DETECTING LARYNX MOVEMENT IN NON-PULMONIC CONSONANTS USING DUAL-CHANNEL ELECTROGLOTTOGRAPHY

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ABSTRACT

In preparation for a study investigating the production mechanisms behind ejectives in Georgian, English and German we examine the possibility of using dual-channel electroglottography (DC-EGG) to detect vertical larynx movement in the production of plosives produced with a glottalic airstream mechanism. Three trained phoneticians were recorded producing textbook ejective stops and pulmonically fuelled stops in a simple intervocalic context ([aCa]), as well as a rising and falling glissando that was predicted to elicit slow upward and downward larynx movement, respectively. The larynx trace signal, calculated from comparing the amplitudes of the signals produced by two pairs of electrodes, provided a robust indication of the presence and the direction of larynx displacement in the ejective stops, showing clear differences during the closure and release phases from the corresponding pulmonically fuelled stops. Expected intersubject variation in the size and shape of the larynx displacement was also found.

Keywords: dual-channel electroglottography, ejectives, glottalic, larynx movement, glissando

1. INTRODUCTION

In this study we set out to demonstrate the viability of using dual-channel electroglottography to detect vertical larynx displacement during the production of glottalically initiated consonants, i.e. ejectives and implosives.

The detection and measurement of larynx movement is difficult. Unlike the tongue, lips, jaw or velum it is impractical to attach sensors directly to laryngeal structures, such as the thyroid cartilage. However, different methods have been developed to track larynx movement during different linguistic and non-linguistic activities. These include external observation of the movement of thyroid cartilage prominence from rest position during singing exercises from individual film frames [15], as well as inference of larynx height from the position of the vocal folds from x-ray [9]. Initially, MRI was used to assess vertical larynx position from images of individual sustained vowels [7, 3]. More recently, it has been possible to track larynx position dynamically using real-time MRI allowing for the analysis of articulatory movements and sounds, whose production cannot be sustained, such as ejectives [6, 10] or swallowing [19].

Less direct methods of observing changes in larynx position have also been employed. Thyroumbrometry uses a battery of photocells located laterally to the neck to register light coming from a source on the other side of the neck [4, 12, 8]. Changes in the position of the thyroid prominence are thus tracked using the shadow cast. Comparable results to thyroumbrometry can be produced using EMA (electromagnetic articulography) to track movements of sensors attached externally to the throat [17, 2]. Movement of sensors on the throat are related to changes in the position of the larynx inferred from changes in the neck contour and, in particular, of the thyroid prominence.

Thyroumbrometry and EMA can only succeed in cases where subjects have a thyroid prominence that is sufficiently distinct from the rest of the throat contour. This restricts the pool of possible subjects primarily to adult males, due to the average greater size and lower location of the post-pubertal male thyroid cartilage.

One method which does not have this problem is dual-channel electroglottography (DC-EGG). This method employs two pairs of electrodes delivering two signals reflecting changes in electrical conductance across the glottis as a function of time [14]. An ideal placement of the electrodes would deliver two identical signals. Although such an ideal placement never arises, the relative amplitudes of the two signals can be used to improve electrode placement [14]. Of course, during regular speech production, larynx height and with it vertical vocal fold position are constantly changing, so dynamically tracking the relative amplitudes of the two signals can be used to track vertical movements of the larynx. Following Rothenberg, we will refer to this signal as the larynx trace (LT). This method of tracking and estimating larynx height has primarily been used to study changes in larynx height during singing [11].

The present study explores the possibility of using the output of a DC-EGG (EG2-PCX2, Glottal Enterprises [14]) to track larynx movements during speech, and in particular, during the production of sounds in which rapid larynx movements are thought to play a crucial role in bringing about supraglottal air pressure changes during oral stop closure in ejectives and implosives. It forms one component of a larger instrumental study investigating the production mechanisms behind phonological ejectives in Georgian, epiphenomenal ejectives in German and sociophonetic ejectives in English. In the pilot study reported here we see how the larynx trace from the DC-EGG responds to the marked larynx movements produced during cardinal, textbook ejectives produced by trained phoneticians. We recognise at the outset that our intended use of DC-EGG is not unproblematic since electroglottography is primarily intended to look at *phonation*, and not at stretches of speech in which periodic vocal fold activity is absent, such as during ejectives. Despite this drawback, electroglottography is a non-invasive, relatively simple method to apply, and especially in the present project, which is not just investigating differences in the production mechanisms of glottalic and pulmonic stops in a single language, but also comparing ejective stop production across three different languages, any evidence of differences in larynx movement is welcome.

2. METHOD

Three trained phoneticians (one male, S1; two female, S2/S3) produced labial, apical and dorsal plosives in a simple intervocalic context using both a pulmonic ([apa, ata, aka]) as well as a glottalic airstream ([ap'a, at'a, ak'a]). However, the first task for each subject, before recording the plosives, was to produce a hum with a slow rising pitch followed by a slow falling pitch. This was predicted to induce not only expected changes in fundamental frequency, but also concomitant changes in vertical larynx height. It was left to each of the subjects to carry out each of the tasks as they felt fit, without any further instructions about how the different plosives or the rising/falling pitched hum should be produced.

