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Laryngeal Variation in the Scottish English Voice Contrast: Glottalisation, Ejectivisation and Aspiration

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Laryngeal Variation in the Scottish English Voice Contrast: Glottalisation, Ejectivisation and Aspiration

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Abstract

Preaspiration of fricatives and glottalisation of syllabic coda stops can be important phonetic correlates of obstruent /±voice/ in some varieties of Scottish English. Within such varieties, this encoding of /±voice/ is based on voice quality (laryngeal settings) and is subject to substantial interspeaker variation.

We analyse the occurrence of preaspiration and glottalisation/ejectivisation in relationship to the laryngeal settings of individual speakers to explain the phonetic diversity of the contrast in Scottish English. The paper is intended as an illustration of how various voice quality contrasts can pave ways into phonological systems, and phonetically become the most important acoustical landmarks in the segmental contexts traditionally described in terms of periodicity or its timing.

Keywords: phonology and phonetics, human speech production, speaker characterization and recognition.

1 Introduction

This paper highlights phenomena which are yet to receive detailed investigation within either phonetic or variationist traditions, and which are challenging for phonological and phonetic theories and can be useful in speech-technological applications: i.e. preaspirated fricatives and glottalised and glottalic stops in some varieties of British English (Gordeeva 2008, Gordeeva & Scobbie 2010).

Periodicity (or phonetic voicing), its timing, and segmental durations are known to be important correlates in most English varieties (Docherty 1992, Haggard 1978, Smith 1997), but recent studies have also found preaspiration and glottalisation to be important correlates of /±voice/ for the two types of syllabic coda obstruents in Scottish English spoken in Edinburgh, or SE-Ed (Gordeeva 2008, Gordeeva & Scobbie 2010). The phonetic variants are systematic in their occurrence, and it appears that individual speakers use different parts of phonetic space: i.e. the timing of phonetic voicing and/or voice quality, to express the same consonantal contrast, which we call /±voice/ in this paper.

The "sameness" of phonetically diverse /±voice/ only makes sense in an abstract phonological relationship, and while it is familiar in vowel labels, what does it mean for a binary consonantal opposition? If the use of phonetic space of a single feature is relatively homogenous across individual speakers, then variation in the phonetic characteristics may be relatively easy to interpret. If, on the other hand, variation smears across a more complex multidimensional phonetic space, then it might appear that different phonologisations are required, even within a single language or variety.

In practical speech technological applications, such cases would mean that whole spectrum analysis of the preceding vowel becomes much more important as an acoustical landmark of obstruent /±voice/ than the timing of canonical periodicity within the obstruents itself.

In this study, we analyse the occurrence of preaspiration, preglottalisation and ejectivisation in word-coda obstruents in relationship to the laryngeal settings of individual speakers, as a way to explain the phonetic diversity of the contrast in SE-Ed. The paper aims to shed light on the question of *how* such laryngeal "extremities" co-exist in one and the same variety: do creaky speakers favour ejectives and breathy speakers favour preaspiration?; Or do the same speakers use both voice qualities to encode /±voice/?

The former scenario would be a result of speaker's continuing muscular laryngeal bias (or a phonatory “setting”, (Laver 1994), p. 115), and present such speech events as more epiphenomenal: i.e. a natural consequence of these settings. The latter one would suggest a categorical individual phonologisation of the contrast using voice quality, rather than traditionally considered timing of voicing, and that independently of speakers' long-term phonatory settings.

2 Method

We analysed recordings of five SE-Ed male speakers to examine the relationship between preaspiration of coda fricatives and glottalisation (and ejectivisation) of coda stops, versus speakers' long-term voice quality using a set of acoustic techniques capturing the two extremes simultaneously (Gordeeva & Scobbie 2006, Gordeeva 2008, Gordeeva & Scobbie 2010).

To ensure the accuracy of periodicity and voice quality measures we performed Laryngograph Processor ™ recording. The analyses of voice quality were based both on a perceptual categorisation of speakers’ long-term laryngeal settings and on acoustical analyses of speech and laryngographic waveforms. Descriptive statistics and Linear Discriminant Analysis (Wilk's Lambda, F-value of 3.84 for predictor entry and 2.71 for removal) were used to quantify the relationship between aspiration, glottalisation and /±voice/.

2.1 Subjects and recordings

The subjects were 5 male SE-Ed subjects (SP1 – 5) recruited in Edinburgh; all of middle class background. The subjects were not paid for their participation.

The recordings were performed in sound-insulated booth with the sampling frequency of 22,5kHz mono 16-bit with a parallel Laryngograph Processor ™ recording. The materials were presented on computer screen, one carrier sentence at a time. The speech rate was kept constant. A directional headset microphone with a fixed position was used for the acoustic recording to ensure that any time delay and fluctuations between the acoustic and laryngographic recordings are minimal and constant, so that the statistical analyses are not biased by this factor in subsequent analyses.

