

Articulatory variability of intervocalic stop articulation in Bininj Gun-Wok

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Abstract

The phonetic correlates of intervocalic stop articulations were investigated in a northern Australian Language, Bininj Gun-Wok. Closure duration, VOT, and intra-oral pressure were measured. Results indicate that although the contrast is chiefly cued by duration differences, there are clear differences in intra-oral pressure, suggesting a more complex contrast than one based on duration alone.

1. Introduction

Australian languages generally have a single phonological stop series that does not contrast for voicing or length. This is considered typologically unusual when compared with other languages of the world. There are a small number of Australian languages however, that have a phonological contrast in the oral stop series, which is seemingly based on either duration or voicing. One such language is Bininj Gun-Wok, a dialect chain, spoken in Western Arnhem Land (Baker, 1999, Evans, 2003, Butcher, 2004).

2. Previous studies

The phonological labels *lenis* and *fortis* have been traditionally used to describe the contrasting short and long oral stops found in these few Australian languages (see Heath, 1978, Jaeger, 1983, Merlan, 1983). The *lenis/fortis* categorization is not particularly productive, however, as phonetic correlates of the contrast have not yet been clearly identified or defined. Ladefoged and Maddieson, (1996) suggest that *fortis* is either an indicator of increased respiratory energy, or that *fortis* is an indicator of greater articulatory energy, relative to its *lenis* counterpart. They maintain that the use of increased respiratory energy is rare, occurring, for example in Korean stiff voice – where a heightened sub-glottal pressure accompanies the more constricted glottis and tenser walls of the vocal tract.

Butcher (2004) has surveyed the literature regarding a phonetic description of the phonological feature $[\pm\text{fortis}]$ and proposes the following summary:

1. $[\pm\text{fortis}]$ is a comparatively rare feature – either airstream or articulatory – with a single underlying phonetic parameter of physical effort.
2. $[\pm\text{fortis}]$ is a laryngeal and an articulatory stricture feature with underlying parameters including peak glottal aperture and articulatory timing, but *separate from* voicing or aspiration.
3. $[\pm\text{fortis}]$ is a laryngeal and articulatory stricture feature with underlying parameters including peak glottal aperture, articulatory timing, and voicing and aspiration. Some of these may be independently variable in some languages (Butcher, 2004: 4).

	Peripheral		Apico-		Lamino Palatal	Glottal
	Bilab.	Velar	Alveolar	Retroflex		
<i>Lenis</i> Oral Stop	p	k	t	ʈ	c	ʔ
<i>Fortis</i> Oral Stop	pː	kː	tː	ʈː	cː	
Nasal Stop	m	ŋ	n	ɳ	ɲ	
Lateral			l	ɭ		
Rhotic			r	ɽ (ɻ)		
Glide	w				j	

Table 1 Bininj Gun-Wok: consonant phoneme inventory (modified from Evans (2003)).

The phonemic inventory of Bininj Gun-Wok (see Table 1. after Evans 2003) has paired oral and nasal stops at five places of articulation. The "*fortis*" oral stop and the glottal stop have a restricted distribution with the former only appearing in a word medial intervocalic position and the glottal stop in a syllable final position.

The most frequent phonological description of the distinction in Australian languages is as a length opposition which does not account for amount of effort expended. Evans (2003) in his description of Bininj Gun-Wok, cites Butcher (1990), who found duration to be the only reliable phonetic correlate of the contrast across a selection of languages from the Gunwinyguan, Maningrida and Yolngu groups.

Butcher (1996) conducted a number of instrumental studies in various Australian languages, including Kunwinjku (Bininj Gun-Wok) which show that the most consistent cue to the contrast is the duration of the articulatory stricture, rather than the voice onset time (VOT) (Butcher, 1992, 1996, 2004). However Butcher (1996) notes that in some languages related to Bininj Gun-Wok (for example, Burarra), the *fortis* (long) stop requires the glottis to be abducted simultaneously with closure of the supraglottal articulators, and then adduction of the glottis has to be co-incident with the release of the articulators at the end of the closure phase. By contrast, in English *fortis* sounds require peak glottal opening to coincide with the moment of articulatory release creating aspiration.

