

When modal phonation becomes non-modal: A pilot study on creaky voice

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Abstract

This exploratory pilot study investigates the perceptual threshold of creaky voice phonation in various stimuli differing in terms of creak duration, location, and F0 with or without jitter. A 2AFC task was used to collect data about phonetically trained participants' perceptions of creaky voice. Our findings showed that listeners are more likely to perceive creaky voice with longer creak duration, lower F0, and added jitter. Furthermore, if creaky voice was localized to the end of a vowel segment rather than at its beginning, listeners were more likely to perceive it. Effects of surrounding segment voicing were also observed, showing that voiceless consonants preceding or following creaky vowels lead to more consistent perception of creaky voice. The study concludes that there is evidence for an additive effect of acoustic cues to perception of creaky voice, although more complex experiments are needed to investigate the relative strength of the associated perceptual cues.

Introduction

Creaky voice is a phonation type that typically manifests as having a low fundamental frequency (F0) and sounding 'rough' or 'harsh' (Garellek, 2019). The roughness generally stems from the low F0 values, the irregularity of the F0 and the overall glottal constriction. This contrasts with modal phonation in which the vocal folds are more open, and their movement is highly periodic which leads to a more regular F0, as well as an overall higher F0 and intensity.

Creaky voice can be found throughout numerous languages of the world as either a phonologically contrastive feature of the language (e.g., Jalapa Mazatec, Danish), a prosodic feature that signals end of utterance (e.g., English) or as a turn-taking cue in conversation (e.g., Finnish) (Davidson, 2021; Grønnum, 2023; Ogden, 2001; Redi & Shattuck-Hufnagel, 2001). It can also be used as a sociolinguistic marker to signal belonging to a specific subgroup (Mendoza-Denton, 2011). Importantly however, creaky voice is an umbrella term for various subtypes of non-modal phonation which differ from each other by their acoustic features (Keating et al., 2015, 2023).

Based on the findings of several studies, the typical F0 range for creaky phonation was found to be between 40 Hz and 80 Hz, although both lower and higher values can be considered creaky and the ranges vary from study to study, suggesting that F0 in creak might be speaker-specific (Blomgren et al., 1998; Dallaston & Docherty, 2020; Davidson, 2021; Van Hugte & Heeren, 2024). Notably, the F0 in creaky phonation does not seem to differ substantially between male and female speakers (Blomgren et al., 1998; Davidson, 2019). The presence of creaky voice can differ in its localization – in some languages it is localized to the vowel or to a sonorant consonant (e.g., Jalapa Mazatec; Garellek & Keating, 2011), in others it is localized to a whole syllable (e.g., Danish; Grønnum, 2023), and even this distinction can be further divided (Davidson, 2021). For instance, in Jalapa Mazatec the creaky phonation is localized to the

beginning of the vowel and proceeds to fade over its course (Garellek & Keating, 2011). In K'ichee' the creaky phonation is localized to the middle of the vowel (Bennett, 2016), and in Danish and Mandarin tone 3 creaky phonation starts in the latter part of the vowel (Huang, 2020; Peña, 2022). However, to the best of our knowledge, the effect of localization of creaky voice on perception of creak has not been investigated.

Present Study

Many studies identify creaky tokens in their data based on acoustic inspection or by a combination of listening and visual reading of the spectrogram (for an overview see Dallaston & Docherty, 2020). Listening to tokens by researchers and other professionals is thus crucial for choosing which tokens will be marked as 'creaky', investigated or even discarded (Kang et al., 2022). Although there exist automatic tools for detecting creaky voice, such as *DeepFry* (Chernyak et al., 2022) or *Creapy* (Paierl et al., 2023), it remains unclear to what extent their detection strategies align with human perception strategies of non-modal voice qualities, as they are generally trained on predefined acoustic features and annotated data, and are not necessarily validated against human perceptual judgments. It is known that in perception, creaky voice is identified via a combination of one or more acoustic features (Keating et al., 2023). In their informal listening to natural tokens, Keating et al. claimed that just low F0 alone could instigate a creaky percept and so could irregular F0 by itself if the irregularity was strong enough. In comparison, constricted glottis (low H1-H2; high Contact Quotient, CQ) alone was not strong enough to cause a creaky percept, instead instigating a percept of tense voice. The combination of low F0 + irregular F0 was shown to consistently cause a creaky percept, however, it is not clear from the study which values for each parameter were measured. The authors state a range from 62-124 Hz for F0 and no measurements are given for F0 irregularity (jitter). In synthesized speech, the authors set a modal baseline of 70 Hz and then proceeded to conduct two manipulations. In one condition, they decreased the F0 to 60 Hz. In the other they introduced irregularity using the *Raspiness* function in the Praat Vocal Toolkit (Corretge, 2012) at a level of 200%. Both the low F0 of 60 Hz and the irregular F0 at a level of 70 Hz were found to sound creaky. However, these perceptions are based merely on informal listening from the authors – no larger-scale perception study was carried out.

