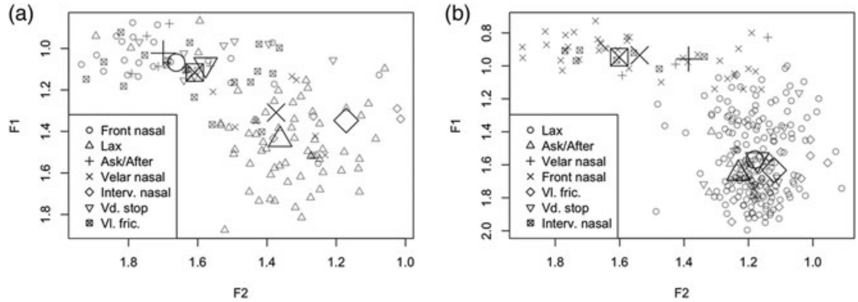

FIGURE 2. F1 ~ F2 plots illustrating two short-a systems. Here, ‘Interv. Nasal’ indicates intervocalic nasal contexts, ‘Vl. Fric.’ indicates following voiceless fricative contexts, and ‘Vd. Stop’ indicates following voiced stop contexts. Panel (a) illustrates the traditional Tragerian system. Panel (b) illustrates the innovative nasal tensing system. The smaller circles represent individual tokens. Larger, darker circles represent context mean values.

woman, shows a pattern described by (1)—tense realizations before nasal sounds and lax elsewhere.

Importantly, Becker (2010) and Coggshall (2017) noted that the nasal system represented by (1) is not the only innovative pattern attested in recent datasets. In particular, Becker (2010) described speakers showing a “continuous” pattern with a hierarchy of tensing environments headed by following nasals and a “single allophone” pattern with little differentiation across contexts. We return to these issues in the discussion below.

DATA

The data presented below were gathered through the CoNYCE corpus project, which, when completed, will make publicly accessible an approximately one million-word audio-aligned and parsed corpus of New York City English (Tortora et al., in progress). The subsample discussed here consists of audio recordings of ninety-seven speakers with years of birth ranging from 1906 to 2001 ($M = 1971$). Of the ninety-seven speakers, fifty-eight self-identified as women and thirty-nine as men. Subjects were coded for occupational prestige on a five-point scale following Baranowski and Turton (2018).[4] Subject data were also coded for whether subjects’ parents were themselves native speakers of New York City English, based on parents’ L1s, and where the parents were raised, as reported by the subjects. Using these data, twenty-nine of the ninety-seven subjects were coded as having two NYCE-native parents. A summary of subject demographic information is provided in Table 3 in the appendix.

The recordings analyzed come from two main sources. Ninety-one subjects were recorded between 2015 and 2018 using standard sociolinguistic interviewing techniques (Labov, 1972, 1984). The interviews, typically lasting between thirty minutes and an hour, followed a template structured around childhood narratives and change in local neighborhoods, concluding with a series of questions on perceptions of linguistic difference within the community and short read-alouds (not included here).[5] The interviews were conducted by City University of New York (CUNY) undergraduate students in linguistics coursework trained by the project PIs. All but a handful of the CUNY undergraduate researchers involved in the project grew up in the New York City area and resided there at the time of recording. Interview subjects were recruited by the undergraduate researchers in their home communities, based on sampling criteria provided by the project PIs. All participants reported having lived since the age of nine within the New York City dialect area defined for our purposes as the five New York City boroughs, western Long Island, and the narrow strip of northeastern New Jersey between the Meadowlands/Hackensack River and the Hudson (Coggshall, 2017; Labov, 1966; Newman, 2014). These recordings were made using Zoom H4N digital recorders at a sampling rate of 44100 Hz.

In addition, six audio samples are oral histories recorded through Bronx Oral History Archive (BOHA) project, which has been incorporated into the CoNYCE project. The BOHA dataset was recorded in the 1980s with analog recorders and has subsequently been digitized.[6] From this dataset we included only subjects for whom we could recover relevant biographical information.

Using a transcription protocol based on English orthography designed by the project PIs, student researchers transcribed recordings in Praat, where utterances were time-aligned with the speech signal. Transcriptions were subsequently checked by graduate research associates. A total of 16,589 short-a vowel tokens bearing main word stress were measured using FAVE Extract (Rosenfelder, Fruehwald, Evanini, Seyfarth, Gorman, Prichard, & Yuan, 2014) and Prosodylab-Aligner (Gorman, Howell, & Wagner, 2011), using the DARLA interface (Reddy & Stanford, 2015). Each individual lexical item was coded by native speakers of the traditional system as phonemically lax versus tense.[7] In addition, all tokens of *and*, even those bearing focal stress, were excluded from the analysis.

The data were normalized using Watt & Fabricius' modified procedure (Fabricius, Watt, & Johnson, 2009). In an effort to model the fact that tensing involves acoustic correlates for both F2 and F1, in the analyses presented below the dependent measure, unless otherwise specified, will be $F2_{normalized}$ - $F1_{normalized}$, the "front diagonal." Higher values for this measure will therefore reflect tenser realizations in acoustic space.

RESULTS AND DISCUSSION

Replicating age and ethnicity effects

We begin by replicating core results for social effects on short-a described in recent literature, particularly Becker (2010), Becker and Wong (2010), Coggshall (2017), and Shapp (2018, 2019).

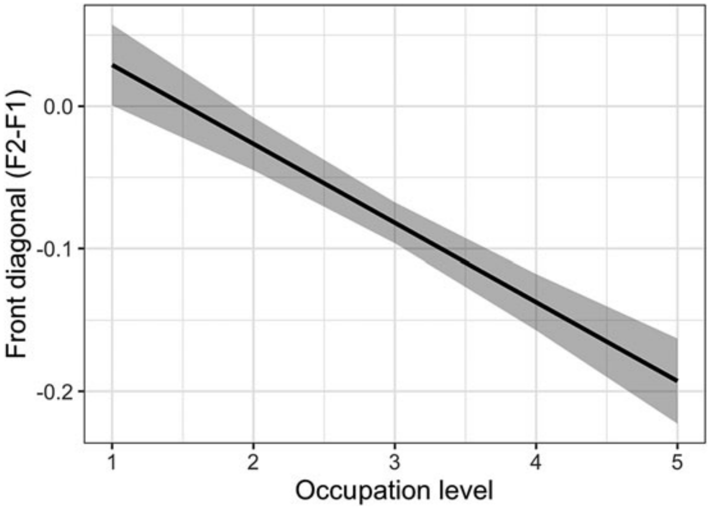

FIGURE 3. Model estimates for occupation level, based on the whole sample. Here and in figures below, the Front diagonal refers to normalized F2-F1. For occupational levels, 1 = Unskilled laborers; 2 = skilled laborers; 3 = lower white collar, retail, and current university students; 4 = lower professionals, including teachers, engineers, and manager; 5 = higher professional occupations.

We first present estimates from a baseline model of short-a tensing from the full sample (ninety-seven subjects, $n = 16{,}163$).[8] Figure 3 shows model estimates from occupation prestige level. It shows that subjects at lower occupational levels tend toward tenser realizations compared with subjects higher on the occupational prestige scale. Importantly, the analysis revealed no interaction with tensing context, suggesting that occupational level is related to short-a sounds as a class, a result that we return to shortly.

More important for the focus of our discussion is that our results reveal an interaction between subject age and tensing context, replicating a core result from Becker (2010) and Becker and Wong (2010). We illustrate this in Figure 4, which shows by-subject loess smoothers for mean front diagonal values by subject birthyear and tensing context. As expected from the perspective of these previous results, older subjects tend toward tenser realizations in (nonnasal) Trager-tensing contexts, and laxer realizations in contexts preceding velar nasals and intervocalic nasals. Over the time-period covered in the sample, these effects shift such that younger speakers show tense realizations in all prenasal contexts and lax realizations elsewhere including contexts preceding voiceless fricatives and voiced stops. In addition, as shown in Figure 4, younger speakers tend toward laxer realizations than their elders even in contexts not implicated in the phonological reorganization discussed above, that is, in Trager lax contexts and in contexts preceding a tautosyllabic front nasal. In other words, similar to the occupational prestige effect just described, there appears to be a lowering change affecting the set of short-a sounds as a class. We return to this result shortly.