2.2 Materials

Target words (see Tables 1 and 2) contained /±voice/ coda stops or fricatives following a range of pre-consonantal vowels. Each target word was embedded in two carriers in a sentence-final and a medial context.

Table 3 sums up the number of tokens used per speaker for coda stops and fricatives.

Table 1**:** *Target words with word-final coda stops.*

/-voice/	/+voice/
greet, wheat, neat, shoot, brute, moot, sheep, cheap, but, bat, boat, bought, bet, bate, ship, chip	greed, agreed, weed, wee'd, need, knee'd, should, shoed, brood, brewed, mood, moo'd

Table 2: *Target words with word-final coda fricatives.*

/-voice/	/+voice/
place, bus, base, dish, fish, best, bath, Beth, boss	plays, buzz, bays

Table 3: *Number of tokens per speaker for word-final coda stops and fricatives across all contexts.*

Speaker	Stops	Fricatives
SP1	120	26
SP2	106	24
SP3	94	26
SP4	133	52
SP5	100	24

2.3 Perceptual and Phonetic analyses

The phonetic analyses scheme was conceptualised by both authors and performed by the first author. They included annotations at five levels:

(1) Vowel and consonantal onset/offset boundaries along with segmental identities.

(2) Articulatory characteristics of the stop burst: no burst at all (i.e. silence), glottal burst without supraglottal constriction, aspiration without supraglottal constriction, (af-)fricated articulation.

(3) In the presence of a supraglottal burst in stops, we annotated the airstream mechanism: pulmonic, strong post-aspirate; pulmonic, weak post-aspirate; unsure, pulmonic or glottalic; weak glottalic; strong glottalic.

(4) For fricatives, we annotated the onset of aspiration noise in the pre-consonantal vowel. We used the spectral/waveform clues: such as aperiodic excitation around F2-F4; points of rapid decrease of amplitude envelope to consonantal levels; formant level weakening; and total offset of periodicity. The complete procedure is can be found in Gordeeva and Scobbie (2010).

(5) Overall perceptual estimation of a speaker's phonatory settings in the vowels preceding the stops: as breathy, modal, creaky or unsure phonation based on criteria in point (4) above.

2.4 Acoustical analyses

Acoustical analyses were performed in Praat (Boersma & Weenink 2009). The following acoustic measures were used to quantify voice quality:

Modal phonation was measured as Voicing Offset Ratio (VoiceOff, %). This is a measure of timing of periodicity in vowel-obstruent (VC) sequences relative to the obstruent onset (Gordeeva & Scobbie 2010, p. 181). The measure quantifies the voicing offset time either prior or post the onset of obstruent stricture, and it normalises for the differences in absolute durations of V or C. The timing of voicing was derived from the DC-filtered 8 kHz laryngographic waveforms using the cross-correlation algorithm.

Aspiration (breathy phonation) was measured as band-pass filtered zero-crossing rate (bZCR, per sec). bZCR is an acoustic correlate of higher frequency aspiration, which we developed in our earlier studies (Gordeeva & Scobbie 2010, p.183), and it was the most successful predictor of aspiration and breath in that study. bZCR is a periodicity-independent measure based on standard ZCR computed from band-pass filtered waveform around F1-F3 in the vowel spectrum. In this study, bZCR was averaged throughout the final 1/5 part of the vowel.

Glottalisation (creaky phonation) was measured as jitter, or pitch-period variation in time. Jitter was computed from DC-filtered 8 kHz laryngographic waveforms throughout the complete vowel preceding coda stops and fricatives.

3 Results

3.1 Patterns of glottalisation, ejectivisation and aspiration derived from the perceptual labels

Glottalisation was quantified as the percentage of "creaky" phonatory settings labels of all phonatory settings labels ("modal", "breathy" or "creaky") in vowels before voiceless stops according to the annotations in section 2.3.(5). The relative differences in the percentages in susceptible segments, such as vowels ((Laver 1994, p.115) reflect speakers long-term tendency to use these phonatory settings *habitually*. The results of the analyses are presented in Figure 1.

The results show that SP3 and SP5 are the biggest glottalisers, with accordingly 78% and 98% of glottalisation rate in voiceless stop contexts. SP2 shows the least glottalisation (41%).

Overall, in pre-stop context, breathy phonation is rarely present, so that all 5 speakers can be considered to vary phonatory settings in the "modal/creaky" continuum.

Ejectivisation was quantified per speaker across /±voice/ stops as a percentage of "glottalic" (jointly weak or strong) stop airstream labels of all stop airstream labels according to the annotations in section 2.3.(3).

The results are presented in Figure 2. The results show that the biggest glottaliser (SP5) from Figure 1 produces no ejectives (glottalic airstream). The least glottaliser (SP2) doesn’t produce ejectives either. Speakers 1, 4 and 3 produce ejectives at a rate of accordingly 55%, 14% and 9 % of all /±voice/ stops.