Intra-oral pressure in Burrara is higher in *fortis* consonants and lower for the related *lenis* stops (Butcher, 1992). There are various ways that an intra-oral pressure opposition may be realised across languages. Either a particular target pressure for each contrasting stop is aimed for, maintained by either varying pulmonic pressure or glottal area. Or, glottal area and pulmonic pressure are equivalent in each of the contrasting phonemes, and the differences in intra-oral pressure are due to differences in the closure duration (articulatory stricture). The *fortis* stop has longer to build up pressure than the *lenis* stop (due to the greater duration). However the pressure rises at twice the rate in *fortis* stops as it does in *lenis* stops regardless of stress position (Butcher 1992).

Butcher proposes two questions, which are as follows: '(1) Is the contrast in peak pressure controlled by lung volume decrement or by the degree of glottal aperture? (2) Is the gesture for the *lenis* sound a truncated or a re-scaled version of the gesture for the *fortis* sound?' (Butcher, 1992). Experimental work by Butcher has led to the application of the label *fortis* vs. *lenis* to the phonological contrast in Gunwinyguan and Burarran languages. On the basis of these conclusions we have provisionally used these terms to describe the phonological status of the stop series contrast in Bininj Gun-Wok.

Evans and Merlan (2004) have examined the stop contrast in the related language Jarwoyn, using an extensive survey of previously published literature and some limited reanalysis of previously gathered acoustic data. Duration of closure is said to be the main phonetic correlate, but no firm claims are made as to any aerodynamic or articulatory differences.

The aim of the current study is to investigate possible phonetic correlates of the phonological stop contrast in Bininj Gun-wok using both acoustic and articulatory phonetic techniques.

3. Methods

3.1. Speakers and materials

The data analyzed in this study were recorded during two field trips to Jabiru NT and Mamardawerre (July 2005, June and August 2006). Four speakers of Kunwinjku, a dialect of Bininj Gun-Wok, 2 female (HM and AB) and 2 male (BD and

JD), were recorded during the first field trip. The speakers produced three repetitions of a set of 56 words containing intervocalic long and short consonants matched for vowel environment and prosodic position where possible. Each word pair contrasting lenis and fortis was embedded in a carrier phrase:

- (1) **bobo** ngarri-yime.
'I say 'bobo'
- (2) Yun yime **bobo** yimen **djobbo**.
'don't say 'bobo' say 'djobbo'

The initial acoustic data consisted of tokens embedded in phrase (1) whereas the subsequent articulatory data consisted of tokens embedded within phrase the carrier phrase (2). Where possible, the words were prosodically controlled to be in a post-tonic (primary stressed) position, with an intonational pitch accent on the preceding vowel. Carrier phrase 2 allows a token to be measured in a stressed and unstressed position and compared if necessary. The measurements below only use the first embedded word of the pair in an effort to ensure a consistent placement of stress.

All acoustic recordings were recorded, using a Sony ECM-MS957 Electret Condenser microphone and recorded onto a Marantz PMD690 Portable Flash recorder, as uncompressed Broadcast WAV files at 48 kHz 16 bit (The highest setting the hardware would allow).

In the second field trip conducted by the first author both acoustic and articulatory recordings were made using a variety of techniques. Oral and nasal pressure and airflow was measured for a number of tokens recorded with an electroglottograph (EGG) channel which will not be examined in this paper. These data were recorded at Mamardawerre, an outstation of Kunbarlanja in Arnhem Land N.T. The articulatory recordings were made using Scicon airflow masks connected to a Dell Latitude D510 laptop running Windows XP and synchronized to an audio channel (11 kHz) with the *PCquirer* software (Scicon, 2003). The bilabial intra-oral pressure was measured using a 2mm diameter tube inserted just inside the speaker's lips. This then measures the changes in intra-oral pressure behind the lips by way of a transducer connected to computer. For the purposes of this paper results of a preliminary data analysis of the articulatory corpus will be presented. The intra-oral pressure and flow were measured for two words (a sub-minimal pair) containing intervocalic bilabial stops for three speakers

3.2. Acoustic analysis.

The files were labelled in Praat (Boersma and Weenink, 2006), and then the label files were converted into EMU (ESPS) format at the Phonetics Laboratory at The University of Melbourne. Formant tracking was done by EMU using the *Snack Pitch and Formant Tool* (Cassidy and Harrington, 2005) and hand corrected.

The files were labelled with 5 interval tiers: word, syllable, phonemic, phonetic, voicing tier and a vowel target point tier. The articulatory records were labelled and analysed in the computer program *PCquirerX* (Scicon, 2006).