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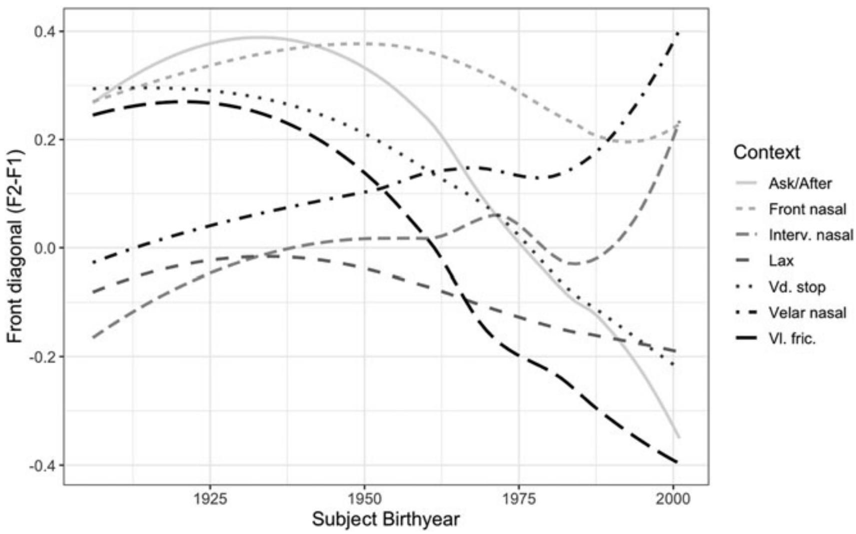

FIGURE 4. Loess smoothers for mean F2-F1 values by subject birthyear and tensing context. 'Interv. Nasal' indicates intervocalic nasal contexts, 'Vl. Fric.' indicates contexts preceding voiceless fricatives, and 'Vd. Stop' indicates contexts preceding voiced stops.

Also notable in Figure 4 are similar smoother shapes for several of these contexts. In particular, the smoothers for *ask/after*, voiceless fricative, and voiced stop contexts, show a similar trajectory with the change beginning in earnest for subjects born in the 1950s. To assess more accurately the onset of this change, we fit a series of models with breakpoints, fitting two different slopes for subject year of birth—one before a given year of birth in the sample (1906–2001) and one after. One model was fit for each year of birth in the sample. The birthyear model with the smallest total deviance between fitted and observed values then serves as a measure of the point of inflection for the change (Baayen, 2008). For the three main Trager-tensing contexts undergoing laxing—*ask/after*, prevoiceless fricative, and prevoiced stop contexts—this analysis reveals an optimum breakpoint at year of birth 1955, as reflected in the smoother shapes in Figure 4. Also similar are the smoothers for the two Trager lax contexts undergoing raising in this process of change—those preceding intervocalic front nasals and velar nasals. Importantly, the principal point of inflection for the latter two contexts undergoing raising is later than that for the preoral obstruent contexts undergoing lowering. The breakpoint modeling procedure, applied to a subset of the data with just intervocalic front nasals and prevelar nasal contexts reveals an optimum breakpoint for subjects born in 1979. These facts, then, suggest different courses of change for these two sets of contexts. We return to these issues later.

A second main social effect on short-a tensing reported in recent studies is ethnicity. In particular, the Tragerian system is reported to be best preserved by

White participants, across age groups, but even among White subjects, younger speakers have been reported to show movement away from the Tragerian constraints (Becker, 2010; Becker & Wong, 2010; Coggshall & Becker, 2009; Newlin-Łukowicz, 2015; Shapp, 2018, 2019). We replicate these findings with a subset of seventy subjects from the sample, excluding subjects born before 1963, which provides a sample more appropriately balanced for age and ethnicity. In particular, the self-identified Latinx (Latino/Latina) and Asian subjects in our sample are almost exclusively middle-aged and younger, reflecting changes in migratory trends in the city in the wake of the Immigration and Nationality Act of 1965 (Hart-Celler Act) (Becker & Coggshall, 2009; Newman, 2014).

Figure 5 shows model estimate for the interaction between subject Ethnicity and tensing context taken from this subsample.[9] It shows, for non-White groups, a clear nasal split—tensing in prenasal contexts and lax realizations in traditional laxing and Trager tensing contexts.[10] For self-identified Latinx subjects, estimates for prefront nasal contexts are below those for White and Black participants, a result reminiscent of reports of a weaker nasal effect among Latinx subjects both in NYCE (Becker, 2010; Coggshall, 2017) and in other speech communities (Eckert, 2008; Thomas, 2001). We return to these facts below.

In addition, Figure 5 shows that White subjects tend toward tenser realizations in Trager-tensing contexts than non-White groups, a result consistent with other recent studies (Becker, 2010; Becker & Wong, 2010; Coggshall & Becker, 2009; Shapp, 2018). Even among White subjects, however, estimates for Trager-tensing contexts do not approach those for front nasals, indicating that, even among White participants, the Trager system is weakening among younger and middle-aged subjects. Similarly, while model estimates for contexts preceding velar nasals and intervocalic nasals for White subjects are below those for front nasals (and show a greater contrast than non-White groups), they are still much higher than traditionally Lax contexts, again, indicating weakening of the Tragerian system for White speakers.

Parent L1 effects

The results so far align with other recent reports suggesting that age and ethnicity interact with contextual effects on short-a quality. As discussed above, a potential confound in previous studies of short-a change concerns parent L1 effects. In examining acquisition of the complex system of constraints on /æ/-tensing in the Philadelphia suburb of King of Prussia, Payne (1976, 1980) found that "complete acquisition of the Philadelphia short-a [system] by an [out-of-state] child [a child with parents from outside the Philadelphia dialect area] is rarely accomplished" (Payne, 1976:204). Notably, with the exception of Newlin-Łukowicz (2015) and Newlin-Łukowicz (2016), none of the previous work on short-a has controlled for parent first-dialect effects on sampling.[10] A possibility raised by this state of affairs, then, is that previously reported age and ethnicity effects instead reflect a misdistribution of parent L1 effects in sampling, given the rise in the foreign-born population of New York City in the wake of the

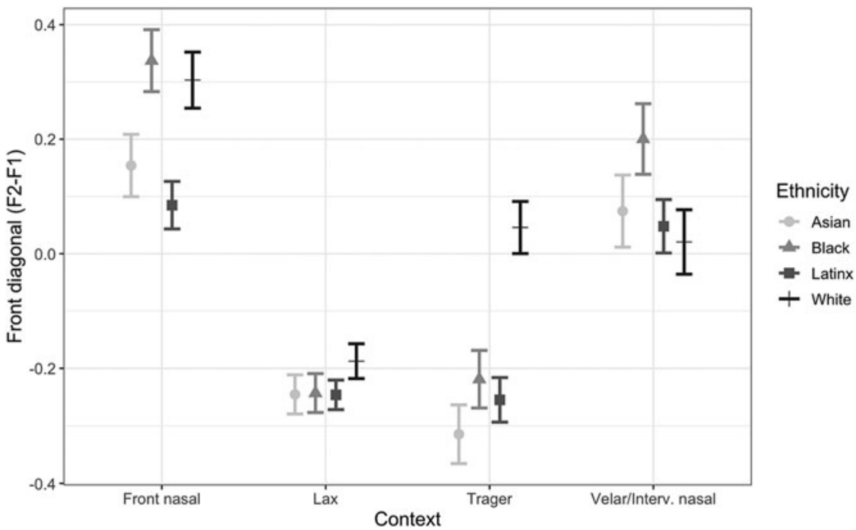

FIGURE 5. Model estimates for Ethnicity:Context. 'Interv. nasal' refers to intervocalic nasal contexts, 'Trager' refers to pre-oral contexts triggering tensing in the Tragerian system, and 'Lax' refers to pre-oral contexts determining lax realizations in the Tragerian system.

