

Variation in /u/ fronting in the American Midwest

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(Received 21 August 2018; revised 19 June 2019; accepted 20 June 2019; published online 18 July 2019)

Previous research has suggested that a greater degree of social indexing of gender, race, and regional background is produced in linguistic contexts that promote phonetic reduction. The goal of the current study was to explore this hypothesis through an examination of the realization of an ongoing sound change in the American Midwest—/u/ fronting—as a function of four linguistic factors that contribute to phonetic reduction: lexical frequency, phonological neighborhood density, discourse mention, and speaking style. The results revealed minimal effects of the linguistic factors on the degree of /u/ fronting among talkers with greater overall advancement in the /u/ fronting change-in-progress, suggesting that the process of /u/ fronting is nearing completion among some American Midwesterners. However, the results also revealed more /u/ fronting in plain laboratory speech than in clear laboratory speech and in low-frequency, low-density words than in low-frequency, high-density words among talkers with lower overall advancement in the /u/ fronting change-in-progress. The directions of these effects are consistent with the hypothesis that social indexing is greater in reduction-promoting contexts. Further, the relative sizes of these effects suggest that speaking style contributes more to variability in social indexing than lexical properties, such as frequency and neighborhood density. © 2019 Acoustical Society of America.

<https://doi.org/10.1121/1.5116131>

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I. INTRODUCTION

Acoustic-phonetic variation in American English is highly structured, reflecting processes related to phenomena such as coarticulation (e.g., Cole *et al.*, 2010; Scarborough, 2013), phonetic reduction (e.g., Aylett and Turk, 2004; Lindblom, 1990), social indexing (e.g., Labov *et al.*, 2006; Thomas, 2001), and ongoing sound change (e.g., Labov, 1994, 2001). Historically, the study of synchronic acoustic-phonetic variation arising from social indexing and sound change has been the purview of sociolinguistics, while the study of variation due to coarticulation, phonetic reduction, and other linguistic processes has been the purview of phonetics and speech science. However, the results of a handful of studies at the intersection of sociolinguistics and phonetics have suggested that phonetic reduction and social variation processes may not be independent (Clopper and Pierrehumbert, 2008; Clopper *et al.*, 2017; Flemming, 2010; Hay *et al.*, 1999; Munson, 2007). In particular, the results of these studies suggest that individual talkers produce a greater degree of social indexing in the same contexts that promote phonetic reduction. The goal of the current study was to further explore this proposed within-talker relationship between social indexing and phonetic reduction in the context of /u/ fronting in the American Midwest.

In an early study connecting social indexing and phonetic reduction, Hay *et al.* (1999; see also Mendoza-Denton *et al.*, 2003) analyzed the speech of Oprah Winfrey, an African American talk show host, and observed that Winfrey was more likely to produce monophthongal /aɪ/ variants in high-frequency words relative to low-frequency words. Given that monophthongization of /aɪ/ is a characteristic feature of African American English (Bailey and Thomas, 1998; Wolfram, 1994), a larger proportion of monophthongal /aɪ/ variants signals greater social indexing of Winfrey's African American identity. In addition, given that phonetic reduction is observed in high-frequency words relative to low-frequency words (e.g., Bell *et al.*, 2009; Munson and Solomon, 2004), the observation that Winfrey was more likely to produce monophthongal /aɪ/ variants in high-frequency words than in low-frequency words provided preliminary evidence for the greater use of stable linguistic forms which have social indexical value in reduction-promoting contexts.

Additional evidence for this connection between social indexing and phonetic reduction has been obtained in more recent work examining gender and phonological neighborhood density (Munson, 2007) and regional dialect and neighborhood density, semantic predictability, discourse mention, and speaking style (Clopper and Pierrehumbert, 2008; Clopper *et al.*, 2017; Flemming, 2010; Scarborough, 2010). In all of these studies, a greater degree of social indexing

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was observed in the contexts in which phonetic reduction is expected to occur. That is, larger gender differences in vowel space expansion were observed in low-density words than in high-density words, and regional dialect variants representing changes-in-progress were more advanced in low-density words than in high-density words, in high-predictability words than in low-predictability words, in second mention words than in first mention words, and in plain laboratory speech directed toward an imagined friend or family member than in clear laboratory speech directed toward an imagined hearing-impaired or non-native listener. These patterns of increased use of stable forms, which have social indexical value, and of more advanced forms in a change-in-progress parallel the findings for phonetic reduction, in which more reduced forms are observed in low-density words than in high-density words (Munson and Solomon, 2004; Scarborough, 2010; Wright, 2004), in high-predictability words than in low-predictability words (Aylett and Turk, 2004; Bell *et al.*, 2009), in second mention words than in first mention words (Baker and Bradlow, 2009; Fowler and Housum, 1987), and in plain laboratory speech than in clear laboratory speech (Ferguson and Kewley-Port, 2007; Kuo and Weismer, 2016; Picheny *et al.*, 1986; Smiljanic and Bradlow, 2005). Thus, across a range of contexts that are known to elicit phonetic reduction, individual talkers have been shown to produce a parallel increase in their degree of social indexing, including more advanced forms of changes-in-progress.

The primary explanation for this relationship between phonetic reduction and social indexing follows the listener-oriented approach to phonetic reduction (Clopper and Pierrehumbert, 2008; Hay *et al.*, 1999; Munson, 2007). From this perspective (e.g., Aylett and Turk, 2004; Lindblom, 1990), phonetic reduction reflects talkers' balancing articulatory ease with listener needs. When talkers estimate that listeners will understand the message (e.g., because the word is frequent or predictable or given in the discourse), talkers can afford to exert less articulatory effort, resulting in phonetic reduction. In contrast, when talkers estimate that listeners will have difficulty understanding the message (e.g., because the word is infrequent or unpredictable or new in the discourse), talkers exert more articulatory effort, resulting in hyperarticulation. The parallel explanation of the relationship between phonetic reduction and social indexing is that when talkers estimate that listeners will understand the message (e.g., because the word is frequent), talkers can afford to produce socially marked forms to index something about themselves. In contrast, when talkers estimate that listeners will have difficulty understanding the message (e.g., because the word is unpredictable), talkers produce socially unmarked forms to facilitate communication. These linguistic factors, such as lexical frequency and predictability, are independent of social factors, such as the identity of the interlocutor, and therefore emerge independently of other socially driven identity marking. Thus, for example, Winfrey produced more monophthongal /aɪ/ variants in high-frequency words than in low-frequency words, regardless of the identity of her guest (Hay *et al.*, 1999).

