LARYNX MOVEMENT IN THE PRODUCTION OF GEORGIAN EJECTIVE SOUNDS

Alexandra BÜCKINS, Reinhold GREISBACH, & Anne HERMES
IfL-Phonetics, University of Cologne, Germany
a103690@smail.uni-koeln.de, reinhold.greisbach@uni-koeln.de,
anne.hermes@uni-koeln.de

Abstract
In this study, we present a non-invasive method for investigating laryngeal movement in the production of ejective sounds. Being non-invasive, this method can be used easily in the study of spontaneous speech. Typically, EMA is used to track the tongue and lip movements in speech production. In this study, we recorded four Georgian native speakers with four sensor coils on the outside of the skin – just above the larynx – in the area of the cricoid cartilage. The analysis reveals that there is considerably greater movement of the coils during the production of ejectives as compared to pulmonal sounds. These movement patterns of the skin above the larynx are admittedly of very complex nature. To attribute the movement solely to the larynx is problematic. Nonetheless, this method may help to understand the production mechanism of ejectives.

Keywords: Georgian, Ejective, Larynxmovement, EMA

1 Introduction

Ejective sounds are relatively rare in European languages and occur only in the Caucasus region (e.g., in Georgian), and by implication are not very well investigated. Ladefoged and Maddieson (1996) refer to ejectives as "not at all unusual sounds, occurring in about 18 percent of the languages of the world", but in quite diverse language families (e.g., Mayan and Chadic). The ejective production mechanism can be applied to produce plosives, affricates and fricatives both midsagitally and laterally. Plosive and affricate ejectives are most common, while fricative and lateral ejectives are only found in a handful of languages worldwide (Maddieson, 2013). Velar articulations seem to be most favored for ejective stops, cf., Greenberg (1970) and Maddieson (1984). Uvular ejective stops are also reported to be fairly common. Amongst the affricates, [ʦ'] and [ʧ'] seem to be widely spread (Maddieson, 2013).

In the Caucasus almost every language of the indigenous language families exhibits ejectives, i.e., languages from the Kartvelian (Southwest Caucasian), from the Nakho-Dagestanian (Northeast Caucasian) and from the Abkhazo-

DOI: http://doi.org/10.18135/CAPSS.127

Adyghean (Northwest Caucasian) language families. But there are also Indo-European languages spoken in the area such as Ossetic and East Armenian which have ejectives included into their phoneme system. Thus, the presence of ejectives seems to be an areal phenomenon of the Caucasus.

In these languages as well as in the languages of the indigenous Caucasian language families there is typically a threefold opposition between voiced, voiceless and ejective plosives and affricates. The plosive triples are most common for the labial, dental, velar and uvular places of articulation, while affricate triples are typically alveolar or palato-alveolar. For the East Caucasian languages, we typically find an additional binary opposition of the lateral ejectives (vs. their voiceless counterparts). Some Northwest Caucasian languages (e.g., Kabardian, Adyghe) also have a threefold opposition for fricatives, which include ejective fricatives (Klimov, 1994; Vinogradov, 1967).

In Georgian, there are three-way oppositions for labial [b ~ p ~ p’], dental [d ~ t ~ t’] and velar [g ~ k ~ k’] plosives on the one hand, and alveolar [ʣ ~ ʦ ~ ʦ’] and palato-alveolar [ʤ ~ ʧ ~ ʧ’] affricates on the other. Additionally, we find a singleton uvular ejective, mostly denoted [q’], which may phonetically surface, depending inter alia on speaker and speaking style, as an ejective plosive, fricative or affricate.

The production of ejectives involves a non-pulmonal airstream mechanism. The airstream is invoked by raising of the closed larynx. At the same time there has to be a constriction (plosive, fricative, or affricate) taking place in the supraglottal space, namely the mouth. The raising of the closed glottis leads to an increase in pressure in the space behind the constriction. Due to greater pressure drop, ejectives sound more prominent compared to pulmonal sounds (Ladefoged & Maddieson, 1996).

Figure 1 illustrates the phases of ejective plosive production. Phase one represents oral and glottal closure, and raising of the larynx. Phase two indicates the compression of air inside the enclosed oral section. Finally, phase three points out the oral release burst, while the glottis remains closed.