The measures include: the entire closure duration of the stop until the release of the articulators (see 1 at Figure 1). Voice onset time (VOT) the portion from the release of the articulators to the onset of regular voicing was measured (2 at

Figure 1) along with Voice termination time (VTT), the period of time from the end of regular voicing and after the closure of the articulators (3 at Figure 1).

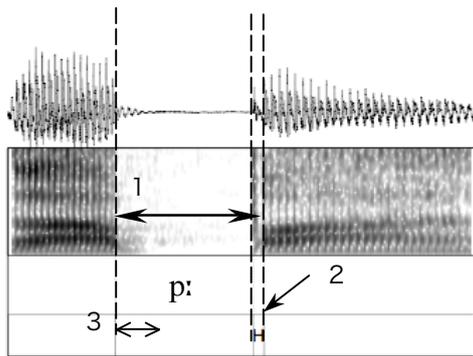


Figure 1. example of measurements

Statistical analysis was performed on all measured intervals using annotations within the EMU/R environment (R, 2006).

4. Results

4.1. Acoustic results

Figure 2 compares overall consonant closure duration for the two phonological classes of bilabial stops (here labelled short and long) for two speakers.

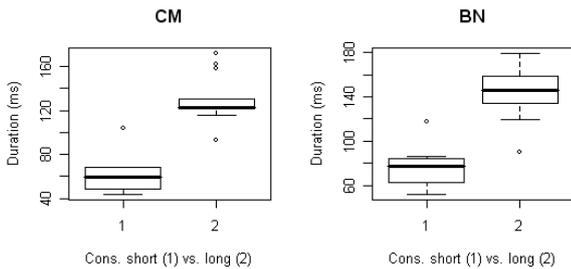


Figure 2. Consonant duration (bilabial) comparing *lenis*(short) and *fortis*(long) consonants for two speakers

Mean duration of short/*lenis* stops were between 45 and 69 ms and 130 and 160 ms for long/*fortis* stops. This difference was significant for both speakers and this is impressionistically the case for other speakers ($t=-18, df=287.8, p < 0.01$ for CM). Speaking rate was different for each speaker but was consistent within speaker. Previous analysis has show that these durational differences are the same for the other places of articulation

Figure 3 shows the data for speaker AB sorted by place of articulation. The duration difference is clearly evident at each place of articulation. Subsequent data gathered restricts the analysis to the bilabial place of articulation allowing for pressure recording. This is more difficult to obtain for the other places of articulation.

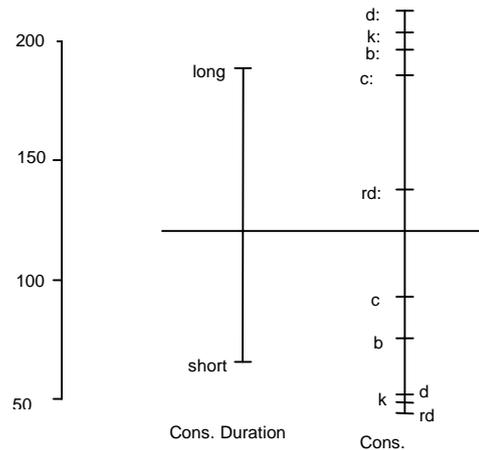


Figure 3. Consonant duration separated by place of articulation for speaker AB

The voice onset time (VOT) is another measure of a phonetic difference between two voiceless stops. There is a measurable difference between the VOT of the durationally short stops vs. the VOT of the long stops. The diagram in figure 4 shows the VOT as measured for one speaker (CM) separated by long or short durations (there is similar patterning for other speakers). This excludes all of the coincident VOT values which are very common for the *lenis* stops.