One alternative account of phonetic reduction phenomena, the talker-oriented approach, also provides a potential explanation for the relationship between phonetic reduction and social indexing (Clopper and Pierrehumbert, 2008; Munson, 2007). From this perspective (e.g., Baese-Berk and Goldrick, 2009; Jurafsky *et al.*, 2001), phonetic reduction occurs when it is easier for the talker to access the target form (e.g., when it is frequent or predictable). Faster lexical access leads to lower lexical activation at the moment of production, which contributes to phonetic reduction. In contrast, when talkers require more time to access the target form, lexical activation is higher at the moment of production, leading to hyperarticulation. The parallel explanation of the relationship between phonetic reduction and social indexing is that socially indexed forms are the default forms for the talker, which are activated quickly, whereas the unmarked forms require additional time to access. Thus, socially indexed forms are produced when it is easier for talkers to access the target form (e.g., when it is frequent) because the socially indexed forms are likely to be the only available forms at the moment of production when lexical access is fast. In contrast, unmarked forms are produced when talkers require more time to access the target form because the unmarked forms require more time to access and are only available at the moment of production when lexical access is slow (e.g., when the word is unpredictable).

Regardless of the theoretical approach, phonetic reduction is assumed to fall at one end of a continuum with hyperarticulation at the other end, socially marked forms are assumed to fall at one end of a continuum with unmarked forms at the other end, and talkers are assumed to have a range of variants along both continua available to them in production. Thus, the phenomena could also be described as phonetic hyperarticulation and social unmarkedness, with the associated prediction that the degree of social indexing is reduced in contexts that promote hyperarticulation. This alternative perspective leads to a qualitatively equivalent interpretation of the observed relationship.

A. Variability in social indexing across contexts

The results of previous studies reveal variability in the magnitude of within-talker differences in social indexing across contexts, depending both on the reduction-promoting context and the sociolinguistic variable being examined. For example, Clopper *et al.* (2017) observed greater social indexing of the Northern dialect of American English through /æ/ raising and/or fronting in low-density words, high-predictability words, and plain laboratory speech, but not in second mention words. At the same time, they also observed greater social indexing of the Northern dialect of American English through /a/ fronting and lowering in second mention words, but not in low-density words, high-predictability words, or plain laboratory speech.

The source of this variability in social indexing across linguistic contexts is difficult to identify because the results obtained in these studies cannot be directly compared. The primary challenge to direct comparisons across the previous studies is the varied nature of the speech materials that were

analyzed (cf. Gahl *et al.*, 2012). In particular, isolated read words were analyzed when neighborhood density was examined (Clopper *et al.*, 2017; Munson, 2007; Scarborough, 2010), read sentences were analyzed when semantic predictability (Clopper and Pierrehumbert, 2008) and speaking style (Clopper *et al.*, 2017) were examined, read short stories were analyzed when discourse mention was examined (Clopper *et al.*, 2017), and partially scripted speech was analyzed when lexical frequency was examined (Hay *et al.*, 1999).

A second challenge to direct comparisons across studies is the linguistic variables themselves, which differed depending on the social categories that were examined. For example, /aɪ/ monophthongization was the linguistic variable in the study of variation in Winfrey's African American English by Hay *et al.* (1999), whereas /a/ fronting and lowering was one of the linguistic variables in the study of variation in the Northern dialect of American English by Clopper *et al.* (2017). These variables index different social meanings related to racial identity and regional background, respectively. Moreover, these variables are evaluated differently by listeners: whereas /aɪ/ monophthongization is a stereotypical feature of African American English (Anderson, 2002; Thomas, 2007), /a/ fronting and lowering is not a stereotypical feature, as defined by Labov (1972), of the ideologically standard Northern dialect of American English (Campbell-Kibler, 2012). Finally, these variables differ in their stability over time. Whereas /aɪ/ monophthongization is a stable property of African American English, /a/ fronting and lowering is part of an ongoing sound change in the Northern dialect of American English. These differences between variables may account for some of the variability that has been observed in their interactions with phonetic reduction processes.

The linguistic variables also differed in terms of how variation in production was assessed, including measures of vowel monophthongization (Hay *et al.*, 1999), centralization (Clopper and Pierrehumbert, 2008; Munson, 2007), and position along each of the two dimensions of the $F1 \times F2$ acoustic vowel space (Clopper *et al.*, 2017). These methodological differences may also at least partially explain the variability in the degree of social indexing that has been observed across contexts. However, the extent to which the variation reflects methodological differences versus theoretically important differences between sociolinguistic variables and/or reduction-promoting contexts cannot be assessed given the existing data.

The primary goal of the current study was therefore to provide an analysis of the potential relationship between phonetic reduction and degree of social indexing, in which more direct comparisons across contexts could be made. Three aspects of the design allowed us to achieve this goal. First, the analysis was based on a single corpus of read short stories, so that the type of speech material was not a mediating or confounding factor in the realization of the target variation. Second, we focused on a single social variable—/u/ fronting—that was defined by a single acoustic measure— $F2$ —which allowed us to directly compare the magnitude of the effects on social indexing of four different factors that

are known to promote phonetic reduction: lexical frequency, neighborhood density, discourse mention, and speaking style. Third, previous work has demonstrated that these four factors interact in phonetic reduction (Baker and Bradlow, 2009; Bell *et al.*, 2009; Burdin *et al.*, 2015), but the previous studies exploring the effects of these factors on the realization of sociolinguistic variables examined them separately (Clopper *et al.*, 2017; Clopper and Pierrehumbert, 2008; Hay *et al.*, 1999; Munson, 2007). To allow for a more complete comparison of the relationship between phonetic reduction and social indexing processes, we considered the combined, and potentially interacting, contributions of these four factors to the realization of /u/ fronting.

B. Fronting of /u/ in American English

Variation in /u/ fronting was selected as the focus of the current study because it is a widespread ongoing sound change in American English (Labov *et al.*, 2006), and /u/ fronting was therefore expected to exhibit substantial variation both within and across talkers. Within talkers, the status of /u/ fronting as an ongoing sound change made it a good candidate for the current study because we were likely to observe structured variation in the realization of /u/ as a function of the target linguistic factors (Labov, 1972). Moreover, /u/ fronting has already been observed to exhibit variation as a function of neighborhood density and, separately, as a function of speaking style for talkers from the American Midwest (Clopper *et al.*, 2017), suggesting that similar patterns of variation would be observable within talkers in the current study.

Across talkers, younger talkers produce more /u/ fronting than older talkers, consistent with an ongoing sound change (Baranowski, 2008; Hall-Lew, 2011; Labov *et al.*, 2006). In some previous studies, female talkers produced more /u/ fronting than male talkers (e.g., Labov *et al.*, 2006), but the lack of an effect of talker gender on /u/ fronting in other studies has been argued to reflect the nearing of completion of the sound change in some communities in the American South (e.g., Baranowski, 2008) and West (e.g., Hall-Lew, 2011). Recent research also suggests that /u/ fronting is observed across ethnicities, including among minority groups such as Asian Americans (Hall-Lew, 2011), Mexican Americans (Fought, 1999), and some African Americans (Anderson, 2008; Eberhardt, 2009; Fridland and Bartlett, 2006; cf. Fridland, 2008; Holt, 2018; Thomas, 2007). Although /u/ fronting is widespread across regions in North America, it is most advanced in the Southern and Midland dialects of American English, whereas it is least advanced, although still present, in the Northern dialect (Labov *et al.*, 2006).