Figure 2 illustrates the main difference between ejective plosive production and ejective affricate production. In phase three the larynx is lifted up even further, while the larynx remains closed. The oral release burst is accompanied by friction.

The following example out of our data represents a typical acoustic pattern of an ejective plosive (Figure 3), in this case for the Georgian syllable [p’a]. This pattern is characterized by three acoustic phases:

- aperiodic noise of pressure release (ASP)
- silence (PAUS)
- (optional) creaky transition into vowel (CREAK).

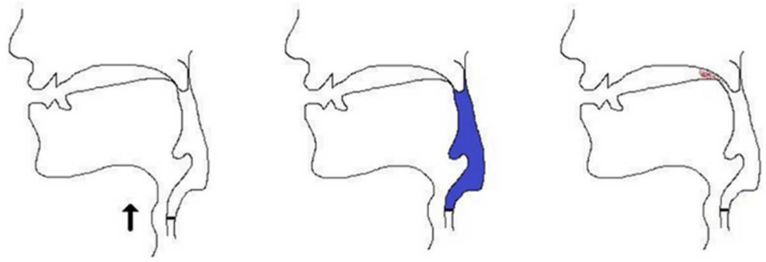

Figure 1.
Phases of ejective plosive production

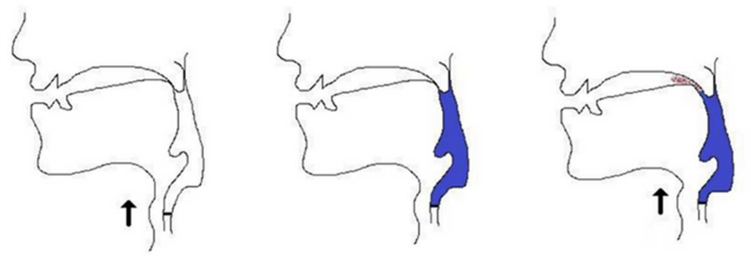

Figure 2.
Phases of ejective affricate production

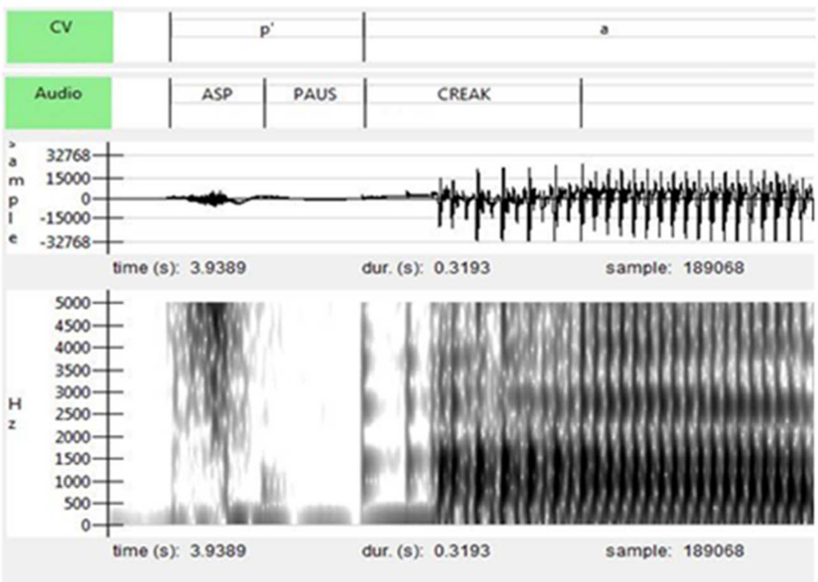

Figure 3.
The acoustics of an ejective plosive; segments in the CV tier; sound phases (Audio tier); oscillogram and sonogram for syllable [p'a], speaker I (f)

Georgian specifically distinguishes on the phonetic level between voiceless plosives / affricates, strong aspirated plosives / affricates, and ejective plosives / affricates. In the traditional grammar of Georgian they are often called voiced plosives / affricates, voiceless plosives / affricates and glottalized plosives / affricates, respectively (e.g., Tschenkeli, 1958, p. XLVII; Cherchi, 1999, p. 2).

Not much is known about variation in ejective production, be it inter-language or inter-speaker specific. Grawunder et al. (2010) give an overview on the production of ejectives in a number of Caucasian languages, but they only focus on specific phonetic parameters not comparing the production across languages. Listening to news in radio broadcasts leads subjectively to the impression that e.g., the ejective production in Avar (a Nakho-Dagestanian language) is stronger, causing auditorily a click-like impression of Avar ejectives compared e.g., to Georgian ejectives, which sound smoother.