Hart-Celler Act of 1965. This influx is supplemented by the arrival of White so-called transplants as the city has become more attractive to professionals.

Evidence for an effect of parent L1 on this process of change comes from the data summarized in Figure 6, which plots model estimates for the interaction between tensing context and parent L1.[11] Here, "L1" denotes subjects with two native-NYCE speaking parents, and "L2" all other subjects. The figure shows that subjects with two NYCE-native parents tend toward tenser realizations in Trager tensing contexts and contexts preceding a tautosyllabic front nasal. Little difference is observed in Trager lax contexts and contexts preceding an intervocalic nasal or velar nasal. The results for Trager tensing contexts, however, suggest that subjects with two NYCE-native parents are more likely to conserve the traditional Tragerian system than other subjects, a result consistent with Labov's (2007) suggestion that parent input is crucial to acquisition of the traditional system.[12]

These results, then, suggest the need to take account of parent L1 effects in the analysis. The present dataset, however, does not permit us to cross ethnicity and parent L1 directly, given that most of the sample's self-identified Latinx and Asian subjects have parents who are not themselves native speakers of NYCE. We examine age effects in a subsample of self-identified Black ($n = 7$) and White ($n = 20$) subjects with two NYCE-native parents. Figure 7 shows model estimates for the interaction between subject birthyear and tensing context for this subset of speakers.[13] It shows, again, increased laxing in Trager-tensing contexts. There is little change in contexts preceding velar nasals and intervocalic nasals, but among

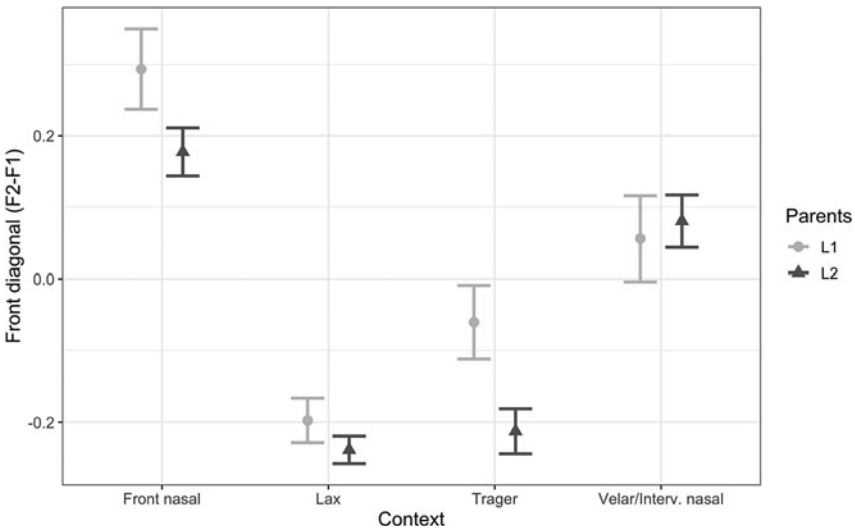

FIGURE 6. Model estimates for Parent L1:Context. ‘Interv. nasal’ refers to intervocalic nasal contexts, ‘Trager’ refers to pre-oral contexts triggering tensing in the Tragerian system, and ‘Lax’ refers to pre-oral contexts determining lax realizations in the Tragerian system.

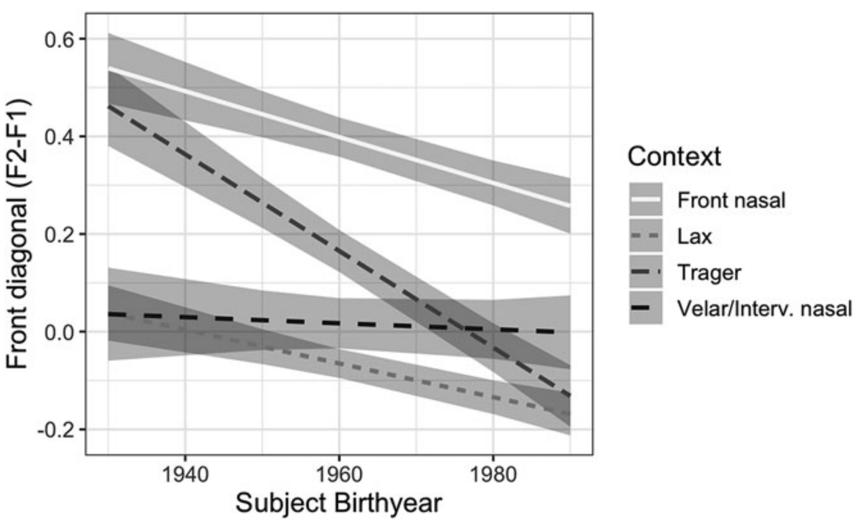

FIGURE 7. Model estimates for Birthyear:Context for subjects with two NYCE-native parents. ‘Interv. nasal’ refers to intervocalic nasal contexts, ‘Trager’ refers to pre-oral contexts triggering tensing in the Tragerian system, and ‘Lax’ refers to pre-oral contexts determining lax realizations in the Tragerian system.

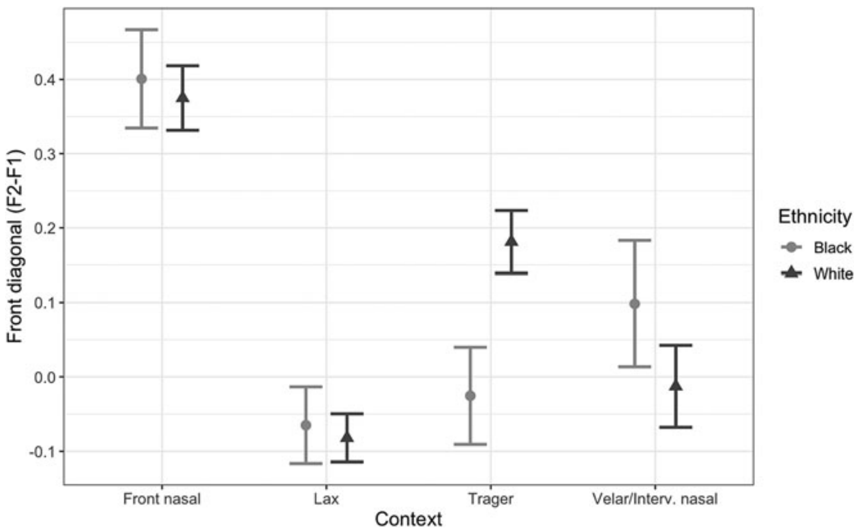

FIGURE 8. Model estimates for Ethnicity:Context for subjects with two NYCE-native parents. "Interv. nasal" refers to intervocalic nasal contexts, "Trager" refers to preoral contexts triggering tensing in the Tragerian system, and "Lax" refers to preoral contexts determining lax realizations in the Tragerian system.

younger speakers, these contexts are increasingly tense relative to Trager lax and Trager tense contexts. The results, therefore, support previous reports suggesting the Tragerian system is weakening among younger New Yorkers.

Figure 8 shows model estimates for the interaction between subject ethnicity (White versus Black) and tensing context from this same model. It shows, again, laxer realizations for Black subjects in Trager tensing contexts and tenser realizations before velar and intervocalic nasals. Taken together, the results support previous reports suggesting (i) the Tragerian system is weakening among younger New Yorkers; and (ii) that the Tragerian system is most robust among White speakers. Importantly, the current results suggest that these reported patterns are unlikely to reflect a confound of parent L1 effects in sampling.