The use of a particular linguistic variable by a particular social group does not necessarily confer social meaning on that variable as an index of that group (Johnstone and Kiesling, 2008). At the same time, variation in production need not be accompanied by explicit perceptual awareness to serve as a social index (e.g., sociolinguistic markers; Labov, 1972). With respect to the social indexing of /u/ fronting in American English, several studies of performances of young people's speech suggest that /u/ fronting is

associated with younger speakers, including young males (Kiesling, 2004) and young white females (Slobe, 2018). Thus, the primary social category associated with /u/ fronting in contemporary American English is age, although gender, ethnicity, and regional background may serve as secondary categories that can be indexed by /u/ fronting across talkers.

Given that the goal of the current study was to explore the within-talker relationship between phonetic reduction and degree of social indexing, we focused our analysis on the speech of young Midwestern adults. These young adults were expected to exhibit substantial /u/ fronting, consistent with the widespread, ongoing sound change in the U.S. The robust presence of /u/ fronting in the speech of our sample of talkers allowed us to examine how the degree of /u/ fronting varied as a function of phonetic reduction related to lexical frequency, neighborhood density, discourse mention, and speaking style. In addition, to obtain variation in the overall degree of /u/ fronting across talkers, which was essential for disentangling the effects of social indexing and phonetic reduction (see Sec. IC), we included both male and female talkers from the Midland and Northern dialects of American English. Talkers of both genders exhibit /u/ fronting, but potentially to different degrees. In particular, as noted above, some studies suggest that female talkers produce more /u/ fronting than male talkers (Labov *et al.*, 2006). Similarly, talkers from the Midland and Northern regions exhibit /u/ fronting, but to different degrees. In particular, as noted above, Midland talkers are among the most advanced when it comes to /u/ fronting, whereas Northern talkers are among the least advanced American English participants in this ongoing sound change (Labov *et al.*, 2006).

C. The current study

A preliminary analysis of the data in the current study (Sec. III A) revealed consistent fronting of /u/ relative to /a, ɔ/ across talkers, confirming that our sample of young Midwestern adults is participating in the widespread /u/ fronting change-in-progress in the U.S. Given the robust evidence of /u/ fronting throughout the corpus, the dependent variable in our analysis was a continuous measure of degree of /u/ fronting, operationalized as $F2$ at vowel midpoint, rather than a binary distinction between fronted and non-fronted productions.

The preliminary analysis also revealed substantial between-talker variation in overall /u/ fronting. Somewhat surprisingly given earlier work on /u/ fronting in American English (Clopper *et al.*, 2017; Clopper *et al.*, 2005; Labov *et al.*, 2006), this variation was orthogonal to regional dialect. That is, both Midland and Northern talkers exhibited a range of /u/ fronting, and no significant effect of regional dialect on /u/ fronting was observed across talkers. However, an inspection of the results of Labov *et al.* (2006) reveals that backed /u/ productions are retained in the Central North region (i.e., Wisconsin and Minnesota), whereas /u/ fronting is robust in at least some consonantal contexts in the Inland North region around the Great Lakes. All of the Northern talkers in the current study were from the Inland North and

the results of the current analysis provide further evidence for substantial /u/ fronting in this region. Moreover, the preliminary analysis suggests variation across talkers in the advancement of the change-in-progress in both the Midland and Northern dialect regions. This within-region, between-talker variability in overall degree of /u/ fronting is consistent with individual differences in socially indexed forms within social groups (e.g., Clopper *et al.*, 2005; Labov *et al.*, 2006) and even within sets of siblings (Kendall and Fridland, 2012; Reed, 2014). We leave an exploration of the social factors underlying the talker variation in overall advancement to future work and assume that participation in the change-in-progress is an indexical feature of all of the talkers' speech.

The observed between-talker differences in overall degree of /u/ fronting have two implications for understanding the relationship between phonetic reduction and degree of social indexing. First, Clopper *et al.* (2017) found that the effects of neighborhood density and speaking style on /u/ fronting were larger for Northern talkers, who exhibited a lower degree of /u/ fronting overall, than for Midland talkers, who exhibited a greater degree of /u/ fronting overall. This result suggests that the Midland talkers in their study may be nearing the end of the /u/ fronting change-in-progress, where less variation due to linguistic factors would be expected, whereas the change is still ongoing for Northern talkers, where more variation due to linguistic factors would be expected (Fridland and Bartlett, 2006; Labov, 1972). Although overall degree of /u/ fronting does not correlate with talker region in the current study, the talkers with greater /u/ fronting overall may be nearing the end of the ongoing sound change. For these talkers, fronted /u/ may have less indexical value (Drager, 2011; Johnstone and Kiesling, 2008), making it less likely to be manipulated as a function of linguistic variables related to phonetic reduction. Thus, we predicted smaller effects of the linguistic factors related to phonetic reduction (i.e., lexical frequency, neighborhood density, discourse mention, and speaking style) on /u/ fronting for talkers with a greater degree of /u/ fronting overall than for talkers with a lower degree of /u/ fronting overall. That is, we expected the magnitude of the effects of the linguistic factors to vary (i.e., interact) with the talkers' overall degree of /u/ fronting in the realization of individual /u/ tokens.

Second, spectral reduction toward the center of the vowel space may be realized differently as a function of overall /u/ fronting. In particular, for talkers whose average /u/ production is back-of-center, spectral reduction of /u/ should involve fronting (and lowering) toward the center of the vowel space, whereas for talkers whose average /u/ production is front-of-center, spectral reduction of /u/ should involve backing (and lowering) toward the center of the vowel space. Phonetic reduction of /u/ may also involve undershoot in lip protrusion, which would have the acoustic effect of raising $F2$. Thus, a talker with a lower degree of /u/ fronting overall may produce fronted /u/ in reduction-promoting contexts, whereas a talker with a greater degree of /u/ fronting overall may produce backed /u/ in reduction-promoting contexts. In the former case, socially indexed /u/

fronting may be indistinguishable from phonetic reduction of /u/ in the $F2$ dimension. However, in the latter case, socially indexed /u/ fronting should be distinguishable in direction from phonetic reduction of /u/ (i.e., backing in the $F2$ dimension). Thus, we expected the direction of the effect of phonetic reduction to vary (i.e., interact) with the talkers' overall degree of /u/ fronting.

To evaluate the expected interactions between the linguistic factors and overall advancement of the /u/ fronting change-in-progress, the degree of overall /u/ fronting by talker was included as an independent variable in the analysis. The interactions between this variable and the linguistic factors capture differences in the magnitude of within-talker variation in /u/ fronting due to the relative completion of the change-in-progress and in the direction of spectral reduction as a function of individual talkers' overall degree of /u/ fronting.

II. METHODS

The data were drawn from the Columbus subset of the Ohio State Stories Corpus (Burdin *et al.*, 2015), which includes speech produced by five college-aged male and ten college-aged female talkers from each of two American English dialect regions: Midland and North. The Midland talkers were from central or southern Ohio and the Northern talkers were from northern Ohio or Chicago, Illinois. The talkers were overwhelmingly white ($N=26$); one male Midland and two female Northern talkers were multiracial, and one female Midland talker declined to report her race.