Empirical evidence for variation in ejective production can be found in Lindau (1984), who points out significant cross-linguistic and inter-speaker variation in the comparison of velar ejectives in Hausa and Navajo.

Independent from speech rate, Lindau (1984) proposes the main difference between Navajo and Hausa speakers to be the long glottal closure in Navajo. The Navajo glottal closure is furthermore released into creaky voice.

Due to the small number of speakers typical for studies on ejective sounds it is difficult to decide whether certain parameters of ejective production are cross-linguistic differences or speaker-specific phenomena.

Articulatory investigations on ejectives are relatively rare. Grawunder et al. (2010) describe in an impressionistic way the elevation of the larynx during ejective production for one speaker of Georgian.

Alongside the examination of prosodic features or the consequences of speech disfluency (e.g., repetitions, repairs, pauses) spontaneous speech offers the most intuitive and therefore natural data of articulatory gestures. To visualize articulatory movement in a spontaneous speech setting with no restriction on speech aside from topic or task given by the supervisor is problematic due to the necessary invasive methods. One of the most common methods to investigate articulatory movement of the frontal area of the vocal tract is Electromagnetic Articulography (EMA). Sensory connector coils are positioned on the lips and inside the subject's mouth to display exact information on lip, tongue and jaw movement.

In this pilot study, we propose the possibility to record articulatory data of laryngeal mechanisms in spontaneous speech. Thus, EMA is used as a non-invasive method to analyze larynx movement in the production of Georgian ejective sounds. This method is non-invasive in that it is quick to adjust, and comfortable for the speaker, in that it does not restrain articulation in any way.

Our main motivation was to

- visualize the ejective production mechanism
- display articulatory movement of the larynx non-invasively
- collect rare articulatory data of ejective sounds

We expect greater movement of the sensory connector coils during the production of ejectives as compared to pulmonal sounds, as well as noticeable changes in the data. Therefore, we propose that the skin movement pattern for ejectives will be more prominent than the movement pattern for pulmonal sounds with the same place and manner of articulation. Furthermore, the skin movement pattern for ejective affricates is expected to be more prominent than the movement pattern for ejective plosives due to the larger raising of the larynx. As male and female speakers differ in gender-specific laryngeal anatomy, more conclusive data might be observed in male speakers.

2 Method

Usually, one can observe the larynx movements in male speakers very easily. Due to their naturally prominent anatomy of the thyroid cartilage the raising and lowering of the larynx is visible. This could be recorded on video, but would *inter alia* require the speaker to be clean-shaven. An adaptive use of the Electromagnetic Articulography (EMA) avoids the necessity of prominent larynx anatomy and the exclusion of female speakers from the study.

Typically, EMA is used to monitor tongue and lip movements in speech production. EMA requires coils behind the ears, the bridge of the nose, and on tongue root, body and tip, which were also included in this study. Figure 4 illustrates how we placed four additional sensor coils on the outside of the skin just above the larynx in the area of the cricoid cartilage of the speaker. A further coil was added on the back of the neck to control for head rotation.

Figure 5 serves as an example of the EMA coils attached to record the movement of the larynx. Recordings were done with the AG501 EMA (Carstens Medizinelektronik) with a sampling rate of 250 Hz. EMA allows to monitor the position of up to 16 coils in a magnetic field, which is positioned above the speaker. The audio signal was registered synchronously at 48 kHz. Labeling was done within EMU Speech Database System (Cassidy & Harrington, 2001), further analysis and graphs with the R programming language.

To focus on the differences between the ejective sounds and their pulmonal counterparts we segmented every word into its segments and evaluated the position of the laryngeal coils at the temporal midpoints. As the movement of the head is expected to be small from one word to the next one within a recording sweep, but may be great from one sweep to the next, we averaged the coil position of the 3 plosives / affricates (taken in the center of every friction part) in every sweep of e.g., [ts'-], [dz-] and [ts-] and set this average to be the origin of the coordinate system (i.e., the data was ipsativated).

