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An Acoustic Analysis of Georgian Stops

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by

Chad Joseph Vicenik

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The thesis of Chad Joseph Vicenik is approved.

Sun-Ah Jun

Megha Sundara

Patricia Keating, Committee Chair

University of California, Los Angeles

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ABSTRACT OF THE THESIS

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Chad Joseph Vicenik

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Professor Patricia Keating, Chair

The Glottalic Theory proposes that the Proto-Indo-European stop system consisted of a voiceless, plain voiced and ejective stop series. Under this hypothesis, the ejective stop series would have had to change to plain voiced stops in the majority of daughter languages. Such a sound change has been criticized as unlikely or impossible. The goal of this study is to examine the acoustics of ejectives more closely and compare them to the acoustics of voiced stops and voiceless aspirated stops, in order to determine how phonetically similar or dissimilar they are. The language studied is Georgian, which has all three stop series. Five female speakers were recorded reading words from a list, embedded in a carrier phrase, and embedded in a story. Acoustic measures include closure duration, voicing during the closure, voicing lag, relative burst and gap intensity, spectral moment of bursts, phonation (H1-H2) and Δf0. The three stop manners were acoustically distinct in voicing into the closure and voicing lag. Ejectives were distinct from both voiced and voiceless stops in phonation and Δf0 (voiced and voiceless stops were not significantly different from each other), and ejectives were distinct from voiced stops in burst intensity. Closure duration, gap intensity and spectral moment did not distinguish stop manner. Possible cases of confusability between ejectives and other stop manners are discussed. Effects of prosodic position and speaking style on Georgian stops is also discussed.

1 Introduction

1.1 Glottalic Theory

Proto-Indo-European (PIE) is the hypothetical ancestor language to many of the modern languages spoken in Europe, India and West Asia. Traditionally, this ancient language is reconstructed with three stop series that differ by laryngeal manner, as laid out in (Lehmann 1955). The three standardly reconstructed (henceforth referred to as ST, for Standard Theory) stop manners for PIE are voiceless, voiced and voiced aspirated (or breathy voiced). There are five places of articulation: labial, dental, palatal, velar, and labio-velar (Barrack 2002).

The Glottalic Theory (GT) is an alternative to the ST reconstruction, proposed independently by Gamkrelidze and Ivanov (1972) and Hopper (1973). The GT reconstruction also proposes three stop series differing by laryngeal manner, but one of these is a series of glottalic stops, most likely ejectives (Hopper 1973). The two reconstructions are laid out in Table 1.

	ST Reconstruction	**GT Reconstruction**
Series 1	Voiceless unaspirated	Voiceless (aspirated)[1]
Series 2	Voiced	Ejective
Series 3	Voiced aspirated	Voiced (aspirated)

Table 1: Comparison of GT and Traditional reconstructions of the Proto-Indo-European stop systems.

[1]Hopper (1973) suggests different dialects might have differed in the presence of aspiration (based on what these stops later became in the various daughter languages). Gamkrelidze & Ivanov claim in their book, reviewed by (Hayward 1989), that the presence of voiced aspirates implies the presence of voiceless aspirates, so if the stops in series 3 are reconstructed in this way, then the stops in series 1 should be reconstructed as aspirated, as well.

The arguments for the alternative reconstruction and the ejective stop series are largely based in typology and are summarized in Hayward (1989) as the following:

1. The ST reconstruction lacks a *b. In languages with voiceless stops, a gap in the series is most likely to occur at the labial place. On the other hand, for voiced stop series, the labial member is least likely to be missing, which suggests that this stop series in ST is unlikely to be voiced. This argument is supported by later research. Maddieson (1984) found that a gap at the labial position is not uncommon for ejective systems. 35% of languages with ejectives in the UPSID database had this gap. A gap at the labial place was rare for voiced stop systems: there were only three languages out of over 150 with a /g/, but no /b/.

2. Stops in series 2 in table 1 occur most infrequently in root morphemes, suggesting that they are the most marked of the three PIE stop manners. However, voiced aspirates should be more marked than plain voiced stops. If the stops in series 2 are reconstructed as ejectives, then the ST voiced aspirated series becomes the only voiced stop series in PIE, and aspiration then becomes a redundant feature (in distinguishing the third stop series from the other two; the only feature needed to distinguish them would be voicing). And, since aspiration would no longer be a distinguishing feature, it need not always be present and these sounds could undergo allophonic variation between aspirated and plain voiced stops. Gamkrelidze & Ivanov claim that the ejective stop series would then become the most marked stop series and

their relative infrequency in PIE would be explained.

3. Stops in series 2 cannot co-occur in roots. Gamkrelidze & Ivanov claim this restriction is observed in other languages only if the stops in series 2 are reconstructed as ejectives, but not if they are reconstructed as voiced. PIE also has a co-occurrence restriction between the voiceless and voiced aspirated stops, as well as a tendency against voiced aspirated stops and plain voiced stops co-occurring in the same root. Gamkrelidze & Ivanov suggest that these two restrictions can be explained as a single rule, or tendency, for stops within a root to agree in voicing if the ST voiced stops are instead reconstructed as ejectives.

The GT proposal, and the evidence supporting it, has met with much criticism. Hayward (1989) points out that the frequency arguments are flawed. Maddieson (1984) lists only 7 languages with voiced aspirated (or breathy voiced) stops, compared to 52 with ejectives, making voiced aspirated stops rare cross-linguistically. However, in the languages in which they appear, such as Hindi, their lexical frequency is not low, indicating that, contrary to argument 2 above, there is no correlation between cross-linguistic rarity and within-language lexical rarity. Hayward uses this same argument to claim that simply because a stop series is rare in PIE does not imply that it must be of a cross-linguistically rare type. She also uses this reasoning to suggest that the infrequency of *b is not worrisome.

Curious about this claim, I, very informally, conducted a phoneme count in a list of 317 common Hindi words, gathered from an introductory Hindi language website. [2] In this list, I counted over 200 plain voiceless stops and over 125 plain voiced stops, indicating that these two stop systems are very common. The two aspirated stop systems had a much smaller frequency: I counted only 37 voiced aspirated stops and 36 voiceless aspirated stops. So, while the voiced aspirated stops may not be the least represented stops in Hindi, they are far less frequent than plain voiced stops. This casts doubt on Hayward's claim and lends support to the original GT argument.

Hayward's argument is further contradicted by the tendency of the daughter languages of PIE, like Latin and French, to correct the infrequency of *b by preserving, borrowing and otherwise adding words with the voiced labial stop over time (Martin To Appear). This historical tendency to increase the lexical frequency of this stop, on the grounds that it is less phonologically marked than other sounds, lends support to Gamkrelidze & Ivanov's claim that the rarity of this stop in ST PIE is problematic. If the stops in series 2 (in table 1) are reconstructed as voiceless stops which later became voiced, then the changes in frequency in the daughter languages can be seen as a corrective measure made to align the languages more closely with innate phonological preferences. If, on the other hand, these stops have always been voiced, it is unclear how their frequency became so abnormally low.

Barrack (2002) finds fault in the supporting argument that traditionally reconstructed voiced stops cannot co-occur in the same root. He suggests that there is no such phonological restriction in PIE and suggests that the fact that roots of this

[2] Hindi Learner: http://www.hindilearner.com/hindi_words.html

type are rare is due to a combination of effects: the rarity of the ST voiced stops in general, the rarity of any stop in coda position, the restriction against two stops of the same place in a root, and the hesitation of etymologists to suggest roots of this form because of the assumption that such a *voiced-*voiced restriction exists. Job (1995) points out that many of the languages cited by GT supporters as having ejective-ejective restrictions in roots, such as Georgian, actually don't have such a restriction. However, it is well known that such restrictions are common in the world's languages (MacEachern 1997). He also points out that Lezgi, a Caucasian language which has four stop manners, including both voiced and ejective stops, allows every combination of stops in roots, but the pattern voiced-vowel-voiced is only found in loan words; but this is his only counter example.

It is difficult to conclude much from the typologically based arguments, either in support of or against GT. While there are certainly cross-linguistic tendencies that should be taken into consideration when performing linguistic reconstruction, there are also enough counter examples to these tendencies that prevent the elimination of typologically rare reconstructions. Therefore other factors should be considered, as well, such as the likelihood of sound changes that might have occurred between the reconstructed language and the current daughter languages.

If GT is correct, then the ejective stops (series 2) would have had to change to non-glottalic stops in all of the daughter languages. Specifically, they would have had to change to a plain voiceless unaspirated stop series in daughter groups like Germanic and Armenian, or to a plain voiced stop series in daughter groups like Italic, Slavic, Greek and Sanskrit (Hopper 1973). Both of these sound changes have been criticized as unlikely, or impossible (Job 1995, Fox 1995). However, no evidence is offered to support these criticisms. They rely on the intuitions of the authors.

As it turns out, these sound changes are discussed in Fallon (2002), where a very thorough review of the cross-linguistic phonology of ejectives is provided. Fallon provides several examples of sound changes and alternations in other languages that are similar to the sound changes called for by GT, including:

- Klamath deglottalization before obstruents and [+constricted glottis] sonorants and word finally.
- Tigre deglottalization before obstruents.
- The loss of glottalization and merger with plain voiceless stops in Resolution Chipewyan and the Axceh dialect of Lezgian.
- Optional deglottalization and voicing in Tsimshian.
- Ejective/voiced alternation in Salish reduplication.
- Ejective/voiced alternation word finally in Lezgian.
- The voicing of ejectives in Georgian words loaned to other languages.

Based on these cases, neither of the sound changes required of ejectives by GT seem impossible. These cases are not frequently discussed by supporters or critics of GT, most likely because these languages and their phonologies are not well known in the linguistic community. Most critics claim the two ejective sound changes seem unlikely based on phonetic grounds. In the following section, a review of current phonetic knowledge concerning ejectives is provided.

1.2 Ejective Phonetics

Most sound change is likely to be phonetically motivated, arising from articulatory variation and misperceptions or natural biases in the articulatory/perceptual system (Ohala 1989). Unfortunately, it is difficult to comment strongly on the ejective sound changes required by GT from a phonetic point of view because ejectives, and how ejectives are distinguished from other sounds in languages that have them, are not well understood phonetically, especially perceptually.

There have been a number of acoustic studies concerned with ejectives in a variety of languages. Many of these look at Voice Onset Time (henceforth, VOT) (Hogan 1976, Lindau 1984, Ingram and Rigsby 1987, Sands et al. 1993, McDonough and Ladefoged 1993, Warner 1996, Maddieson et al. 2001, Wright et al. 2002, Billerey-Mosier 2003, Wysocki 2004). Some look at various other measures, such as closure duration (Lindau 1984, McDonough and Ladefoged 1993, Warner 1996, Wysocki 2004), voicing jitter (Wright et al. 2002), or amplitude measures, such as the amplitude of the burst or the amplitude rise time of the following vowel (Ingram and Rigsby 1987, Wright et al. 2002).

Below, in Table 2, is a summary of VOT data for various languages with ejectives, taken from various sources. In most languages, the VOT of ejectives falls between the VOT of the other two pulmonic stops. Exceptions to this are Gitksan, which only has two manners, and Kiowa, which has four. In Kiowa, the ejectives have the longest VOT. All data in this table was gathered from speakers reading from a word list.

Closure duration does not distinguish stop manner, or at least does not distin-

Language	Voiced	Voiceless unaspirated	Ejective	Voiceless aspirated	Notes
Apache [velar] (Cho and Ladefoged 1999)		31 ms	60 ms	80 ms	
Gitksan (Ingram and Rigsby 1987)		11.1 ms (sd 36.1 ms)	89.2 ms (sd 31.3 ms)		Two speakers
Hupa [velar] (Cho and Ladefoged 1999)		44 ms	80 ms	84 ms	
Ingush (Warner 1996)	Negative		26.2 ms	45.1 ms	Single speaker
Kiowa (Billerey-Mosier 2003)	-98 ms	16 ms	129 ms	67 ms	Single speaker
Navajo [velar] (Cho and Ladefoged 1999)		45 ms	94 ms	154 ms	
Navajo [coronal] (McDonough and Ladefoged 1993)		6 ms (sd 2 ms)	108 ms (sd 31 ms)	130 ms (sd 29 ms)	
Tlingit (Maddieson et al. 2001)		24.6 ms (sd 23.4 ms)	102.7 ms (sd 40.6 ms)	127.6 ms (sd 36.8 ms)	
Witsuwit'en [coronal] (Wright et al. 2002)		18 ms (sd 4.3 ms)	33 ms (sd 19.4 ms)	59 ms (sd 10.9 ms)	
Georgian [coronal] (Wysocki 2004)	20 ms		63 ms	90 ms	

Table 2: VOT data for various languages with ejectives, given with standard deviations when available. For some languages, only data for specific place of articulations could be reported.

guish the ejective stop manner in Navajo (McDonough and Ladefoged 1993), Ingush (Warner 1996) or Georgian (Wysocki 2004). Ingram and Rigsby (1987) looked at two speakers of Gitksan, one male and one female. They found that vowel amplitude rise time following stops does not distinguish stop manner in Gitksan overall, but individually, their speakers did make a distinction (they showed opposite trends). In the Gitksan study, only 26% of the vowels following ejectives showed aperiodicity, and there were no general differences in the f0 following stops, though, like with amplitude rise time, there were consistent trends within each of the two speakers. In Witsuwit'en (Wright et al. 2002), ejectives showed a slower amplitude rise time than the other two stop manners and showed more jitter. The effect of stops on f0 was gender specific: women showed a sizable lowering of f0 (-22 Hz), while men showed a slight raise in f0 (8 Hz) following ejectives.