Aspiration was compared against glottalisation patterns. Vowels before voiceless fricatives were categorised as aspirated if the duration of aspiration noise prior to the onset of supraglottal fricative constriction was longer than 50 ms. Figure 3 shows the relationship between aspiration (X-axis) and glottalisation rate in stops (Y-axis).
The biggest glottaliser, SP5, also shows the highest rate of preaspirated fricatives (100%). The speakers with ejectives (SP1, 3 and 4) produce a small number of preaspirated fricatives. The least glottaliser (SP2) produces preaspiration at rates similar to the speakers producing ejectives.

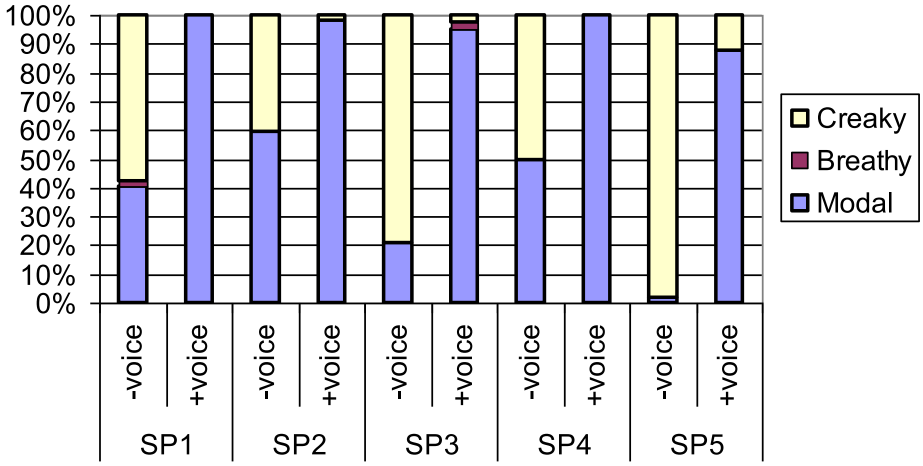

Figure 1: *Glottalisation as percentages of creaky, breathy and modal labels in pre-stop vowels per speaker and /voice/.*

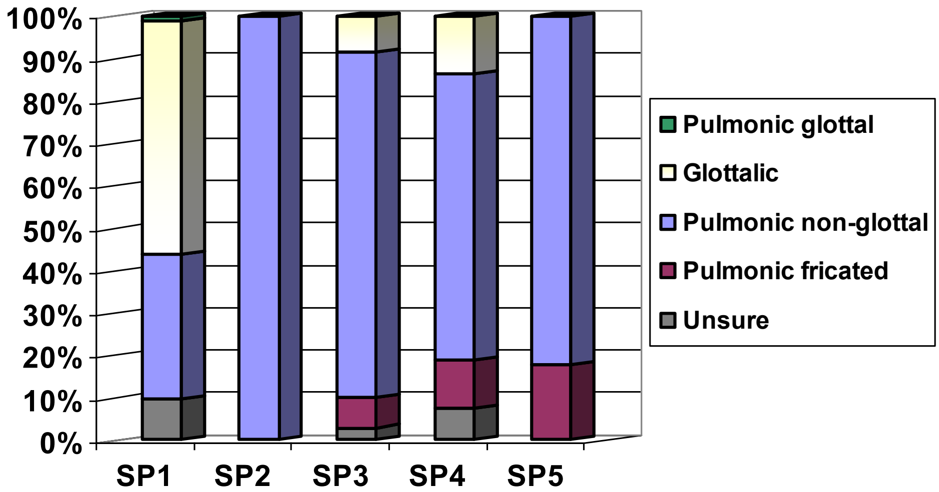

Figure 2*: Airstream and articulation labels across all stops as percentages per speaker.*