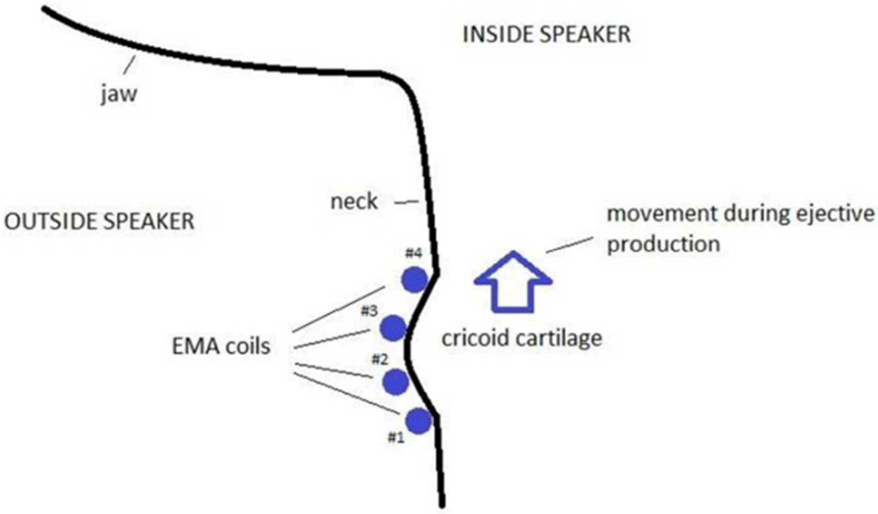

Figure 4.
Position of the EMA coils on the outside of the neck just above the larynx in midsagittal plane

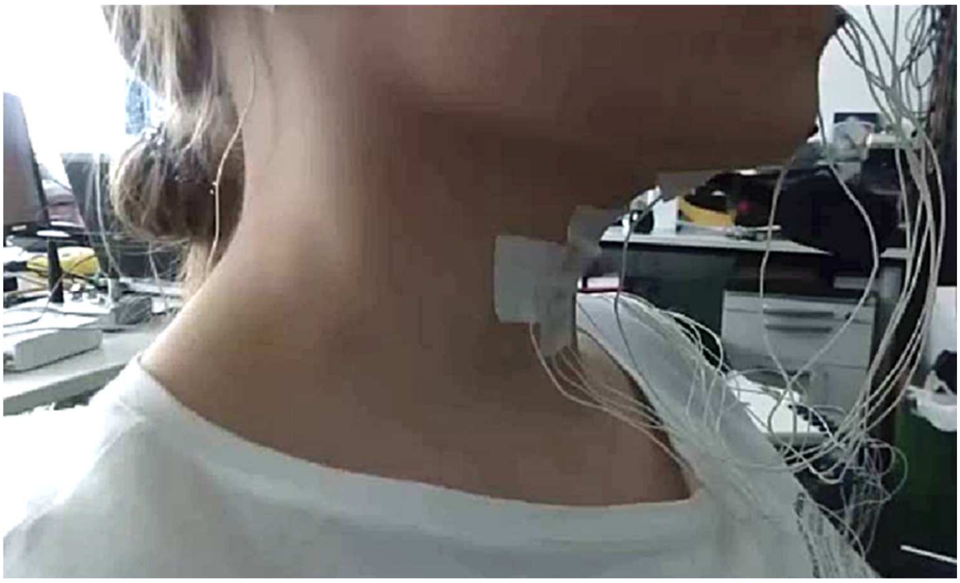

Figure 5.
EMA coils for speaker E during EMA recording

2.1 Subjects

For this study, four native Georgian speakers between 20 and 40 years were recorded (three female, one male). The female speakers are referred to as E, I and N. The male speaker is referred to as B. All speakers lived in Cologne or proximate vicinity at the time of recordings. They were all fluent in their native language and also competent in its literacy.

2.2 Speech Material

The corpus of this pilot study is based on the ejective contrast in Georgian, which is summarized for the apical consonants in Table 1.

For this pilot study we used word lists, consisting of minimal pairs or triples. The contrastive pairs and triples are summarized in Table 2. To avoid the influence of strong prosodic boundaries (end of the utterance), the first word of the respective contrast was repeated at the end of every recorded sweep and excluded from the analysis.