There are fewer articulatory studies. Pinkerton (1986) performed a study of the oral air pressure of Quichean glottalized stops and Lindsey et al. (1992) performed an EGG study on Hausa glottalic stops. Pinkerton discovered that many Quichean languages defy Greenberg (1970) generalization, which states that ejectives are more likely to have posterior places of articulation and implosives are more likely to have anterior places of articulation. Many of the glottalized uvular stops in these languages were implosive and marked by a small rise in oral pressure followed by a sharp fall to negative pressure, whereas the velar stops were true ejectives. The ejectives had oral pressures that were, on average, between 1.5 to 2 times higher than for the non-glottalized stops.

Fewer still are perceptual studies on ejectives. Some preliminary perceptual work can be found in Wright et al. (2002), accompanying their acoustic study. They had native listeners categorize tokens produced by two speakers, one whose ejectives and voiceless unaspirated stops were distinct on more than one of their acoustic measures, and one whose ejectives and unaspirated stops were more confusable, based on their acoustic measures. They found that subjects were more accurate with the clearer speaker than with the speaker whose stops were more similar based on the acoustic dimensions examined in the paper, though both speakers elicited accuracy above 85%. They also tested subjects on control stimuli, which highlighted different phonetic contrasts, such as voiced vs. voiceless or aspirated vs. unaspirated. Subjects were worse overall at differentiating the ejectives from the unaspirated stops, even for tokens from the better speaker, than they were at differentiating all other contrasts.

As mentioned above, critics have said the ejective to voiced stop sound change required by GT seems phonetically unlikely. However, none of the studies listed have been concerned with the similarities and differences between ejectives and voiced stops. In fact, voiced stops have been left out of a few of the studies entirely on the assumed basis that the two stop types were so different, no comparisons needed to be made. Many of the acoustic studies have looked only at VOT. While VOT is undoubtedly an important property, and has been shown to distinguish stop manners in languages like English, which has only two pulmonic stop manners, none of these studies, nor any other that I have found, have shown that listeners of languages with stop systems that include ejectives use VOT to distinguish ejectives from the other stop manners found in the language.

A closer look at the phonetic similarity between ejectives and voiced stops is in order. This study will examine a number of acoustic measures in an attempt to describe the similarities and differences between ejectives and the other stop manners in a language more completely than has been done before. This information will be used to make predictions about which acoustic features might best serve as perceptual cues, and when and how the ejective and voiced stop manners might be perceptually confusable.

1.3 Georgian

This study concentrates on the stops in Georgian. Georgian, a Caucasian language spoken in Georgia, has three stop manners: voiceless aspirated, voiced and ejective. This system is similar to the stop system proposed by GT and, thus, is an appropriate language for this study. Their stop inventory is given below.

		Bilabial	**Alveolar**	**Post-alveolar**	**Velar**	**Uvular**
Stops	**Aspirated**	p^h	t^h		k^h	
	Ejective	p′	t′		k′	q′
	Voiced	b	d		g	

Table 3: Stop inventory of Georgian.

Robins and Waterson (1952) offered a descriptive analysis of Georgian phonology, and performed a kymograph study of Georgian stops. In their study, they noted that, within the ejective stops, ejection was only heard word initially, but glottalization was coarticulated with the following vowel. Intervocalic ejectives were heard with some voicing, an impression supported by some kymographic evidence.

Wysocki (2004) performed an acoustic study of Georgian stops located word initially and intervocalically in words read from a list. She found that stop manner was not distinguished by closure duration, but that there was a three way distinction in manner by VOT. Aspirated stops had the longest VOT, voiced stops had the shortest, and ejectives had an intermediate VOT. Intervocalically, the average VOT of ejectives shortened dramatically from its value word initially, compared to the other two stop manners.

In this study, the similarity and differences between the Georgian stop manners will be examined with respect to seven acoustic measures:

- Voicing lag
- Closure duration
- Duration of voicing into the closure
- Phonation of the vowel onset (measured by H1-H2)
- Change in f0 between post-stop vowel onset and vowel midpoint
- Relative intensity of stop burst compared to the following vowel
- Relative intensity of the aspiration or segment between the stop burst and the vowel onset compared to the following vowel
- Burst spectral measures (mean, standard deviation, skew, and kurtosis)

Voicing lag, which is nearly equivalent to voice onset time (voicing lag can only be positive), closure duration and change in f0 are measured because these measures are common in previous acoustic studies of ejectives, and at least voicing lag and f0 have been shown to distinguish ejectives from other stop manners in other languages (see previous section). The duration of voicing into the closure is likely to separate voiced stops from the aspirated and ejective stop manners. This measure is also of interest because of the finding by Robins & Waterson about voicing into the closure of ejectives in Georgian, which is an unexpected characteristic of Georgian ejectives. Phonation is measured because of the expectation for ejectives to induce creaky voicing. Ejectives are commonly described as unique because of their sharp, popping bursts. Therefore, the bursts are examined in intensity and spectral moments. The intensity of the period following the burst and before the vowel onset is measured and is expected to show a difference between the aspirated and ejective stops, due to the presence or absence of aspiration noise. Hypotheses will be made about which of these measures might serve as perceptual cues and their robustness.

Many of the ejective studies listed above look at ejectives in isolated words, and therefore in only one prosodic position. However, it is known that certain sound changes are more likely to happen in some prosodic positions than others. For example, stops are more likely to undergo voicing in an intervocalic position and devoicing in a word final position. If the ejective to voiced stop sound change is possible, it may be more likely to occur in a specific prosodic position.

An additional reason to look at stops in different prosodic positions is to see how they behave with respect to the phenomenon of initial strengthening. In previous research, consonants have been found to be more strongly articulated in higher prosodic positions. For example, in higher prosodic positions, the VOT of Korean aspirated stops is longer (Jun 1993) and coronals show more linguopalatal contact

(Fougeron and Keating 1997). The effect of initial strengthening on ejectives has not previously been explored.

It has been shown that there is a difference between the perceptual intelligibility of clear speech and conversational speech in English and other languages (Smiljanic and Bradlow 2005, Ferguson 2004) and that there is more coarticulation in faster speech (Kohler 1990). Traditional phonetic studies look at speech elicited from word lists or carrier phrases of the form, “Please say XXX again,” which is likely to elicit articulation closer to clear speech than to normal conversational speech. Sound change is probably more likely to result from fast or conversational speech. Therefore, this study will also examine the effect of different speaking styles on the acoustic measures listed above, as well as the effects of prosodic position.

2 Methods

2.1 Procedure

This study looks at nine stops in Georgian that differ in place (labial, alveolar and velar) and manner (aspirated, voiced and ejective). The uvular ejective was excluded because its realization varies freely between a glottal stop, an ejective stop and an ejective fricative.

Five adult women were recorded: 1M, 2N, 3M, 4T, and 5N. All participants were native, literate speakers of Georgian and were bilingual in English. Recordings were made using a Shure head mounted microphone. Its signal was run through an XAudioBox pre-amp and recorded using PCQuiererX in the UCLA sound attenuated booth at a sampling rate of 44,100 Hz. Data was segmented using a waveform display supplemented by a wide band spectrogram and analyzed using Praat (Boersma 2001) and Pitchworks (Scion R&D).

2.2 Materials

The target stops were located in real Georgian words, which were found in a dictionary and confirmed with a consultant. Stops appeared either word initially or intervocalically, beginning the second syllable, and were followed by the low vowel /a/.

Tokens of the words were recorded in two different conditions: in two carrier phrases and in three short stories (see Appendix B), which were written with the aid of a consultant. In the carrier phrase condition, the vowel preceding the targeted stop was always the low vowel /a/. In the story condition, the preceding vowel was not controlled. The two conditions were used in an attempt to elicit two styles of speech, more formal and less formal, in order to see if and how the significant acoustic correlates differ between speech styles. In the carrier phrase condition, it is obvious to the speaker which words are of interest to the experimenter. Therefore, it is expected that these tokens will be well articulated and the differences between stop manners will be exaggerated. On the other hand, target words should be harder to locate when embedded in stories, and it is hoped that speakers will revert to a more normal speaking style in this condition. Articulations should then be less exaggerated and differences in stop manner should be more likely to be obscured or lost. The target words in the carrier phrase condition are not necessarily the same as the target words in the story. In the recording, the stories were read before the carrier sentences. Tokens in the carrier phrase condition were presented in random order. Approximately one-fourth of the presented items were fillers. Each targeted sound was recorded at least five times in each prosodic position in the carrier phrase condition and nearly five times in the story condition.

Targeted stops appeared in three different prosodic positions: intonational phrase initial, accentual phrase initial[3] and word medially. In the carrier phrase condition, in order to appear in the intonational phrase initial position (henceforth IP initial), words were placed in the carrier phrase *XXX kartuli sit'q'vaa*, "XXX is a Georgian word." For both the accentual phrase initial (henceforth aP initial) and word medial prosodic positions, words were placed in the phrase *sit'q'va XXX davts'ere*, "I wrote the word XXX."

The prosodic positions of the targeted words were confirmed after recording by identifying phrasal tone contours and by judging break strength. Words in Georgian have stress on the initial syllable, which is marked tonally using pitch accents. In general, each word makes up one accentual phrase, which, in declarative sentences, is usually marked by a low tone on the stressed syllable and a high tone on the aP final syllable. The ending of an IP phrase is marked by a boundary tone, usually with an increased pitch range compared to the aPs. The break

[3] In the story condition, some of these cases may have actually been intermediate phrase initial. These cases were grouped together with the aP initial cases. See Jun et al. (2007) for a detailed description of the prosodic structure assumed in this study.

between two IPs is also considerably larger than between two aPs (Jun et al. 2007). Cases where the exact prosodic phrasing could not be determined were removed from the analysis. The most common difference from what was predicted was the break-up of the sentences in the story condition, resulting in the placement of a predicted aP initial word in an IP initial position. These tokens were recategorized in the analysis.

2.3 Analysis

Seven acoustic measures were made for each targeted sound, when possible. Closure duration and voicing into the closure were measured only for tokens appearing aP initially and word medially because there is no marking of the closure onset in IP initial position. Phonation at the vowel onset (H1-H2) and change in f0 (Δf0) were measured only for tokens read in the carrier phrase. This was done to reduce the time required for analysis and because many of the tokens in the story condition would have had to be excluded due to overly creaky, irregular phonation, where no reliable H1-H2 or f0 measure could be made. All other measures were made for all tokens.

Closure duration was taken to be the duration between the stop implosion and the stop burst. The stop implosion was marked by either a sharp fall in the waveform amplitude or the cutoff of higher energy in the spectrogram. The stop burst was marked by a sudden rise in the waveform amplitude. Voicing lag (which can only be positive) was examined rather than voice onset time (which can be negative or positive) because voicing into the closure was also examined. There were no tokens that showed partial prevoicing, so tokens with negative VOT had voicing throughout the entire closure. This information is captured by the measure of voicing into the closure. Voicing lag was taken to be the duration between the stop burst and the onset of voicing, which was marked by the beginning of periodicity in the waveform and taken at the first zero-crossing. Tokens with negative VOT were recorded as having a value of zero, indicating zero voicing lag. Voicing into the closure was measured from the stop implosion to the last appearance of periodicity in the waveform. The ratio of voicing duration and total closure duration is used in the analysis. These measures are indicated in Figure 1 for a word medial /t'/, from the word *[s**at'a**xt'o]*.

Burst intensity and the shape of the burst spectrum were calculated over the entire burst duration beginning at consonantal release. The size of the analysis window thus varied from token to token; it was determined by the duration of the burst. The period between the burst and the vowel onset (which included aspiration, as in the aspirated stops, or silence, as in some of the ejectives and voiced stops) was not included in the burst intensity measurement. The intensity of this period, referred to as gap intensity, was measured independently. Visual inspection of the spectrogram and waveform was used to distinguish the burst duration from subsequent gap. The end of the burst was characterized by a sudden drop in intensity and reduced energy at lower frequencies. These portions of the stop are also indicated in Figure 1.