Based on this informal evidence, we find it likely that there exists a threshold reached through a combination of acoustic features of various strengths, that changes the perception of voice quality from modal to non-modal. For instance, a token with a regular F0 of 60 Hz might be perceived as creaky and one with a regular F0 of 70 Hz might not. However, if enough irregularity in the F0 is introduced to the 70 Hz token, it should theoretically

be perceived as creaky. Existing research leaves a gap in measuring where this threshold lies and how different levels of various acoustic features contribute to reaching this threshold. Furthermore, it is also unclear what effect the localization of non-modal phonation within a segment (e.g., vowel onset, vowel end) has on this perceptual threshold. In this exploratory study, we investigate perceptual sensitivity to speech tokens depending on their F0 values, its irregularity, and the localization of creaky voice within vowel segments.

Method

We investigated the perception threshold through a two-alternative forced-choice task (2AFC). Four CVC syllables (/dad/, /dat/, /tad/, /tat/) were produced by a male speaker, the first author. The vowel portion of each syllable was shortened to 100ms using PSOLA resynthesis in Praat (Boersma & Weenink, 2026). Then, using a script, F0 was set to 90 Hz throughout the entire vowel. To create creaky stimuli, F0 was lowered and F0 irregularity (jitter) was added to either 10%, 25%, or 50% of the vowel. This manipulation was either done forwards from the vowel onset or backwards from the end of the vowel, creating early and late creak stimuli sets. For one set, the F0 was lowered to 60 Hz, for another set it was lowered to 70Hz, and for the last set it was lowered to 70 Hz and jitter was added using the *Raspiness* function (level = 30%) in the Praat Vocal Toolkit (Corrette, 2012). As the jitter is added as Gaussian noise centered around the F0, the level of added jitter was ~2.1%. These manipulations yielded a total of 72 stimuli (4 syllables * 3 durations * 2 locations * 3 manipulations). Additionally, 4 fully modal stimuli where the F0 was kept at 90 Hz were included, yielding a total of 76 stimuli. An overview of these manipulations can be found in Table 1.

Table 1. An overview of the manipulations carried out on each of the 4 syllables (/dad/, /dat/, /tad/, /tat/) to create the experimental stimuli.

	90 Hz	70 Hz	70 Hz + jitter	60 Hz
Duration of creak from vowel onset		10ms 25ms 50ms	10ms 25ms 50ms	10ms 25ms 50ms
	0ms			
Duration of creak from vowel end		10ms 25ms 50ms	10ms 25ms 50ms	10ms 25ms 50ms

Experiment

In total, data from 17 participants was collected, however, data from one participant was excluded due to them having given only one type of response to all stimuli. The analysis thus contained data from 16 participants (M = 4, F = 12, mean age = 38.8 years). We exclusively selected phoneticians, speech pathologists, and speech scientists as individuals who work with voice or speech every day. This was done to explore the perceptual effects from listeners who are already familiar with the concept of creaky voice. The experiment was sent via email and contained instructions, a link to a metadata survey, and the experiment file. Based on the

survey, the native languages of the participants were all Indo-European (English, Swedish, Icelandic, Czech, Polish, German, French, Italian, Dutch) except for one participant whose native languages were Mandarin and Hakka Chinese.

The experiment was carried out using Praat Experiment MFC (Boersma & Weenink, 2026). Participants were instructed to wear headphones. The instructions specified that they were going to hear sounds, and that they were supposed choose whether they heard creaky voice in the sound or not by pressing the ‘Yes’ or ‘No’ button. Then they listened to the 76 stimuli in a fully randomized order. Each stimulus was only heard once, and no option was given to listen to the same stimulus again. There was a 1s-long delay between clicking on a button and the next stimulus playing. There were 4 self-timed breaks throughout the experiment, but the entire experiment usually did not take more than 10 minutes to complete.

