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Glottal squeaks in VC sequences

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Abstract

This paper reports results related to the phenomenon referred to as a "glottal squeak" (coined by [1]). At present, nothing is known about the conditioning and the articulation of this feature of speech. Our qualitative acoustic analyses of the conditioning of squeaks (their frequency of occurrence, duration, and f_0) found in Aberystwyth English and Manchester English suggest that squeaking may be a result of intrinsically tense vocal fold state associated with thyroarytenoid (TA) muscle recruitment [2] required for epilaryngeal constriction and vocal-ventricular fold contact (VVFC) needed to produce glottalisation [3]. In this interpretation, we hypothesise that squeaks occasionally occur during constriction disengagement: at the point when VVFC suddenly releases but the TAs have not yet fully relaxed. Extralinguistic conditioning identified in this study corroborates findings reported by [1]: females are more prone to squeaking and the phenomenon is individual-dependent.

Index Terms: glottal squeaks, glottalisation, larynx

1. Introduction

This study focuses on the phenomenon referred to as a "glottal squeak". This term has been coined by [1], who define it as "a sudden shift to a relatively high sustained f_0, which was usually very low amplitude" [1, p. 414, sic]. Figure 1 presents an example of a glottal squeak, which corresponds to squeaks shown in [1].

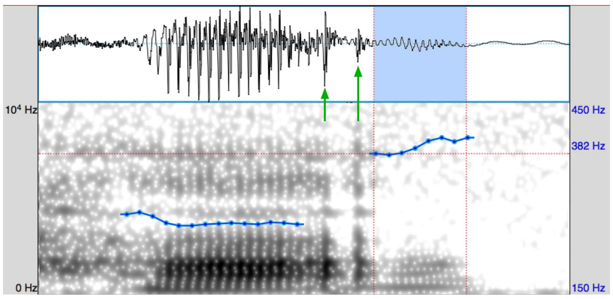

Figure 1: *Glottal squeak (highlighted).*

[1] report five characteristics of the feature: 1. squeaks are a rare phonatory feature; 2. it is speaker-dependent; 3. squeaking seems to occur in multiple environments (foot-initially with resonants, foot-finally with resonants, foot-medially with resonants – judged from the illustrations used by the authors); 4. it almost always co-occurs with glottalisation which is adjacent to it; and 5. females appear to be the primary squeakers [1, pp. 414, 416-417, 423-425]. The authors conclude that more research is necessary to confirm these findings, and this study aims to contribute to doing so.

[4] and [5, chapter 5] note that glottal squeaks are found in some speakers from Aberystwyth and Manchester (i.e. in Welsh and English varieties of English). Using data from these two studies, the following questions are explored here.

- Do squeaks co-occur with glottalisation and is this glottalisation always adjacent?
- Are squeaks found only in some individuals and are these individuals more likely to be females?
- Limiting contexts to VC sequences (***pit***, ***pity***, ***gullet***), are squeaks sensitive to various segmental and prosodic factors?

Furthermore, answering these questions will enable us to infer what squeaks may be articulatorily. For example, their potential co-occurrence or complementarity with glottalisation would be suggestive of the general laryngeal settings associated with squeaking. In addition, if squeaks are associated with female speech, sex differences in the laryngeal structures must be reflected in the articulatory description. Finally, the character of the potential segmental or prosodic conditioning can provide useful information as well, especially if related to vowel height, backness, or stress.

2. Methodology

2.1. Dataset

The data used here come from English spoken in Aberystwyth (10,006 tokens) and Manchester (410 tokens). The former dataset is based on 18 speakers (12 females, 6 males) producing words containing sequences of vowels and fortis plosives and vowels and fortis fricatives (***matter***, ***matt***, ***pass***), produced once in isolation and twice in a carrier sentence *Say X once*. The latter dataset is based on 5 speakers (3 females, 2 males) producing comparable words in a carrier sentence *That's the word X*. The datasets were not originally collected to study glottal squeaks, but pre-aspiration, which is why all the consonantal environments present in this study are fortis obstruents. Both datasets contain all the places of articulation available for fortis plosives and fricatives.

2.2. Data processing

The recordings for the Aberystwyth speakers and three of the Manchester speakers were done with H4 Zoom Handy

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recorder and C520 AKG head-mounted microphone. Two Manchester speakers were recorded with Logitech USB Desktop Microphone. All recordings were sampled at 44.1 kHz. The analyses were conducted using Praat [7] and R Studio [8].