Relative burst intensity and relative gap intensity were calculated relative to the intensity of the following vowel to factor out the effect of differences in overall

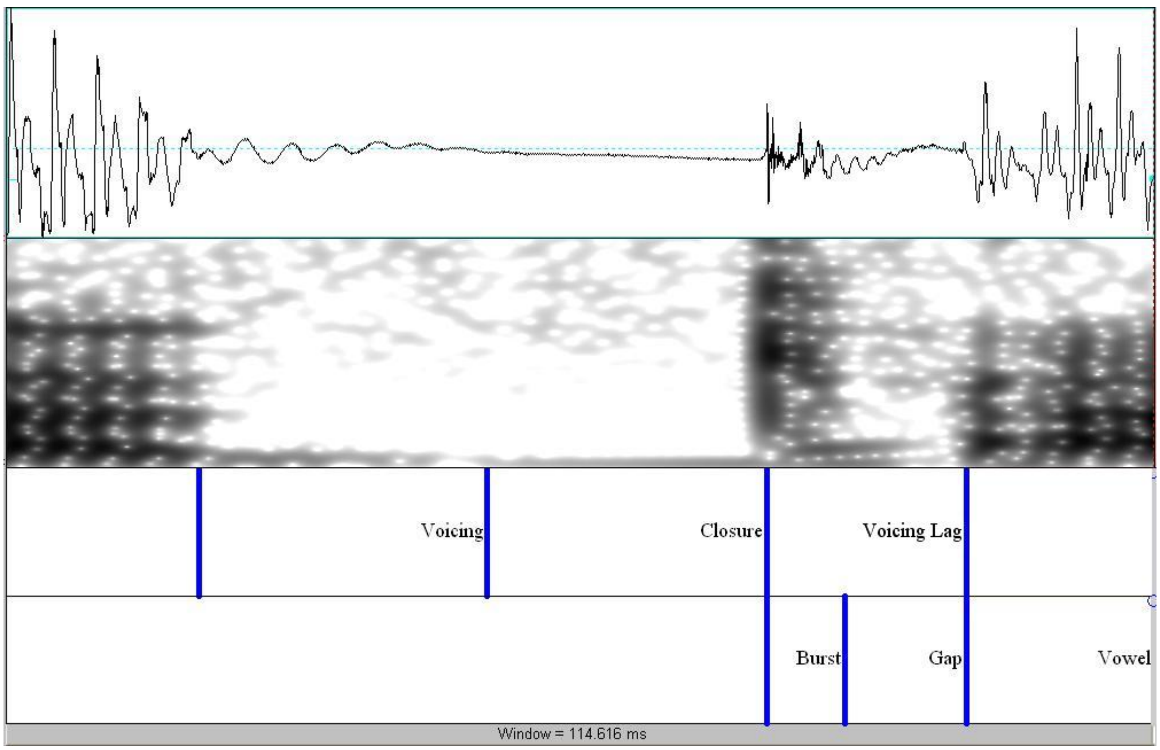

Figure 1: A token of word medial /t'/, from the word *[sat'axt'o]* illustrating the portions of the stop segmented for analysis. The portion of the closure that showed voicing and the portion without voicing (labeled as 'closure') add to give the total closure duration. Voicing lag, burst, gap and total duration of the following vowel (only the beginning portion is shown) are also labeled.

intensity across speakers. The maximum intensity of the burst (in dB) and the minimum intensity during the gap were subtracted from the maximum intensity of the vowel (in dB) to obtain these measures (Stoel-Gammon et al. 1994).

The shape of the burst spectrum was characterized by four measures: mean, standard deviation, skew and kurtosis. Spectral moments were derived from the power spectra over the entire burst duration for frequencies up to 22,050 Hz. To make the procedure for calculating spectral moments consistent with that used by Forrest et al. (1988) and Sundara (2005), bursts were pre-emphasized prior to making spectral measurements; above 1000 Hz the slope was increased by 6 dB/oct. Stops were also filtered using a 200 Hz high-pass filter, making the procedure consistent with Jongman et al. (1985) and Sundara (2005).

Phonation was measured at the vowel onset by taking a 21 Hz-bandwidth FFT spectrum over a window of 40 ms, measuring the intensity of the first and second harmonics, and then taking the difference (H1-H2). If harmonics could not be resolved at the vowel onset, phonation was measured at the earliest place in the vowel where clear harmonics could be seen. Tokens where this measure could not be made within the first 10 ms of the vowel were excluded.

Change in f0 was calculated by measuring the f0, using the cepstral method with a window of 35 ms and step size of 5 ms, at the vowel onset and the midpoint of the vowel, and then subtracting. If there was no accurate pitch track at the vowel onset, the f0 at the earliest location within the vowel that did show an accurate pitch track was measured. Tokens which did not show a pitch track within the first 10 ms of the vowel were excluded.[4] Tokens which showed greater than 10 Hz variation over the central 50% of the vowel were also excluded. This last criterion was meant to eliminate tokens with a rising or falling pitch accent.

Tokens which did not show a full closure or that were mispronounced were also excluded, as were tokens where the following vowel was whispered. These tokens made up about 1% of the data.

For each measure, a repeated measures ANOVA was run with four within-subjects factors of speaking style (2 levels), prosodic position (3 levels), manner (3 levels) and place (3 levels) with an alpha set at 0.05. These ANOVAs seek to avoid the possibility of type 1 error caused by inflated n by using each speaker's mean as the dependent variable. Sphericity violations are corrected by using the Huynh-Feldt correction, which adjusts the degrees of freedom downward in order to reach a more accurate significance value. Because post-hoc tests are not available for RM-ANOVAs, significant interactions and main effects were explored using paired t-tests. To examine the behavior of individual speakers, a second four-factor ANOVA was performed for each speaker. These factors are the same as those used in the group RM-ANOVA. Because the behavior of stops produced at different places of articulation is not of primary interest, only unexpected results and interactions with stop manner leading to, for instance, no significant difference between stop manners at a particular place of articulation, will be discussed.

[4]Because of the nature of the cepstral method, these tokens were the same as those removed in the phonation measure.

3 Results

3.1 Closure Duration

3.1.1 Group Results

The primary interest of this study is the acoustic differences between stop manners. Across speakers, there was little difference in the mean closure duration of the three stop manners, confirming the findings of Wysocki (2004). All manners had average closure durations between 64-65.5 ms, as shown in Figure 2a; the differences were not significant. Voiced stops showed considerably more variation than the other stop manners. This was due to the bilabial stops in particular. The closure duration values reported in Wysocki (2004) are between 90-100 ms, suggesting the speakers in this study spoke at a faster rate than her speakers.

In general, consonants in higher prosodic positions are articulated over a longer period of time than consonants in lower positions (Keating et al. 2003); likewise, it is expected that consonants will have longer articulations in a more formal speaking style (Picheny et al. 1986). For closure duration, it is expected that stops in higher prosodic positions will have longer closures than stops in lower prosodic positions, and that stops elicited in the carrier phrase condition will have longer closures than stops that were embedded in a story.

In Georgian, both of these effects can be seen, but only the main effect of prosodic position was significant. On average, closure durations for stops were longer in the carrier phrase condition (69.4 ms, sd 20.0) than in the story condition (60.5 ms, sd 17.2), though this difference was not significant. Closure durations for stops in

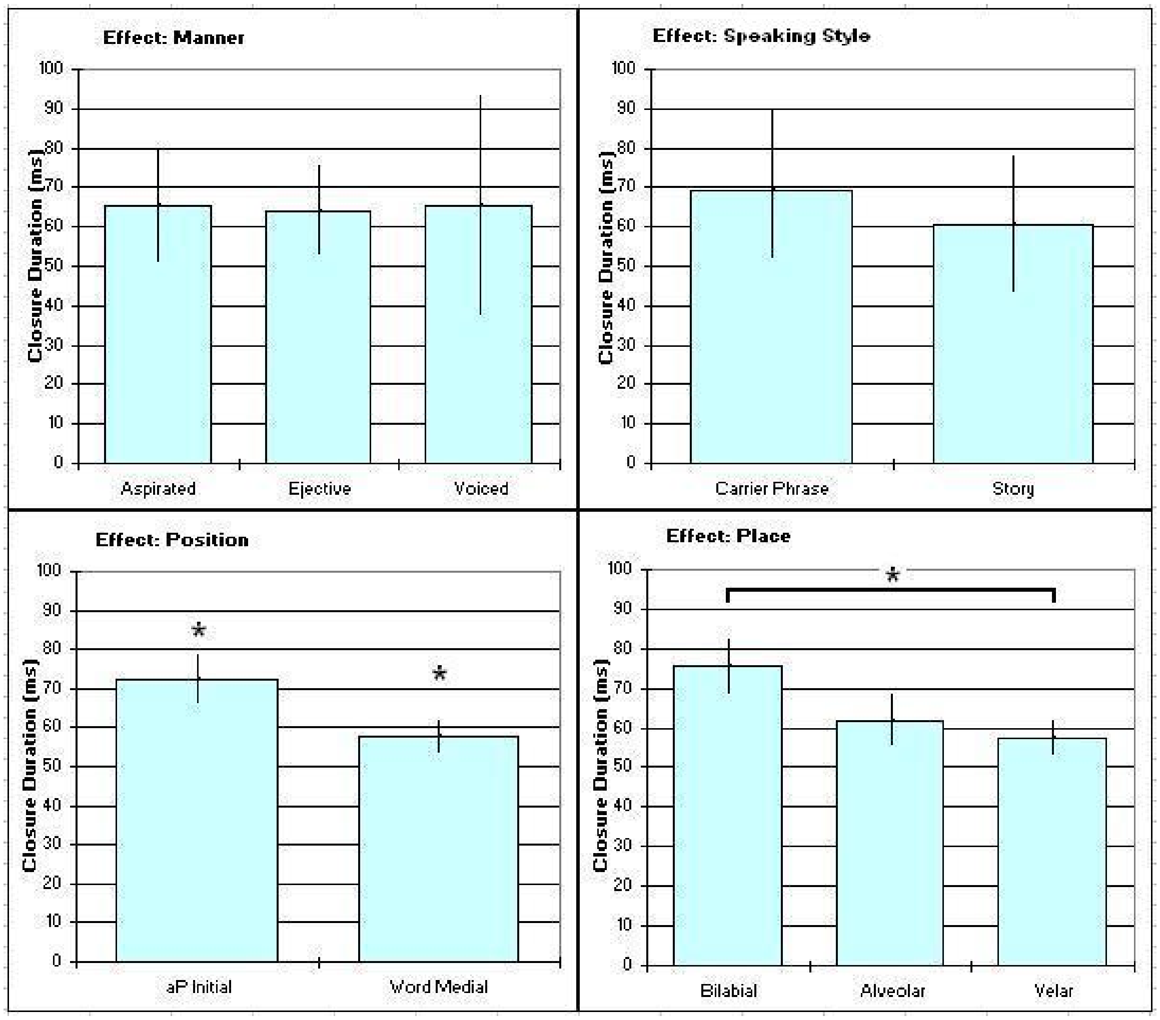

Figure 2: Average closure durations, in milliseconds, for a) Stop Manner, b) Speaking style, c) Prosodic Position and d) Place of Articulation. Error bars show ±1 standard deviation. Measures that were distinct from all others, at α=0.05, are indicated with an asterisk. If only one comparison was significant, that comparison is shown.

an aP initial position were longer (72.2 ms, sd 6.4) than stops in a word medial position (57.7 ms, sd 4.1), and this difference was significant ($F(1,4) = 32.13$, $p = 0.005$).

There was a significant three-way interaction between prosodic position x manner x place ($F(4,16) = 3.569$, $p = 0.029$), but there is no obvious phonetic interpretation of this interaction.

3.1.2 Individual Results

All five speakers behaved similarly with regard to stop manner and prosodic position. The group trend for closure durations in the different speaking styles was determined by four of the five speakers. Closure durations were longer in the carrier phrase condition than the story condition. Speaker 3M showed the opposite trend: her stops showed longer closure durations in the story condition ($F(1,280) = 7.954$, $p = 0.005$).

3.2 Voicing During the Closure

3.2.1 Group Results

In Georgian, all stop manners showed voicing into the closure as a continuation of the preceding voiced sound. This voicing usually died out before the stop release, but, for some voiced stops, it continued uninterrupted throughout the closure. There were no instances of stops in an intervocalic position (either aP initial or word medial) that showed prevoicing, where the voicing started during the middle of the closure and continued through the stop burst. There were a handful of IP initial tokens which showed prevoicing (9 of 223), but these were not included in the analysis.

There was a main effect of manner ($F(1.735,6.941) = 70.427$, $p < 0.001$). Voiced stops showed considerable voicing into the closure (75.8%, sd 22.0), and were significantly different from the ejective ($t(4) = 8.868$, $p < 0.001$) and aspirated stops ($t(4) = 8.834$, $p < 0.001$). Ejective stops and aspirated stops both showed little voicing into the closure (26.7%, sd 10.9; 17.4%, sd 9.1, respectively), but were statistically distinct ($t(4) = 2.994$, $p = 0.040$). With an average closure duration of about 65 ms, this equates to about 49 ms for voiced stops, 17 ms of voicing for ejective stops and 11 ms for aspirated stops. This contrast is shown in figure 3.

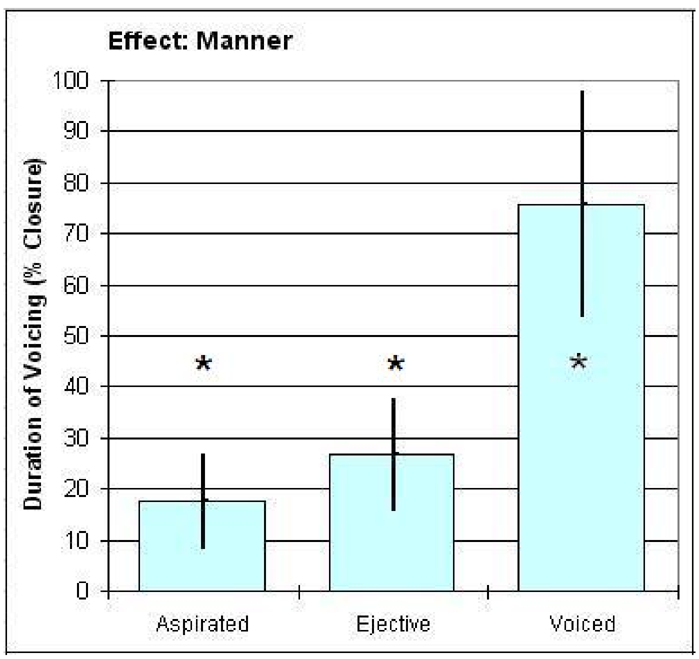

Figure 3: Average duration of voicing into the stop closure, given as a percentage of total closure duration, by stop manner. Error bars show ±1 standard deviation. Manners that were distinct from all others, at α=0.05, are indicated with an asterisk.