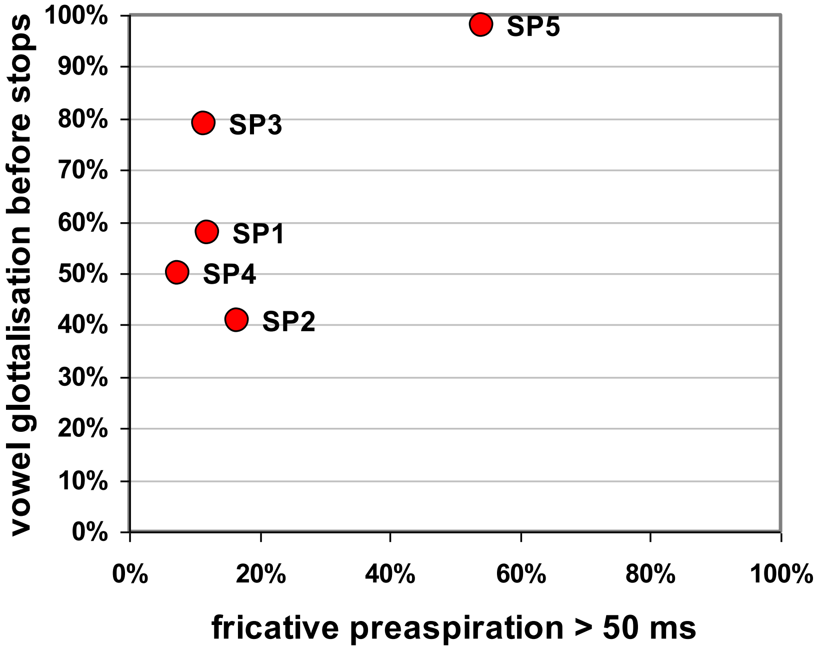

Figure 3: Speaker-specific relationship between pre-stop glottalisation rate (Y-axis) and pre-fricative aspiration (X-axis) from perceptual labels.

3.2 Acoustic correlates of /±voice/ in coda stops and fricatives

Step-wise Linear Discriminant Analysis (LDA) was used to evaluate, per speaker, the relative strength of the three acoustic variables: voicing (VoiceOff), aspiration (bZCR) and glottalisation (Jitter) in predicting /±voice/ for coda stops and fricatives. The results of the LDA-classification are shown in Table 4.

All the results are above 90% of correct discrimination and show that the considered acoustical variables are highly representative for the encoding of /±voice/ in SE-Ed word-final obstruents.

Table 4*: Percentage of correct classification by LDA in predicting /±voice/ in coda stops and fricatives.*

Speaker	Stops	Fricatives
SP1	97.5%	92.3%
SP2	98.1%	100%
SP3	100%	92.3%
SP4	94%	92.3%
SP5	99%	95.8%

Pooled within-groups correlations of /±voice/ in *stops* per acoustic variable are presented in Figure 4. The results show that the main correlate of /±voice/ in stops is voicing (VoiceOff) for all speakers, except for SP5, who is also the biggest perceptually-labelled glottaliser: i.e. SP5's main correlate is glottalisation (jitter). Glottalisation is the second most important correlate for other speakers.

Pooled within-groups correlations of /±voice/ in *fricatives* per acoustic variable are presented in Figure 4. The results show that the main correlate is VoiceOff in three speakers (SP1,2,4). However, SP3, and SP5 encode /±voice/ primarily with aspiration (bZCR). Aspiration is also the second most important correlate for other speakers.

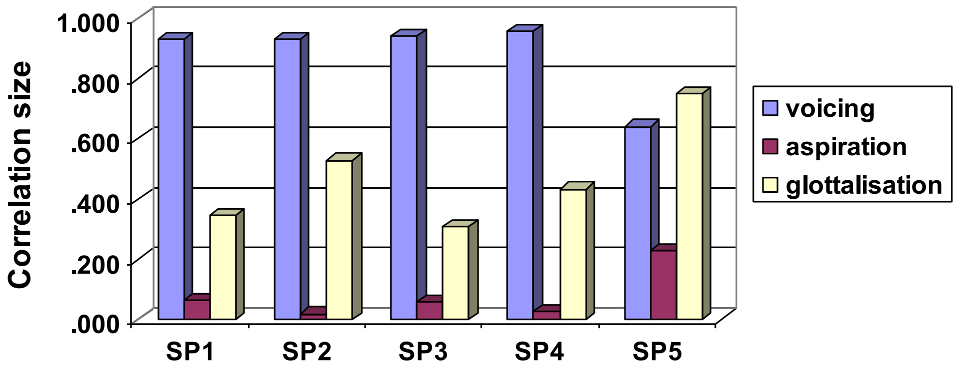

Figure 4: *Pooled within group correlation size for the three acoustic variables (voicing, aspiration, glottalisation) used in LDA as predictors of /±voice/ across stops per speaker.*

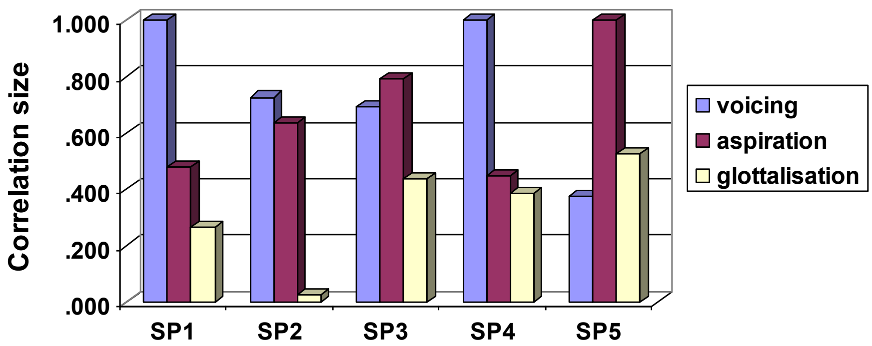

Figure 5: *Pooled within group correlation size for the three acoustic variables (voicing, aspiration, glottalisation) used in LDA as predictors of /±voice/ across fricatives per speaker.*

4 Discussion and Conclusions

Several findings above support the claims that (a) preaspiration and glottalisation of coda obstruents are "uncoupled" from a speaker's voice quality settings; and (b) they are an important part of some individuals' phonologisation of the SE-Ed /±voice/ contrast.