TRAP-lowering/retraction

Recall that Figure 4 showed subject age effects for contexts not targeted by the phonological reorganization from the Tragerian system to a nasal system. In particular, younger speakers in the sample show lower values than their elders for Trager lax contexts (realized as lax in both Trager and nasal grammars), and contexts preceding a front nasal (tense in both grammars). These results suggest the possibility that there is an independent process of change–orthogonal to the changes reorganizing the allophonic conditioning of short-a, producing lower and backer short-a across the board, that is, "TRAP-backing." Lowering and/or retraction of /æ/ in such contexts has been described in several North American varieties (D'Onofrio, Praat, & Van Hofwegen, 2019; Eckert, 2008; Jacewicz, Fox, & Salmons, 2011; Kendall & Fridland, 2017; Wassink, 2015). Kendall and Fridland (2017), moreover, noted that in many of these descriptions, /æ/-retraction co-occurs with backing and/or raising of LOT. Based on perception data and acoustic results from three regional samples, Kendall and Fridland (2017) suggested that the two vowels are phonologically related, that is, in a chain-shifting relationship in many North American dialects.

We consider evidence for such a relationship in the present dataset by comparing individual subjects' aggregate measurements for LOT with their measurements for Trager lax contexts.

Figure 9 shows, on the x-axis, by-speaker random slopes for Trager lax contexts (excluding all pre-nasal contexts) and by-speaker random intercepts for LOT.[14] The figure shows a positive relationship between the two sets of measurements, such that the same speakers with low F2 values for LOT also generally show low front diagonal values for Trager lax contexts. The figure shows that the subjects with the greatest degree of retraction for both LOT and Trager lax classes—those in the lower left corner of the plot—are younger subjects, principally Asian and Latinx. The relationship is positive for all four ethnicity categories used here ($r = .386$, $p = .0001$ for the four sets combined).[15]

The two different changes suggested by these results—the loss of the Tragerian system and across the board lowering/retraction of short-a—have similar, but not altogether identical, social correlates. Recall that Figure 5 showed that self-identified White subjects are conservative vis-à-vis non-White participants in lowering/retraction of short-a in both Trager tensing and Trager lax contexts. However, this ethnicity effect is stronger for Trager tensing contexts than it is for Trager lax contexts. A model for a data subset with only Trager tense and Trager lax contexts, and Ethnicity recoded to levels non-White versus White reveals a significant Ethnicity:Context interaction with a greater ethnicity effect in the Tense condition.[16]

Second, as discussed above, occupational level scores correlate with higher front diagonal measurements of short-a as a class, but there is no interaction between occupational level and context. This result suggests that occupational prestige is implicated in short-a lowering/retraction change, but not in the loss of Tragerian constraints.

Finally, the process of short-a retraction in Trager lax and front nasal contexts began later than the onset of the loss of the Tragerian system. Figure 4 shows that the changes in the smoother shapes for the contexts implicated in loss of the Tragerian system come first: contexts preceding velar nasals, voiceless fricatives, and voiced stops. It is only afterward that the drop for smoothers occurs for the contexts preceding front nasals and Trager lax environments.

To summarize, the present dataset suggests an additional change affecting the class of short-a sounds as a whole, namely, lowering/retraction of short-a sounds across contexts, a process similar to TRAP-backing in other contemporary North American English varieties (D'Onofrio et al., 2019; Eckert, 2008; Jacewicz et al., 2011; Kendall & Fridland, 2017; Wassink, 2015). The results

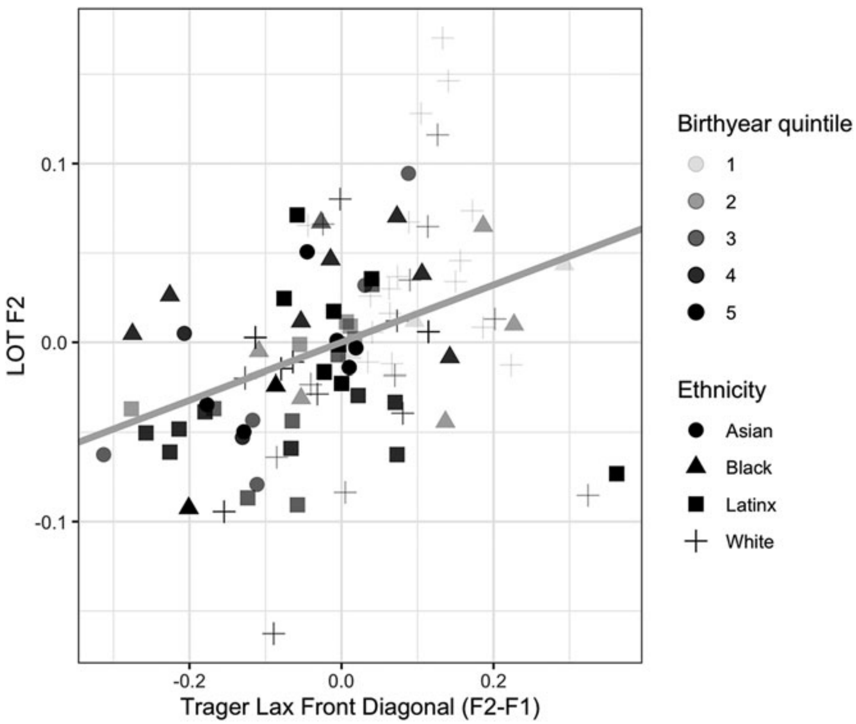

FIGURE 9. By-speaker model estimates for Trager lax contexts and LOT.

suggest that social correlates for this change are somewhat different from change involved in the phonological reorganization of short-a constraints, that is, the loss of Tragerian system. We consider further social correlates on short-a in traditionally lax contexts in the following section.

Social correlates of different short-a systems

A central question in much of the recent literature on short-a change in mid-Atlantic varieties concerns the number and nature of the different short-a systems in the speech community and whether these different systems have social correlates. For White Philadelphians, Labov et al. (2016) and Sneller (2018) proposed a single process of change from a traditional system (similar in many ways to the Tragerian system) to the nasal tensing rule in (1). This analysis, then, entails two abstract systems whose distribution is conditioned by several factors including speaker age. The most extensive discussion of these issues for NYCE is by Becker (2010). Based on visual inspection of F1 ~ F2 plots, Becker (2010) classified sixty-four subjects into one of five categories based partly on the classification in Labov et al. (2005) and Labov (2007): (i) the "Labovian" (Trager) system; (ii) Labovian transitional; (iii) continuous; (iv) nasal-transitional; and (v) nasal. Becker found that the first two of these systems, in particular, are characteristic of older speakers, and that the nasal system is characteristic of the youngest speakers in the sample. To date, none of the literature on NYCE short-a has addressed this problem using unsupervised procedures. We consider these issues using a Divisive Analysis (DIANA) clustering algorithm based on by-speaker random slopes for context extracted from an LMER model.[17]

As with all clustering procedures, this mechanism supplies an output that groups individuals in terms of similarity in N-dimensional space; this output can be represented in a dendogram with binary branching nodes, and individual "leaves" whose stem length represents distance in N-dimensional space. Whereas better-known agglomerative clustering procedures begin by grouping individuals in terms of similarities, the DIANA algorithm begins with the whole dataset as a single cluster, which is then split. It then takes the most heterogenous cluster and divides that until it separates out each individual "leaf." We adopt this algorithm as best suited to the question of which large-scale groupings are salient within the sample. Although the clustering continues until each individual is separated, we focus here on the highest-level groupings.