Two analog signals were captured from the DC-EGG: larynx trace (LT) and the more familiar electroglottographic waveform (EGG) showing changes in electrical conductance across the larynx as a function of time. The sound wave was captured using a Behringer ECM-8000 omnidirectional microphone attached to an audio interface (M-Audio Fast Track Ultra). All three signals were digitised with a digital acquisition device (Adlink USB-2405) at 16 kHz sampling rate and 24-bit amplitude resolution using proprietary software (Visual Signal DAQ Express). Signals were converted to 3-channel audio files in WAV-format. Annotation and analysis was carried out using *praat* [1].

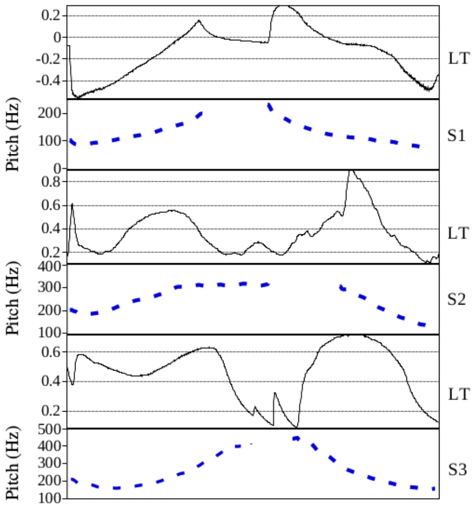
3. RESULTS

We present a qualitative analysis of the LT (and EGG) signals considering three different aspects: (a) comparison of the ejective stops with their pulmonic counterparts; (b) possible differences between three different places of articulation (labial, apical, dorsal); (c) intersubject variation.

Each subject began their recording by producing a rising or falling pitched hum. This was predicted to be accompanied by a raising or lowering of the larynx, respectively. The larynx traces shown in Figure 1 broadly confirm this expectation. The larynx trace rises then falls for all three subjects, correlating coarsely with concomitant changes in the f0 contour. However, despite similarities in the contours in Figure 1, there is also considerable variation between the different subjects regarding the shape of the contours. For both S2 and S3 the larynx trace rising pattern is preceded by an initial fall which is longest for S3. One possible reason for differences in the size and shape of the contours might relate to differences in the fundamental frequency patterns produced. However, the f0 contours plotted below each larynx trace in Figure 1 do not seem to confirm this.

Figure 2 contains traces from the male subject (S1) producing ejectives (left) and pulmonically fuelled plosives (right) at three places of articulation (labial, apical, dorsal). In each case, glottalic and pulmonic tokens at the same place of articulation have been spliced together from the same recording. Most apparent in all the examples is the marked difference in the amount of movement in the larynx trace of the glottalic stops (left) compared to the relatively steady traces of the pulmonic plosives on the right. However, changes in the larynx trace around the ejective release are not easy to interpret. In all three ejectives there is downward excursion of the larynx trace, but there are differences in the synchronisation of this movement with the plosive release. In the bilabial ejective the downward excursion occurs prior to stop release, in the apical and dorsal plosives, the downward movement occurs directly after the release. In none of the three cases is there any evidence of a marked *upward* excursion of the

Figure 1: Larynx movement traces and f0 contours of rising and falling pitched hums produced by the three subjects.



larynx trace *prior* to plosive release.

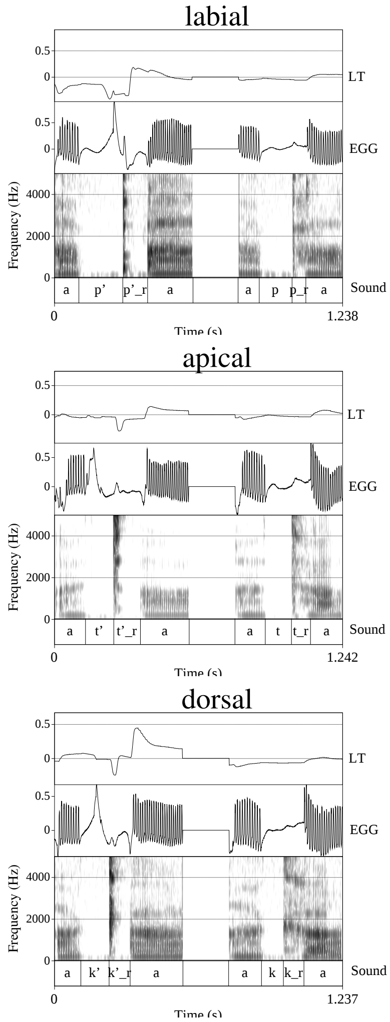
Figure 2 also contains the regular EGG signal. Most noticeable here, again in comparison with the pulmonically fuelled plosives, is the strong isolated peak during the closure phase, presumably indicating the closure of the glottis occurring during the oral closure of the ejective.