The former claim follows, because Linear Discriminant Analysis shows that aspiration is a secondary correlate of voice in fricatives for all speakers; this, irrespective of the overall "modal/creaky" long-term phonatory setting of the 5 speakers (cf. Figure 1). SP3 and SP5, are the creaky speakers following the auditory analysis, yet both of them employ aspiration as a primary correlate of the word-final /±voice/ contrast in fricatives (cf. Figure 5). Thus, their overall phonatory creakiness/modality does not preclude other voice qualities to pave ways into their phonological system where appropriate. On the contrary, it seems they use and vary their phonatory settings more predominantly as a function of phonological /±voice/, than other speakers in this study. The tendency for preaspiration does not preclude the tendency for preglottalisation, but rather forms a speaker-dependent strategy to employ "voice quality" as the main correlate of coda obstruent voicelessness, rather than periodicity and its timing.

The second claim follows because, based on Linear Discriminant Analysis, phonetic voicing is the most important correlate of /±voice/ across all speakers (confirming established views e.g. (Docherty 1992, Haggard 1978, Smith 1997). However, glottalisation is an important secondary correlate of stop /-voice/ for all the speakers (apart from SP5), to add to the previously established importance of preaspiration as a correlate of fricative /-voice/ for Scottish English (Gordeeva & Scobbie 2010). We can state that in the Edinburgh Scottish English phonetic system voicing and voice quality compete as correlates phonological /±voice/ in obstruents.

Finally, the presence of ejectives in Edinburgh Scottish English is a noteworthy finding on its own, since ejectives are only sporadically mentioned in relation to English (Chirrey 1999, Ladefoged & Maddieson 1996), and are yet to be described systematically. The context of ejectivisation occurs across utterance-medial and final positions, and thus is not necessarily influenced by the glottalisation in the following vowels or consonants as e.g. in German (Simpson 2007). The data in this paper also suggests that the production of ejectives here is not epiphenomenal in the sense of coupling to the creaky long-term voice quality of speakers. In this study, SP5 is the biggest pre-stop vowel glottaliser (Figure 4) and is least prone to produce ejective (glottalic) stops (Figure 2). Similarly, SP1 produces most ejectives of the five speakers (with 55% of ejectives of all /-voice/ stops in Figure 4) and shows only 4th lowest rate of pre-stop vowel glottalisation out of five (Figure 4). Therefore, ejective stops are not likely to be a natural consequence of increased long-term glottalised voice quality setting, but are separate phonetic variants serving other (linguistic or communicative) functions than /±voice/. This conclusion is supported by apparent social-class differences in their distribution and systematic acquisition in child speech in our ongoing work. The exact function of ejectives in the Ed-SE sound system remains subject to further studies.

Acknowledgements

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Appendix – Content of Poster (2006)

Gordeeva O.B. and Scobbie J.M. (2006) *Phonetic conditioning of word-final ejective stops in the speech of Scottish English pre-school children,* Edinburgh: Colloquium of the British Association of Academic Phoneticians. Queen Margaret University College

Abstract

Ejective stops are produced with glottalic airstream initiated by an upward action of the closed glottis, while there is an occlusion in the oral cavity (Ladefoged & Maddieson 1996). In English, ejective stops have been occasionally observed as free variants occurring in word-final positions (Ladefoged 1993). However, there are no systematic studies addressing their phonetic conditioning factors.

We describe the distributional characteristics of the word-final ejective stops found in the speech of Scottish English children (Gordeeva 2005). The subjects (N=7; aged 3;4 to 4;9) grew up in Edinburgh in Middle Class families. Three were recorded longitudinally. The children produced CVC-words ending with oral obstruents in semi-structured elicitation tasks. The words appeared in utterances of variable length in initial, medial or final positions. Ejective stops were identified auditorily and acoustically based on the burst amplitude, duration and the lack of glottal friction.

Five out of the seven children produced ejective stops. The longitudinal data suggest that the subjects use them rather categorically: i.e. some children don't produce them. Among the children with ejectives, 13.5 % of all word-final obstruents (N=896) involved the glottalic airstream production. The ejectives appear significantly more frequently in phrase-final positions than initially or medially. While they appear predominantly in lexemes ending with phonologically voiceless stops, 11.7% of the ejectives also appeared in items PIG and FOOD accompanied by complete final de-voicing.

We further discuss the appearance of these typologically rare sounds in the speech of the children in relation to the adult input, acoustic salience and the elicitation mode.