Specifically, the data we used are by-speaker estimates for four contexts: (i) Trager lax contexts; (ii) following tautosyllabic front nasals; (iii) other Trager tensing contexts, including contexts preceding a tautosyllabic voiceless fricative or voiced stop; and (iv) contexts preceding an intervocalic nasal or a velar nasal. The latter set of contexts—those preceding an intervocalic or velar nasal sound—were grouped in the modeling in light of their similar distribution across speakers as discussed above. (See also discussion below.) Clusterings were based on Euclidean distances, that is, the square roots of the sum of squares of differences between two nodes. The results of this procedure are illustrated in the dendrogram in Figure 10, with each circle along the x-axis representing a subject. Shading indexes quintile of subject year of birth, with younger participants' data points more darkly hued.[18]

We focus on the four patterns in the data distinguished by the three highest level splits. The first split separates two constituents whose top nodes are labeled Group 1 and Group 2 in the figure. The first of these is a set of thirty-one subjects instantiating one of two conservative patterns illustrated in Figure 11. The two panels in this plot show distributions for the sets of subjects under Group 1's daughter nodes, labeled 1.1 and 1.2 in the figure. The second of these (panel [b]) corresponds to subjects who adhere most closely to the traditional short-a pattern described above, with raised and fronted values in the traditional tensing contexts and lower, retracted values elsewhere (see Figure 2a, above). Group 1.1, by contrast, represents a transitional pattern, with Trager tensing contexts still somewhat raised and fronted relative to Lax contexts and contexts preceding velar and intervocalic nasals, but to a lesser degree than for Group 1.2. As shown in the figure, these two groups contain the oldest subjects in the sample. The two groups are comparable in terms of age, with a mean birthyear of 1963 for Group 1.1 and a mean birthyear of 1961 for Group 1.2 (n.s.). More

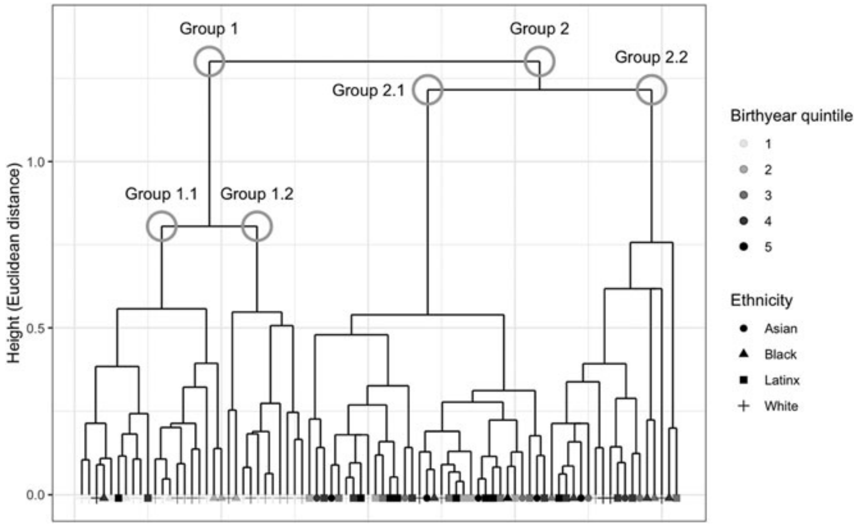

FIGURE 10. Dendrogram of a DIANA cluster analysis for eighty-two subjects, using by-speaker random slopes for context. The points at 0 along the y-axis represent individual participants, whose shape indexes ethnic category. Shading indexes quintile of subject year of birth, such that younger speakers are more darkly hued. The points denoting each speaker are terminal nodes, and each higher-level node is binary branching connecting two (possibly singleton) sets of speakers. The length of each branch corresponds to the Euclidean distance (square root of sum of squares of difference) between the vocalic measurements for the two sets. Each node, therefore, reflects, for two daughter nodes, similarity in the realization of short-a in these contexts.

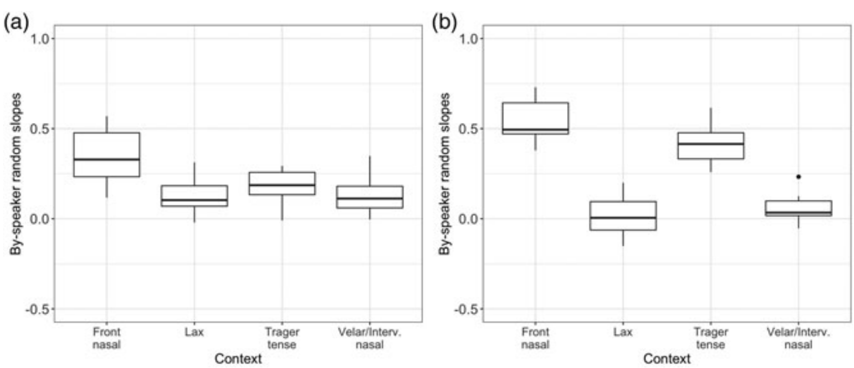

FIGURE 11. Model estimates by context for Group 1.1 (panel [a]) and Group 1.2 (panel [b]). 'Interv. nasal' refers to intervocalic nasal contexts, 'Trager' refers to preoral contexts triggering tensing in the Tragerian system, and 'Lax' refers to preoral contexts determining lax realizations in the Tragerian system.

conservative Group 1.2 has a larger proportion of White subjects on aggregate (ten White, one Black) than Group 1.1 (twelve White, six Black, two Latinx), a result consistent with previous work suggesting that the traditional system is best maintained among older Whites (Becker, 2009; Becker & Wong, 2010).

The sister node in this dendrogram splits to two main innovative patterns among the remaining fifty-one speakers in the subsample, labeled Group 2.1 and Group 2.2 in the figure. Distributions of by-speaker random slopes for these groups are shown in Figure 12. The two panels in this figure are distinguished principally by the degree of raising in prenasal contexts. For Group 2.2, front diagonal values for contexts preceding tautosyllabic front nasals and intervocalic and velar nasals are much higher than those for Group 2.1. In addition, Group 2.2 shows somewhat lower front diagonal values for Lax and Trager tensing contexts.

Figure 10 shows that Group 2.1 is somewhat older than Group 2.2 with mean years of birth 1982 and 1990 (n.s.). In addition, the two groups differ in Ethnic composition. While Group 2.1 is largely Latinx (twenty Latinx, seven Asian, four White, two Black), Group 2.2 is more mixed (five Black, five Latinx, four White, four Asian). The fact that Latinx subjects in the sample cluster in Group 2.1—20/27 Latinx subjects in this subsample fall into Group 2.1—is in keeping with previous results on NYCE and other North American varieties suggesting less pronounced raising of short-a in prenasal contexts in Heritage Spanish communities (see above) (Becker, 2010; Coggshall, 2017; Eckert, 2008; Thomas, 2001).

To summarize, a DIANA clustering analysis identifies four main patterns for contextual effects. One group (1.2), consisting almost entirely of older White subjects, adheres closely to the Tragerian system. The remaining subjects show one of three innovative patterns: (1) a transitional pattern (Group 1.1) with lower front diagonal values in traditional tensing contexts; (2) a sharply distinguished nasal pattern (Group 2.2), characteristic of the youngest group in our sample; and (3) a nasal system with a less pronounced nasal split, consisting principally of Latinx subjects (Group 2.1). Importantly, these results, and those presented above, suggest that prenasal contexts behave somewhat differently in this process of change from those preceding oral obstruents. We consider this issue further in the remaining discussion.

Systemic versus constraint-by-constraint change

In this section, we consider a set of issues raised by Labov et al.'s (2016) study of a similar process of change in Philadelphia. PhilE, like NYCE, has been reported to be undergoing change to a nasal tensing pattern, from a traditional system similar in nature and complexity to the Tragerian system (Labov et al., 2016; Sneller, 2018). Labov et al. (2016) argued that the traditional constraints are not being lost piecemeal but rather in one fell swoop. They take these facts to indicate that the change involved is not at the level of individual constraints (i.e., individual contextual conditioning effects), but rather at a more general level, between two

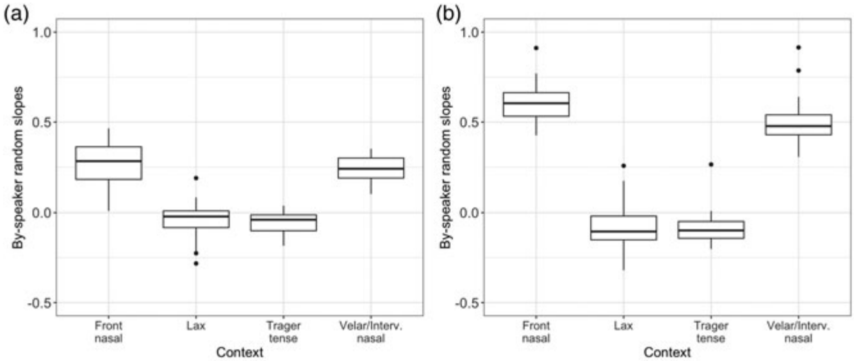

FIGURE 12. Model estimates by context for Group 2.1 (panel [a]) and Group 2.2 (panel [b]). "Interv. nasal" refers to intervocalic nasal contexts, "Trager" refers to preoral contexts triggering tensing in the Tragerian system, and "Lax" refers to preoral contexts determining lax realizations in the Tragerian system.

sets of constraints—the traditional system and the nasal system—which they represent as in (2).