2.3. Conditioning factors

Four aspects of glottal squeaks are considered: presence (i.e. frequency of occurrence), position with respect to glottalisation, duration, and f_0. Eight segmental conditions (1. phonological vowel length; 2. phonological vowel backness; 3. phonological vowel height; 4. vowel duration; 5. F1; 6. F2; 7. manner of articulation of the consonant; 8. place of articulation of the consonant) and three prosodic conditions are also taken into account (1. position within the foot: *pa*$^{\mathbf{squeak}}$*tter* vs *pa*$^{\mathbf{squeak}}$*t*; 2. word uttered in isolation vs in the middle of a carrier sentence – Aberystwyth data; 3. stressed vs unstressed syllable: *pi*$^{\mathbf{squeak}}$*ck*, *pi*$^{\mathbf{squeak}}$*cker* vs *froli*$^{\mathbf{squeak}}$*c* – Aberystwyth data). The words used for the segmental analyses were of the ˈ(C)VC and ˈ(C)VCV structures. The vocalic and consonantal properties listed in the eight segmental conditions relate to the underlined segments. Another factor considered was that of presence of glottalisation.

2.4. Glottalisation

Glottalisation was defined in line with [1], i.e. as a period of aperiodic f_0 (see two aperiodic pulses in Figure 1, highlighted with two arrows) or a sudden drop in f_0 (with respect to the immediate context as well as the general phonation of the speaker).

2.5. Durational measurements

Squeaks were identified in line with [1], i.e. as low amplitude sustained phonation of relatively high frequency. The identification was done independently by two authors and ambiguous examples were excluded from the analyses. The duration of squeaks was measured from the beginning of the low amplitude onset of phonation, which typically follows an irregular glottal pulse (in all but one case).

Two other intervals were measured for duration: that of the glottalisation and that of the vowel. Glottalisation duration excluded the duration of the following squeak. Vowel duration was quantified in two ways: once excluding the glottalisation and once including it since the segmental affiliation of glottalisation is ambiguous (see also [5]). Vowel onsets were identified as the onset of voicing based on the sound wave.

2.6. Measures of f_0

The Praat pitch setting was set to work with the range of 50-500Hz of f_0. The whole extent of individual squeaks was selected for the measurements of their average f_0.

2.7. Formant measurements

Vowel formants were measured in the midpoint of the vowel (excluding squeaks, including glottalisation). The optimal setting was found for each individual separately. Nearey formant intrinsic normalisation method [9] was used, as well as raw values, the former of which was obtained via the NORM Suite [10].

3. Results

The factors conditioning the occurrence of squeaks are discussed first to establish in which contexts squeaking occurs. Durational and periodicity aspects are discussed subsequently.

3.1. Occurrence of squeaks

The frequency of occurrence of squeaks is most sensitive to the presence of glottalisation, which always precedes these squeaks. Squeaks are found in the data only if glottalisation is found: squeaks imply glottalisation, but importantly glottalisation does not imply squeaks. Figure 2 shows the number of squeaks found in Aberystwyth and Manchester English, respectively, plotted against tokens with and without glottalisation (expressed as a percentage, where 1.0 = 100%).

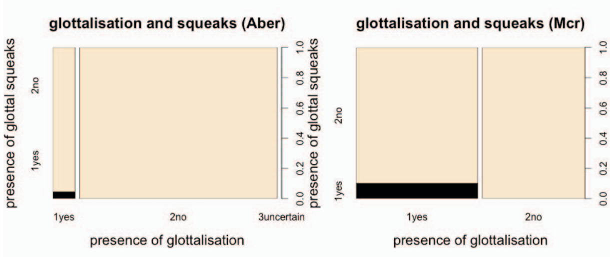

Figure 2: *Co-occurrence of glottalisation and squeaks (left: Aberystwyth English; right: Manchester English).*

Other important factors are the manner of articulation of the following consonant, position within the foot, individual speaker, and sex. The first two are, however, confounded with glottalisation.

Squeaks are never found in the sequences of vowels and fricatives (*mass*), whilst they occur in those of vowels and plosives (*matt*): 31 in the Aberystwyth data and 19 in the Manchester data, giving 50 squeaks for further analyses in total. Furthermore, all the squeaks appear foot-finally. Glottalisation is fairly rare in the sequences of vowels and fricatives and the non-occurrence of squeaks in this context may thus be due to the non-occurrence of glottalisation. The same issue arises regarding the position within the foot: glottalisation applies primarily foot-finally.