Introduction

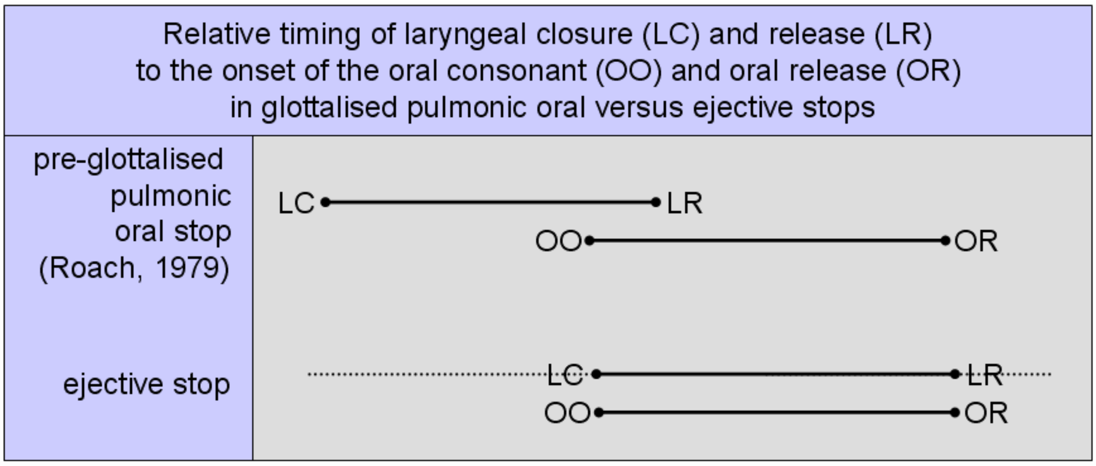
On a daily basis, we observe many cases of word-final ejective stops in Scottish Standard English (SSE) spoken in Edinburgh. In this study, we try to link available quantitative child data to general properties of the language. We explore the systematicity of occurrence of word-final ejective stops found in the speech of pre-school children with the aims to:

(1) Discuss the phonetic conditioning factors (place of articulation and voicing, prosodic factors)
(2) Relate the children's ejectives to adult input: the issue of glottalisation in British English varieties and occurrence of ejectives in adult speech.

Ejectives and Glottalisation

Ejective stops are produced with glottalic airstream initiated by an upward action of the closed larynx (&glottis), while there is an occlusion in the oral cavity (*Laver, 1994*) → increased intraoral pressure delimited by glottal and oral closures.
There are occasional notes of ejectives in English in word-final positions (Ladefoged 1993, Ladefoged & Maddieson 1996, Chirrey 1999, Fabricius 2000), but so far no systematic studies.
Glottal reinforcement (*Roach, 1973,1979;Wells, 1982; Milroy et al. 1984)*:

- the glottal closure
- glottal release (LR) before the oral release (OR)
- no social value attached (Wells, 1982)
- in word-final /p t k tS/ (Wells, 1982)
- raised larynx (Roach, 1979)
- glottal reinforcement is common in SSE *(Wells, 1982; C. Jones (1997); Stuart-Smith, 1999; Chirrey, 1999)*



Research Questions

(1) What is the incidence of occurrence of ejectives in these child data?
(2) Does the location of carrier words in the phrase influence the glottalic/ pulmonic production of the stops?
(3) Does the voicing of the following consonant (C2) affect the distribution of ejective and non-ejective stops?
(4) Does the place of articulation of voiceless C2 affect the glottalic/ pulmonic production of the stops?
(5) Are children's ejectives merely developmental, or derived from the target adult language?

Methodology

Subjects

7 children aged 3;4 to 4;9 ...3 recorded 2x longitudinally … (10 cases in total) … All from Middle Class families … Data collected in 2001 to 2004.

Subject	Age	Sex	Residence
C3	3;4 and 3;11	M	Rosyth
C4	3;8 and 4;1	F	Edinburgh
C5	4;0	F	Edinburgh
C6	4;0	F	Edinburgh
C7	4;2 and 4;8	F	Edinburgh
C8	4;2	F	Dunbar
C9	4;10	M	Edinburgh

Materials

C_1 V C_2 words (MacArthur CDI, *Dale & Fenson, 1996*)
C_1 voiceless oral obstruents
C_2 [±voice] and place of articulation /p t k/

C_2= stop –v SHEEP FEET COOK PUT SOUP
C_2= stop +v PIG FOOD

Elicitation

Semi-structured picture naming games

Collected utterances

(N=1133): a mix of single word (N=703) and multi-word utterances (N=430)

Auditory Labelling

- Salient strong ejectives
- Acoustics: lack of glottal friction, strong and short burst
- In case of uncertainty → labelled as non-ejectives