Each of the 30 talkers was recorded reading a set of 30 short stories, first in a plain speech style directed toward an imagined friend or family member and then in a clear speech style directed toward an imagined hearing-impaired or non-native listener. The 30 short stories ranged in length from 66 to 243 words ($M=144$ words) and were constructed to elicit 234 unique target words containing 1 of 6 stressed vowels (/i, e, æ, ɑ, ɔ, u/), with 34–45 target words per vowel. Within each vowel category, target words were selected with a range of log lexical frequencies ($M=2.32$, range: 1–4.66) and phonological neighborhood densities ($M=13$, range: 1–37), as defined in the Hoosier Mental Lexicon (Nusbaum *et al.*, 1984). Lexical frequency and neighborhood density were uncorrelated within each vowel category and across the full set of target words (all $r^2 < 0.11$). Each target word was produced twice in the same story; the distance between first and second mentions varied from 4 to 231 words ($M=52$ words). Together, the corpus includes a total of 28080 target word tokens (234 word targets \times 2 mentions \times 2 styles \times 30 talkers) in a fully factorial within-subject design in which lexical frequency, neighborhood density, discourse mention, and speaking style were manipulated.

The short stories were forced-aligned for words and segments using the Penn Phonetics Lab Forced Aligner (Yuan and Liberman, 2008). The segmental boundaries returned by the forced-aligner for the stressed vowel in each target word were hand-corrected using visual cues from the waveform and spectrogram (Peterson and Lehiste, 1960). First and second formant frequencies were estimated at five time points within each target vowel at 15% increments between 20%

and 80% of the vowel's duration. The formant frequency estimates were converted to the Bark scale (Traunmüller, 1990). Target vowels produced with non-modal voicing (13%), disfluencies (<1%), and outlier formant frequency or duration values (3%) were removed, leaving a total of 23262 vowel tokens for analysis.

The goal of the statistical analysis was to explore the effects of lexical frequency, neighborhood density, discourse mention, and speaking style on the magnitude of /u/ fronting. This analysis was therefore limited to the subset of the data involving the target vowel /u/, including 37 unique target words, shown in Table I, and 3526 vowel tokens. The dependent measure in the analysis was $F2$ at the temporal midpoint of /u/, which is affected by the consonant environment (Hillenbrand *et al.*, 2001; Stevens and House, 1963). In the change-in-progress in American English, /u/ fronting is most advanced following onset coronal consonants, excluding /r/, somewhat advanced following onset labial, velar, and obstruent + liquid clusters, and least advanced preceding coda /l/ (Labov *et al.*, 2006). An inspection of Table I reveals that 23 (62%) of the target words contain an onset coronal consonant (singleton or in a cluster, excluding singleton /r/), and another 12 (32%) of the target words contain an onset labial, velar, or obstruent + liquid cluster. None of the target words contain a coda /l/. Given that all of the talkers produced the same set of target words, variability in /u/ fronting due to consonant environment is expected to be consistent across talkers. Thus, consonant context was captured in the statistical analysis using random effects for target words.¹

III. RESULTS

A. Variation in /u/ fronting across talkers

A preliminary analysis was conducted to explore the effects of talker gender and regional dialect on /u/ fronting so that the overall advancement in /u/ fronting across talkers could be considered. A linear mixed-effects regression model predicting $F2$ values of /u/ in Bark with gender and region as fixed effects, random intercepts for talkers and words, and random by-word slopes for gender and region with Satterthwaite approximation of degrees of freedom revealed the expected main effect of gender ($t=4.61$, $p < 0.001$), in which female talkers produced higher formant frequencies than male talkers. The main effect of region and the interaction between region and gender were not significant, confirming that /u/ fronting did not vary within this sample as a function of regional background. In contrast, although talkers from both regional dialects exhibited substantial /u/ fronting, the Northern talkers produced fronted

TABLE I. Target words containing /u/ in the Ohio State Stories Corpus.

Onset coronal (excluding /r/)	cute, feud, flute, huge, juice, june, loose, news, nude, shoe, shrew, sleuth, smooth, snooze, soothe, stew, suit, true, truth, tube, tunic, view, youth
Onset labial, velar, or obstruent + liquid cluster	booth, boots, bruise, crew, food, fruit, goose, group, mood, moon, moose, proof
Other onset	ooze, root

/æ, ɑ/ relative to the Midland talkers, consistent with the Northern Cities Shift (Labov *et al.*, 2006). Linear mixed-effects regression models predicting $F2$ values in Bark of /æ, ɑ/ with gender and region as fixed effects, random intercepts for talkers and words, and random by-word slopes for gender and region confirmed marginally greater /ɑ/ fronting ($t = -1.91, p = 0.066$) and marginally greater /æ/ fronting ($t = -1.83, p = 0.077$) for Northern talkers than Midland talkers. Thus, the talkers in this corpus produced substantial /u/ fronting alongside expected dialect differences reflecting regional participation in the Northern Cities Shift. Given this independence between /u/ fronting and the Northern Cities Shift, we combined the Midland and Northern talkers for the analysis of /u/ fronting.

As noted in Sec. IC, /u/ fronting raises a question about how phonetic reduction of /u/ is realized in the vowel space. In particular, although fronting (and lowering) of /u/ toward the center of the vowel space would be predicted for a backed production of /u/, backing (and lowering) of /u/ toward the center of the vowel space might be predicted for a fronted production of /u/. Thus, the definition of the center of the vowel space critically affects the interpretation of the results. The center of the vowel space can be defined phonologically as a mid-central or neutral vowel, such as /ə/ (Fourakis, 1991; van Bergem, 1993), articulatorily as a neutral tongue position (e.g., Browman and Goldstein, 1992), or acoustically as the grand mean of all (e.g., Bradlow *et al.*, 1996; Munson and Solomon, 2004; Wright, 2004) or a subset (e.g., Chung *et al.*, 2012; Harrington *et al.*, 2008; Holt, 2018; Scarborough and Zellou, 2013; Zellou and Scarborough, 2015) of the vowels in the system. When only a subset of vowels is used to define the acoustic center, the subset typically consists of either the point vowels (Chung *et al.*, 2012; Holt, 2018) or /i, ɑ/ as the most peripheral high-front and low-back vowels, respectively (Harrington *et al.*, 2008; Scarborough and Zellou, 2013; Zellou and Scarborough, 2015). Following this latter approach, we defined the center of the vowel space as the grand mean of the high-front and low-back vowels. In previous work, /i, ɑ/ were used to represent these peripheral points. However, given that /ɑ/ varies in our data as a function of regional dialect and /ɔ/ was produced as a relatively low vowel by all of the talkers in the dataset, we used /i, ɔ/ as the peripheral vowels, after confirming that neither of these two vowels varied in either $F1$ or $F2$ as a function of region or its interaction with gender. Thus, the acoustic center of the vowel space was defined as the grand mean of /i, ɔ/ in the $F1 \times F2$ Bark space for each talker.