Stops elicited in a less formal speaking style may be more lenited than stops in more formal speech. With regards to the amount of voicing into the closure, it was expected that voicing would last longer in the story condition, compared to tokens read in an artificial carrier phrase. Similarly, it was expected that the amount of voicing into the closure would increase for stops in lower prosodic positions. This was only partially borne out in the data. There was a main effect of speaking style ($F(1,4) = 11.702$, $p = 0.027$). There was no main effect for prosodic position, but there was an interaction between the two factors ($F(1,4) = 34.693$, $p = 0.004$). The amount of voicing in the stop closure was significantly greater in the story condition than in the carrier phrase condition only for stops in a word medial prosodic position ($t(4) = 5.132$, $p = 0.007$). The amount of voicing was greater in the story condition for stops in an aP initial position, as well, but this difference was not significant. Stops in a word medial position in the story condition showed greater voicing than stops in an aP initial position in the story condition ($t(4) = 3.128$, $p = 0.035$). Stops in the carrier phrase condition showed the opposite trend. There was slightly more voicing in the aP initial position than in a word medial position, contrary to expectations, but this difference was not significant ($t(4) = 1.036$, $p = 0.358$). This is shown in figure 4.

There was no main effect of place. In general, stops in different places of articulation did not significantly differ in the amount of voicing during the closure. However, there was a three way interaction between prosodic position, stop manner and place of articulation ($F(2.861, 11.443) = 5.093$, $p = 0.019$). In the aP initial position, there was no significant difference, under a Bonferroni corrected paired

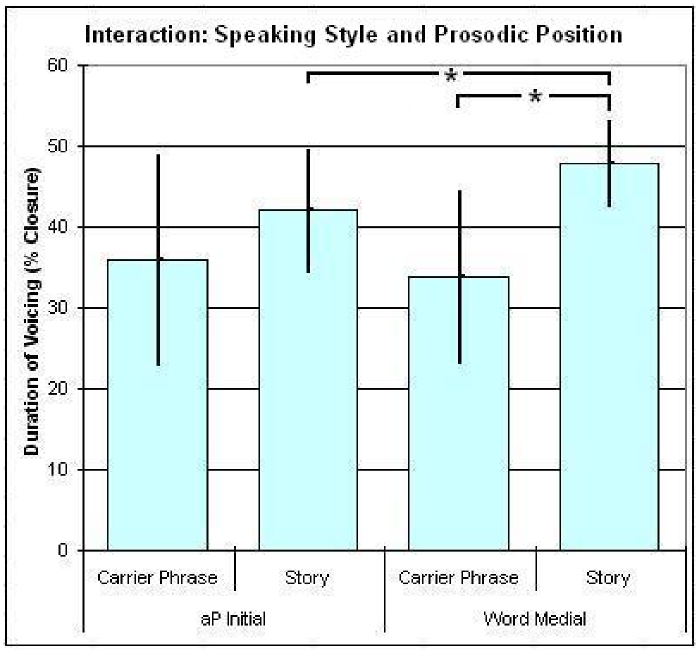

Figure 4: Average duration of voicing into the stop closure, given as a percentage of the total closure duration, by speaking style and prosodic position. Error bars show ± 1 standard deviation. Significant comparisons, at α=0.05, are shown and marked with an asterisk.

t-test, between the ejective and voiced velar stops ($t(4) = 4.181$, $p = 0.014$ (alpha is 0.005)). In general, velar voiced stops showed the least amount of voicing into the closure of the three places of articulation, and velar ejectives showed the most.

3.2.2 Individual Results

Four of the five speakers behaved similarly. The one differing speaker, 4T, had different results than the group for prosodic position, showing the opposite trend. Stops produced by the other speakers showed more voicing into the closure in a word medial prosodic position, whereas speaker 4T showed less voicing in a word medial position than in an aP initial position. This difference was significant ($F(1,279) = 8.968$, $p = 0.003$).

Four of the speakers showed an interaction between manner and place. Voiced velar stops showed less voicing into the closure than stops produced at either the bilabial or alveolar places, making them more like the velar ejectives.

3.3 Voicing Lag

3.3.1 Group Results

There was a main effect of manner ($F(2,8) = 76.625$, $p < 0.001$), prosodic position ($F(2,8) = 10.262$, $p = 0.006$) and place of articulation ($F(1.176,4.705) = 35.018$, $p = 0.002$). However, there was also a three way interaction ($F(7.467,29.87) = 4.528$, $p = 0.001$). Three smaller RM-ANOVAs were run within each prosodic position with two factors: stop manner and place of articulation.

On average, stops had the longest voicing lag in an IP initial prosodic position (42.3 ms, sd 10.2). Stops in an aP initial position had intermediate voicing lag (37.5 ms, sd 10.7) and stops in a word medial position had the shortest voicing lag (25.8 ms, sd 4.7). Only the voicing lag in the word medial position was significantly different from the other two positions (vs. IP initial position: $t(4) = 4.769$, $p = 0.009$; vs. aP initial position: $t(4) = 3.652$, $p = 0.022$). The difference in prosodic position is shown in figure 5. The differences in stop manner, broken down by prosodic position is shown below in figure 6.

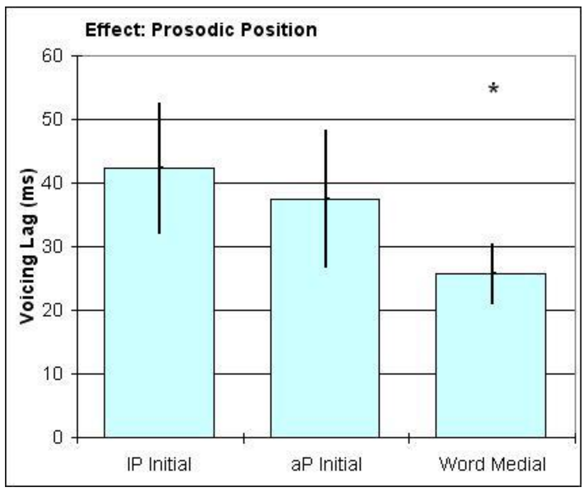

Figure 5: Average voicing lag, in milliseconds, by prosodic position. Error bars show ±1 standard deviation. Prosodic positions that were distinct from all others, at α=0.05, are indicated with an asterisk.

Within the word medial tokens, there was a main effect of stop manner ($F(1.259,5.035) = 160.326$, $p < 0.001$). All three manners were significantly different from one another. Aspirated stops showed the longest voicing lag (45.8 ms, sd 5.9), ejectives showed an intermediate voicing lag (22.9 ms, sd 5.3) and voiced stops had the shortest voicing lag (8.6 ms, sd 4.9).

Results within the aP initial position were similar. There was a main effect of manner (F(1.731,6.926) = 47.195, p <0.001). Aspirated stops showed the longest voicing lag (69.1 ms, sd 16.3), ejectives showed an intermediate voicing lag (32.0 ms, sd 15.0) and voiced stops had the shortest voicing lag (11.5 ms, sd 5.6). All manners were significantly different.

In the IP initial position, there was an interaction between stop manner and place of articulation (F(3.956,15.823) = 13.562, p <0.001), due to the lack of significant difference between the voicing lag for aspirated and ejective stops in the alveolar and velar places of articulation. At the bilabial place of articulation, all three stop manners were significantly different from one another. For all places of articulation, aspirated stops had the longest voicing lag (average 64.1 ms, sd 14.9), ejectives showed an intermediate voicing lag (average 46.1 ms, sd 13.8) and voiced stops had the shortest voicing lag (average 16.8 ms, sd 5.6).

	Word Medial		aP Initial		IP Initial	
	t-value	p-value	t-value	p-value	t-value	p-value
Aspirated vs. Ejective	13.814	<0.001	11.419	<0.001	3.671	0.021
Aspirated vs. Voiced	12.945	<0.001	8.032	<0.001	5.434	0.006
Ejective vs. Voiced	9.688	<0.001	3.017	0.039	9.593	<0.001

Table 4: Statistics for comparisons between stop manners in different prosodic positions. The degrees of freedom for all comparisons is 4.

These results generally confirm the findings of Wysocki (2004), who found that VOT distinguished between all three stop manners in Georgian. However, the voicing lag values obtained in this study are smaller than the VOTs in Wysocki's (again, most likely due to the apparent faster rate of speech by the speakers in this

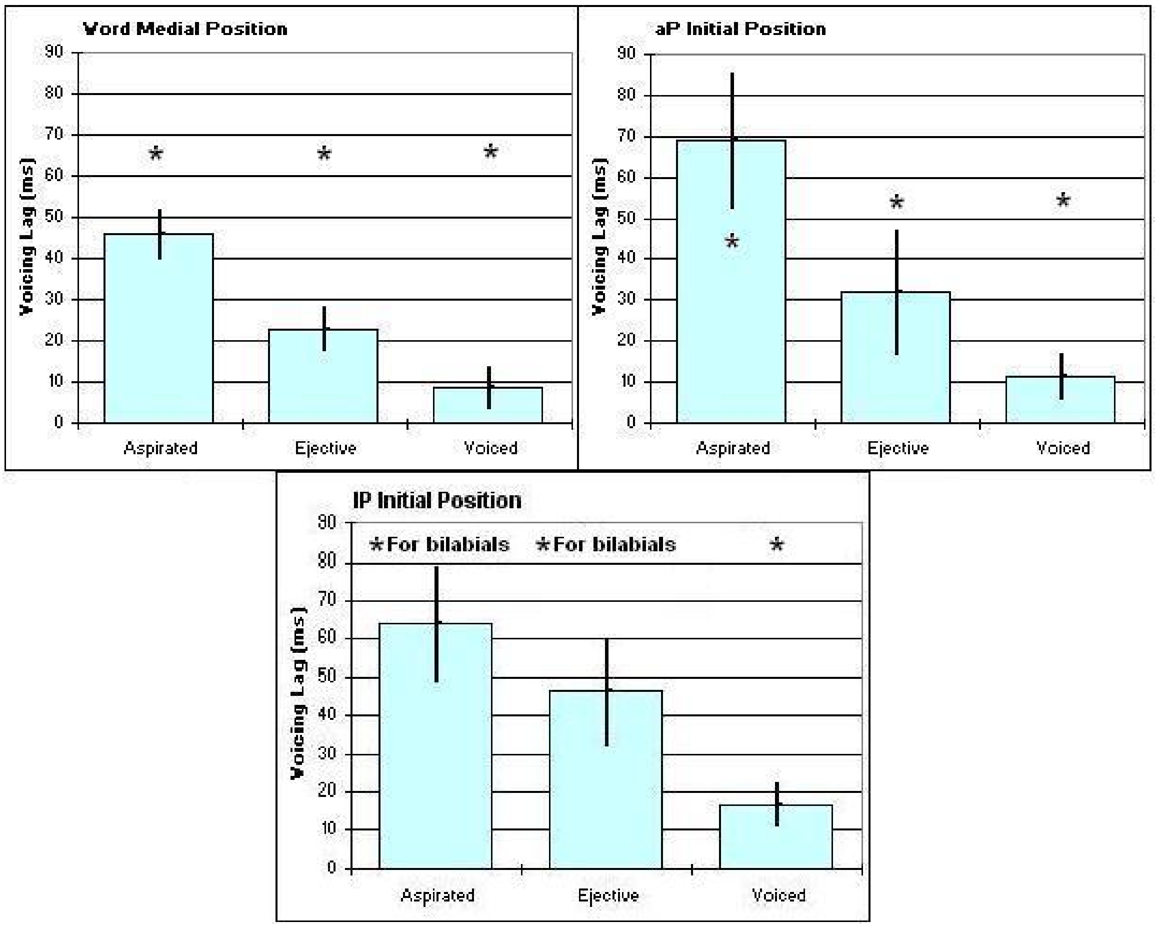

Figure 6: Average voicing lag, in milliseconds, by stop manner for a) word medial position, b) aP initial position and c) IP initial position. Error bars show ± 1 standard deviation. Manners that were distinct from all others, at α=0.05, are indicated with an asterisk. If a stop manner was different from the other manners at only one place of articulation, that place is specified.

study). In general, these results are similar to VOT studies in other languages. In the languages in Table 2 with only three stop manners, ejectives have an intermediate VOT, between the other two stop manners. The voicing lags in Georgian are closest to the VOTs of the stops in Ingush and Witsuwit'en.

3.3.2 Individual Results

There were no speakers that behaved remarkably different from the group as a whole. All five speakers showed a similar distinction between stop manner through voicing lag. Aspirated stops had the longest voicing lag for all speakers, ejectives had an intermediate voicing lag and voiced stops had the smallest voicing lag.

Even though all speakers distinguished between stop manner in voicing lag, when looking at individual tokens, there was considerable overlap between the ejectives and the other two stop manners. This is illustrated in figure 7 with alveolar stops. In IP initial position, there is considerable overlap between the ejectives and the aspirated stops. In this position, ejectives were more likely to have a significant pause between the stop burst and the vowel onset, which was filled with relative silence, caused by a delay in glottal release. In weaker prosodic positions, the ejective tokens overlap more with the voiced tokens in voicing lag. In these positions, the ejectives were more likely to have a (near) simultaneous oral and glottal release and did not show a silent gap.

