Phonetic Evidence for Fortis-lenis Contrast in Kufo Pulmonic Plosives

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Abstract

The Kufo language of Sudan has pulmonic and non-pulmonic consonants. Within the pulmonic consonants, it has until recently been unclear how many plosive series are contrastive. Early studies suggest that there is a voicing contrast, and perhaps a length contrast as well, but more recent work proposes the possibility of a fortis-lenis type contrast which involves both voicing and length. This paper examines the phonetic evidence for the proposed contrast, based on data collected with one speaker. Results for Voice Onset Time and closure duration support the analysis of two pulmonic plosive series in Kufo, and align with an interpretation of fortis vs. lenis as the basis of the contrast.

Index Terms: Kufo, plosives, fortis-lenis, manner of articulation, closure duration, Voice Onset Time

1. Introduction

Kufo[1] is a variety of the Kanga language, which is traditionally spoken in the Nuba Mountains in South Kordofan, Sudan. Kanga is classified as part of the Kadugli-Krongo language family, and with approximately 8,000 speakers, it is viewed as severely endangered [1][2]. All of the Kadugli-Krongo languages are understudied, and for Kufo, previous work is largely limited to phonological observations in the context of comparative discussions. The current study is part of a wider documentation project involving the only diasporic Kufo speaker residing in Australia, and examines the phonetic evidence for a proposed fortis-lenis contrast in Kufo pulmonic plosives.

1.1. Kufo and Kadugli-Krongo pulmonic plosives

Early work on Kufo and closely related varieties points to plosive contrasts at five supralaryngeal places of articulation, including non-pulmonic plosives /ɓ, ɗ/, and at least one pulmonic plosive series. In [3][4], contrastive voiced and voiceless pulmonic plosives are proposed, and 'most consonants' reportedly also occur as geminates. Other work instead proposes a single pulmonic plosive series, with no voicing contrast, and phonetic voicing in intervocalic contexts [5][6]. [5] also notes that all plosives can occur as geminates, but does not analyse these as contrastive, and they are not mentioned in [6]. Across the Kadu language family, it is also unclear what the typological and historical patterns of plosives contrasts are [5].

More recent work proposes that the Kufo pulmonic plosives exhibit a 'fortis' vs. 'lenis' type contrast [7]. The proposed Kufo plosive inventory (Table 1) has supralaryngeal pulmonic plosives including four lenis-fortis pairs at bilabial /p, pː/, dental /t, tː/, retroflex /ʈ, ʈː/, and velar /k, kː/ places of articulation, plus the lenis palatal plosive /c/ which does not have a fortis counterpart. This proposal is based on phonological evidence that while short voiced and voiceless plosive phones both occur, they do not occur in the same environments, and correspond to a single plosive series. Based on auditory impressions, these 'lenis' plosives are realised as voiceless in word-initial position and voiced in word-medial position. The allophonic variation is evident in the process of pluralisation [7]. For example, the lexical item 'stick' is /tɔlɔ/ [tɔlɔ] in its singular form, where the lenis plosive is phonetically voiceless in initial position, but with the addition of the plural prefix /na-/, the stem-initial plosive is word-medial and phonetically voiced, as in /natɔlɔ/ [nadɔlɔ]. In comparison, the fortis plosives only occur in word-medial position, and are always voiceless, and impressionistically longer than the lenis plosives. There is clear evidence for contrast between the fortis and lenis plosives, e.g., /mutu/ [mudu] 'wine waste' and /mutːu/ [mutːu] 'horse'. However, the phonetic cues to the proposed fortis-lenis contrast among Kufo pulmonic plosives have not yet been examined phonetically.

Table 1: *Proposed Kufo plosive inventory [7].*

	bil.	den.	ret.	pal.	vel.	glo.
lenis	/p/	/t/	/ʈ/	/c/	/k/	/ʔ/
fortis	/pː/	/tː/	/ʈː/		/kː/	
implosive	/ɓ/	/ɗ/				

1.2. Fortis-lenis contrasts in other languages

The terms 'fortis-lenis' were adopted in [7] because the perceived nature of the contrast in pulmonic plosives aligns with contrasts described similarly in other languages (e.g.[10]), noting, however, that the difference between 'fortis-lenis' (also 'tense-lax') vs. 'geminate-singleton' is not clear cut. Fortis-lenis contrasts are generally described as relating to consonantal strength, involving differences in respiratory and articulatory energy and with a range of language-specific acoustic correlates [8]. For example, in Korean, fortis, lenis, and aspirated plosives are distinguished by acoustic and aerodynamic parameters including Voice Onset Time (VOT), fundamental frequency (f0), intraoral air pressure and air flow [9]. In varieties of Germanic languages such as English and German, a primary correlate of fortis-lenis contrasts is VOT, with long-lag VOT for fortis plosives and short-lag VOT for lenis. Reported secondary correlates include closure duration, f0, burst intensity and often voicing intervocalically (e.g. [24]).