Figure 1 shows the mean values of $F1$ and $F2$ in Bark relative to this acoustic center (i.e., centered $F1$ and $F2$ values), estimated at the temporal midpoint, for each of the six target vowel categories for each talker, separated by gender and region. An inspection of these vowel spaces reveals substantial /u/ fronting by all talkers. The mean by-talker /u/ productions for females (top panels) and males (bottom panels) from both the Midland (left panels) and the North (right panels) had $F2$ values that were comparable to their mean /ε, æ/ productions and well in front of their mean /ɑ, ɔ/ productions, resulting in a parallelogram-shaped vowel space for all four groups.

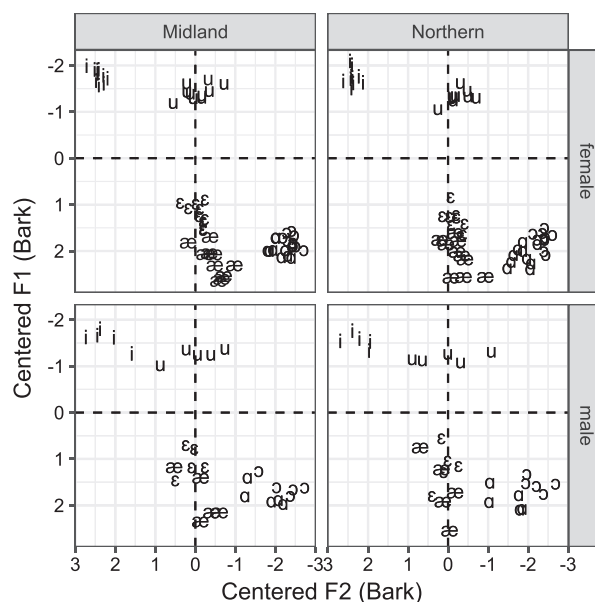


FIG. 1. Mean centered vowel spaces in Bark for each of the 30 talkers, separated by gender and regional dialect. The acoustic center of the vowel space (defined as the grand mean of /i, ɔ/ in the $F1 \times F2$ Bark space) is located at the origin (0,0).

The median of the by-talker mean centered $F2$ values of /u/ shown in Fig. 1 is -0.131 Bark, indicating that less than half of the talkers had a mean $F2$ value of /u/ that was higher than the overall mean $F2$ of their vowel space, suggesting a general tendency among this group of young Midwestern talkers for /u/ fronting that does not cross the center of the vowel space. Only 11 of the 30 talkers had a mean centered value of $F2$ for /u/ that was greater than 0, meaning that nearly $\frac{2}{3}$ of the talkers ($N = 19$) produced a mean $F2$ of /u/ that was back-of-center in their vowel space. Further, as expected based on Fig. 1, overall advancement of /u/ fronting was essentially orthogonal to gender and regional dialect. Talkers with mean centered $F2$ values of /u/ above the median included three male Midland, three male Northern, five female Midland, and four female Northern talkers, whereas talkers with mean centered $F2$ values below the median included two male Midland, two male Northern, five female Midland, and six female Northern talkers. We therefore included mean by-talker centered $F2$ values of /u/ as a continuous measure of overall advancement of /u/ fronting in the statistical analysis in Sec. III B to allow for consideration of the interactions between the degree of overall /u/ fronting and the reduction-promoting variables on by-token variation in /u/ fronting. We defined overall advancement of /u/ fronting as a continuous measure because the distribution of the by-talker mean centered $F2$ values is unimodal, as confirmed by a non-significant dip test for multi-modality ($D = 0.05, p = 0.82$).

B. Assessing factors that contribute to variation in /u/ fronting

Variation in /u/ fronting was examined using a linear mixed-effects regression model predicting raw $F2$ values of /u/ in Bark at temporal midpoint from lexical frequency,

neighborhood density, discourse mention, speaking style, and overall advancement of /u/ fronting, defined as the by-talker mean $F2$ of /u/ in Bark relative to the center of the individual talker's vowel space.² Lexical frequency, neighborhood density, and overall advancement of /u/ fronting were continuous predictors and were centered for analysis. Discourse mention and speaking style were binary predictors and were coded with sum contrasts (discourse mention: first = 1, second = -1; speaking style: clear = 1, plain = -1). Vowel duration and its interaction with advancement were included as covariates, given that shorter vowel duration is expected to correspond to spectral reduction in the vowel space (Moon and Lindblom, 1994), and the direction of this spectral reduction may vary depending on the overall degree of /u/ fronting, as discussed above. The maximal data-driven random effect structure was used (Bates *et al.*, 2015), including random intercepts for talkers and words, random by-talker slopes for lexical frequency, discourse mention, and speaking style, and random by-word slopes for discourse mention and speaking style. A random by-talker slope for neighborhood density was not supported by the data and was removed. Statistical significance was determined using the Satterthwaite approximation of degrees of freedom.

The results, summarized in Table II, revealed significant main effects of overall advancement of /u/ fronting, speaking style, and the duration covariate, as well as significant interactions between speaking style and advancement, between the duration covariate and advancement, and between lexical frequency, neighborhood density, and advancement. As expected, /u/ productions from talkers with greater advancement (i.e., a greater degree of /u/ fronting overall) had higher $F2$ values than /u/ productions from talkers with lower advancement (i.e., a lower degree of /u/ fronting overall), consistent with their respective overall degrees of /u/ fronting. Consistent with the results of Clopper *et al.* (2017), plain speech /u/ tokens exhibited higher $F2$ values than clear speech /u/ tokens, suggesting more fronting of /u/ in the reduced, plain speech style relative to the hyperarticulated, clear speech style. The effect of the duration covariate was negative, which is the predicted direction for backed /u/ productions: shorter vowel duration corresponded to higher $F2$ values, suggesting fronting of /u/ may be associated with temporal reduction even for front-of-center /u/ productions (cf. Moon and Lindblom, 1994).

The interaction between the duration covariate and overall advancement of /u/ fronting is shown in Fig. 2. An inspection of Fig. 2 reveals that the negative relationship between duration and fronting of /u/ is larger for talkers with lower advancement (lighter/yellow lines) than for talkers with greater advancement (darker/blue lines), suggesting a stronger relationship between fronting of /u/ and temporal reduction for talkers with a lower degree of /u/ fronting overall than for talkers with a greater degree of /u/ fronting overall.

The interaction between speaking style and overall advancement of /u/ fronting is shown in Fig. 3. An inspection of Fig. 3 suggests that the speaking style effect is smaller for talkers with greater advancement (darker/blue lines) than for talkers with lower advancement (lighter/yellow lines) and

TABLE II. Summary of the linear mixed effects regression model predicting raw $F2$ of /u/ in Bark from lexical frequency, neighborhood density, discourse mention, style, and overall advancement of /u/ fronting for all 30 talkers. Significant effects ($p < 0.05$) are shown in bold.

