**Socially constrained variation in nonmodal phonation for more
than 2,500 speakers of British English**

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Abstract: This study examines the status of nonmodal phonation in British English using smartphone recordings from over 2,500 speakers. The acoustic correlates that were examined include fundamental frequency, $H1^*$ - $H2^*$, cepstral peak prominence, and harmonic-to-noise ratio. The results confirm that existing findings on nonmodal phonation—such as greater use of creaky voice by male speakers than female speakers—hold for a much larger and more diverse sample than has been considered previously. The study also uncovers effects that have not been reported in past work, such as a relationship between speakers' education levels and their production of nonmodal phonation.

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1. Introduction

Creaky voice—a type of nonmodal phonation resulting from the constriction of the glottis—has inspired a steady stream of frenzied editorials and news pieces in the American and British media over the past decade. The *Spectator* asked whether “creaky voice make[s] you a female yuppie—or an updated Vicki Pollard?” The *Washington Post* claimed that it hurts young women’s job prospects, and the *AARP Magazine* warned that it could damage their vocal cords. Despite this attention from the popular media, there has been little scholarly inquiry into the status of nonmodal phonation types in British English since the 1980s (Henton and Bladon, 1985). While nonmodal phonation has received more attention in American English, most studies of it have relied on sample sizes of less than 50 participants and have been limited to speakers from specific geographical areas, age groups, and socioeconomic classes. This study attempts to address these gaps by investigating the use of nonmodal phonation in a diverse group of over 2,500 speakers from across the United Kingdom.

1.1 *Phonation types*

Phonation types refer to the different methods of producing sound through the vibration of the vocal cords (Keating and Esposito, 2006). Ladefoged (1971) represented phonation types as falling on a one-dimensional articulatory continuum based on the degree of glottal constriction, an assumption that underlies much of the literature on this topic (Keating and Esposito, 2006; Lancia *et al.*, 2016; Yuasa, 2010).

1.2 *Acoustic correlates of nonmodal phonation*

Multiple acoustic measures may be necessary to fully describe the phonation types on this articulatory continuum, the most common of which are H1-H2 and harmonics-to-noise ratio (HNR). H1-H2 is the difference between the first and second harmonics and serves as a measure of spectral tilt, which is highly correlated with the degree of glottal constriction. In general, lower H1-H2 is associated with creaky voice, while higher H1-H2 occurs with breathy voice. HNR describes the periodicity of the speech signal; nonmodal phonation results in lower HNR values than modal phonation, as the vibration of the vocal cords is usually less regular.

1.3 Sex differences in the production of nonmodal phonation

Previous work has found differences in the production of nonmodal phonation between men and women using read and spontaneous speech, typically with sample sizes of less than 50 participants and manual coding of phonation types. [Henton and Bladon \(1985\)](#) investigated sex and dialect differences in the the production of breathy voice in Received Pronunciation (RP) and Northern British English speakers' open vowels. They selected citation forms of the open vowels /æ/, /ʌ/, /ɑ/, and /ɒ/ from 61 speakers in a preexisting corpus and measured raw H1-H2 values. The study found that British women produced breathier voice than their male counterparts, and, consequently, that male speakers used creaky voice more frequently than female speakers. [Hanson et al. \(2001\)](#) examined sex differences in the production of open vowels in non-spontaneous speech as part of a larger study on models of phonation types. Specifically, they elicited the vowels /æ/, /ʌ/, and /ɛ/ in carrier phrases from 21 male and 22 female participants. The authors then reported H1*-A3* and H1*-A1

to determine whether there were significant differences in nonmodal phonation between the two sexes. They also reported F1 to draw conclusions about intra-speaker variation. Yuasa (2010) investigated sex differences in American English speakers' production of creaky voice. She elicited spontaneous speech from 23 California English speakers, randomly selected 401-word samples from each one, and impressionistically coded occurrences of creaky voice. Yuasa (2010) found that women produced more creaky voice than men, a finding which was supported by Podesva (2011). Podesva and Callier (2015) contend that this difference may be due to men's generally lower F0. Garellek and Seyfarth (2016) examined acoustic differences between /t/ glottalization and phrasal creak. They used recordings of spontaneous speech from a gender-balanced corpus of 40 adults in Ohio. The researchers identified creaky phonation using annotations in the corpus and manual inspection. They concluded that linear discriminant models could be used to distinguish between different sources of creaky voice and that cepstral peak prominence (CPP) was important for identifying this distinction.