In other languages, the primary acoustic correlate of contrasts described as fortis-lenis is duration, which, being the primary correlate for geminate-singleton contrasts, presents challenges in determining the most appropriate phonological descriptors [11] [22]. In Swiss German, fortis plosives have longer closure durations than lenis plosives, and the two series do not differ in VOT [21]. In Bininj Gun-wok, one of many Australian languages described as having a fortis-lenis contrast, fortis plosives are around twice as long as lenis plosives, and also have

[1]ISO 639-3: kcp, Glottolog: kang1288

higher intro-oral pressure, distinguishing them from morphological geminates [12]. Both lenis and fortis plosives in Bininj Gun-wok have short-lag VOT, and word-medial lenis plosives are often realised as fricatives or approximants. A number of Oto-Manguean languages are also described as having fortis-lenis contrasts drawing on duration. In Itunyoso Trique, fortis obstruents have longer closures than lenis obstruents, and also exhibit preaspiration [13]. Lenis obstruents also show variable voicing and spirantization, which [13] argues can be explained by their reduced durations, suggesting that the consonant contrast may be best considered one of length rather than strength. Arguments in the opposite direction can also be found; for example, the length contrast attested for Somali voiced plosives is primarily realised as a manner contrast, with short voiced plosives largely produced as approximants [23]. It is clear that understanding the phonetic and phonological typology of strength and length contrasts requires more detailed studies of diverse languages.

2. Research aim

This study aims to examine the phonetic evidence for the proposed fortis-lenis contrast in Kufo pulmonic plosives. The following questions will be addressed: What are the phonetic realisations of the two pulmonic plosive series in Kufo, in different word positions? Do the acoustic cues to the contrasts support an interpretation of fortis vs. lenis as the basis of the contrast?

3. Method

3.1. Participant

The speech data for this study was collected with Haroun Kafi, the only Kufo speaker residing in Australia. Haroun was born in the 1960s, grew up in Sudan, and currently resides in rural Victoria. Besides Kufo, Haroun also speaks Sudanese Arabic and English.

3.2. Materials and procedures

A wordlist of 54 disyllabic words was developed based on lexical data and phonological analyses in recent work [7]. Table 2 presents some of the lexical items included in the wordlist, based on phoneme and word position. The words in the wordlist predominantly have a CV.CV structure and short vowels only, to the extent which current data allows.

Table 2: *Example words included in the wordlist.*

lenis	INI	translation	MED	translation
/p/	/paʔja/	'all'	-	-
/t/	/tafa/	'have'	/mutu/	'wine waste'
/ʈ/	/ʈiko/	'dam'	/taʈe/	'cut'
/c/	/coːno/	'dig'	/teca/	'wake'
/k/	/kaʈɛ/	'wings'	/kika/	'where'
fortis	INI	translation	MED	translation
/pː/	-	-	/napːa/	'fathers'
/tː/	-	-	/mutːu/	'horse'
/ʈː/	-	-	/ʈaʈːo/	'woodpecker'
/kː/	-	-	/tukːu/	'write'

Data collection was conducted in a quiet room at the speaker's home. Audio was recorded with a Zoom H6 audio recorder and a Røde NT3 cardioid microphone, at an archival sampling rate of 96kHz and 24-bit depth. Lexical items in the wordlist were elicited with English verbal prompts in a random order. Each word was produced 5 times consecutively within the utterance-medial frame *aʔa nɪkːi ... ɓɪtɛnɪ* 'I say ... today'.

3.3. Data processing and analysis

The sound files were downsampled to 44.1kHz and 16-bit depth for acoustic analysis, and segmented and annotated in Praat [14]. VOT and closure duration are the primary measures of interest in this study, depending on segment position and phonetic realisation. For word-initial and word-medial plosives, VOT was segmented based on the onset of the release burst and the onset of periodicity for the following vowel (see Figure 1). Closure duration for plosives in word-medial position was segmented based on the last glottal pulse of the preceding vowel and the onset of the release burst of the target plosive. For plosives in word-initial position, closure duration was not annotated, as the speaker typically produced a short pause before the target word and the onset of the closure for the phonetically voiceless plosives in this word position could not be reliably segmented. Intervocalic plosives were sometimes phonetically realised as approximants. As such, VOT and closure duration are not reported for these cases.