(2) PHL ➔ NAS

Given the superficial similarity in the changes in Philadelphia and New York, a question invited by Labov et al.'s (2016) results is whether short-a change in NYCE is similarly of a piece, such that individual contextual effects are being lost in one fell swoop, as in (3).

(3) TRAGER ➔ NAS

Following Labov et al. (2016), we approach this question from the perspective of Kroch's (1989) generalization about grammatical change, the *constant rate hypothesis* (CRH). The CRH holds that, for any single abstract process of change, contextual effects on the choice of variants will be constant across the course of the change. If, in the general case, language learners faithfully acquire from input sources the probabilities for different contexts independently of the overall probability of application of a given variable rule, then one expects no contextual reordering across time/speakers. The CRH is supported by an extensive set of results on syntactic change in production corpora (Ball, 1994; Cukor-Avila, 2002; Durham, Haddican, Zweig, Johnson, Baker, Cockeram, Danks, & Tyler, 2011; Kallel, 2007; Kroch, 1994; Pintzuk, 1999; Santorini, 1993), and, more recently, has been described in phonological change by Fruehwald, Gress-Wright, and Wallenberg (2009) and Labov et al. (2016). The CRH is typically characterized as a generalization about change over time, but the proposal about acquisition underlying the CRH allows one to take it as a generalization about constancy in variation across speakers in a community as well. In particular, Guy (1980, 2007) called this the *shared constraints hypothesis*—the generalization that, for any single abstract locus of variation, contextual effects will be constant across speakers in an acquisition community.

If, indeed, change in NYCE short-a involves a single abstract process of change as in (3), we expect contextual effects on these changes to be similar across speakers. We examine this by considering cross-speaker correlations among four contexts of the Tragerian system undergoing change listed in (4). We selected these four contexts because they provide a suitable number (3) of tokens/speaker/context. Other contexts involved in the change, including tensing of nasals before a morphological boundary and "learned" lexical items, yielded few tokens/contexts and have therefore been excluded. Here, we report on data from thirty-three subjects that meet this minimum distribution of tokens.

(4) *Four contexts undergoing short-a change.*

a) Closed syllables with following voiced stop (Tragerian tense).
b) Closed syllables with following voiceless fricative (Tragerian tense).
c) Open syllables with following front nasal (Tragerian lax).
d) Following velar nasal (Tragerian lax).

In particular, the approach in (3) predicts (i) a positive relationship between the two lax contexts in the Tragerian system; (ii) a positive relationship between the two tense contexts in this system; and (iii) a negative relationship for pairs of Trager lax/Trager tense contexts. Table 1 shows Spearman's rho values for correlations between each of the ten pairs of contexts in our comparison. The *p*-values shown are based on the Spearman's rho values and are unadjusted for multiple comparisons. It shows support for the first two of the predictions of (3) just outlined. In particular, tensing before velar nasals correlates positively across speakers with tensing of front nasals in open syllables. Similarly, the table shows a strong correlation across speakers in tensing before voiceless fricatives and voiced stops in closed syllables. Table 1, however, shows that the predicted negative relationships between contexts preceding nasal and oral obstruents are all indeed in the expected direction, but quite weak (Spearman's rho range: -.23: -.04, n.s.). These results suggest that the abstract process of change represented in (3) is not an effective model for this subsample of thirty-three speakers. The results, rather, indicate two distinct processes of change—one affecting oral obstruents and another affecting nasals, as foreshadowed by results discussed above.

A question immediately raised by these results is whether this misprediction of (3) reflects some vagary of sampling. In other words, if (3) is not an appropriate model for community-wide change, does it describe change across some socially defined subset of the community, for example, subjects with NYCE-native parents or White communities (as in Labov et al.'s [2016] analysis for PhilE)? Another way of posing the problem is to ask, which is the set of speakers in the

TABLE 1. *A matrix of Spearman's rho values showing cross-speaker correlations in mean values of front diagonal measurements for four contexts.* n = *33.* *p = *.002.* **p < *.001*

	Open front nasals	Velar nasals	Voiced stops	Voiceless fricatives
Open front nasals	1.00	*0.53	-0.04	-0.10
Velar nasals		1.00	-0.12	-0.23
Voiced stops			1.00	**0.91
Voiceless fricatives				1.00

dataset for whom (3) is the best fit. To test this, we examined correlation matrices for unique combinations of subjects in this subset of thirty-three speakers. For each combination of speakers in the set ${}_nC_k$, beginning with $n = 33$ and $k = 32$, and in descending order for n and k, we examined Spearman's rho values and associated p-values for each pairwise comparison. For successive iterations, speakers who fit the correlations matrix most weakly were excluded. The combination selected as optimal was that with the lowest p-values associated with each pairwise comparison among the four contexts in (4).[19] This is a set of fifteen subjects that yield a correlation matrix illustrated in Table 2, which indeed aligns very well with the predictions of (3). That is, the same speakers with tensing in the prenasal contexts show laxing in the preoral obstruent contexts.

Importantly, the set of speakers selected under this procedure show no evidence of forming a natural class sociolinguistically, that is, of being defined by any of the external, social factors typically reported in the literature as conditioning short-a change or vocalic change more generally in contemporary NYCE. Relative to the remaining speakers in the subsample of thirty-three speakers, the selected set shows no effects of age, ($t(21.3) = 1.02$, $p = .32$), occupation level, ($t(29.8) = .74$, $p = .46$), ethnicity ($\chi^2(3) = 3.35$, $p = .34$), gender ($\chi^2(1) = 2.65$, $p = .10$) nor whether subjects' parents are NYCE-native ($\chi^2(2) = .52$, $p = .77$). In addition, the set shows no geographic patterning within the city. These results therefore suggest that, if indeed (3) describes change in a relevant community of NYCE-speakers, there is little to suggest that it is sociolinguistically distributed according to social factors that have been predictive in previous sociolinguistic research. As a reviewer observes, there could well be third wave practice-oriented features that unify these speakers in a way not discernable by our dataset. Future work might usefully explore this possibility.[20]

If, indeed, there are two distinct abstract processes of change responsible for the transition to the nasal system—one affecting short-a in prenasal contexts and another in contexts preceding oral obstruents—a question that arises is whether these distinct changes have separate social correlates. The subset of thirty-three speakers used in this section provides somewhat limited resolution for cross-group comparisons, but we suggest a partial answer here. Figure 13 plots by-speaker means for these two pairs of correlations. The left panel in this figure (13a) shows that the most conservative speakers for the changes affecting preoral obstruent contexts—those toward the top right corner of the plot—tend to be

TABLE 2. *A matrix of Spearman's rho values showing cross-speaker correlations in mean values of front diagonal measurements for four contexts.* n = *15. For all values,* $p < .001$

	Open front nasals	Velar nasals	Voiced stops	Voiceless fricatives
Open front nasals	1.00	0.83	-0.81	-0.84
Velar nasals		1.00	-0.85	-0.86
Voiced stops			1.00	0.92
Voiceless fricatives				1.00