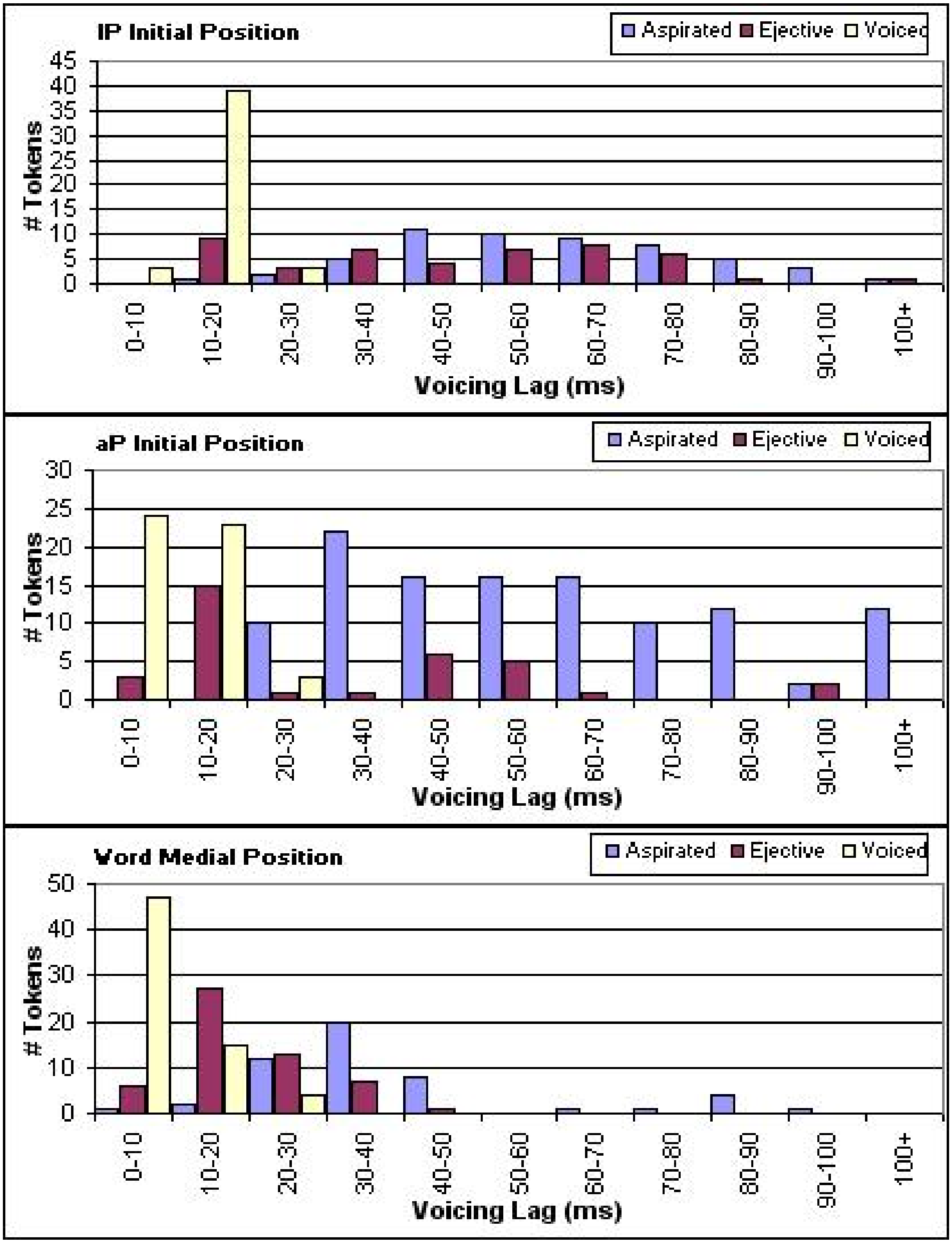

Figure 7: Histograms of voicing lag for alveolar stops in a) IP initial position, b) aP initial position and c) word medial position.

3.4 Relative Burst Intensity

3.4.1 Group Results

Of over two thousand tokens measured, 7.5% had no detectable burst. The majority of these tokens were voiced stops (58.1%), 31.7% were aspirated and 10.1% were ejective stops. Of all the tokens measured, only 17 ejectives showed no burst. Stops that had no burst were also more likely be produced at a more anterior place of articulation: 49.1% of the burstless stops were bilabial, 31.1% were alveolar and 19.8% were velar.

Because relative burst intensity was calculated by subtracting the absolute intensity of the burst from the intensity of the following vowel, a larger difference indicates a weaker release, relative to the intensity of the following vowel. In the ANOVA, there was no main effect for stop manner, nor place, but there was an interaction ($F(3.429,13.715) = 6.036$, $p = 0.006$). Burst intensity did not distinguish stop manner at any place of articulation except bilabial and alveolar, where the ejectives were significantly weaker than the voiced stops (bilabial: $t(4) = 5.679$, $p = 0.005$; alveolar: $t(4) = 3.533$, $p = 0.024$). In general, however, ejective stops had the weakest relative burst intensity of the three stop manners at the bilabial and alveolar places of articulation, but the strongest at the velar place. In all three places, aspirated stops had weaker bursts than voiced stops. This is shown in figure 8.

Stops produced at a velar place of articulation have the smallest sealed oral cavity. Ejectives are made by raising the constricted glottis or by constricting muscles lining the sides of the oral cavity, decreasing the volume of the sealed oral cavity

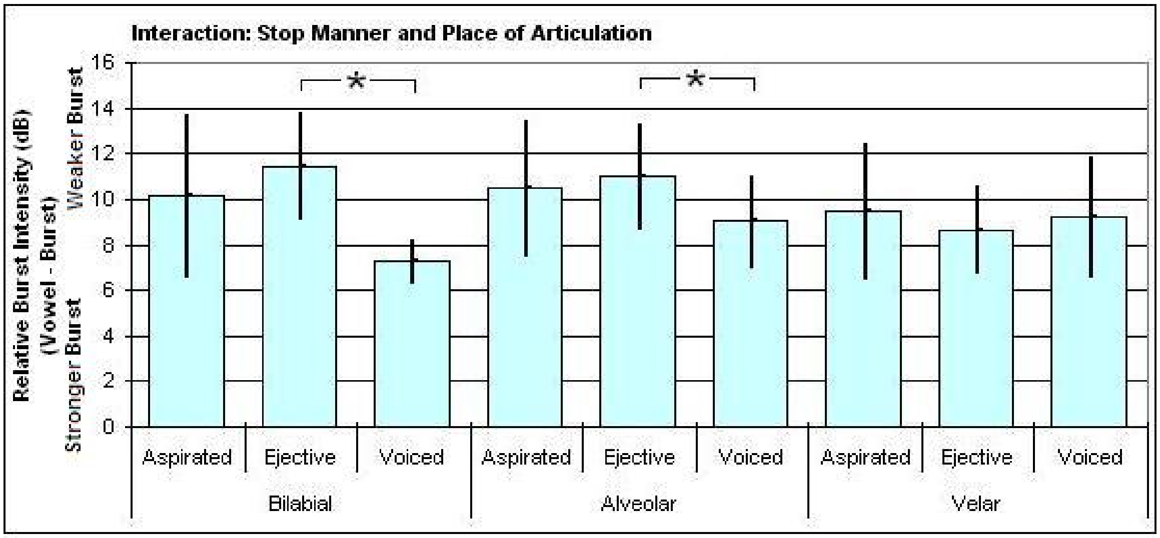

Figure 8: Average relative burst intensity, in dB, by stop manner and place of articulation. Error bars show ±1 standard deviation. Relative burst intensity was calculated by subtracting the burst intensity from the intensity of the following vowel, so a larger value indicates a quieter stop compared to the following vowel. Significant comparisons, at α=0.05, are marked with an asterisk.

and increasing the pressure. Velar ejectives should have the highest pressure, and therefore should produce a burst louder than at other places of articulation. However, ejectives are known for their sharp, pop-like releases. It is surprising that their relative burst intensity is the weakest of the three stop manners in the bilabial and alveolar places of articulation.

When the absolute intensity measurements for the bursts and vowels were examined, the ejective and voiced stops had the loudest bursts. Aspirated stops had bursts that were about 2 dB weaker. This was true for three speakers. Vowels following ejective stops, on the other hand, were between 2-5 dB louder than vowels following either voiced or aspirated stops, for three speakers. This difference in vowel intensity explains the relative weakness of ejective bursts.

There was a significant effect of prosodic position (F(1.593,6.370) = 58.049, p

$<$0.001), shown in figure 9. Relative burst intensity was significantly different in all prosodic positions. Bursts were weakest in IP initial position relative to the following vowel (11.2 dB, sd 1.6), stronger in aP initial position (9.4 dB, sd 1.9) and strongest in word medial position (8.3 dB, sd 1.8). This should not be taken to indicate that stop bursts themselves were stronger in a word medial position compared to IP initial position, only their intensity relative to the following vowel. Across speakers, bursts and vowels both had greater intensity in higher prosodic positions than in lower ones. If the vowel intensity increased in higher prosodic positions more than the burst intensity, the relative difference would be greater. This is what occurred. In Georgian, the first vowel of a word takes stress, so in an IP and aP initial position, the vowel following the first stop is stressed and should therefore be realized with a greater intensity than the vowel following the stop in a word medial position, or in this case, the vowel in the second syllable. There was no effect of speaking style; relative burst intensity was not significantly different between the story and carrier phrase conditions.

3.4.2 Individual Results

Two speakers, 2N and 4T, had significantly stronger bursts for voiced stops than for the other two stop manners. For these same two speakers, the aspirated stops had the weakest bursts, but this was only significant for one of them, 4T. Two of the five speakers, 1M and 5N, had no differences in relative burst intensity between different stop manners. Ejectives had the weakest bursts for the final speaker, 3M, and her aspirated stops had the strongest bursts. This individual variation casts

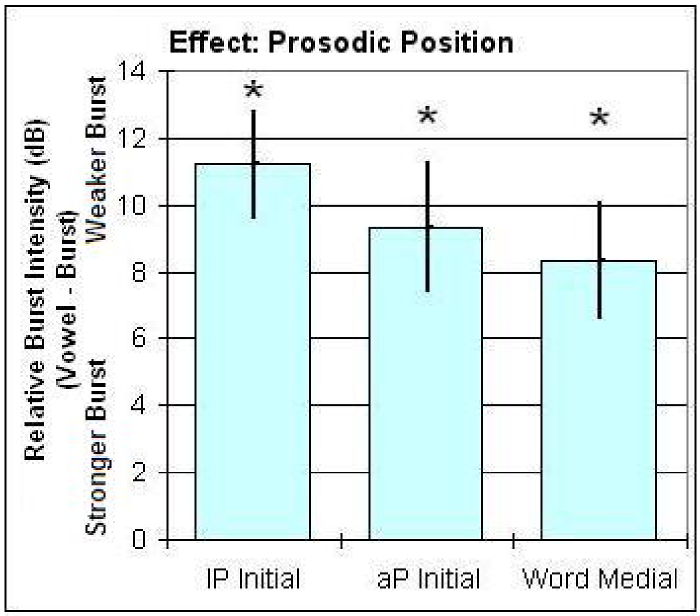

Figure 9: Average relative burst intensity, in dB, by prosodic position. Error bars show ±1 standard deviation. Relative burst intensity was calculated by subtracting the burst intensity from the intensity of the following vowel, so a larger value indicates a quieter stop burst compared to the following vowel. Positions that were distinct from all others, at α=0.05, are indicated with an asterisk.

doubt on the validity of the group results.

For three speakers, 1M, 3M and 5N, stop bursts in the story condition were significantly weaker than stop bursts in the carrier phrase condition. Speakers 2N and 4T showed no difference in relative burst intensity between speaking styles.

3.5 Relative Gap Intensity

3.5.1 Group Results

There were too many tokens without gaps between the stop burst and vowel onset to run a full ANOVA. Therefore, a one-way RM-ANOVA was conducted for each independent variable separately.

There was an effect of stop manner ($F(1.284,5.138) = 7.946$, $p = 0.032$). Canonically, the gap following the burst in aspirated stops should be filled with aspiration noise, while the gaps in ejectives should be filled with silence. Contrary to expectations, there was no significant difference in the relative intensity of the period between the stop burst and vowel onset between the the aspirated and ejective stop manners (12.2 dB, sd 2.2 versus 12.1 dB, sd 2.9, respectively). The gap between the burst and vowel onset in voiced stops, when present, was more noisy, relative to the following vowel (7.6 dB, sd 0.8) and was significantly different from the other two manners (vs. aspirated stops: $t(4) = 6.103$, $p = 0.004$; vs. ejective stops: $t(4) = 3.683$, $p = 0.021$). Because relative intensity was calculated by subtracting the absolute gap intensity from the intensity of the following, louder vowel, a smaller difference indicates a stronger gap intensity, relative to the following vowel. The large relative intensity associated with the voiced stops is explained by the very short gap duration in most voiced stops. When a gap was present in these sounds, it was caused by a delay between the burst offset and the voicing onset, which was filled with aspiration noise. Because the duration of these gaps was so short, the intensity measurement is artificially pulled up by the surrounding burst and vowel. So, in effect, there are no meaningful differences between the three stop manners.