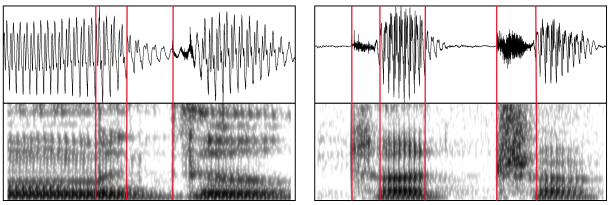

Figure 1: */mutu/ 'wine waste' & /ʈoʈː/ 'woodpecker'.*

Based on the .wav files and paired .TextGrids, a hierarchical speech database was created using the EMU Speech Database Management System [15]. In total, the database consists of 377 consonant tokens, including 219 phonemic lenis plosives in word-initial position, 88 phonemic lenis plosives in word-medial position, and 70 phonemic fortis plosives in word-medial position. A summary of the number of tokens in this dataset is presented below in Table 3. For the relevant consonants realised phonetically as plosives, measures of VOT and closure duration were extracted and analysed with R [16], using the emuR package [17]. The lenis bilabial plosive /p/ has an extremely low functional load and occurs in one lexical item in initial position only based on available data.

Table 3: *Number of tokens, by phoneme and word position.*

lenis	INI	MED	total	fortis	MED
/p/	5	-	5	/pː/	10
/t/	117	21	138	/tː/	15
/ʈ/	26	20	46	/ʈː/	15
/c/	15	16	31		
/k/	56	31	87	/kː/	30
total	219	88	307		70

4. Results

4.1. Phonetic realisation

A summary of the realisations of all consonant tokens in this dataset is given in Table 4. Phonetic catgorisations are based on

auditory impressions with reference to waveforms and corresponding spectrograms. Lenis plosives in word-initial position are mostly realised as phonetically voiceless plosives (95% of the time), though 47% of tokens of the lenis palatal plosive /c/ and 5% of tokens of the lenis velar plosive /k/ are realised as approximants. Lenis plosives in word-medial position are always phonetically voiced, and realised more often as approximants [ɪ, j, ɰ] (63%) than plosives [d, ɟ, g] (37%). Phonemic plosives are more likely to be realised as approximants as the place of articulation goes back, except the retroflex plosive /ʈ/, which is predominantly realised as the voiced plosive [ɖ] (95%). Fortis plosives in word-medial position are always realised as phonetically voiceless plosives, and never as approximants.

Table 4: *Phonetic realisation of lenis and fortis plosives in word-initial and -medial position.*

lenis	INI		MED		fortis	MED	
	plo.	appr.	plo.	appr.		plo.	appr.
/p/	5	0	-	-	/pː/	10	0
/t/	117	0	9	12	/tː/	15	0
/ʈ/	26	0	19	1	/ʈː/	15	0
/c/	8	7	4	12			
/k/	52	3	1	30	/kː/	30	0
total	208	10	33	55		70	0

The distributions in Table 4 show that the lenis plosives are more variable in terms of voicing and manner of articulation, with more (voiced) approximant than (voiceless) plosive phonetic realisations word-medially, while the fortis plosives, which only occur word-medially, do not show the same variation. The next section presents durational measures for the plosive phonemes that are phonetically realised as plosives.

4.2. Durational measures

4.2.1. Closure duration

Closure duration measures for lenis and fortis plosive phonemes realised as phonetic plosives in word-medial position are shown in Table 5 and Figure 2. On average, fortis plosives have a closure duration of 117ms, approximately 1.9 times the average duration of lenis plosives, 62ms. Based on a linear mixed-effects model with closure duration as the dependent variable, fortis/lenis as the independent variable, and word and place of articulation as random effects, the difference in closure duration between fortis and lenis phonetic plosives in word medial position is statistically significant ($p<0.001$***).