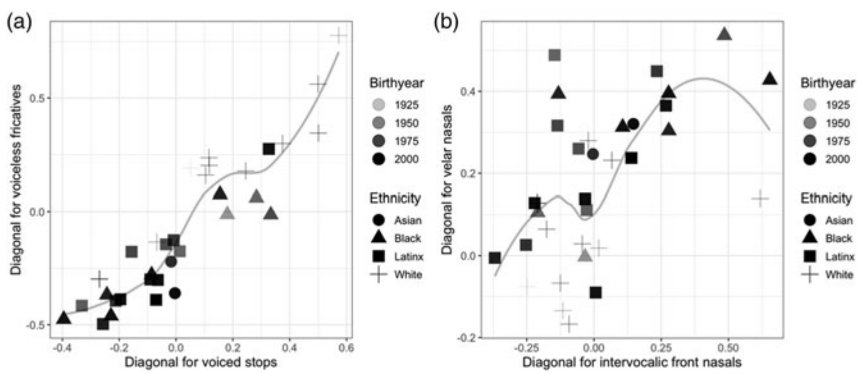

FIGURE 13. Cross-speaker correlations in front diagonal measurements (F2-F1) for prenasal contexts and preoral obstruent contexts, with speaker age and ethnicity shown. $n = 33$.

older White subjects, as expected in light of the results presented above. The right panel in the figure shows results for prenasal contexts, with conservative speakers in the bottom left part of the figure (i.e., those with the laxest realizations for these contexts). Among these are most of the older White subjects, as expected, but also some young Latinx subjects. These results are again reminiscent of reports suggesting laxer realizations for prenasal contexts in heritage Spanish communities both in New York (Becker, 2010; Coggshall, 2017) and in other speech communities (Thomas, 2001; Eckert, 2008). The figure reveals considerable variation, however, across Latinx subjects, a pattern that future work might usefully consider in greater detail.

To summarize, our results suggest constancy across speakers in the effect of following nasals on the one hand and following oral obstruents on the other (Figure 13), but our dataset provides no evidence of constancy across speakers in all four of these contexts, as predicted by (3). These results suggest the possibility that there is no single abstract process of change underlying the loss of the traditional system, as Labov et al.'s (2016) results suggest is the case for PhilE. Rather, the results suggest that the reorganization of the short-a system in New York City involves (minimally) two separate changes affecting prenasal and preoral obstruent contexts. In addition, as discussed previously, results from contexts not implicated in this phonological reorganization—that is, lax and contexts preceding tautosyllabic front nasals—suggest a third independent lowering/backing change affecting the class of short-a sounds as a whole.

A question raised by the present results, alongside those of Labov et al. (2016) and Sneller (2018), is how to understand the relationship between the changes in the two cities. Sneller's (2018:30) results indicate that, in PhilE, a single process of change affecting all contexts began for speakers born around 1983. The present dataset suggests that, at least for contexts preceding tautosyllabic oral obstruents, the change began earlier in NYCE, for speakers born around 1955, as discussed above. For the change affecting intervocalic front nasal contexts and those preceding tautosyllabic velar nasals, the change appears to have begun for speakers born around 1979. This timeline raises the possibility of diffusion change into PhilE of a change originating in NYCE, a scenario consonant with Sneller, Fruehwald, and Yang's (2019) results from computational simulations, suggesting that the change in Philadelphia English is exogenous, that is, driven by children exposed to learning input from outside the community. In this light, a reviewer wonders whether the differences between PhilE and NYCE in the social patterning of short-a change might reflect more general properties of endogenous versus exogenous change. In particular, the reviewer suggests that the "fell swoop" system-level competition described for PhilE by Labov et al. (2016) and Sneller (2018) may be a property of diffusion change more generally, while the phonologically incremental change described here is characteristic of endogenous innovations. We believe the suggestion warrants further study.

CONCLUSION

The data presented here support two main conclusions about change in NYCE short-a vowels.

1. Our findings converge with results reported by Newlin-Łukowicz (2015, 2016), Coggshall (2017), and Shapp (2018), suggesting that the short-a system in NYCE, like in PhilE, is undergoing regional leveling, that is, a shift to a simpler, pan-local norm (Kerswill, 2003; Watt, 2002). In NYCE, this change interacts with ethnicity, much like the loss of raised THOUGHT (Becker, 2009). Specifically, White subjects in the sample diverge from other groups in adhering most closely to the Tragerian system, but all groups show a weakening of the Tragerian system across time. Importantly, the current results suggest that neither age nor ethnicity effects are likely to reflect a confound of parent L1 in sampling (Payne, 1976, 1980).

   Many younger speakers tend toward a pattern typically described as the "nasal system" in other varieties whereby short-a vowels are raised and fronted before nasal sounds and lowered and retracted elsewhere. Results from a cluster analysis support previous findings suggesting that, among younger speakers, less pronounced raising in prenasal environments is prevalent among Latinx speakers (Becker, 2010; Coggshall, 2017). In addition, younger speakers in the sample show laxer realizations for contexts not implicated in a change from a Tragerian system to a nasal system. Younger subjects show laxer realizations than their elders for contexts preceding tautosyllabic front nasals despite the fact that both the Tragerian and the nasal systems have relatively tense realizations in such contexts. Similarly, younger speakers show laxer realizations than their elders for /æ/ in contexts preceding a voiceless stop even though both systems have laxing in these contexts. We take this to indicate a separate process of change affecting /æ/ generally, that is, "TRAP-backing."

2. Unlike short-a change in Philadelphia as described by Labov et al. (2016) and Sneller (2018), the change away from the traditional system in NYCE does not appear to be a unified process of change within the community. Tensing in pre-nasal contexts correlates strongly across speakers, as does tensing in contexts preceding voiceless fricatives and voiced stops closing a syllable. Both of these results are predicted under the single-change hypothesis. Not borne out by this hypothesis, however, is the further prediction that tensing in the former set of contexts (pre-nasals) will be inversely correlated with tensing in the latter (preceding voiceless fricatives and following stops). Why the two speech communities, otherwise undergoing very similar processes of change in the short-a system, should diverge in this way warrants further study.

ACKNOWLEDGMENTS

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NOTES

1. The New York City dialect area is defined for our purposes as the five New York City boroughs, western Long Island, and the narrow strip of northeastern New Jersey between the Meadowlands/Hackensack River and the Hudson (Coggshall, 2017; Labov, 1966; Newman, 2014).

2. Silverman (2002) attributed the divergence between these analyses to the fact that the distribution is an "incipient split," that is, with characteristics of both allophonic variation and phonemic differences.

3. This is a simplification of the facts that will suffice for the purposes of the following discussion. As described extensively by Coggshall (2017), there is considerably more variation and gradience to this system than often noted in the literature. Most notably, Labov (1972, 2001) described contexts preceding voiced fricatives as "variable," and Trager (1940) grouped these unambiguously with the set of sounds triggering tensing.

4. 1 = Unskilled laborers; 2 = skilled laborers; 3 = lower white collar, retail, and current university students; 4 = lower professionals including teachers, engineers, and manager; 5 = higher professional occupations.

5. We do not analyze subjects' metalinguistic descriptions here.

6. The Oral History Collection of the Bronx Institute Archives of Lehman College Library, CUNY (the City University of New York), 1981–1991, consists of tapes and transcripts (ca. 40%

transcribed) of some 410 oral history interviews conducted with residents of Bronx neighborhoods such as: Fordham, Tremont, Morrisania, Belmont, Clason Point, Riverdale, Williamsbridge, South Bronx, and others.

7. The authors are immensely grateful to Benji Wald for help with this portion of the analysis and for guidance on data coding more generally. Each item was judged by two native speakers.

8. Model formula: Front diagonal ~ Occupation level + Log_{10}(Duration) + Preceding Sound + Context * Age + (Context | Subject) + (1 | Lexical root). Reference levels were *Lax* for Context and *Back sonorants* for Preceding sound. A by-subject random slope for Preceding context was not fittable. For space reasons we do not discuss in detail effects of duration and preceding sound included as covariates. For duration, longer tokens favored tenser realizations. We take this to reflect the ingliding diphthongal quality of tense realizations, and articulatory undershoot in shorter-duration contexts. Preceding [h], laterals, and back vowels favored laxer realizations with respect to preceding sound, while preceding dentals and postalveolars favored tenser realizations.