In the Aberystwyth data, squeaks are highly individual: 94% (29 cases) of the Aberystwyth squeaks come from one speaker, and the remaining 6% from two speakers (1 case each). None of the male speakers (6 in total) produces squeaks and only three females (12 in total) squeak. In the Manchester data, squeaks are found in all three females and also in one of the two males (but least frequently, with two instances). Squeaking would thus seem to imply that the speaker is more likely to be a female, but it is not the case that all female speakers would necessarily squeak even if they glottalise. In the Aberystwyth data, there may again be a confound with glottalisation: two of the squeaky individuals are also those who glottalise most; generally, glottalisation is rather infrequent in the vast majority of the speakers. Considering the Manchester data, we can conclude that squeaking is an individual-dependent phenomenon more conclusively because all the five speakers have obligatory glottalisation foot-finally in the plosive environment (*pat*), but it is certainly not the case that they would squeak to the same extent.

All the squeaks are found in the sequences of vowels and plosives in stressed syllables (*dip* vs *Philip*; tested only on the Aberystwyth speakers): no squeaks are found in the unstressed environment. In the Aberystwyth dataset, the frequency of occurrence of squeaks is not conditioned by the preceding vowel, the place of articulation of the plosive, foot-position (medial: *patter*; vs final: *pat*; Aberystwyth data), and at least immediately not so by utterance position (in a carrier sentence: 14 cases; vs isolation: 20 cases; Aberystwyth data). In the Manchester dataset, the place of articulation of the following consonant does not affect squeaks either. However, the tokens available indicate that squeaking may be more frequent in high vowels, as shown in Figure 3.

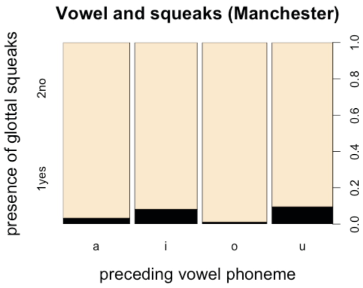

Figure 3: *Preceding vowel phoneme and squeaks in Manchester English. Vowel symbols are orthographic.*

3.2. Position of squeaks

Squeaks are always found following glottalisation in both datasets. However, in some cases there is a short period of silence between the glottaliation and the squeak ("1yes" for separated in Figure 4). The articulation of squeaks may commence during glottalisation in at least some cases.

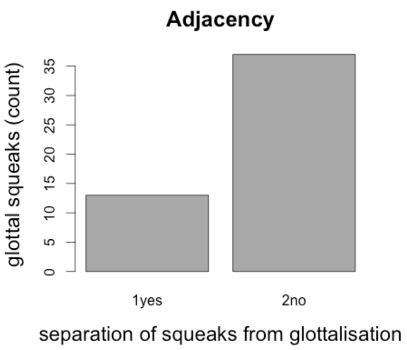

Figure 4: *Adjacency of squeaks to the preceding glottalisation. "yes" stands for separated by a period of silence.*

3.3. Duration of squeaks

The duration of squeaks ranges from 14.8-85.4ms. One speaker is responsible for the values above 50ms.

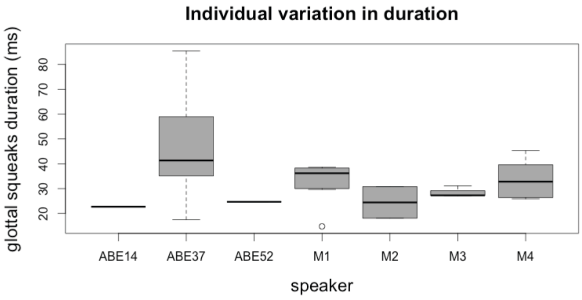

Figure 5: *Individual variation in squeak duration (ms).*

Although this would seem to confirm that squeaking is a highly individual phenomenon, when the segmental conditioning is considered, it becomes clear why this speaker shows a wider range of values: the two vowels mostly responsible for these results are the only phonologically long vowels in the dataset: PALM ([aː ~ ɑː]) and NORTH/FORCE ([oː]). The only speaker who glottalises in this environment in the Aberystwyth dataset is the one who shows the high values for squeak duration, and long vowels were not recorded for the Manchester speakers. The only potential correlation between vowel duration and squeak duration is found within the long vowels: the longer the vowel, the longer the squeak. Within short vowels, no unambiguous correlation pattern is found; however, if there is any, it is that of a positive correlation. Inclusion of the intervals of glottalisation within the period of the vowel does not change these results. No obvious conditioning by the other factors has been identified.