Coefficient	Estimate	t -value	p -value
Intercept	11.820	85.60	<0.001
Frequency	-0.047	-0.31	0.756
Density	-0.003	-0.24	0.815
Mention (first)	-0.022	-0.83	0.413
Style (clear)	-0.052	-2.34	0.025
Advancement	0.632	3.23	0.003
Duration	-0.004	-12.27	<0.001
Frequency \times density	0.023	1.00	0.326
Frequency \times mention	0.020	0.55	0.586
Frequency \times style	-0.011	-0.55	0.588
Frequency \times advancement	-0.037	-0.55	0.585
Density \times mention	0.002	0.47	0.643
Density \times style	0.003	1.46	0.152
Density \times advancement	0.000	-0.04	0.966
Mention \times style	-0.008	-0.73	0.467
Mention \times advancement	0.028	1.12	0.263
Style \times advancement	0.102	2.35	0.026
Advancement \times duration	0.003	6.15	<0.001
Frequency \times density \times mention	0.001	0.13	0.901
Frequency \times density \times style	0.001	0.21	0.838
Frequency \times density \times advancement	-0.026	-2.67	0.012
Frequency \times mention \times style	0.004	0.28	0.778
Frequency \times mention \times advancement	-0.018	-0.53	0.594
Frequency \times style \times advancement	-0.003	-0.08	0.934
Density \times mention \times style	-0.001	-0.90	0.370
Density \times mention \times advancement	0.000	-0.14	0.889
Density \times style \times advancement	-0.003	-1.04	0.299
Mention \times style \times advancement	0.001	0.05	0.962
Frequency \times density \times mention \times style	-0.003	-1.09	0.277
Frequency \times density \times mention \times advancement	0.002	0.45	0.655
Frequency \times density \times style \times advancement	0.005	0.95	0.344
Frequency \times mention \times style \times advancement	-0.017	-0.49	0.626
Density \times mention \times style \times advancement	0.001	0.36	0.720
Frequency \times density \times mention \times style \times advancement	0.005	0.92	0.355

appears to be non-existent for the most advanced talkers. That is, for talkers with positive mean centered $F2$ values of /u/ (i.e., those who consistently produce front-of-center /u/), speaking style has a limited effect on the fronting of /u/, as expected for talkers for whom the change-in-progress is nearing completion (Fridland and Bartlett, 2006; Labov, 1972). The three-way interaction between lexical frequency, neighborhood density, and overall advancement of /u/ fronting is illustrated in Fig. 4. Although lexical frequency was treated as a continuous variable in the statistical analysis, it is visualized in Fig. 4 as a binary variable (high- versus low-frequency) based on a median split. An inspection of Fig. 4 suggests that the interaction between lexical frequency and neighborhood density is smaller for talkers with greater advancement (darker/blue lines) than for talkers with lower advancement (lighter/yellow lines), as expected. For talkers with lower advancement, low-frequency words exhibit the expected pattern for neighborhood density, in which low-density words have higher $F2$ values than high-density words,

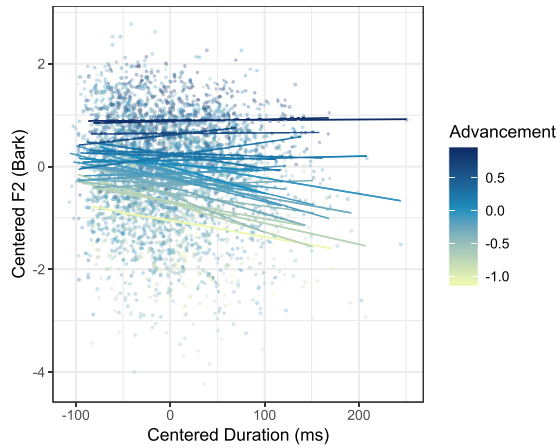


FIG. 2. (Color online) Centered F_2 of /u/ as a function of vowel duration and overall advancement of /u/ fronting. Each point represents one token. Regression lines reflect by-talker simple linear relationships among the variables. Darker (blue) colors indicate talkers with greater overall advancement, and lighter (yellow) colors indicate talkers with lower overall advancement.

but the F_2 of /u/ for high-frequency words is not strongly affected by neighborhood density. In contrast, for talkers with greater advancement, lexical frequency and neighborhood density have limited effects on the F_2 of /u/. Together, these two significant interactions reveal that talkers with a greater degree of /u/ fronting overall exhibit less structured variation independent of vowel duration and driven by lexical frequency, neighborhood density, and speaking style than talkers with a lower degree of /u/ fronting overall, as expected as the change-in-progress nears completion (Fridland and Bartlett, 2006; Labov, 1972).

IV. DISCUSSION

The results reveal that the factors correlated with the degree of /u/ fronting in the current study include speaking style, lexical frequency, neighborhood density, vowel duration, and overall advancement of /u/ fronting. The main effects reveal more fronting of /u/ for plain speech than for

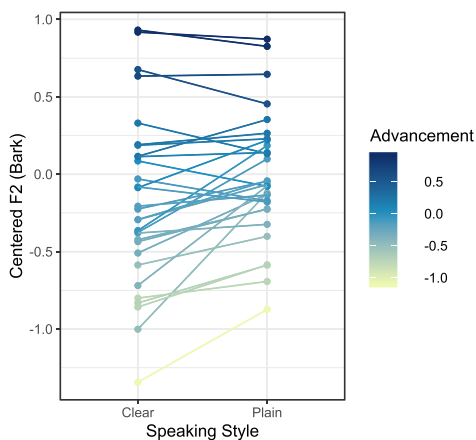


FIG. 3. (Color online) Centered F_2 of /u/ as a function of speaking style (clear, plain) and overall advancement of /u/ fronting. Each pair of points represents by-style means for one talker. Darker (blue) colors indicate talkers with greater overall advancement, and lighter (yellow) colors indicate talkers with lower overall advancement.

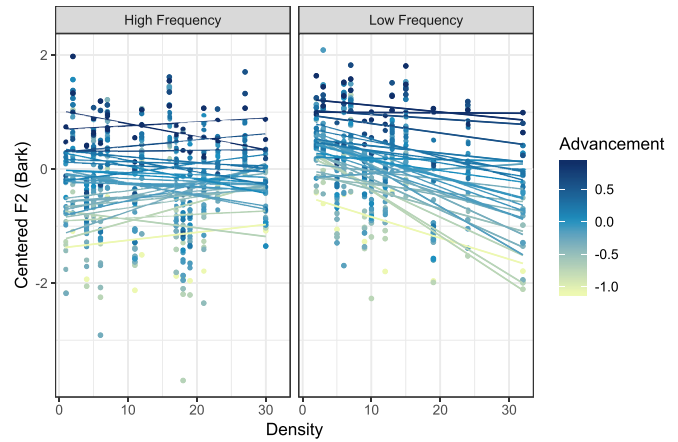


FIG. 4. (Color online) Centered F_2 of /u/ as a function of lexical frequency, neighborhood density, and overall advancement of /u/ fronting. Lexical frequency was treated as a continuous numerical predictor in the statistical model, but is plotted as a binary variable (defined by a median split) to facilitate interpretation. Each point represents one talker mean over items. Regression lines reflect by-talker simple linear relationships among the variables. Darker (blue) colors indicate talkers with greater overall advancement, and lighter (yellow) colors indicate talkers with lower overall advancement.