Finally, Figure 3 presents larynx traces, EGG and sonagrams of tokens of the intervocalic apical ejective [t'] for the three subjects. We can see that there is a good deal of activity in the larynx trace around the release phase of the ejective for all three subjects and there are intersubject differences in the size of the excursions. By comparison with the male subject, S1, ejective utterances from the two female subjects produce much larger excursions, in particular, with respect to the size of the downward excursion accompanying stop release. The excursion size in combination with the duration of the closure and release phases of the ejectives produced by S2 and S3 reflects to some extent the amount of articulatory effort invested by each of the subjects. However, common to all subjects is the downward movement of the larynx trace accompanying the release phase.

4. DISCUSSION

This is to our knowledge the first study that has considered the possibility of detecting larynx movement during the articulation of ejective stops using DC-EGG. As was already noted in the Introduction, we recognise that DC-EGG is not ideally suited to the task at hand, i.e. detecting larynx displacement

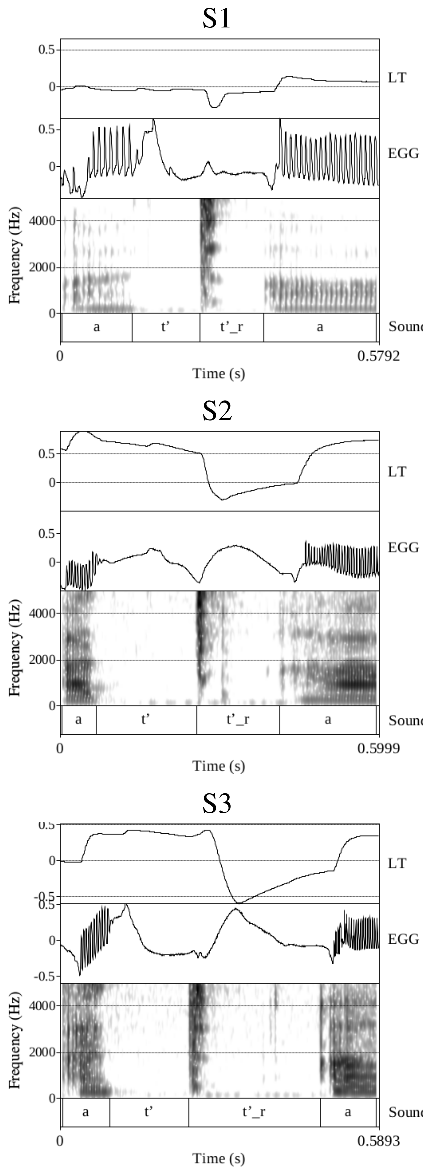
Figure 2: Larynx traces, EGG and sonagrams of intervocalic glottalic (left) and pulmonic (right) stops at three places of articulation. Examples at each place of articulation have been spliced from the same recording. All examples are taken from the male subject (S1). `C_r` annotates the VOT interval for each plosive.



during unvoiced stretches of speech. Nevertheless, this qualitative pilot study has shown that the larynx trace excursions provide a robust indication of the presence of larynx movement during the production of ejective stops, in particular, when compared to corresponding pulmonic stops. What the LT curves failed to register, however, was any systematic raising of the larynx prior to the release of the ejectives. Although this will require further investigation, the one positive thing that we can take from this negative result is that it was also systematically absent.

In the larger study, DC-EGG will be one part of an experimental setup also capturing intraoral air-pressure, as well as, in separate recording sessions,

Figure 3: Larynx traces, EGG and sonagrams of intervocalic [t'] from the three different subjects. C_r annotates the VOT interval for each plosive.



rt-MRI to look at the way in which glottal activity, larynx movement and articulation are synchronised to bring about intraoral air pressure changes in ejectives from three different languages, in which they play very different roles: Georgian, English and German. In German, word-final fortis stops before a word with an initial vowel typically exhibit a stop release that in auditory and acoustic terms shares all the features of an ejective. However, the epiphenomenal account that has been offered for this has shown that such a stop release can be fuelled by an intraoral pressure increase caused by pulmonic airflow before the glottis is closed prior to oral stop release, e.g. [veːt'ʔ ae̯n] (*weht ein* "blows a") [18]. In other words, while we get the auditory impression of an ejective, no vertical movement of the larynx, or any other reduction in the size of the supraglottal cavity, is required to bring about an intraoral pressure change, since this has already been accomplished using a pulmonic airstream while the vocal folds were still open during the intial phase of stop closure. Besides investigating whether such epiphenomenal ejectives are indeed produced in this fashion, one central hypothesis we will also test is whether a similar mechanism may also be employed in a language in which ejectives make up a regular part of the sound system, i.e. Georgian [16, 5]. One indication of this, which we predict will be provided by DC-EGG, are differences in LT between ejective and non-ejective stops, but in particular between ejectives at different places in structure [13].

5. REFERENCES

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