Table 1. Exemplary plosive and affricate contrasts in Georgian

Plosive	Affricate	Grammar	Phonetics
[d]	[dz]	voiced	voiceless
[t]	[ts]	voiceless	strong aspirated
[t’]	[ts’]	glottalized	ejective

Table 2. Contrastive minimal pairs and triples

პაპა [p’ap’a] ‘grandfather’	ფაფა [papa] ‘porridge’	
	ფარი [pari] ‘shield’	ბარი [bari] ‘spade’
პური [p’uri] ‘bread’	ფური [puri] ‘cow’	
ტარი [t’ari] ‘handle’	თარი [tari] ‘tar’ (musical instrument)	დარი [dari] ‘good weather’
წელი [ts’eli] ‘year’	ცელი [tseli] ‘scythe’	ძელი [dzeli] ‘log’
წერა [ts’era] ‘write’	ცერა [tsera] ‘little finger’	ძერა [dzera] ‘vulture’
კერა [k’era] ‘hearth’	ქერა [kera] ‘blond’	

Seven repetitions of these contrasts, and therefore 476 target words were taken into analysis. The subjects simply read them out.

3 Results

In the following, we present the results for the movement of the coil fixed above the larynx. Since all of the coils attached on the larynx did show a similar movement, we focused on the upper central coil #3 (see Figure 4).

The movement (of the skin) above the larynx can be illustrated by discrete production phases, as displayed in Figure 6 for [ts'eli]. It is possible to stepwise track the movement pattern of the coil centered above the larynx. The trace of the coil starts on the bottom left. It represents the closure phase (here the larynx is lowered and in the back). The following part (denoted /ts'/) shows the phase of the non-pulmonal burst mechanism: the closed glottis is pushed up, thus increasing the air pressure above the glottis and producing a fricative noise in the alveolar region. When the upward movement stops, the fricative noise in the audio signal ends immediately and the vowel (denoted /e/) begins. Throughout the rest of the word (denoted /li/) the laryngeal coil moves continuously downwards.

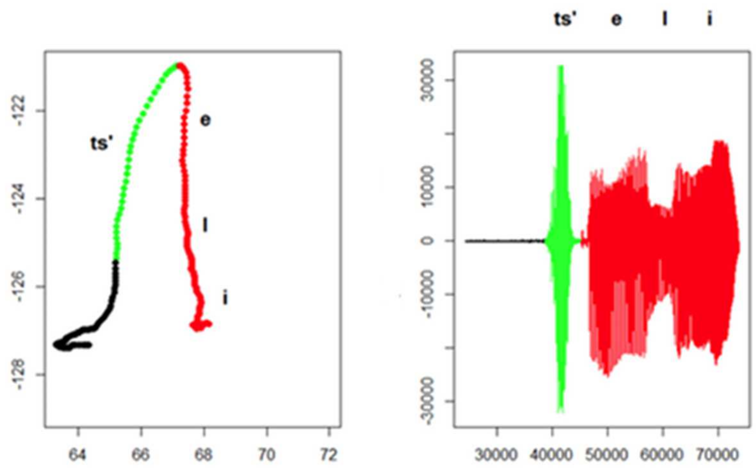

Figure 6.
Dynamics of coil centered above the larynx (left; scales in mm) and acoustic signal (right) for [ts'eli] relative to the bite plane; speaker N (f)

3.1 Ejective affricate contrasts

We find a relatively consistent pattern of the skin position just above the larynx over all 7 repetitions. The following example refers to the affricate contrast in the minimal triple [ts'eli] vs. [dzeli] vs. [tseli] and includes all 4 speakers (Figure 8). Displayed is the coil position in the center of every sound relative to the x-y-coordinate system defined by the bite plane. Depending on the general physiological posture of a person (e.g., upright or buckled) and the posture of the head during the recording the contour of the neck as well as the movement direction of the larynx will be more or less perpendicular to this coordinate system. Any componential interpretation of the patterns in upward-downwards and forward-backward direction has therefore to be done with caution.