Statistical Analysis

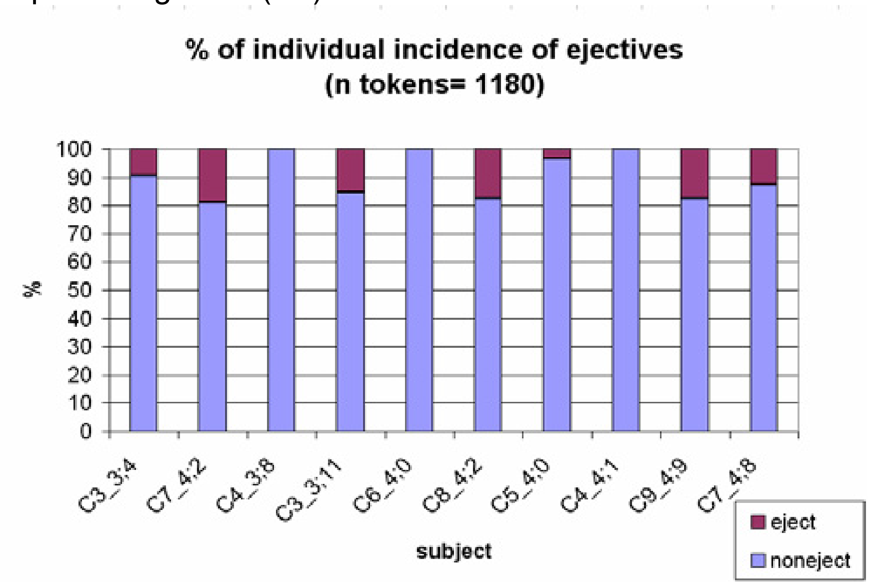
Chi-Square → frequencies of the phonetic labels [ejective, non-ejective] of the word-final stops and their association with:

- *Phrasal position* [initial, medial, final, single word]
- *Voicing* [-voice, +voice]
- *Place of articulation* [bilabial, alveolar, velar]

Results

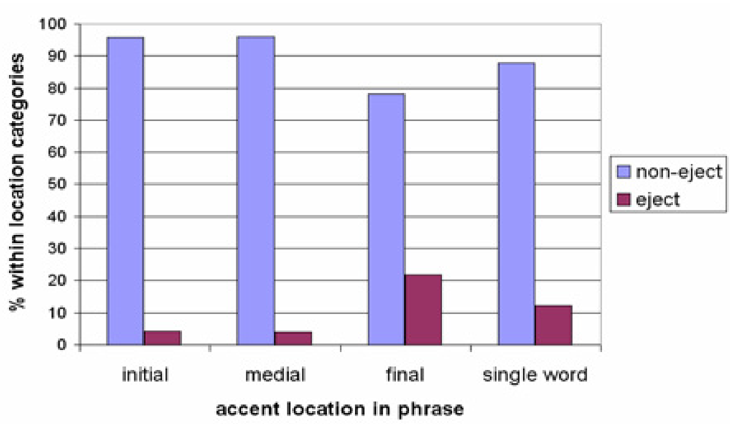
1. Incidence

- 10% of all word-final stops are ejectives (120 tokens out of 1133)
- 5 of the 7 children produce them
- three longitudinal subjects are coherent in either producing (C3, C7), or not producing them (C4).



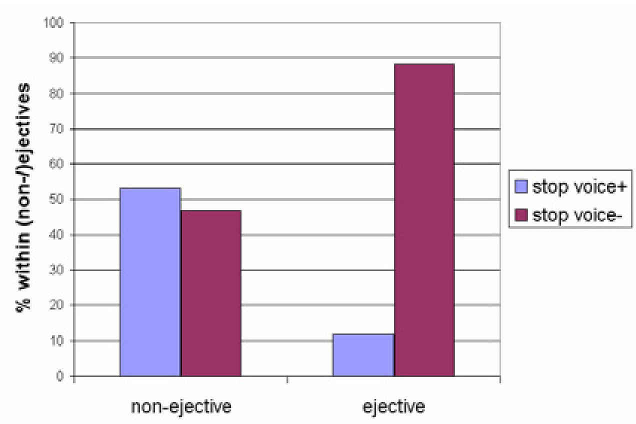
2. Effect of the position of the target word in phrase [initial, medial, final, single word] on the production of (non-)ejectives

Very highly significant association [$\chi 2 = 24.1$; df=3; $p<.0001$] Most ejectives appear in phrase final position and single word utterances.