9. Seventy subjects $n = 10{,}825$. Model formula: Front diagonal ~ Occupation + Log_{10}(Duration) + Preceding Sound + Context * Ethnicity + (Context | Subject) + (1 | Lexical root). Reference levels were *Lax* for Context, and *Back sonorants* for Preceding sound. A by-subject random slope for Preceding context was not fittable.

10. Newlin-Łukowicz's (2015, 2016) sample included Polish-English bilinguals, whose parents migrated to the City from Poland between 1970 and 1990.

11. Seventy subjects, $n = 10{,}819$. Model formula: Front diagonal ~ Log_{10}(Duration) + Preceding Sound + Occupation + Context * Age + Context * Parent L1+(Context | Subject) + (1 | Lexical root). Reference levels were Lax for Context, *L1* for Parent L1 and *Back sonorants* for Preceding sound. A by-subject random slope for Preceding sound was not fittable. This model includes only subjects born after 1962, to balance for age and parent L1.

12. In our data, there is no significant parent L1:Context interaction when subjects with ≥ 1 NYCE native parent are distinguished from those with no NYCE-native parents.

13. 29 subjects, $n = 4143$. Model formula: Front diagonal ~ Log_{10}(Duration) + Preceding Sound + Context * Age + Ethnicity * Age + (Context | Subject) + (1 | Lexical root). Reference levels were *Lax* for Context, *Back sonorants* for Preceding sound, and *White* for Ethnicity. A by-subject random slope was not fittable for this model.

14. We use quintiles for speaker year of birth only to make the distribution of speaker ages better visible in the plot. Formula for LOT-model: F2 ~ Log_{10}(Duration) + Following Sound + (Following Sound | Speaker) + (1 | word); Ninety-six subjects; $n = 10{,}328$. Formula for short-a model: Front Diagonal ~ Log_{10}(Duration) + Preceding sound + Context + (Context | Subject) + (1 | Lexical root); 96 subjects; $n = 16{,}517$.

15. A consequence of these results, which we set aside in the remaining discussion, is that LOT-THOUGHT approximation in many speakers—suggested by homophony judgment results (Haddican, Newman, Johnson, & Kim, 2016; Johnson, 2007)—may reflect not just THOUGHT-lowering Becker (2010, 2014), but also LOT-backing.

16. Model formula: Front diagonal ~ Age + Log10(Duration) + Context*Ethnicity + (Context | Subject) + (1 | Lexical root), 70 speakers, $n = 8618$.

17. Eighty-two subjects, $n = 10{,}469$. Model formula: Front diagonal ~ Log_{10}(Duration) + Log_{10}(Frequency + 1) + Preceding sound + Context + (Context | Subject) + (1 | Lexical root). Frequencies were taken from the Subtlex corpus (Brysbaert & New, 2009).

18. We use age quintiles only to make the distribution of participant ages more visible in the plot.

19. The most straightforward way of addressing this question is to examine all possible combinations of sets of, say ten or greater of the speakers in the subset of thirty-three speakers and see which combinations generate a pattern of correlations that best fits the predictions of (3), that is, as in (5).

$$(5) \quad \sum_{k=10}^{33} nCk$$

The number of combinations generated by this approach ($8.53 \cdot 10^9$) is computationally unwieldy, however, and we therefore use the procedure described above, which excludes unpromising combinations in a stepwise fashion, and thereby simplifies the procedure.

20. A reviewer wonders whether the eighteen speakers not selected by this algorithm show any linguistic coherence. For this set, the two Tragerian contexts prevoiceless fricative and prevoiced stop contexts indeed correlate as expected, (rho = .88, $p < .001$), as do the two prenasal contexts (rho = .56, $p = .012$). None of the other four pairwise relationships are significant.

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APPENDIX

TABLE 3. *Subject demographic information*

Subject	Birthyear	Gender	Ethnicity	Occupation level	L1 Parents
1	1906	Man	White	2	0
2	1910	Man	White	3	1
3	1922	Woman	White	4	0
4	1934	Woman	White	3	2
5	1937	Man	Black	2	2
6	1940	Man	White	5	0
7	1942	Woman	White	4	2
8	1942	Man	White	3	1
9	1942	Man	Black	2	1
10	1944	Woman	White	2	2
11	1951	Woman	White	4	2
12	1953	Man	White	3	1
13	1953	Man	White	5	2
14	1954	Woman	White	3	0
15	1956	Woman	Black	4	1
16	1956	Man	White	3	2
17	1956	Woman	White	4	2
18	1957	Man	White	3	2
19	1957	Man	White	3	2
20	1957	Man	White	3	2
21	1957	Woman	White	1	0
22	1959	Man	White	2	1
23	1960	Man	Black	3	2
24	1960	Man	Latinx	1	0
25	1962	Woman	White	3	1
26	1962	Woman	White	4	2
27	1962	Woman	Latinx	4	0
28	1963	Woman	Latinx	4	0
29	1964	Man	White	4	2
30	1964	Woman	White	3	2
31	1965	Man	Black	2	2
32	1965	Woman	Black	1	2
33	1966	Woman	Black	4	1
34	1968	Woman	Latinx	4	0
35	1969	Man	White	3	2
36	1969	Man	Latinx	1	0
37	1969	Man	White	2	0
38	1970	Man	White	3	0
39	1971	Woman	White	3	0
40	1971	Woman	Black	3	1
41	1972	Woman	White	3	2
42	1973	Man	Latinx	2	0
43	1976	Woman	Latinx	3	0
44	1979	Man	Latinx	2	1
45	1980	Woman	Latinx	3	2
46	1981	Woman	White	3	2
47	1981	Woman	Latinx	3	0
48	1983	Man	Asian	3	0
49	1984	Woman	White	3	2

Continued

TABLE 3. *Continued*

Subject	Birthyear	Gender	Ethnicity	Occupation level	L1 Parents
50	1984	Woman	Asian	4	0
51	1985	Woman	White	3	2
52	1985	Man	Asian	3	0
53	1985	Man	White	3	0
54	1986	Woman	Latinx	4	0
55	1987	Man	Asian	5	0
56	1987	Man	Asian	3	1
57	1988	Woman	White	3	0
58	1988	Man	Black	1	1
59	1988	Woman	Asian	4	0
60	1988	Man	Black	1	1
61	1988	Woman	Latinx	3	0
62	1989	Woman	Black	1	0
63	1991	Man	Latinx	2	0
64	1991	Man	Latinx	2	0
65	1991	Woman	Latinx	4	0
66	1991	Woman	Black	3	2
67	1992	Woman	White	3	2
68	1992	Woman	Asian	3	0
69	1992	Woman	Asian	3	0
70	1992	Woman	Black	1	2
71	1993	Woman	Black	4	0
72	1993	Woman	Latinx	3	0
73	1993	Man	Black	3	2
74	1993	Woman	Latinx	3	0
75	1993	Woman	Black	3	0
76	1993	Woman	Latinx	3	0
77	1993	Woman	Latinx	3	0
78	1994	Woman	White	3	0
79	1994	Man	White	3	2
80	1994	Woman	Latinx	3	0
81	1994	Woman	Black	3	0
82	1994	Woman	Latinx	3	0
83	1994	Man	Latinx	1	0
84	1994	Woman	Asian	3	0
85	1994	Woman	Asian	3	0
86	1995	Woman	Latinx	2	0
87	1995	Woman	White	3	0
88	1995	Man	Asian	3	0
89	1995	Woman	Latinx	3	0
90	1995	Man	Latinx	3	0
91	1996	Woman	White	3	1
92	1996	Woman	Asian	3	0
93	1996	Man	Asian	3	0
94	1997	Woman	Black	3	0
95	1998	Woman	Latinx	3	0
96	1999	Woman	Asian	3	2
97	2001	Man	Latinx	3	1