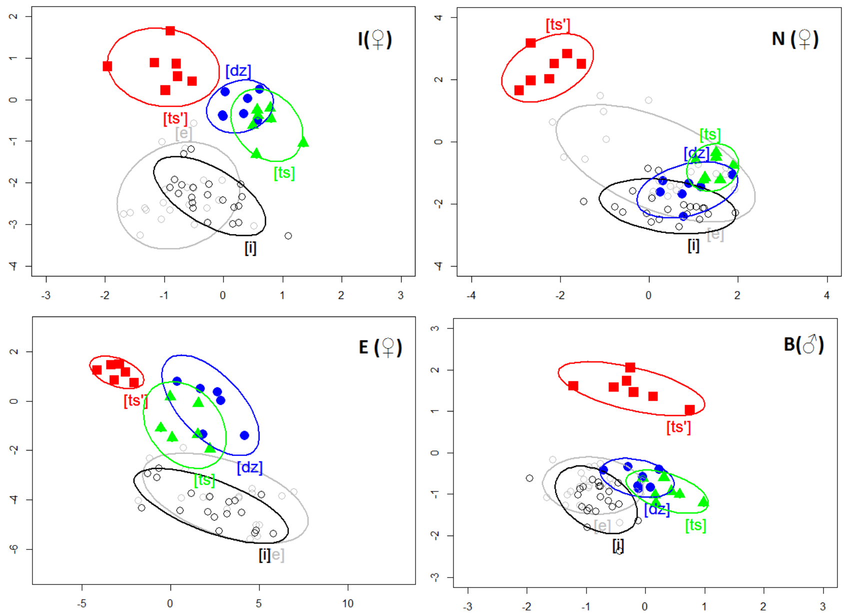

Figure 8.
Larynx coil in [ts'eli] vs. [dzeli] vs. [tseli] for speakers I, N, E (all female) and B (male); scales are in mm; the ellipses denote the 80% confidence interval

The 80% confidence ellipses surrounding the squares (Figure 8) reflect the position of the larynx coil while producing the affricate ejective [ts']. It is positioned above all other ellipses especially the one surrounding the triangles (voiceless [ts]) and the filled circles (voiced [dz]), which indicates the larynx has been in a more raised position. For the vowels [e] (grey empty circles) and [i] (black empty circles) of the minimal triple frame ([-eli]) the larynx is in a lower position for most speakers as compared to all of the consonants. These coordinates serve as points of reference. Furthermore, the ejective coordinates (squares) are displayed on the left, for all three female speakers, which means that the skin is being pulled back in relation to the vowels, not pushed out. For the male speaker there is no backward shift in relation to the reference bite plane.

3.2 Ejective plosive contrasts

The following example (Figure 9) refers to the ejective plosive contrasts in the triple [t'ari] vs. [dari] vs. [tari] and includes 7 repetitions of all 4 speakers. The results are comparable to the ejective affricate contrasts (Figure 8), even though the movement in up-down-direction is not as prominent for the ejective plosives.

To compensate for any movements of the speaker during a recording session, we took the ipsative coordinate values of every minimal triple taken in the center of every consonant. What we do compare are the differences between the consonants uttered in immediate neighborhood of an utterance.

Thus, a direct comparison between plosive ejectives and affricate ejectives is not possible, because the reference points of the coordinate systems depend on the coordinates of all members of the triple the sound in question belongs to, and not on the absolute values. All we can say is that the distribution patterns between affricates and plosives are similar and the magnitude of the displacement relative to the vowels is larger for ejective affricates than for ejective plosives.

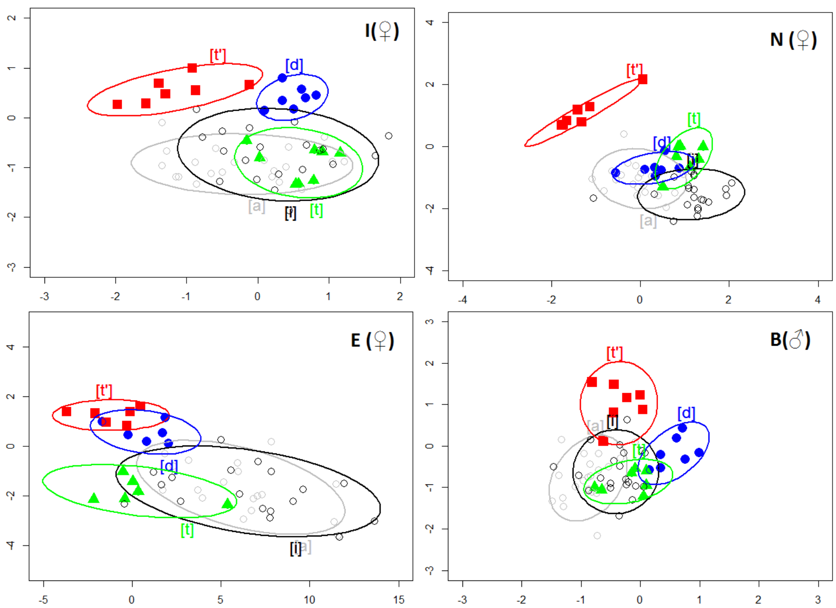

Figure 9.
Larynx coil in [t’ari] vs. [dari] vs. [tari] for speakers I, N, E (all female) and B (male); scales are in mm; the ellipses denote the 80% confidence interval