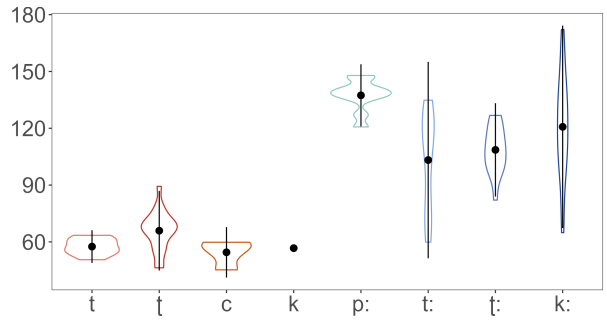

Figure 2: *Closure duration (ms) of lenis and fortis plosive phonemes in word-medial position, when phonetically realised as plosives.*

Table 5: *Closure duration (ms) of lenis and fortis plosive phonemes in word-medial position, when phonetically realised as plosives.*

lenis	phone	mean	sd	fortis	phone	mean	sd
				/pː/	[pː]	137	8
/t/	[d]	58	4	/tː/	[tː]	103	26
/ʈ/	[ɖ]	66	11	/ʈː/	[ʈː]	109	12
/c/	[ɟ]	54	7				
/k/	[g]	57	NA	/kː/	[kː]	121	27
total		62	10			117	24

4.2.2. Voice Onset Time

As seen in Table 4, when lenis plosives in word-initial position are not realised as approximants, they are realised as voiceless plosives [p, t, ʈ, c, k], with positive VOT as shown in Table 6 and Figure 3. The average VOT across different places of articulation is 40ms, which aligns with tendencies for languages in which plosives are described as unaspirated or weakly aspirated, with short-lag positive VOT (e.g. [19], [20]). For lenis plosive phonemes in word-initial position that are phonetically realised as plosives, there is a tendency for VOT to get longer as the place of articulation goes back, apart from for the retroflex, which has the longest VOT, but VOT differences by place are not statistically significant according to a linear mixed-effects model with VOT as the dependent variable, place as the independent variable, and word as a random effect.

Table 6: *VOT (ms) of lenis plosive phonemes in word-initial position, when phonetically realised as plosives.*

lenis	phone	mean	sd
/p/	[p]	30	8
/t/	[t]	37	10
/ʈ/	[ʈ]	52	26
/c/	[c]	34	31
/k/	[k]	46	14
total		40	16

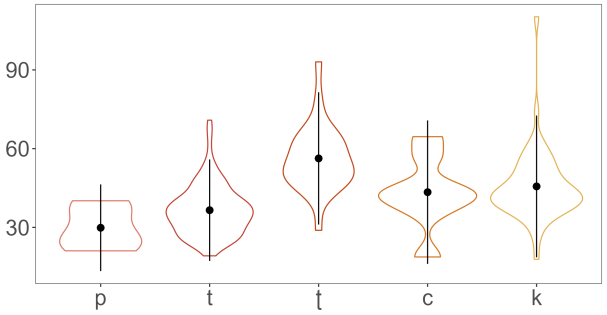

Figure 3: *VOT (ms) of lenis plosive phonemes in word-initial position, when phonetically realised as plosives.*

Table 4 showed that in word-medial position, lenis plosive phonemes are always voiced when phonetically realised as plosives, and this is evidenced by negative VOT values in Table 7 and Figure 4. (Note that only one /k/ token in word-medial position is realised as a plosive [g].) Given that they are fully voiced, the VOT of medial lenis plosives is the same as their closure duration. The average negative VOT of -62ms is dif-

ferent to the positive VOT for lenis plosives in word-initial position. For fortis plosive phonemes, which are always realised as phonetically voiceless plosives [pː, tː, ʈː, kː], positive VOT values are shown in Table 7 and Figure 4. The average VOT across different places of articulation is 50ms, slightly longer than for word-inital lenis plosives. VOT for fortis plosives in word-medial position shows a similar pattern to the lenis plosives in word-initial position, with a tendency for VOT to get longer as the place of articulation goes back, apart from for the retroflex, which has the longest VOT. Based on a linear mixed-effects model with VOT as the dependent variable, fortis/lenis as the independent variable, and word and place of articulation as random effects, the difference in VOT for fortis compared to lenis phonemes realised as plosives in word medial position is statistically significant ($p<0.001$***).

Table 7: *VOT (ms) of lenis and fortis plosive phonemes in word-medial position, when phonetically realised as plosives.*

lenis	phone	mean	sd	fortis	phone	mean	sd
				/pː/	[pː]	29	7
/t/	[d]	-58	4	/tː/	[tː]	44	11
/ʈ/	[ɖ]	-66	11	/ʈː/	[ʈː]	71	5
/c/	[ɟ]	-54	7				
/k/	[g]	-57	NA	/kː/	[kː]	51	10
total		-62	10			50	16