Statistical analysis

The results from the experiment were analyzed in RStudio (RStudio Team, 2026). Plots were made using the *ggplot2* library (Wickham, 2016). A generalized linear mixed-effect model was built using the *lme4* library (Bates et al., 2015) using the following formula: $response \sim syllable + location * (duration * manipulation) + (1 + location | participant)$. Due to convergence issues, only random slopes for location were included in the model. Duration was treated as a continuous predictor, since we expected the participants’ sensitivity to hearing creaky voice to linearly increase with creak duration.

Results

The results show that an average participant’s odds (transformed from log-odds) of making a ‘Yes’ choice across all conditions were 1.68 times larger (95% CI = [1.06, 2.66]; $p = 0.024$) than making a ‘No’ choice, which demonstrates that listeners were overall sensitive to the creak manipulations.

Importantly, all three manipulations were found to be statistically significant. In terms of duration, for every millisecond of creaky voice the odds for a ‘Yes’ response increased by a ratio of 1.05 (95% CI = [1.04, 1.06]; $p < 0.001$). In practice, a 10ms increase in creak would mean an increase of the odds ratio by 1.63 (95% CI = [1.48, 1.79]), and the 40ms increase from 10ms to 50ms in our stimuli meant that the odds of the stimulus being classified as creaky increased by a ratio of 7.02 (95% CI = [4.81, 10.25]). For location, the odds for making a ‘Yes’ choice were 1.86 times larger (95% CI = [1.31, 2.64]; $p < 0.001$) when the creak manipulation was made from the vowel end. Finally, the F0 and jitter manipulations were also found to be significantly different. A pairwise comparison showed that adding jitter to the 70 Hz condition significantly increased the odds of a ‘Yes’ response (estimated odds ratio = 1.63; 95% CI = [1.08, 2.46]; $p = 0.017$) compared to no jitter added. A second contrast compared the difference between the 60 Hz and 70 Hz + jitter conditions. The odds for a ‘Yes’ response were larger in the 60 Hz condition by a ratio of 1.8 (95% CI = [1.18, 2.76]; $p = 0.005$) than in the 70 Hz + jitter condition. No significant

two-way or three-way interaction effects between the manipulations were found. The proportion of responses depending on the manipulation can be seen in Figure 1.

Additionally, there were significant differences between the four syllables heard in the experiment. The syllables with voiceless onsets (i.e., /tad/, /tat/) had 2.46 times higher odds (95% CI = [1.83, 3.3]; $p < 0.001$) of obtaining a ‘Yes’ choice than those with voiced onsets. Even larger was the difference for syllables with voiceless codas (i.e., /dat/, /tat/) as compared to ones with voiced codas (estimated odds ratio = 5.26; 95% CI =

[3.87, 7.15]; $p < 0.001$). Moreover, syllables that matched vs. mismatched voicing in both onset and coda (i.e., /dad/, /tat/ vs. /dat/, /tad/) also significantly differed. Mismatching voicing instigated odds 1.34 times larger (95% CI = [1, 1.79]; $p = 0.046$) to obtain a ‘Yes’ choice than mismatching voicing. A detailed look at the odds for individual syllables shows that /tat/ had the highest odds of instigating a ‘Yes’ response, followed by /dat/, then /tad/, and then /dad/ separated by a sizable gap.

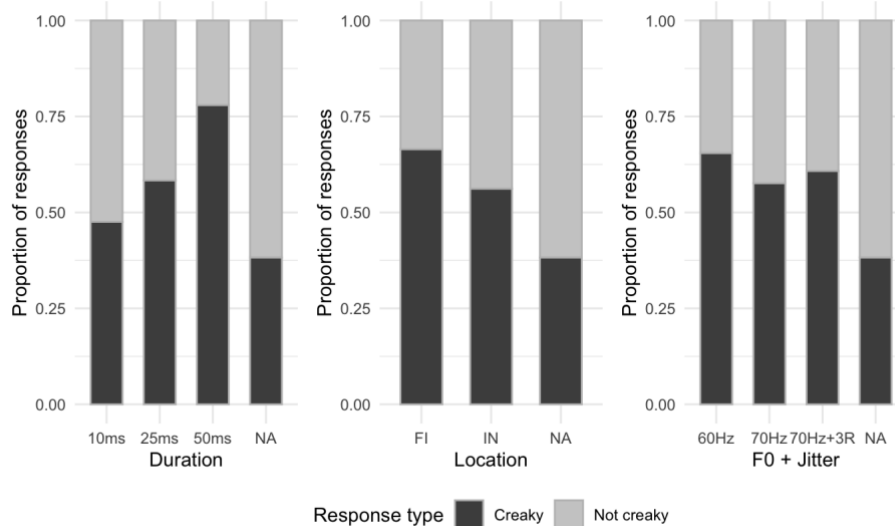


Figure 1. Proportions of responses to stimuli based on the manipulation. ‘Creaky’ signals a ‘Yes’ response. ‘NA’ refers to the stimuli with an F0 of 90 Hz and fully modal phonation.