4 Summary

This pilot study on Georgian provides preliminary evidence that there is a larger movement of the skin in ejectives compared to pulmonal sounds. The skin above the larynx is shifted higher upwards than in the following vowels. The magnitude of the skin movements depends on the individual anatomical disposition of the speaker, but seems to be a little bit higher for affricates than for plosives. No difference in magnitude of the movement between male and female speakers was found.

In the female speakers there is a simultaneous backward shift of the skin, probably due to the angle between neck and bite plane. For the male speaker no backward shift is noted. This difference might be attributed to the anatomical differences of the male and female cricoid cartilage. Fixed on the skin slightly above the cricoid cartilage in rest position, the coil under observation is moving upwards, as the skin is pulled upwards by the cricoid cartilage. Typically, the cricoid cartilage is moving further up than the skin above it, which is clearly visible in male speakers. Thus, in the most upward position the coil will no longer be situated above the cricoid cartilage, but probably exactly on the top of the cricoid cartilage or even below it. As in male speakers the cricoid cartilage forms an outward bulb on the skin, the coil is expected to be shifted in the front-back direction as well, either forward or backward, depending on its initial position.

5 Conclusions

We were able to visualize movement patterns of the ejective production mechanism, but we are aware that these patterns are of a very complex nature. The movement of the skin above the larynx is influenced not only by the movement of the larynx, but also by

- movement of the hyoid bone and attached muscles on the neck while speaking,
- movement of the mimic muscles while speaking and opening the jaw (platysma),
- movement of the head and attached muscles on the neck while speaking (sternomastoid) (Gray & Drake, 2008).

To attribute the recorded movements exclusively to the larynx is therefore problematic, as well as controlling for all those factors above. Nonetheless we did observe movements that are consistent with the laryngeal mechanism for ejective production, and propose our adapted version of Electromagnetic Articulography to be used for laryngeal research in spontaneous speech.

References

Cassidy, S., & Harrington, J. (2001). Multi-level annotation in the Emu speech database management system. *Speech Communication, 33,* 61-77.

Cherchi, M. (1999). *Georgian.* München, Newcastle: Lincom Europa.

Gray, H., & Drake, R. L. (2008). *Gray's atlas of anatomy.* Philadelphia: Churchill Livingstone.

Grawunder, S., Simpson, A., & Khalilov, M. (2010). Phonetic characteristics of ejectives – samples from Caucasian languages. In S. Fuchs, M. Toda, & M. Zygis (Eds.), *Turbulent sounds* (pp. 209-244). Berlin: De Gruyter Mouton.

Greenberg, J. (1970). Some Generalizations Concerning Glottalic Consonants, Especially Implosives. *International Journal of American Linguistics, 36,* 123-145.

Klimov, G. A. (1994). *Einführung in die kaukasische Sprachwissenschaft.* Hamburg: Buske.

Ladefoged, P., & Maddieson, I. (1996). *The sounds of the World's Languages.* Oxford: Blackwell.

Lindau, M. (1984). Phonetic differences in glottalic consonants. *Journal of Phonetics, 12,* 147-155.

Maddieson, I. (1984). *Patterns of Sounds.* Cambridge: Cambridge University Press.

Maddieson, I. (2013). Glottalized Consonants. In M. S. Dryer, & M. Haspelmath (Eds.), *The World Atlas of Language Structures Online.* Leipzig: Max Planck Institute for Evolutionary Anthropology. (Available online at http://wals.info/chapter/1, Retrieved on 04.05.2018.)

Tschenkéli, K. (1958). *Einführung in die Georgische Sprache.* Zürich: Amirani Verlag.

Vinogradov, V. V. (1967). *Jazyki narodov SSSR.* Moskva: Ibersijsko-Kavkazskie jazyki.