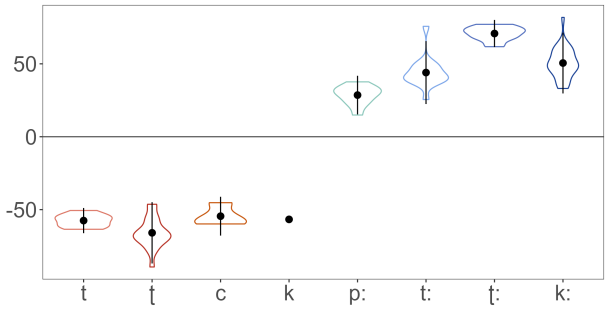

Figure 4: *VOT (ms) of lenis and fortis plosive phonemes in word-medial position, when phonetically realised as plosives.*

5. Discussion and conclusion

This study addressed two research questions. The first related to the phonetic realisation of Kufo pulmonic plosives, following recent proposals that Kufo has two contrastive pulmonic plosive series viewed as 'fortis' and 'lenis' [7]. Phonetic results provide supporting evidence for the phonological analysis of two plosive series, rather than three (voiced, voiceless, voiceless geminate [3][4]) or one (voiceless [6]), with different phonetic realisations depending on phonological environment. The differences in phonetic realisations involve voicing, duration, and manner of articulation. Fortis plosive phonemes, which only occur word-medially, are always realised as voiceless plosives, and never as approximants. Lenis plosive phonemes in word-initial position are mostly realised as voiceless plosives and occasionally approximants. Lenis plosive phonemes in word-medial position are always voiced, and are more likely to be realised as approximants than plosives, except the retroflex /ɽ/, which is almost always phonetically realised as a plosive. Compared to the fortis plosive phonemes, the lenis plosive phonemes in Kufo are more variable regarding their phonetic realisations.

The acoustic correlates investigated in this study include closure duration and VOT. In word-medial position, closure duration for fortis plosives is significantly longer than for lenis plosives, with fortis plosives on average 1.9 times longer. For VOT, lenis plosives in word-initial position have positive (short-lag) VOT, whereas lenis plosives in word-medial position have negative VOT. The fortis plosives, which occur in word-medial position only, have positive VOT (also short-lag). The VOT difference between fortis and lenis plosives in word-medial position is significantly different. For both lenis plosives in word-initial position and fortis plosives in word-medial position, there is a non-significant tendency for VOT to increase as the place of articulation goes back, in line with crosslinguistic tendencies [18], but the retroflexes /ʈ, ʈː/ always have the longest VOT across all places of articulation. As can be seen in the spectrograms in Figure 1, the magnitude of the positive VOT for retroflexes could be interpreted as affrication. Auditory impressions are that there is limited evidence for a subapical articulation for the retroflexes, but instead more of an apico-postalveolar articulation.

Taken together, these results indicate that an interpretation of the contrast between the Kufo plosives as 'fortis' vs. 'lenis', as proposed in [7], is reasonable. The nature of the contrast is similar to contrasts described as fortis-lenis in various Australian and Oto-Manguean languages, in that duration is a major but not the only correlate, and medial lenis plosives are prone to voicing and incomplete closures in medial environments [12][13], which in Kufo results in frequent approximant realisations. However, the acoustic phonetic results also highlight the complexities regarding conceptualisations of 'fortis-lenis' vs. 'geminate-singleton' contrasts, given the importance of duration as a cue in both cases, as well as various secondary cues. A crucial next step would be perceptual studies investigating which cues Kufo speakers are attending to, and whether duration is the most important. Articulatory studies of different sorts are also needed, in order to better understand the production differences between the two plosive series, as well as more comprehensive acoustic analyses, for example including intensity, f0, and burst amplitude. Future acoustic, articulatory and perceptual work on the sounds of Kufo would also ideally involve multiple speakers.

Although based on data collected with a single speaker, this study of Kufo plosives adds to our understanding of fortis-lenis contrasts in the world's languages. The acoustic evidence of the fortis-lenis contrast in Kufo pulmonic plosives shows that length and/or voicing contrasts established based on auditory impressions only may not always be accurate, and reinforces that contrasts between consonant series may involve multiple phonetic correlates rather than just one. The variation in voicing exhibited by Kufo lenis plosives explains why some early work suggests two pulmonic plosive series with a voicing contrast [3][4], whereas others suggest phonetic voicing conditioned by environment [5][6]. The clear role of duration as an important acoustic correlate distinguishing the fortis and lenis plosives in Kufo explains why some previous proposals include geminates [3][4]. This study highlights the need for more studies on consonant strength and length in African languages in order to add to our understanding of phonetic typology across the world's languages.

6. Acknowledgements

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