There was an effect of prosodic position ($F(1.873, 7.491) = 17.927$, $p = 0.002$). Like relative burst intensity, the relative gap intensity was weaker in higher prosodic positions. IP initial stops had the least intense gaps (12.8 dB, sd 1.4), aP initial stops had an intermediate relative gap intensity (10.6 dB, sd 2.1) and word medial stops had the most intense gaps (8.6 dB, sd 1.3). Only the word medial stops were significantly different from the other two prosodic positions (vs. IP initial: $t(4) = 6.099$, $p = 0.004$; vs. aP initial: $t(4) = 4.284$, $p = 0.013$). Like with relative burst intensity, this pattern is largely due to the increase in intensity of the vowel in higher prosodic positions. It may also be due to the artificial raising of the absolute minimum gap intensity from the surrounding burst and vowel in smaller gaps (caused by the shorter voicing lags in lower prosodic positions).

There was no significant difference in gap intensity between the two speaking styles, nor between the three places of articulation.

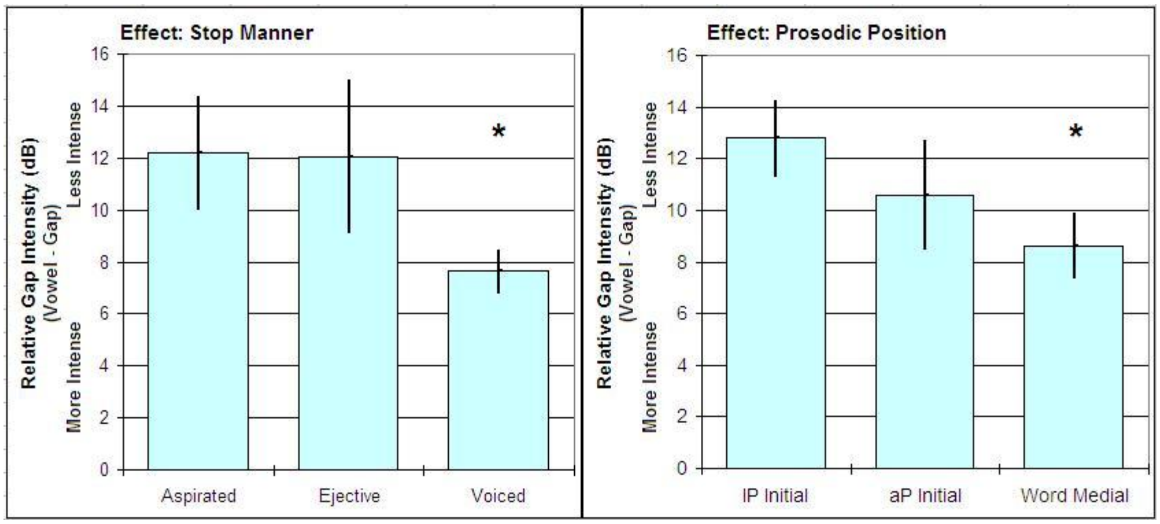

Figure 10: Average relative gap intensity, in dB, by a) stop manner and b) prosodic position. Error bars show ±1 standard deviation. Relative gap intensity was calculated by subtracting the gap intensity from the intensity of the following vowel, so a larger value indicates a less intense stop gap compared to the following vowel. Measures that were distinct from all others, at α=0.05, are indicated with an asterisk.

3.5.2 Individual Results

Only one speaker differed from the group with regards to stop manner. Speaker 3M's ejectives had the least intense relative gap intensity of all the stop manners, and this remained true in all prosodic positions. For the other four speakers, contrary to the group results, aspirated stops had the least intense relative gap intensity, and was significantly different from the other two stop manners for three of these speakers. For these speakers, the relative gap intensity of the ejective stops was equivalent to, or less intense than, that of the aspirated stops in IP initial position, but increased in a word medial prosodic position, becoming more like the voiced stops, which had the highest intensity in all positions for all five speakers.

3.6 Spectral Moments of Bursts

3.6.1 Group Results

For manner, there was a main effect for mean burst frequency ($F(2,8) = 7.673$, $p = 0.014$), skew ($F(2,8) = 7.854$, $p = 0.013$) and kurtosis ($F(2,8) = 6.897$, $p = 0.018$). However, when these effects were explored with paired t-tests only the difference between aspirated and voiced stops proved significant in all three measures. Aspirated stops had the largest mean burst frequency (4300 Hz, sd 750) and voiced stops had the lowest (3480 Hz, sd 710). Aspirated stops had a skew and kurtosis that was most like a normal distribution (1.63, sd 0.30, and 4.63, sd 1.78, respectively) and voiced stops had the least normal skew and kurtosis (2.16, sd 0.63, and 8.09, sd 4.08). Ejective stops had an intermediate value for all three measures. These relationships are shown in Figure 11, along with the measure of standard deviation (which did not distinguish between manners).

Measures of spectral moment did not significantly differ between the two speaking styles or between different prosodic positions. There was, however, an interaction between prosodic position, stop manner and place of articulation for all four spectral measures. These interactions arose because of the behavior of the different stop manners in different prosodic positions produced at a bilabial place of articulation. In general, the voiced manner had a trend opposite of the aspirated and ejective manners in all measures. For the mean burst frequency and standard deviation, the voiced stops had smaller values in lower prosodic positions while the other two stop manners had larger values. The opposite trend was true for

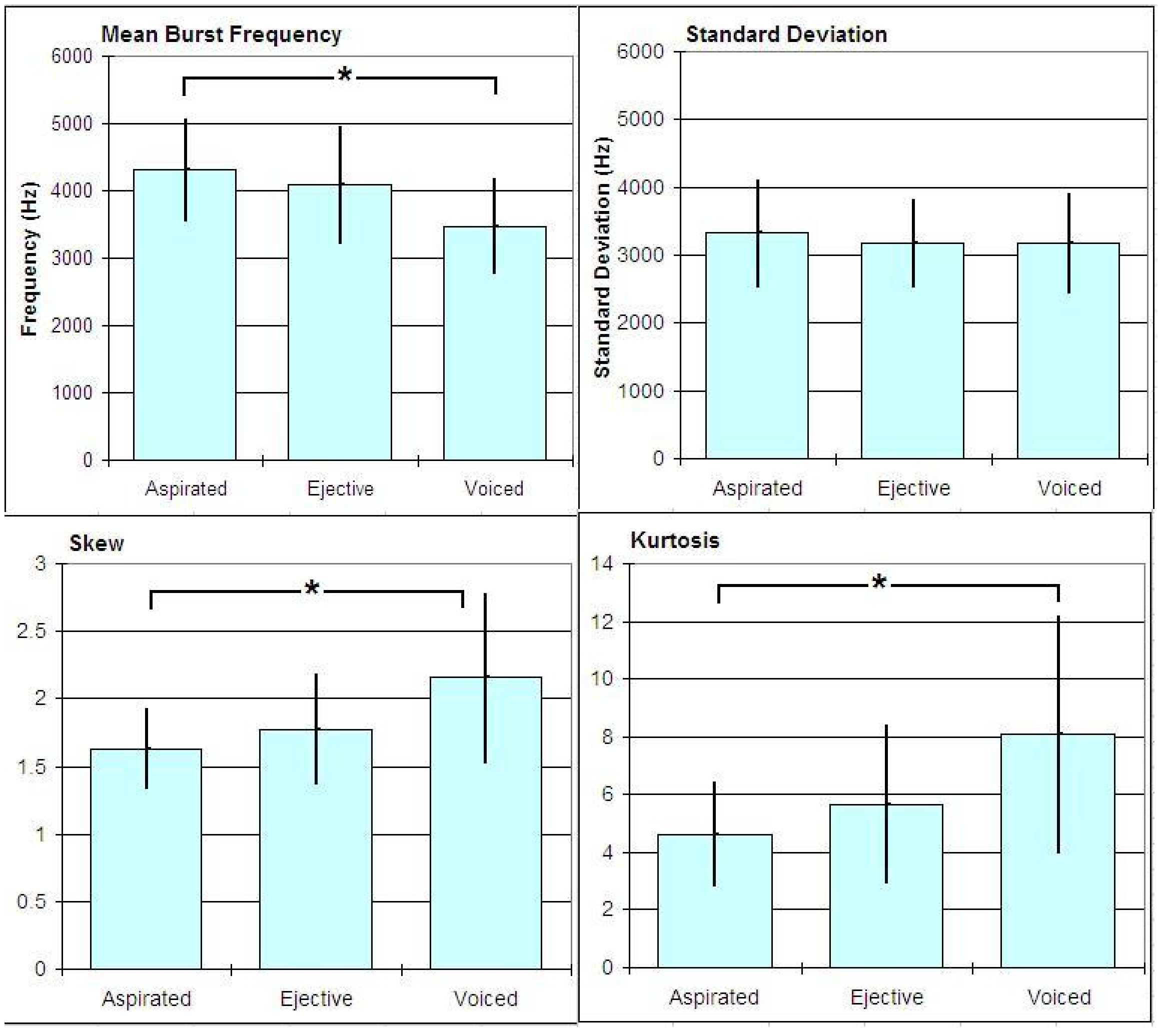

Figure 11: Average measures of a) mean burst frequency (Hz), b) standard deviation (Hz), c) skewness and d) kurtosis divided by stop manner. Error bars show ±1 standard deviation. Significant comparisons, at α=0.05, are marked with an asterisk.

the skew and kurtosis measures. Voiced bilabials had greater skew and kurtosis in lower prosodic positions and aspirated and ejective stops had lower skew and kurtosis. The voiced stops were significantly different from the aspirated and ejective stops only in word medial position for all measures but standard deviation. There were no differences in stop manner in different prosodic positions for the other two places of articulation.

3.6.2 Individual Results

Speakers varied somewhat in how their stops differed in spectral moment. Three speakers, 1M, 2N, and 5N had the highest mean burst frequency for aspirated stops, significantly higher than the other stop manners. Voiced stops for two of these same three speakers, 1M and 2N, as well as a third speaker, 4T, had the lowest mean burst frequency. Speaker 3M, on the other hand, had the highest mean burst frequency for ejectives. Voiced stops had the largest amount of skew and kurtosis for three of the five speakers, 2N, 3M and 4T.

3.7 Phonation

3.7.1 Group Results

Phonation was only measured for stops in the carrier phrase condition. This was done to reduce the time required for analysis and because many of the tokens in the story condition would have had to be thrown out due to non-modal, aperiodic phonation, where no reliable H1-H2 measure could be made. There was a main effect of stop manner ($F(1.353,5.410) = 9.269$, $p = 0.022$) and prosodic position ($F(2,8) = 4.756$, $p = 0.044$).

Vowels immediately following ejectives had the most creaky phonation (H1-H2 = -0.58 dB, sd 2.17). The ejectives were the only stops significantly differentiated by phonation (vs. aspirated: $t(4) = 3.138$, $p = 0.035$; vs. voiced: $t(4) = 3.203$, $p = 0.033$). Vowels following voiced stops had a more modal phonation (H1-H2 = 3.00 dB, sd 2.16) and vowels following aspirated stops had a more breathy phonation (H1-H2 = 4.89 dB, sd 2.39). However, these two manners were not significantly different. The phonation following different stop manners is shown in figure 12a. These results are similar to results found for other languages. Phonation following ejectives in Witsuwit'en showed more jitter than after other stop manners.

Voicing was overall more creaky in lower prosodic positions, as shown in figure 12b. Vowels following IP initial stops were the most modal (H1-H2 = 3.51 dB, sd 1.96), were creakier in aP initial position (H1-H2 = 2.34 dB, sd 1.37) and the most creaky voiced in word medial position (H1-H2 = 1.46 dB, sd 1.82), but only the difference between IP initial stops and word medial stops was significant ($t(4) = 3.033$, $p = 0.039$). These results contrast against those found in Epstein (2002), which found that, in English, phonation was more tense phrase initially. In English, it is known that phonation becomes more irregular throughout the course of the utterance, but this is caused by a gradual drop in subglottal pressure (Hanson et al. 2005), which should not necessarily impact the measure of H1-H2. No precise measurements were made, but in the story condition, voicing overall tended to be more creaky.

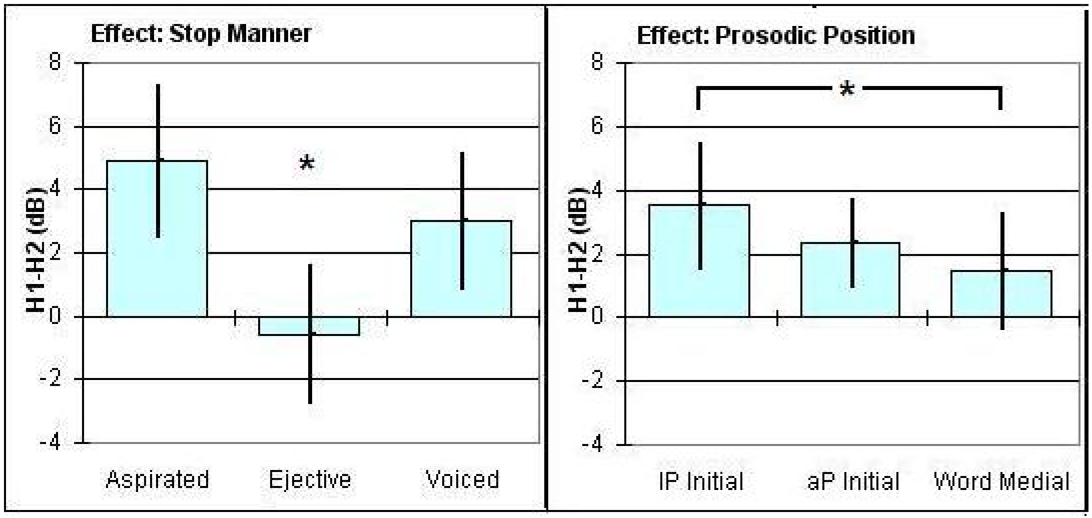

Figure 12: Average phonation, H1-H2, by a) stop manner, b) prosodic position. Error bars show ±1 standard deviation. Measures that were distinct from all others, at α=0.05, are indicated with an asterisk. If only one comparison was significant, that comparison is shown.