3.4. F_0 of squeaks

The values of f_0 range from 205-418.7Hz, confirming a phonatory phenomenon of high frequency. Individual differences are again found. Rather than a property of squeaking, this seems to be due to the individual differences related to the vocal tract.

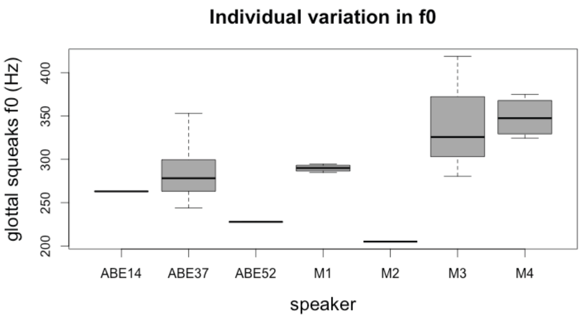

Figure 6: *Individual variation in squeak f_0 (Hz).*

Positive correlations are found between f_0 of the squeaks and F1 and F2 of the preceding vowel when all speakers are considered together. However, this is a result of the natural individual differences in f_0: once the speakers are looked into individually, no obvious correlations are found. No obvious conditioning by the other factors is identified.

3.5. Squeaks and release type

Squeaks are found with three broad types of a release: a. post-aspirated, b. unaspirated, and c. non-existent (at least in acoustic terms). As Figure 8 shows, most of the squeaks co-occur with post-aspirated release.

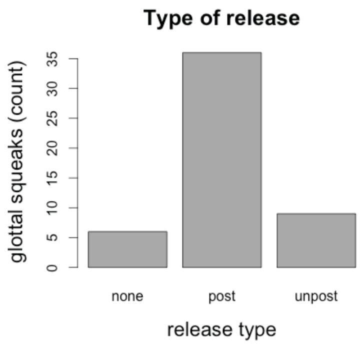

Figure 7: *Squeaks and release type (none = oral gesture not present in the acoustic signal; post = post-aspirated; unpost = unaspirated).*

It is of interest that both varieties show frequent affrication – rather than post-aspiration – of /t/ – practically all /t/'s in both the Aberystwyth and Manchester speakers are affricated when released. A question suggesting itself is whether the aspirated cases are in fact /t/'s rather than /p/'s or /k/'s, which are not affricated. This is of relevance because affrication is associated with a different articulatory gesture than aspiration [11] and could at least in theory affect squeaking.

However, the type of release does not correspond to the place of articulation of the plosive and so the results are not an effect of affrication. 81% of the Aberystwyth squeaks co-occur with post-aspirated release and 19% with unaspirated release. In the Manchester data, most of the squeaks co-occur with post-aspirated release as well (47.3%), and an equal number co-occur with either no release (26.3%) or unaspirated release (26.3%).

3.6. Are glottal squeaks glottal whistles?

Comparing Figure 1 with Figure 8 reveals important differences between glottal squeaks and glottal whistles.

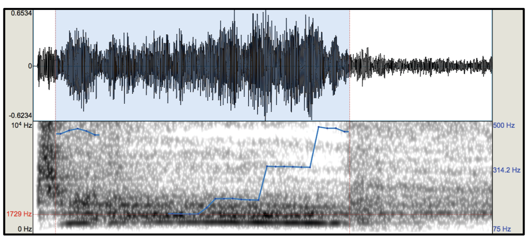

Figure 8: *Glottal whistle.*

Indeed, [12, p. 34] define a glottal whistle as "[a] register in which the sound is perceived as a whistle, usually high in pitch and flute-like in quality; physiologically, the claim is that a posterior glottal gap can serve as an orifice for vortex shedding and an epilaryngeal resonator can reinforce the sound, but the resonance mechanism is yet speculative". Glottal squeaks, on the other hand, show periodicity, low amplitude, and lack friction. This suggests very different articulation mechanisms behind the two phenomena.

4. Discussion

This study has set out to shed light on three questions.

Firstly, we corroborate [1]'s results that squeaks co-occur with glottalisation, which is adjacent to them in the sense that no phonation is found between the period of glottalisation and the squeak itself. However, in some cases a short period of silence is found between the two.