1.4 Accent and ethnicity in the production of nonmodal phonation

The roles of demographic factors such as accent and ethnicity in the production of nonmodal phonation types have been studied less extensively than that of sex, but existing literature suggests that they may be related as well. Within British males, Henton and Bladon (1985) found that RP speakers creaked more than Northern British English speakers. Ethnicity may also play a role in nonmodal phonation—for instance, Alim (2004) linked African American identity to falsetto and “strained” voice qualities. Podesva and Callier (2015) noted that

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listeners could distinguish African American English speakers from white ones, even in the absence of lexical and syntactic features of African American Vernacular English; they suggested that nonmodal phonation could be responsible for this result.

1.5 Contributions

In this study, we present the first large-scale analysis of nonmodal phonation for more than 2,500 speakers of British English. We examine how geography, word duration, and social factors such as sex, age, and education affect the production of nonmodal phonation.

1.6 Hypotheses

We investigated the following hypotheses based on the findings described in (1.2) and (1.3).

The acoustic correlates used to investigate each hypothesis are described in greater detail in (2.4).

- Young, highly educated women creak more than men of a similar age and older men and women (Melvin and Clopper, 2015; Podesva and Szakay, 2013; Yuasa, 2010).
- Men (of all ages) creak more than women (Henton and Bladon, 1985; Stuart-Smith, 1999).

2. Methods

2.1 Materials

We used audio data from the English Dialects App (Leemann *et al.*, 2016, 2018) to conduct analyses of nonmodal phonation. The app allows users to record a short passage in their native dialect on their smartphones. Such recordings have been shown to be sufficient for

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formant analysis (Decker and Nycz, 2011). Grillo *et al.* (2016) demonstrated that various Apple and Samsung smartphones produced similar F0, HNR, and CPP measurements to laboratory-quality microphones.

Users were shown a passage from *The Boy Who Cried Wolf* sentence by sentence on the screen and provided metadata about their age, gender, education, mobility, and ethnicity before submitting the audio material to our servers. They identified their dialect by placing a pin on the locality that best corresponded to it. Participants consented to the privacy agreement shown on the metadata screen.

2.2 Speakers

Given that the originally collected data did not contain any participant identifiers, we created a participant ID using latitude, longitude, age, gender, qualification and ethnicity. This yielded 2,708 participants. On that basis, we found that some participants had recorded the same word more than once. We excluded those participants ($N = 143$) from the analysis, leaving 2,565 speakers. In total, we considered 14,602 data points.

2.3 Signal processing

All fully voiced tokens from the 10 sentences in *The Boy Who Cried Wolf* were identified as candidates for analysis. To narrow down this list of candidates, utterances were automatically segmented using WebMAUS (Kisler *et al.*, 2017), which aligned recordings with the corresponding sentence’s orthographic and phonemic transcription. The SAMPA phonemic transcriptions of these utterances were generated using the MAUS grapheme-to-phoneme (G2P) model and were manually verified before use. For each token, a random subset of 25

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recordings was examined by hand to ensure that the forced alignments were correct. Tokens were only selected for analysis if at least 24 out of the 25 recordings were correctly aligned. This process led to a final list of six tokens in utterance-initial, medial, and final positions. These tokens were then extracted from their respective utterances using a Praat (Boersma and Weenink, 2018) script and the TextGrids generated by WebMAUS.

2.4 Data analysis

As noted in (1.2), a wide variety of acoustic correlates have been used to study nonmodal phonation in previous literature. Therefore, all commonly used metrics were investigated in this study to ensure comparability with previous work. These included HNR35, H1*-H2*, CPP, and F0. We used the corrected H1*-H2* rather than the raw H1-H2 measure to account for the fact that the formants (especially F1) can inflate the values of the amplitudes of the harmonics (Hanson *et al.*, 2001).