3.7.2 Individual Results

All speakers showed similar trends in the phonation of the vowels following different stop manners. Vowels following ejectives always had the lowest H1-H2 value, and this was significant for all speakers. Two speakers, 1M and 2N, also had a significant difference between the phonation of vowels following aspirated and voiced stops. Speakers differed in overall phonation. Speakers 1M, 2N and 5N were, on average, much creakier than speakers 3M and 4T.

One speaker showed a trend that was different from the group with respect to prosodic position. For speaker 2N, stops in an aP initial position were more modal than stops in an IP initial position, though this difference was not significant.

3.8 Δf0

3.8.1 Group Results

Δf0 was only measured for stops in the carrier phrase condition. This was done to reduce the time required for analysis and because many of the tokens in the story condition would have had to be omitted due to oaperiodic phonation, where no reliable f0 measure could be made. There were too few tokens to run a full RM-ANOVA, so a one-way RM-ANOVA was conducted for each independent variable separately.

Speakers had a similar pitch range. Four of the five speakers had a range that varied between about 125 Hz and 250 Hz, but usually remained within a 150-200 Hz range. Speaker 5N had a slightly lower range, between 100 and 200 Hz.

Across speakers, stop manner was distinguished by the f0 of the following vowel ($F(1.667,6.668) = 7.569$, $p = 0.022$). Like with phonation, only the ejectives were significantly different from the other two stop manners (vs. aspirated: $t(4) = 2.870$, $p = 0.045$; vs. voiced: $t(4) = 3.207$, $p = 0.033$). Vowels following ejectives had a flat-to-falling f0 (Δf0 = -1.2 Hz, sd = 3.2). Vowels following voiced and aspirated stops had a slightly rising f0 (Δf0 = 3.8 Hz, sd = 3.4 and Δf0 = 5.8 Hz, sd = 4.8, respectively). These results are somewhat similar to Witsuwit'en. In that language, women show a falling f0 after ejectives (-22 Hz) and a slight rise following the voiceless unaspirated and aspirated stops (about 10 Hz). For the Georgian women, the aspirated and voiced stops show a rise in f0, but to lesser degree. The f0 following Georgian ejectives, on the other hand, is virtually flat.

There was no significant difference in Δf0 for stops in different prosodic positions or stops produced at different places of articulation.

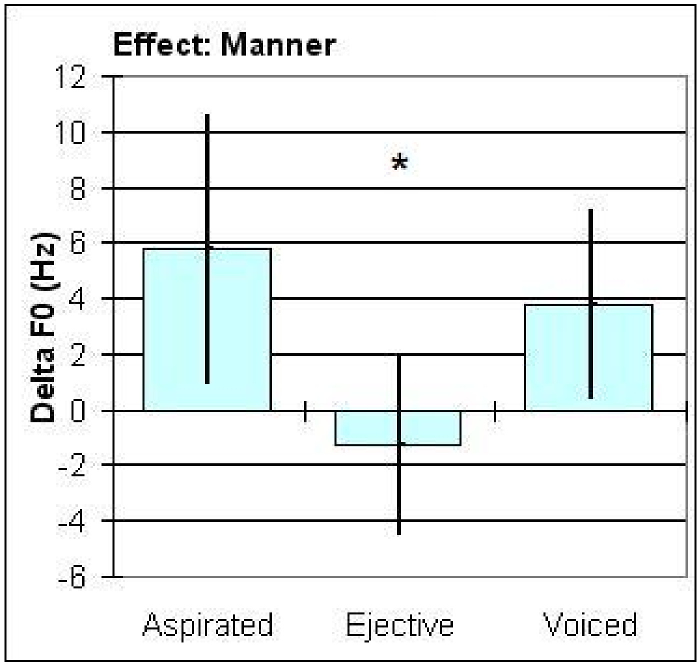

Figure 13: Average change in f0, in Hz, by stop manner. Error bars show ±1 standard deviation. Manners that were distinct from all others, at α=0.05, are indicated with an asterisk.

3.8.2 Individual Results

All five speakers behaved similarly with respect to stop manner. However, the range of Δf0 is different for different speakers. Speaker 1M had the smallest significant Δf0 difference, +2 Hz for aspirated stops, and -1 Hz for ejectives. Speaker 2N had the largest difference, +14 Hz for aspirated stops and -4 Hz for ejectives.

For three speakers, there was an effect of prosodic position. For two speakers, 1M and 3M, f0 fell after stops in an IP initial position. Δf0 in this position was significantly different from the other positions. f0 rose after stops in aP initial position, moreso than after stops in word medial position, though this difference was not significant. Speaker 4T showed a different trend. f0 rose after stops in IP initial position, more than after stops in other prosodic positions.

4 Discussion

4.1 Prosodic Position and Speaking Style

In general, stops in Georgian behaved as expected with regards to initial strengthening. In higher prosodic positions, stops had longer closure durations, longer voicing lags, and less creaky phonation. Bursts and vowels in higher prosodic positions were more intense than those in lower prosodic positions, but there was a greater change in the vowels, resulting in weaker relative burst intensities in higher prosodic positions. This was also true for relative gap intensity: stops in higher prosodic positions had weaker relative gap intensities. There was also less voicing into the closure in higher prosodic positions, though this was only significant for stops in the story condition. There was no significant difference in Δf0 after stops in different prosodic positions.

There were only three acoustic measures that showed individual speaker variation from the group result: voicing into the closure, phonation and Δf0. Results for individual speakers is given in table 5. It is likely these differences are simply a result of speaker variability rather than due to any deeper theoretical reason. This study thus adds to the literature on the importance of prosodic position in determining segmental phonetic detail.

Acoustic Measure	Speaker				
	1M	2N	3M	4T	5N
Voicing Into Closure	Word Med. > aP Initial	Word Med. > aP Initial	Word Med. > aP Initial	*aP Initial > aP Initial > Word Med.*	Word Med. > aP Initial
Phonation (H1-H2)	IP Initial > aP Initial > Word Med.	*aP Initial > IP Initial > Word Med.*	IP Initial > aP Initial > Word Med.	IP Initial > aP Initial > Word Med.	IP Initial > aP Initial > Word Med.
Δf0	*aP Initial > Word Med. > IP Initial*	No Difference	*aP Initial > Word Med. > IP Initial*	*IP Initial > aP Initial > Word Med.*	No Difference

Table 5: Individual results in prosodic position. Only those measures which showed individual variation are given. Differences from the group trend are shown in italic.

Stops elicited in the carrier phrase condition, the more careful speaking style, had longer closure durations and less voicing into the closure than stops in the story condition, or the less careful speaking style. The difference between speaking styles was not significant for other measures, suggesting either that there is no difference between speaking styles for these measures, or that the effort to elicit two different speaking styles was not very successful.

4.2 Manner

4.2.1 Acoustic Differences

Table 6 gives a summary of which acoustic measures distinguished the stop manners.

The two acoustic measures that best distinguish stop manner appear to be voicing lag and voicing into the closure. Voicing lag distinguished all stop manners, except in IP initial position, where only the voiced stops were distinct at all places of articulation. In this position, aspirated and ejective stops were not significantly

Acoustic Measure	Distinguishes Manner	Notes
Closure Duration	No	
Voicing into Closure	Yes	Velar voiced and ejectives had closer values than other places.
Voicing Lag	Yes	Dependent on prosodic position
Relative Burst Intensity	Ejectives vs. Voiced	For bilabials and alveolars. Considerable speaker variation.
Relative Gap Intensity	No	Voiced stops were distinct, but due to measurement process.
Spectral Moment	No	
Phonation (H1-H2)	Ejectives from other manners	
Δf0	Ejectives from other manners	

Table 6: Summary of which acoustic measures examined distinguished between stop manner. When not all three manners were distinguished, the significantly different manners are specified.

different at the alveolar and velar places of articulation. In general, however, aspirated stops have the longest voicing lag, voiced stops have the shortest and ejectives have an intermediate voicing lag. The amount of voicing into the closure distinguished all stop manners in all measured prosodic positions. Voiced stops showed the most voicing and aspirated stops showed the least. Ejectives again had an intermediate value.

Other acoustic measures failed to make a three way distinction, but still categorized different stop manners. Phonation and f0 in the vowels following ejectives are different than in vowels following either the aspirated or voiced manners. Phonation after ejectives was more creaky than after aspirated and voiced stops. f0 was fairly flat following ejectives, while it rose slightly after aspirated and voiced stops.

Ejectives in Georgian are almost certainly produced with a constricted glottis, which may or may not raise. However, the amount of voicing into the closure present in ejectives suggests that the muscles in the vocal folds are not held together tightly until the latter portion of the closure. In aspirated stops, the vocal folds are opened almost immediately after the closure, and kept open to allow aspiration after the burst. The opening motion occurs more quickly than the constriction, as indicated by the smaller amount of voicing into the aspirated stop closure. In ejectives, the glottal release was occasionally simultaneous with the oral release, but the glottis was commonly held shut for several milliseconds after the oral release. The vocal folds are most likely held shut throughout voiced stops, but in a looser configuration than for aspirated or voiced stops that allows voicing to continue throughout most of the closure. Cessation of voicing in these stops is most likely caused by the equalization of subglottal and supraglottal pressures, rather than a tensing of the glottis.

Relative burst intensity might distinguish between voiced and ejective stops, at least for bilabial and alveolar stops, but this group result was determined by only two speakers. Two other speakers showed no variation in relative burst intensity by stop manner. Therefore, it seems unlikely that relative burst intensity can truly distinguish stop manners. This was the only acoustic measure for which the group result suggested a possible difference between the ejectives and the other two stop manners, voiced and aspirated, that individual speakers showed variation. For all other acoustic measures that distinguished the ejectives from the other manners, all individuals behaved similarly.

4.2.2 Predicted Confusabilities

Because Georgian is a living, functional language, it is expected that the three stop manners are acoustically and perceptually distinct from one another. However, the acoustic differences found here, when examined more closely, were not overwhelming. This section will look first at how confusable the aspirated and ejective stops may be with one another and then at how confusable the ejective and voiced stops may be with one another.

Aspirated and ejective stops were most similar, in terms of voicing lag, in an IP initial position. In this position, the difference between aspirated and ejective stops was significant only for bilabial stops. Aspirated stops, on average, had a voicing lag of about 65 ms (sd 15 ms) and ejectives had a voicing lag of about 45 ms (sd 14 ms). As can be seen in Figure 7 above, there was considerable overlap between these two manners in the IP initial position.

There was no difference in relative gap intensity between the aspirated and ejective stops, contrary to expectations. Aspirated stops, of course, have aspiration, which should be louder than the relative silence between the burst and vowel onset in ejectives, but this was not borne out in the data. However, there may be a spectral difference, which was not measured, that listeners could use to distinguish these two manners. Listeners may also attune to the phonation or f0 differences. Vowels following ejectives have a significantly creakier phonation than vowels following aspirated stops, and ejective and aspirated stops had the most Δf0. Following ejectives, f0 was relatively flat, or fell slightly (about 1 Hz), but f0 rose after aspirated stops (about 6 Hz). Such small changes in pitch may not be easily perceived, especially following word initial stops, where the language's pitch accents are realized.

If the aspirated and ejective stops are confusable by listeners in any environment, it will most likely be in the IP initial position.

Ejectives and voiced stops were distinguished by voicing lag in all positions. However, in word medial position, the average voicing lag values for the two stop manners are very close. In this position, ejectives have an average voicing lag of about 23 ms (sd 5 ms) and voiced stops have an average voicing lag of about 9 ms (sd 5 ms). This is a difference of less than 15 ms, and both values fall within the unaspirated categories of 2-category languages (Keating 1984). Like with the aspirated and ejective stops, there is quite a bit of overlap in the production of voiced and ejective stops (Figure 7 above). It is also a research question in itself as to whether three distinct categories in VOT can be perceived reliably or not, without the assistance of other cues.

In word medial position, where ejectives and voiced stops are most similar in terms of voicing lag, listeners could use the amount of voicing into the stop closure to distinguish them. On average, 75% of the stop closure was voiced for voiced stops, while only a little over 25% was voiced for ejective stops. However, voicing during a stop closure is of very small amplitude. It seems unlikely that this could serve as a robust cue in the face of noise.

Again, phonation may be used, though the difference between ejectives and voiced stops is smaller than between ejectives and aspirated stops. The fact that phonation appeared to be more creaky overall in the story condition (which was meant to elicit a more casual speaking style) and that phonation became more irregular over the course of an utterance suggests that phonation may not be the most useful cue for listeners to attend to. However, in the face of noise masking the voicing during the stop closure, phonation may still be useful. Δf0 also distinguished the ejective and voiced stop manners (the difference in Δf0 in this case was about 5 Hz), but, again, such small differences may not easily be perceived. Voiced stops and ejectives were distinguished by relative burst intensity, but as discussed above, this measure does not seem promising as a perceptual cue in Georgian.