Discussion

Our participants were overall highly sensitive to hearing creaky voice, no matter which acoustic features were manipulated. Importantly, the manipulations significantly increased the chances of a ‘Yes’ response across the board. What came as a surprise was that no interaction effects between the three types of manipulation were found, which indicates that individual effects were additive and did not depend on one another.

Firstly, duration manipulation played a great role. The 10ms-long creak did not overwhelmingly instigate ‘Yes’ responses, as the likelihood of a ‘Yes’ response was slightly less than chance. The 25ms manipulation caused a slight increase in ‘Yes’ responses, causing participants to hear creak more than half the time. Consequently, it can be deduced that the crossover point lies between 10ms and 25ms. If the effect of duration is assumed to be linear, Figure 1 suggests that the crossover point lies somewhat closer to 10ms than to 25ms. The 50ms manipulation clearly instigated a consistent creaky percept; over 75% of the responses indicated that creaky voice was heard. Based on our results, we would expect the odds of a ‘Yes’ choice to nearly linearly increase with creak duration. However, it should be noted that even in the 50ms condition a quarter of the tokens were identified as not containing creak, which demonstrates that listeners differ from each other in how they utilize duration of creaky phonation in perception.

Secondly, location of creak also significantly influenced whether our listeners heard creaky voice or

not. When creaky voice appeared at the end of the vowel, participants reported hearing it much more consistently compared to when it was in the vowel onset. At close observation, the tokens with creak in onset instigated responses barely above chance. It could be expected that creaky voice which appears towards the end of a word or utterance would be more easily perceptible, given that in English and many other Indo-European languages, creaky voice most typically appears utterance-finally (González et al., 2022; Heldner et al., 2019; Redi & Shattuck-Hufnagel, 2001; Van Hughte & Heeren, 2024). All but one of our participants were native speakers of an Indo-European language which might have played a role in this regard. This finding directly answers one of our research questions – localization of creak within the segment does matter in perceptual identification of creaky voice, at least for listeners with an Indo-European L1. An investigation of listeners with L1s in which creaky voice is associated with vowel onsets would be a valuable complement to the current study.

For the F0 and jitter manipulations, the results reflected the expected outcome – the 60 Hz manipulation instigated the greatest odds of a ‘Yes’ response, followed by the 70 Hz + jitter manipulation, and the 70 Hz manipulation without jitter. Based on our own listening and on the findings of Keating et al. (2023), the 60 Hz manipulation was expected to be highly consistent in instigating creaky percepts, especially since Keating et al. position the value of 60 Hz as their F0 baseline for creaky percepts. Adding jitter to the 70 Hz

only caused a marginal improvement in the odds for a ‘Yes’ response, although it suggests that at an ambiguous F0 value, such as 70 Hz, introducing irregularity in F0 sways the perceptual threshold towards non-modal. This was in accordance with our expectations. At closer inspection of the results, even the 70 Hz tokens without jitter caused our participants to make a ‘Yes’ choice slightly more than half the time. Based on these results, we cannot conclude whether there is a singular value or small range of F0 values that cause a creaky percept across the board. A future experiment which would introduce more levels of jitter modulation is needed to draw any conclusions.

The results show that there was an overall tendency in the experiment to answer ‘Yes’ even though the acoustic cues for creak were rather weak. For instance, if we inspect the 90 Hz tokens with fully modal phonation, the results show that they were considered to contain creaky voice about 40% of the time. This could be explained by the fact that participants were instructed to listen for creaky voice, therefore they might have become hypersensitive to creak or more lenient in what they considered to sound creaky. This tendency also could have been reinforced due to having used a male voice in the stimuli. Some participants informally expressed after the experiment that it is generally more challenging to distinguish modal phonation from creaky voice in male voices than in female voices. An experiment with a female voice would offer much needed comparison.