Each of the measures was calculated for 10 time steps across the word, and the mean value of those 10 measurements was used for analysis. Numerical predictors were z-scaled to use the same scale for all the predictors and to allow for comparability of the effect sizes. The following variables were used as predictors in our analyses:

- Gender (reference female).
- Age (mean = 34.3, sd = 14.8) .

- Qualification. We transformed the speakers' qualifications into a ranked scale and excluded speakers from the analysis who had not yet finished school ($N = 1340$). Higher values corresponded to higher qualifications and vice versa.
- The duration of the word. Word duration was log-transformed to reduce overly strong influence from outliers.
- Mean fundamental frequency in the extracted word (F0).

3. Results

3.1 The F0 measure

Variable	Estimate	Standard error	t-value
(Intercept)	205.698	7.192	28.600
WordDuration	-2.493	0.331	-7.536
GenderMale	-85.238	0.940	-90.665
SpeakerAge	-7.902	0.663	-11.925
Qualification	3.335	0.466	7.154
GenderMale:SpeakerAge	5.996	0.938	6.396

Table 1: Linear mixed-effects regression summary table for F0.

We tested models with three different F0 trackers: Snack ([Sjölander, 2004](#)), STRAIGHT ([Kawahara et al., 1998](#)), and SHR ([Sun, 2002](#)). We used the output from each of these track-

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ers as dependent variables and found that STRAIGHT yielded the best model fit (total AIC decrease of 5280 between Snack and Straight, with SHR in between). This model, summarized in Table 1, found lower F0 values in longer words and for male speakers, older speakers, and speakers with less education. Furthermore, the significant gender and age interaction indicates that the effect of age was smaller in male speakers than in female speakers.

3.2 The HNR35 measure

Variable	Estimate	Standard error	t-value
(Intercept)	35.418	1.181	29.992
F0	2.760	0.083	33.425
WordDuration	0.675	0.058	11.611
GenderMale	-3.531	0.232	-15.217
SpeakerAge	0.584	0.138	4.247
Qualification	0.248	0.097	2.566
GenderMale:SpeakerAge	-0.747	0.194	-3.843

Table 2: Linear mixed-effects regression summary table for HNR35.

Testing models with HNR05, HNR15, HNR25 and HNR35 as dependent variables against each other, we found that the HNR35 measure resulted in the best model fit (AIC decrease of 7031 between HNR05 and HNR35, with HNR15 and HNR25 in between). In

addition to the predictors presented above, we included F0 as a predictor for HNR. In spite of its significant correlation with all other predictors, no signs of collinearity were present in this and all following models, which is why we regard its inclusion as safe (Tomaschek *et al.*, 2018).

We found significantly lower HNR values in words with lower mean F0, in shorter words, in male speakers relative to female speakers, in younger female speakers, and in speakers with lower qualifications (see Table 2). The significant gender and age interaction indicates that male speakers have lower HNR values the older they get.

3.3 The $H1^*$ - $H2^*$ measure

Variable	Estimate	Standard error	t-value
(Intercept)	1.506	0.175	8.626
F0	3.714	0.078	47.487
WordDuration	-0.091	0.054	-1.685
GenderMale	-1.939	0.202	-9.600
SpeakerAge	0.194	0.115	1.680
Qualification	-0.034	0.081	-0.415
GenderMale:SpeakerAge	-0.420	0.162	-2.588

Table 3: Linear mixed-effects regression summary table for $H1^*$ - $H2^*$.

We found lower H1*-H2* values in words with lower mean F0 and in male speakers than in female speakers (see Table 3). The significant gender an age interaction indicates that older male speakers have lower H1*-H2* values. No effect of age was found for female speakers. Also, no effect was found for duration, latitude, longitude, or qualification, so these variables have been omitted in the models presented here.