Although ejectives and voiced stops are statistically distinct on at least four acoustic measures, none of these measures seem like fool-proof perceptual cues. It is likely that listeners use all of them in combination to make the decision about what they heard. If ejective and voiced stops are confusable by listeners in any environment, it will most likely be in a word medial position. In this position, the values for the two most likely cues, voicing into the closure and voicing lag, are the most similar.

These results suggest that ejectives and voiced stops may not be as acoustically dissimilar as the intuitions of GT critics would suggest, at least in Georgian. If the ejective and voiced stops are confusable, this could allow a possible path for historical change like that suggested by the Glottalic Theory: ejectives to voiced stops. This question will be explored in future perceptual research.

There was also overlap between the ejectives and aspirated stops, but it is unlikely that a sound change from ejectives to voiceless aspirated could occur. The ejective stops with long voicing lag, those which were most similar to the aspirated stops in this study, were more strongly articulated than other ejectives. They had a distinct burst followed by a period of relative silence. It seems unlikely that strengthened ejectives of this type would undergo deglottalization. Also, even if perceptually the primary cue distinguishing the two manners is the presence of aspiration, it seems unlikely that there is enough noise in nature to consistently mask a cue of such long duration. The prosodic position in which these two manners are most similar, IP initial, is the least common in normal speech. Thus, a change from ejectives to voiceless aspirated stops seems unlikely. If these two manners are as confusable as ejectives and voiced stops, it is unclear what this would mean to the validity of the Glottalic Theory.

Appendices

A Measured Means

A.1 Closure Duration

		Mean (ms)	St. Dev.
Stop Manner	Aspirated	65.3	14.4
	Ejective	64.2	11.2
	Voiced	65.3	27.9
Speaking Style	Carrier Phrase	69.4	20.0
	Story	60.5	17.2
Prosodic Position	aP Initial	72.2	6.4
	Word Medial	57.7	4.1
Place of Articulation	Bilabial	75.4	6.9
	Alveolar	62.0	6.2
	Velar	57.5	4.2

A.2 Voicing Into the Closure

		Mean (%)	St. Dev.
Stop Manner	Aspirated	17.4	9.1
	Ejective	26.7	10.9
	Voiced	75.8	22.0
Speaking Style	Carrier Phrase	34.9	28.7
	Story	45.0	30.0
Prosodic Position	aP Initial	39.1	27.2
	Word Medial	40.9	32.2
Place of Articulation	Bilabial	41.6	32.1
	Alveolar	40.4	30.4
	Velar	37.9	26.9

Interaction: Speaking Style and Prosodic Position

		Mean (%)	St. Dev.
aP Initial	Carrier Phrase	36.3	13.0
	Story	42.1	7.5
Word Medial	Carrier Phrase	33.8	10.7
	Story	47.9	5.3

A.3 Voicing Lag

		Mean (ms)	St. Dev.
Stop Manner	Aspirated	59.7	19.0
	Ejective	33.7	19.0
	Voiced	12.3	8.9
Speaking Style	Carrier Phrase	37.9	27.2
	Story	32.5	23.1
Prosodic Position	IP Initial	42.3	10.2
	aP Initial	37.5	10.7
	Word Medial	25.8	4.7
Place of Articulation	Bilabial	27.7	24.3
	Alveolar	35.2	26.2
	Velar	42.7	23.5

Interaction: Prosodic Position and Stop Manner

		Mean (ms)	St. Dev.
IP Initial	Aspirated	64.1	14.9
	Ejective	46.1	13.8
	Voiced	16.8	5.6
aP Initial	Aspirated	69.1	16.3
	Ejective	32.0	15.0
	Voiced	11.5	5.6
Word Medial	Aspirated	45.8	5.9
	Ejective	22.9	5.3
	Voiced	8.6	4.9

A.4 Relative Burst Intensity

		Mean (dB)	St. Dev.
Stop Manner	Aspirated	10.1	4.0
	Ejective	10.4	3.3
	Voiced	8.5	2.9
Speaking Style	Carrier Phrase	9.0	3.5
	Story	10.3	3.4
Prosodic Position	IP Initial	11.2	3.4
	aP Initial	9.4	3.3
	Word Medial	8.3	3.1
Place of Articulation	Bilabial	9.6	3.8
	Alveolar	10.2	3.0
	Velar	9.1	3.6

A.5 Relative Gap Intensity

		Mean (dB)	St. Dev.
Stop Manner	Aspirated	12.2	2.2
	Ejective	12.1	2.9
	Voiced	7.6	0.8
Speaking Style	Carrier Phrase	10.7	1.5
	Story	10.7	1.5
Prosodic Position	IP Initial	12.8	1.4
	aP Initial	10.6	2.1
	Word Medial	8.6	1.3
Place of Articulation	Bilabial	10.0	1.7
	Alveolar	10.3	1.9
	Velar	11.8	1.5

A.6 Spectral Moments

A.6.1 Mean

		Mean (Hz)	St. Dev.
Stop Manner	Aspirated	4300	750
	Ejective	4090	860
	Voiced	3480	710
Speaking Style	Carrier Phrase	3830	1340
	Story	4080	1420
Prosodic Position	IP Initial	4100	1240
	aP Initial	3910	1360
	Word Medial	3860	1530
Place of Articulation	Bilabial	3780	1100
	Alveolar	5000	660
	Velar	3090	640

A.6.2 Standard Deviation

		Mean (Hz)	St. Dev.
Stop Manner	Aspirated	3320	790
	Ejective	3170	640
	Voiced	3180	730
Speaking Style	Carrier Phrase	3090	830
	Story	3350	1030
Prosodic Position	IP Initial	3220	830
	aP Initial	3220	980
	Word Medial	3220	1010
Place of Articulation	Bilabial	3650	60
	Alveolar	3230	60
	Velar	2780	50

A.6.3 Skew

		Mean	St. Dev.
Stop Manner	Aspirated	1.63	0.30
	Ejective	1.77	0.40
	Voiced	2.16	0.63
Speaking Style	Carrier Phrase	1.91	1.04
	Story	1.80	1.00
Prosodic Position	IP Initial	1.61	0.81
	aP Initial	1.87	0.97
	Word Medial	2.09	1.20
Place of Articulation	Bilabial	2.09	1.44
	Alveolar	0.97	0.99
	Velar	2.50	1.58

A.6.4 Kurtosis

		Mean	St. Dev.
Stop Manner	Aspirated	4.63	1.78
	Ejective	5.67	2.73
	Voiced	8.09	4.08
Speaking Style	Carrier Phrase	6.43	6.81
	Story	5.83	6.29
Prosodic Position	IP Initial	4.44	4.17
	aP Initial	6.16	5.95
	Word Medial	7.79	8.42
Place of Articulation	Bilabial	7.29	2.70
	Alveolar	2.08	1.44
	Velar	9.02	3.00

A.7 Phonation

		Mean (dB)	St. Dev.
Stop Manner	Aspirated	4.89	2.39
	Ejective	-0.58	2.17
	Voiced	3.00	2.16
Prosodic Position	IP Initial	3.51	1.96
	aP Initial	2.34	1.37
	Word Medial	1.46	1.82
Place of Articulation	Bilabial	1.75	1.43
	Alveolar	3.04	1.56
	Velar	2.52	1.77

A.8 Δf0

		Mean (Hz)	St. Dev.
Stop Manner	Aspirated	5.8	4.8
	Ejective	-1.2	3.2
	Voiced	3.8	3.4
Prosodic Position	IP Initial	1.7	8.0
	aP Initial	5.0	1.1
	Word Medial	2.3	1.1
Place of Articulation	Bilabial	3.3	5.0
	Alveolar	2.2	1.8
	Velar	3.4	3.5

B Recorded Materials

B.1 Carrier Phrase Wordlist

B.1.1 IP Initial Words

baghi
balakhi
bali
bat'oni
bavshvi
dabali
dak'arguli
damnashave
daraji
datvi
gakhdili
gamousts'orebeli
gantiadi
garegnoba
gargari
kalaki
kalghmerti
kandak'eba
k'ape
k'arada
k'araki
k'argi
kari
k'art'oplili
katami
paipuri
panjara
papa
p'ap'anakeba
p'arask'evi
parda
p'arik'mekheri
paruli
p'at'ara
p'at'ivsatsemi
t'abak'a
t'adzari
taghliti
tagvi
t'akhi
t'anadi
tapli
t'arkhuna
taro
tavadi

B.1.2 aP Initial and Word Medial Words

abazana
adamiani
agarak'i
baghi
balakhi
bali
bat'oni
bavshvi
dabali
dak'arguli
dapa
dap'at'imreba
dap'at'izhebuli
datvi
gadasakhadi
gakhdili
gamousts'orebeli
gantiadi
garegnoba
gargali
k'aba
kadagi
kadami
k'ak'ali
k'ak'ani
kandak'eba
k'ape
k'arada
kari
k'art'opili
k'at'a
laka
lap'arak'i
mada
magari
natargmni
paipuri
panjara
papa
p'ap'anakeba
parda
p'arik'makheri
paruli
p'at'ara
p'at'ardzali
p'at'avsatsemi
sagalobeli
sagani
sagareo
sak'ani
sakartvelo
sapasuri
sat'akht'o
satauri
shabati
shakari
sts'rapad
t'abak'a
t'adzari
taghliti
tagvi
t'akhi
t'anadi
t'apa
tapli
t'arkhuna
taro
tavadi
vada
zghap'ari

B.2 Stories

B.2.1 Story 1

es zghap'aria. iq'o da ara iq'o ra, iq'o erti mokandak'e romelits sakartvelos mokalake iq'o. igi ulamazes kandak'ebebs kmnida. mokandak'es hq'avda amkhanegi, romelits damajerebeli taghliti iq'o. znedatsemulma taghlitma tavi mokadaged gaasagha da gadats'q'vit'a tavads sts'veoda. t'adzarshi shesvlistanave igi tavads shemdegi sit'q'vebit daimukra: "tu shen ar aghiareb shen parul pant'aziebs karis kalghmertis ts'inashe, kveq'anas dzlieri karishkhali daat'q'deba, zghvebi akapdeba da kalaki saprtkheshi chavardeba"-o. tavadi daetankhma, radganats igi daarts'muna mokadagis damajerebelma sit'q'vebma. damnashavem utkhra tavads rom sat'akhto kalakis gamzirit gareubanshi, nak'adultan mdebare agark'ze misuliq'o. p'arask'evs tavadi gaemgzavra agark'ze. p'at'ara kandak'eba ip'ova. t'anshishveli kandak'eba dzalian lamazi iq'o. damnashave da mokandak'e imis uk'an imalebobdnen da tavads utvaltvalebdnen. tavadma gaando karis kalghmerts tavisi otsnebi rom mas surda ubralo p'arik'makheri q'opiliq'o da ara gamochenili mepe. gamousts'orebelma taghlitma kalghmertivit khmit am sit'q'vebit up'asukha:"momit'ane khutasi katami, khutasi t'akhi da mravali gandzeuli. am p'irobis shesrulebis shemdeg gadzlev uplebas rom p'arik'makheri gakhde." gantiadze tavadma kalghmerts mout'ana is sagnebi rats man moitkhova. damnashave da mokandak'e gamdidrdnen. tavadi k'i saq'vareli da p'at'ivsatsemi p'arik'makheri gakhda.

B.2.2 Story 2

ts'amoidginet rom sach'meli adamians hgavdes. t'adzarshi sach'meli k'vebis shesakheb sheists'avlida. k'arg sach'mels umsats shech'amdnen. p'ap'anakeba sitskhit tsud sach'mels dasjidnen. tapli korts'ildebodes da shakari misi p'at'ardzali gakhdeboda. o, ra taplobistve ikneboda! gargali q'velaze ch'k'viani bavshvi ikneboda sk'olashi. misi tanak'laseli papa mteli dghe panjarashi gaimzireboda da iotsnebebda rom gemrieli q'opiliq'o. papa meotsnebe ikneboda. k'apeshi q'ava daraji ichdeboda imit'om rom mas arasdros ar sdzinavs. t'anadi k'art'opili k'arakshi itsuravebda. mdidari bat'k'ani pasdaudebel paipuris sinze dabrdzandeboda. p'at'ara dak'arguli up'at'rono bali q'ovel shabats tavisi baghis dzebnashi ikneboda. bali dzalian mart'okhela ikneboda. katami k'anonmdebeli gakhdeboda. tu k'arg k'anons gamoushvebda, igi q'velas eq'vareboda. tu gadasakhads gazrdida, mas t'abak'ad gadaaktsevdnen. karapshut'a p'avidlo msakhiobi gakhdeboda. k'ak'ali t'ak'imaskhara gakhdeboda. dabali t'arkhuna t'anmaghali arasdros gaizrdeboda, imit'om rom t'arkhuna tsot'ats sak'marisia. O, ekhla k'i madaze movedi.

B.2.3 Story 3

bat'oni k'akhas agarark'i ulamazoa. pardagi mts'vanea. pardebi iasamnisperia. taroebi k'alisganaa gak'etebuli. kandak'ebebi utavoa. k'alatebi nagvitaa savse. k'arada k'epalis peria. panjrebi mrgvalia. k'arebits aseve. balakhi gamkhmaria. baghshi up'at'rono k'at'a tagvs misdevs. bat'on k'akhas sisuptave ar uq'vars. aravin ighebs dap'at'izhebas agarak'ze bat'on k'akhasgan radganats agarak'i aseti ushnoa. garegnova sakhe mnishvnelovania.

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