An inspection of individual performances showed that not every participant made ‘Yes’ responses more than 50% of the time. Some participants displayed a large tendency to give ‘Yes’ responses – even 75-80% of the time – suggesting that for these listeners, the threshold at which they consider a voice to sound creaky is rather loosely defined. The participant, whose data was discarded due to only making ‘Yes’ responses, self-reported that they were overly sensitive to hearing creak because they listen to speech containing creaky voice regularly. In comparison, the listeners who made ‘Yes’ responses less than half of the time did not display such overwhelmingly large tendencies – most of them hovered slightly below the 50% point. This again validates that listeners have differing strategies pertaining to creaky voice identification.

Moreover, differences between the respective syllables employed in the experiment were found. These results, as seen in Figure 2, point to a systematic interaction between segmental voicing and how listeners perceive voice quality. Voiceless consonants increased the odds of ‘Yes’ responses at the onset and even more strongly in the coda. This is logical, as voiceless stops naturally involve adduction of the vocal folds and cessation of voicing. When the vowel follows or precedes such segments, the laryngeal system must transition into or out of voicing, often producing irregular vocal fold vibration which may manifest as creaky voice. The overall higher odds for a ‘Yes’ response when the coda was voiceless are also supported by the result found for location, mentioned earlier. This result suggests that perception of creaky voice is not based solely on the acoustic information in the vowel

itself, but that it is strongly influenced by laryngeal context from adjacent consonants.

Returning to the primary research question posed in this study, could a perceptual threshold be determined for creaky voice? Our results do suggest that adding a secondary cue, such as jitter, to an ambiguously low F0 value increases the chance that listeners will hear creaky voice. The findings support the idea that the perceptual threshold for creaky voice is influenced by multiple cues of differing strengths, although more research on the interplay of cues is warranted, in addition to investigations of other cues in perception, such as spectral balance. On the other hand, the limited range of manipulations in this experiment and the very narrow choice of participants also limit the conclusions we can make about the threshold.

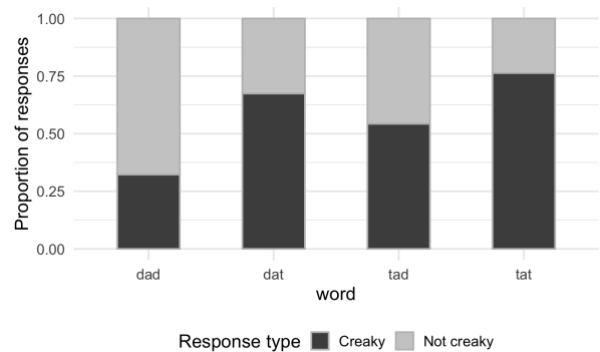


Figure 2. Proportions of responses to different syllables. ‘Creaky’ signals a ‘Yes’ response.

Lastly, some limitations of the present pilot study should be addressed. First, the manipulations exercised on the stimuli did not involve a direct manipulation of H1-H2 as the goal was to create stimuli that sounded most natural. A choice to perform the fewest manipulations to the recordings as possible was thus made. Due to time constraints, no acoustic measurements of H1-H2 were made, although it is suspected that low or negative values would be found for at least the 50ms-long 60Hz manipulations. The absence of a spectral balance manipulation leaves the perceptual value of that dimension in creaky voice unexplored in the context of the present study. Existing research suggests that for a successful creaky percept, the H1-H2 values should be very low or negative, however, it is unclear how low they need to be to indicate glottal constriction (Keating et al., 2015; Siem, 2024). A further study manipulating this dimension alongside other acoustic features would prove useful.

Conclusions

This pilot study investigated whether phonetically trained listeners heard creaky voice in various stimuli manipulated in terms of creak duration, localization, and F0 + jitter. Results show that longer duration and lower F0 contribute to perception of creaky voice, and that adding jitter also increased the proportion of creaky percepts. Our findings furthermore show that it is easier for listeners to perceive creaky voice if it is localized to the vowel end compared to the onset. We observed some effects of surrounding segment voicing, wherein voiceless consonants in syllable onsets and codas instigated a greater number of creaky percepts than

voiced ones. This suggests that perception of creaky voice is related to both the acoustic information in the vowel and the surrounding segments. It is concluded that there exists an additive effect of acoustic cues to perception of creaky voice, although more complex investigations of the relative strengths of these cues are warranted.

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