Secondly, we confirm that squeaks are dependent on the individual: some individuals never squeak whilst others do. In the Aberystwyth data, this could be due to the fact that most of the 18 individuals do not glottalise in VC sequences; nevertheless, this is not so in the Manchester data, where glottalisation is obligatory foot-finally (*pat*) [4], and individual differences in squeaking are not conflated with individual differences in glottalisation.

Sex seems to affect the frequency of occurrence of squeaks as well. In the Aberystwyth data, only females exhibit squeaks. In the Manchester data, all the females squeak to a variable extent; one male squeaks as well, but his squeaks are the least frequent in the dataset.

We can expect that if squeaking is conditioned by glottalisation, those dialects of English which exhibit more glottalisation will be more likely to exhibit squeaks as well. This prediction can be extended to other languages irrespective of whether glottalisation is purely phonetic or contrastive, since squeaks seem to be infrequently occurring, accidental/unintended and therefore non-coded, non-communicative property of speech (as defined by [6, p. 22-23]), a mechanical consequence of glottalisation. It is doubtful that such a low amplitude phenomenon would be perceptible by the listener. Squeaking would therefore seem to be an articulatory incident rather than something which is controlled by the speaker.

Thirdly, the only segmental and prosodic conditioning that affects any aspect of squeaks (occurrence, duration, f_0) is that of the manner of articulation of the consonant, position within foot, and vowel length. The first two findings are confounded with the presence of glottalisation, which is a feature occurring with plosives and foot-finally in the vast majority of cases in the two datasets analysed. Squeaks are longer with phonologically long vowels: this finding is based on one speaker only and more evidence is needed to confirm it.

We can hypothesise that, articulatorily, glottal squeaks reflect the intrinsically tense vocal fold state associated with thyroarytenoid (TA) muscle recruitment [2] required for epilaryngeal constriction and vocal-ventricular fold contact (VVFC) needed to produce glottalisation [3]. In this interpretation, squeaks might occasionally occur during constriction disengagement: at the point when VVFC suddenly releases but the TAs have not yet fully relaxed. The gradually opening, but still narrow epilaryngeal tube may further contribute to the proneness to vibration [13].

5. Acknowledgements

We are grateful to James Scobbie for providing us with an example of a glottal whistle.

6. References

[1] L. Redi and S. Shattuck-Hufnagel, “Variation in the realization of glottalization in normal speakers,” *Journal of Phonetics*, vol. 29, pp. 407–429, 2001.

[2] J. H. Esling, C. Zeroual, and L. Crevier-Buchman, “A study of muscular synergies at the glottal, ventricular and aryepiglottic levels,” *Proceedings of the 16th International Congress of Phonetic Sciences*, vol. 1, pp. 585–588, 2007.

[3] S. R. Moisik, J. H. Esling, L. Crevier-Buchman, A. Amelot, and P. Halimi, “Multimodal imaging of glottal stop and creaky voice: evaluating the role of epilaryngeal constriction,” *Proceedings of the 18th International Congress of Phonetic Sciences*, 2015.

[4] M. Hejná and J. Scanlon, “New laryngeal allophony in Manchester English,” *Proceedings of the 18th International Congress of Phonetic Sciences*, 2015.

[5] M. Hejná, *Pre-aspiration in Welsh English: A case study of Aberystwyth*. PhD thesis, University of Manchester, 2015.

[6] J. Laver, *Principles of Phonetics*. Cambridge: CUP, 1994.

[7] P. Boersma and D. Weenink, “Praat: doing phonetics by computer,” version 5.3.78, 2014-2015.

[8] “R Studio,” version 0.98.1049. <http://www.rstudio.com> [accessed in 2013-2015]. 2009-2013.

[9] T. M. Nearey, *Phonetic Feature Systems for Vowels*. PhD thesis, University of Alberta, 1977.

[10] E. R. Thomas and T. Kendall, “NORM: The Vowel Normalization and Plotting Suite,” version 1.1. <http://lvc.uoregon.edu/norm/> [accessed in 2014]. 2007-2014.

[11] B. Hutters, “Vocal fold adjustments in Danish voiceless obstruent production,” *ARIPUC*, vol. 18, 293–380, 1984.

[12] I. Titze, *Workshop on Acoustic Analysis*. 1994.

[13] I. Titze, “Nonlinear source-filter coupling in phonation: theory,” *JASA*, vol. 123, no. 5, pp. 2733-–2749, 2008.