clear speech, for shorter vowels than for longer vowels, and, trivially, for talkers with a greater degree of /u/ fronting overall than for talkers with a lower degree of /u/ fronting overall. The significant interactions suggest that the style effect is larger and that neighborhood density interacts with lexical frequency more strongly for talkers with lower advancement than for talkers with greater advancement in the change-in-progress. Discourse mention was not a significant predictor of /u/ fronting, consistent with the results of Clopper *et al.* (2017) with a different set of materials. This lack of an effect may reflect critical differences between discourse mention and the other factors examined in this study (cf. Clopper *et al.*, 2017; Watson, 2010) or the measure of discourse mention itself, which included first and second mentions of target words separated by as few as 11 and as many as 155 words (see also Clopper *et al.*, 2018).

The results suggest structured variation in fronting of /u/ related primarily to vowel duration for talkers with a greater degree of /u/ fronting overall. The effect of duration was smaller in magnitude for talkers with greater advancement than for talkers with lower advancement (see Fig. 2), but the direction of the effect was consistent across talkers, regardless of overall advancement of /u/ fronting. In particular, more fronting of /u/ was observed for shorter vowels. This result is somewhat surprising from the perspective of phonetic reduction, given that 11 of the 30 talkers produced a mean F_2 of /u/ that was front-of-center in their vowel space (see Fig. 1) and that fronting of /u/ cannot be interpreted as spectral reduction toward the center of the vowel space for talkers whose mean /u/ is front-of-center. This relationship between fronting of /u/ and temporal reduction for talkers with greater advancement could be interpreted as evidence that we have not appropriately defined the center of the vowel space. As discussed in Sec. III A, the center of the vowel space may be defined phonologically (e.g., Fourakis, 1991), articulatorily (e.g., Browman and Goldstein, 1992), or acoustically (e.g., Bradlow *et al.*, 1996). In defining the

center of the vowel space acoustically based on by-talker grand means of high-front and low-back vowels, we followed Harrington *et al.* (2008), who examined /u/ fronting in British English. Thus, the results of the current study may suggest that more research is needed to appropriately define the acoustic center of the vowel space for American English. More generally, additional research is needed to understand the target of phonetic reduction—as the acoustic center of the vowel space versus /ə/ or some other central vowel—especially in the context of sound changes such as /u/ fronting, in which the shape of the vowel space changes, leading to a change in the acoustic center of the space relative to the point vowels (cf. Clopper *et al.*, 2017).

Alternatively, this result may be interpreted as providing additional evidence for the independence of phonetic reduction across acoustic domains (e.g., Clopper *et al.*, 2017; Turnbull, 2017; Watson, 2010). Spectral reduction associated with neighborhood density is not always accompanied by temporal reduction (Munson and Solomon, 2004; Zellou and Scarborough, 2015), and temporal reduction associated with discourse mention is not always accompanied by reduction in intensity (Lam and Watson, 2010). Thus, the finding that temporal and spectral reduction are not correlated for talkers with greater advancement in the current study is consistent with previous work, suggesting that phonetic reduction varies across acoustic domains.

The smaller magnitude of the duration effect for talkers with greater advancement relative to talkers with lower advancement may also point to individual differences among talkers with greater advancement in the realization of spectral variation associated with temporal reduction. For some talkers, temporal reduction may co-occur with fronting of /u/, consistent with a presumably older pattern of centralization of back vowels in reduction-promoting contexts, whereas for other talkers, temporal reduction may co-occur with backing of /u/, consistent with synchronic centralization of back vowels in reduction-promoting contexts. For the former talkers, the historical pattern of implementing spectral reduction as fronting of back-of-center /u/ toward the center of the vowel space is retained even after /u/ moves front-of-center, so that spectral reduction of /u/ continues to involve fronting. This pattern may be learned from ambient speech as listeners accumulate exemplars from other talkers of /u/ being fronted in reduction-promoting contexts. When those listeners become talkers, they may produce even more fronting of /u/ in reduction-promoting contexts, reflecting an abstraction of the pattern of fronting of /u/ as reduction. In contrast, for the latter talkers, spectral reduction is implemented as centralization relative to the current production, so that spectral reduction of /u/ involves backing. This pattern may reflect a biomechanical or other articulatory “effort code” that is used to compute how to reduce /u/ in reduction-promoting contexts, leading to backing for talkers for whom /u/ is front-of-center. Although this proposal is highly speculative, individual differences in the realization of spectral reduction could suggest that some talkers weigh abstractions over exemplar information more strongly, whereas other talkers weigh biomechanical information more strongly in the phonetic implementation of segmental reduction. Given

the larger overall magnitude of variation in fronting of /u/ for talkers with lower advancement relative to talkers with greater advancement, this individual differences interpretation is difficult to directly assess. However, an inspection of Fig. 3 suggests greater variation in the style effect among talkers with greater advancement than among talkers with lower advancement, who are more homogeneous in both the direction and the magnitude of the effect. This heterogeneity among talkers with greater advancement is consistent with an individual differences interpretation. As noted above, further research is needed to understand how phonetic reduction is implemented in the context of an ongoing sound change such as /u/ fronting, in which the predicted direction of spectral reduction switches over the course of the change.

The main effect of speaking style revealed greater fronting of /u/ in plain speech than in clear speech, consistent with the results of Clopper *et al.* (2017). The finding that talkers with lower advancement exhibited a stronger style effect than talkers with greater advancement (see Fig. 3) is also consistent with the results of Clopper *et al.* (2017), which revealed a stronger style effect for Northern talkers, who showed a lower degree of /u/ fronting overall, than for Midland talkers, who showed a greater degree of /u/ fronting overall. Given that Midland and Northern talkers were evenly distributed among the talkers with higher-than-median and lower-than-median advancement in the current study, the results suggest that the magnitude of the style effect is driven by overall advancement of /u/ fronting, rather than by regional dialect. That is, talkers with greater advancement exhibit a smaller style effect than talkers with lower advancement.

This relationship between the magnitude of the style effect and overall advancement of /u/ fronting suggests that talkers with greater advancement may be reaching the end of the /u/ fronting change-in-progress, whereas the change is still ongoing for talkers with lower advancement. For talkers with greater advancement, stylistic variation is minimal because they have reached a ceiling effect of /u/ fronting—either the natural endpoint of the change-in-progress or maximal fronting without encroaching on /i/—even in clear speech and further fronting in plain speech is not possible. That is, the social indexing that /u/ fronting provides cannot be further increased for these talkers in plain speech relative to clear speech because it is already maximized in clear speech. For talkers with lower advancement, however, /u/ fronting is not maximized in clear speech and social indexing through /u/ fronting can be increased in plain speech. Alternatively or in addition, talkers with greater advancement may not exhibit a style effect because they are so advanced in the change-in-progress that they no longer have robust access to the social indexing function of /u/ fronting (see Drager, 2011). In contrast, talkers with lower advancement are not yet nearing the end of the change-in-progress and therefore still have access to its social indexing function and can manipulate their productions accordingly across styles.