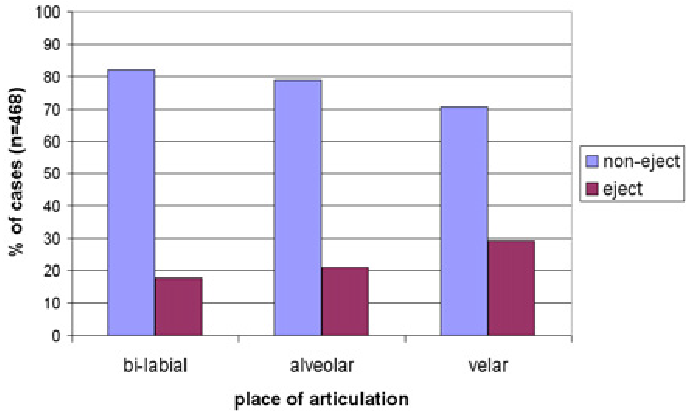
3. Effect of stop voicing [-voice, +voice] on the production of (non-) ejectives

Very highly significant association [$\chi 2=71.5$; df=1; $p<.0001$] Most ejectives occurring in [- voice] stops.
Ejectives are not exclusive to the voiceless stops: they also appear in PIG and FOOD (14 cases out of 120)



4. Effect of place of articulation [bilabial, alveolar, velar] on the production of (non-)ejectives

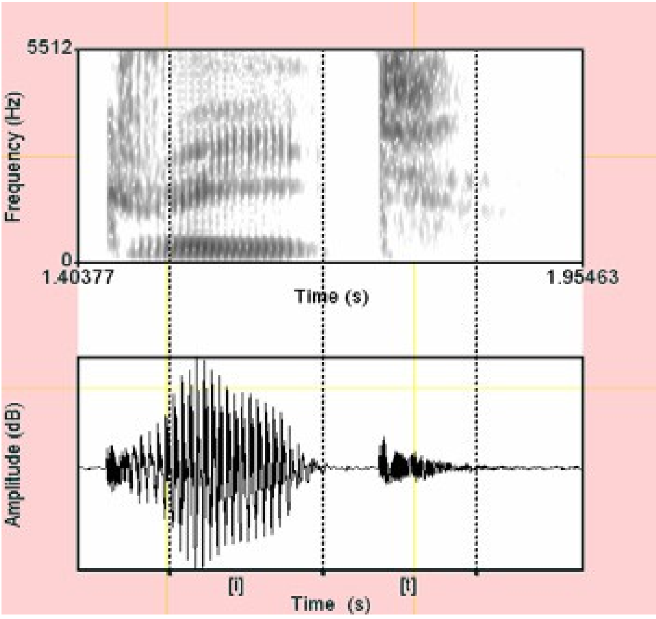
Significant association [$\chi 2=6.1$; df=2; $p<.05$] Most ejectives occur in velar stops. Despite the significance, the joint number of non-dorsal stops is actually higher than of dorsal (58% versus 42%).



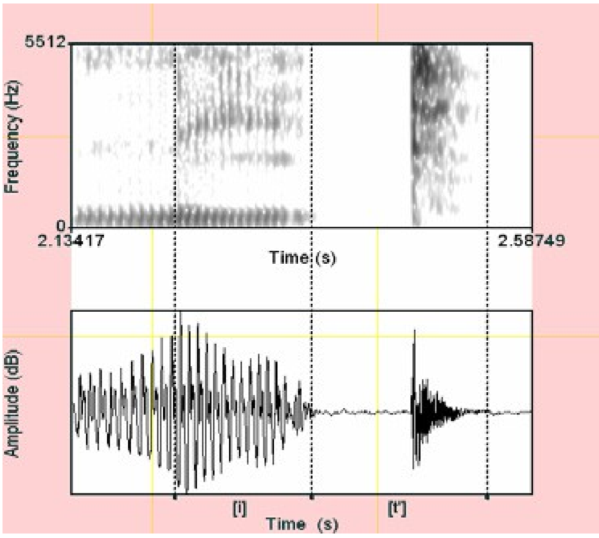
5. Adult Input

On-going research on the Scottish Vowel Length Rule containing word final stops: 5 male MC Edinburgh residents → 2 out of 5 adults produce ejectives systematically: 15.2% of all stops (n=277) in read speech. Also numerous examples are observed and recorded from spontaneous phone-in and interviews on radio, varied Scottish dialects and registers.

Acoustics of a typical pulmonic and glottalic stop (male adult speaker):



[t] in "GREET":
•Longer release with glottal and oral friction
•Lower amplitude of the stop burst



Right [t'] in "NEAT":
•Shorter release, no glottal friction (oral friction possible)
•Very high amplitude of the stop burst

Summary

- Word-final ejectives occur systematically in the speech of Scottish English pre-school children from Edinburgh: a substantial 10% in these final stop data are ejective stops.
- Occur in /p t k/ as in glottal reinforcement (Wells, 1982: SSE; Chirrey, 1999: Edinburgh).
- Correlate with phonetic rather than phonological voicelessness (e.g. Giegerich,1982) Cf. 11.7 % of all ejectives occur in PIG and FOOD tokens.

- Voiceless velar stops in phrase final positions are most likely to be produced with glottalic airstream.
- The occurrence of ejectives in child speech is warranted by adult input.
- SSE ejectives can be considered as a distinct type of "glottalisation" in British English varieties, plausibly connected to the SSE tendency to pre-glottalise the word-final stops.
- Ejectives may combine existing articulatory "glottalising" patterns with enhanced perceptually relevant place of articulation information.