3.4 The CPP measure

Variable	Estimate	Standard error	t-value
(Intercept)	19.633	0.212	92.736
F0	-0.449	0.037	-12.177
WordDuration	-0.039	0.026	-1.497
GenderMale	0.143	0.093	1.532
SpeakerAge	-0.272	0.053	-5.151
Qualification	-0.068	0.037	-1.827
GenderMale:SpeakerAge	-0.107	0.074	-1.441

Table 4: Linear mixed-effects regression summary table for CPP.

Pitting the CPP measure against our predictors, we found significantly lower CPP values associated with higher F0 values and with older age (see Table 4). None of the other effects yielded significance.

4. Discussion

This discussion will consider the effect of demographic variables (sex, age, and education) and F0 on the production of nonmodal phonation in British English. The results indicate that male speakers, older speakers, and less educated speakers produce more nonmodal phonation than female, younger, and more educated speakers and that more nonmodal phonation is associated with lower F0.

4.1 Sex

Overall, our findings indicated that male speakers produced more creaky voice than female speakers and vice versa. This was borne out in the fact that men had lower HNR than women, where lower HNR is associated with less periodicity in the speech signal and more nonmodal phonation. H1*-H2*, which measures the difference between the first and second harmonics, was also lower for men than women, confirming that men creaked more than women.

These findings are consistent with [Henton and Bladon \(1985\)](#) and [Stuart-Smith \(1999\)](#) who, for a subset of UK speakers, found that male speakers tend to produce more creaky voice than female speakers. In American English, two relatively recent studies ([Podesva and Szakay, 2013](#); [Yuasa, 2010](#)) demonstrated that women creaked more than men; the present results indicate that this change has not spread into British English.

4.2 Age

Older speakers generally exhibited more nonmodal phonation than younger speakers, though this effect was modulated by sex. The fact that older speakers exhibited lower CPP values

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than younger ones suggests that older people produce more nonmodal phonation. For men, HNR decreased with age, indicating that older men produced more nonmodal phonation, though the opposite was true for women. This finding contrasts with that of [Ferrand \(2002\)](#), who found that elderly females had substantially lower HNR values than the two other age cohorts they compared to.

4.3 Qualification

The results for qualification suggest that less highly educated speakers produced more creaky voice. Specifically, they exhibited both lower F0 and HNR values. Lower HNR indicates increased likelihood of nonmodal phonation—either creaky or breathy—while lower F0 suggests that the speakers are producing creaky voice. To the best of our knowledge, this effect has not been previously reported and could suggest that a rising prevalence of creaky voice in highly educated American women (as described in (1.6)) has not spread to the United Kingdom.

4.4 F0

Findings on sex and age differences in F0 align with previous research in this area, suggesting that the large-scale automated F0 tracking produced valid results. For instance, men exhibited a lower F0 than women. We also found that women’s F0 decreased with age, an effect that has been reported in previous literature ([Linville and Fisher, 1985](#)).

Lower F0 was generally associated with more nonmodal phonation, even when sex was taken into account. Lower values of H1*-H2*, HNR, and CPP—all of which indicate an increased likelihood of nonmodal phonation—were associated with lower F0. This may

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occur because lower frequencies of vocal fold vibration make it more likely that phonation becomes irregular, and thus creaky (Keating *et al.*, 2015).

4.5 Conclusion

A natural progression of this work would be to conduct a perceptual study of voice quality metrics. That is, do listeners perceive a difference in voice quality if words or utterances are resynthesized with different values for F0, H1*-H2*, CPP, HNR, etc.? Future work should also consider the effect of phrase position on nonmodal phonation, as it has been suggested that creaky voice often occurs phrase-finally.

The results of this study indicate that conclusions about the interaction of age, sex and nonmodal phonation from the 1980s and 1990s with small and geographically limited samples hold true for a large and demographically diverse group of current-day British English speakers. The use of crowdsourced big data also allowed this study to uncover previously unobserved effects, such as a relationship between nonmodal phonation and education level. Taken as a whole, these results support the validity of using big data in phonetic studies and demonstrate that other researchers should use such datasets to confirm or challenge previous conclusions about the acoustic properties of British English speech.

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