These talker differences in the manipulation of social indexing through speaking style are critically separable from phonetic reduction processes, because greater /u/ fronting

and shorter vowel duration are correlated across talkers. That is, talkers with greater advancement can and do produce variable degrees of /u/ fronting, but this within-talker variation is structured primarily by vowel duration. Vowel duration is typically correlated with phonetic reduction (Moon and Lindblom, 1994; cf. Munson and Solomon, 2004), especially in the context of speaking style (Smiljanic and Bradlow, 2008). Thus, to the extent that vowel duration reflects phonetic reduction processes, talkers with greater advancement exhibit variation in fronting of /u/ primarily as a direct result of phonetic reduction rather than independently as a function of speaking style. In contrast, the variation in /u/ fronting produced by talkers with lower advancement is independently structured by both vowel duration and speaking style, suggesting that both phonetic reduction (captured by vowel duration) and social indexing (captured by speaking style) are at play for these talkers.

One alternative explanation for the speaking style effect is that it reflects age-graded social indexing related to the imagined interlocutor (i.e., audience design; Bell, 1984), rather than social indexing of the talkers themselves. The instructions in the plain speaking style condition were to imagine a friend or family member as the interlocutor, whereas the instructions in the clear speaking style condition were to imagine a hearing-impaired or non-native interlocutor. If in the plain condition participants imagined a friend or sibling, the imagined interlocutor would be of approximately the same age as the participant (i.e., a young adult), and if in the clear condition participants imagined an older hearing-impaired relative or non-native university professor, the imagined interlocutor would be older than the participant. More /u/ fronting in plain speech than in clear speech could then be attributed to the imagined interlocutor's age with more /u/ fronting produced for younger imagined interlocutors and less /u/ fronting produced for older imagined interlocutors. We did not ask participants about their imagined interlocutors, however, so it is also possible that participants imagined an older family member, such as a parent, in the plain speaking style condition and a younger non-native speaker, such as a classmate, in the clear speaking style condition. Thus, testing this explanation would require further data about how talkers respond to instructions about imagined interlocutors, as well as comparison data from real interactions involving older and younger interlocutors to demonstrate that /u/ fronting is subject to this kind of age-graded audience design (see Scarborough *et al.*, 2007; Scarborough and Zellou, 2013).

The audience design interpretation would also not explain the effects of lexical frequency and neighborhood density that were observed in the current study. As shown in Fig. 4, the three-way interaction between lexical frequency, neighborhood density, and overall advancement suggests a modest effect of neighborhood density—in which words with fewer neighbors are produced with greater fronting of /u/—that is limited to low-frequency words for talkers with a lower degree of /u/ fronting overall. The observation of this effect of neighborhood density for talkers with lower advancement is consistent with the interpretation of the style effect discussed above, in which more structured variation is

observable for talkers with lower advancement because, unlike talkers with greater advancement, they have not reached ceiling-level production of /u/ fronting and/or still have access to the social indexing function of /u/ fronting. That is, talkers with greater advancement exhibit variation in the fronting of /u/ primarily as a direct result of phonetic reduction rather than independently as a function of neighborhood density or lexical frequency. In contrast, the variation in /u/ fronting produced by talkers with lower advancement is independently structured by vowel duration, neighborhood density, and lexical frequency, suggesting that both phonetic reduction (captured by vowel duration) and social indexing (captured by neighborhood density and lexical frequency) are at play for these talkers.

The overall direction of the neighborhood density effect for talkers with lower advancement is consistent with previous studies examining its interaction with social indexing (Clopper *et al.*, 2017; Munson, 2007), in which a greater degree of social indexing was observed for low-density words than high-density words. Moreover, the overall weakness of the statistical evidence for the effect of neighborhood density, including the lack of an overall effect of neighborhood density, is consistent with the fragility of neighborhood density effects on spectral variation (Clopper *et al.*, 2017; Gahl *et al.*, 2012; Munson and Solomon, 2004; Scarborough, 2010; Wright, 2004). In particular, although neighborhood density effects on spectral reduction have been reported by a number of different researchers, a close inspection of the data reveals substantial variation in the magnitude of the effect across vowel categories within studies and within vowel categories across studies. That is, the combined results in the literature do not provide consistent evidence for robust neighborhood density effects for any particular vowel or set of vowels (see Clopper *et al.*, 2017, for discussion).

Taken together, the results reveal substantial variation in /u/ fronting within and across Midwestern young adults. The variation across talkers is orthogonal to gender and regional dialect, suggesting either variation in the degree of social indexing of age for these talkers or social indexing of some other variable by /u/ fronting within this population. Further research is needed to explore other factors that may be indexed by /u/ fronting among American Midwesterners, including social class, race, and urban versus rural background. The variation within talkers suggests that for talkers with a greater degree of /u/ fronting overall, the change-in-progress may be nearing completion. This near-completion of the change leads to limited variation in the magnitude of /u/ fronting as a direct function of speaking style and other reduction-promoting contexts, although shorter duration remains correlated with greater /u/ fronting for these talkers. As noted above, additional research is needed to explore how temporal and spectral reduction are related as acoustic-phonetic vowel changes progress past the center of the vowel space. For talkers with a lower degree of /u/ fronting overall, the variation within talkers provides evidence for a greater degree of social indexing in the plain speaking style than in the clear speaking style, as well as an interaction between lexical frequency and neighborhood density in the

magnitude of /u/ fronting, independent of vowel duration. These results are consistent with previous work demonstrating a greater degree of social indexing in reduction-promoting contexts, and further suggest that speaking style provides a more robust context for manipulating social indexing in connected read speech than lexical factors such as frequency and neighborhood density.

ACKNOWLEDGMENTS

This work was partially supported by the National Science Foundation (Grant No. BCS-1056409). We would like to thank Nathanael Fath, Erin Luthern, Sarah Mabie, Rachel Monnin, and Christine Prechtel for assistance with corpus annotation.

¹An analysis including onset consonant (coronal versus non-coronal) as a covariate did not reveal a significant effect of onset consonant, and this factor was not included in the final model.

²The overall advancement measure is talker intrinsic and normalized relative to the talker's vowel space center. It differs conceptually from the random by-talker intercept, which is the model estimate of the by-talker mean F_2 of /u/ in Bark relative to the grand mean across talkers. The random by-talker intercept is talker-extrinsic and, because raw F_2 values in Bark were used as the dependent variable, not normalized. The lack of relationship between the overall advancement measure and the random by-talker intercept was confirmed by a non-significant correlation ($r^2 \approx 0$). The overall advancement measure likewise accounts for very little of the variance in raw F_2 values ($r^2 = 0.06$) because there is substantial within-talker variability as a function of the linguistic factors included in the analysis.

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