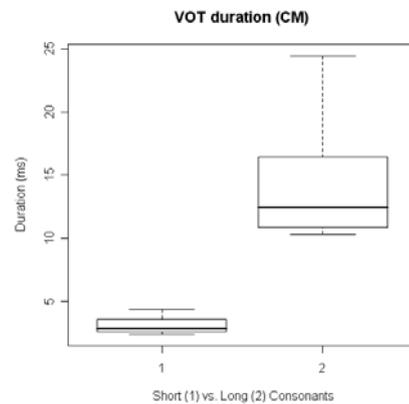


Figure 4. VOT for speaker CM (bilabial stops)

VOT was not a consistent indicator of phonetic difference between the *lenis* and *fortis* series, although there is an observable difference between the two stops. A high degree of variation was observed in the *lenis/fortis* realizations and was dependant on place of articulation. The bilabial place of articulation has a short or coincident VOT but articulations that involve the tongue as the primary articulator had longer voice onset times. The short/*lenis* stop can be either voiced or voiceless with negative, positive or coincident VOT. By contrast, the long/*fortis* stop is invariably voiceless with a positive VOT, and for this reason VOT is not a reliable indicator of whether a stop can be classed as *lenis* or *fortis*.

The measured VTT for *fortis/long* and *lenis/short* stops was not significantly different in this corpus. It, was usually

very short (less than 20 milliseconds) and was not a consistent correlate of the contrast. This will not be discussed further here, but may be of interest in future investigations when looking at the phonetic differences associated with fortis stops which span morpheme boundaries (eg. *bak-bak-ke* ‘break into bits’).

4.2. Articulatory results

Figures 5 and 6 show the intra-oral pressure records time-aligned to the audio signal from a male Kunwinjku speaker (CM) producing a bilabial lenis and fortis stop. These tokens were both in the first position of the carrier phrase to control for stress interference (“Yun yime *bobo* yimen djobbo”). The first relatively short stop (figure 5) has a peak oral pressure of approximately 1.1 cm H₂O, which is simultaneous with the point of stop release. Whereas the contrasting durationally fortis/long stop has a higher intra-oral pressure of 3.5 cm H₂O. The rate of flow in the durationally long stop is much greater than the short stop. These values are typical of other data in the corpus and will become the basis of a larger scale quantitative investigation.

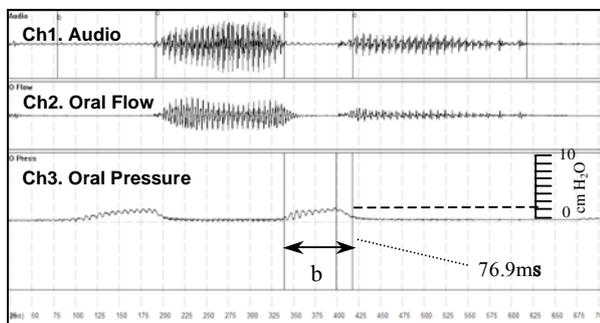


Figure 5. Duration (76.9ms) and peak intra-oral pressure (1.1 cm H₂O) for CM_B_R2_B11_bobo [bɔbɔ].

Figure 7. plots the intra-oral pressure of various bilabial stops at different positions within a word. The intervocalic bilabial voiceless long oral stop has a higher intra-oral pressure value than those stops that occur either at the periphery of the word or when compared to the voiced short intervocalic oral stop.

This pressure difference may be dependant on the longer duration enabling a higher peak pressure to be attained in the durationally long stop. This does not appear to be the case however because there is a much sharp rise in the intra-oral pressure in the durationally long/fortis stop which is not evident in the corresponding short stop. This greater pressure value is then maintained for until the release of the articulators. This sharp rise coupled with the maintenance duration may be evidence that there is greater respiratory effort needed for the long/fortis stop and potentially justifies the use of the phonological label. Systematic statistical analysis will be needed to test whether these findings are consistent across all Kunwinjku and by extension Bininj Gun-Wok speakers. Our initial qualitative data points to a regular pressure difference between the two classes articulations across all speakers recorded.

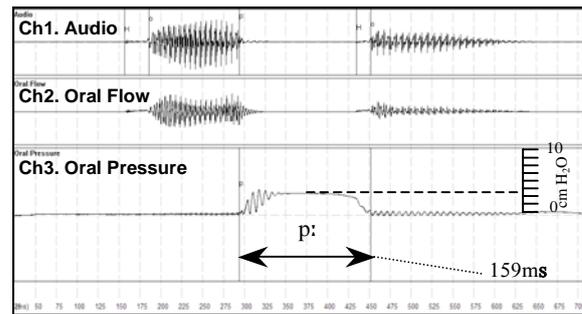


Figure 6. Duration (159.2 ms) and peak intra-oral pressure (3.5 cm H₂O) for CM_B_R2_B21_djobbo [ɔp:ɔ].

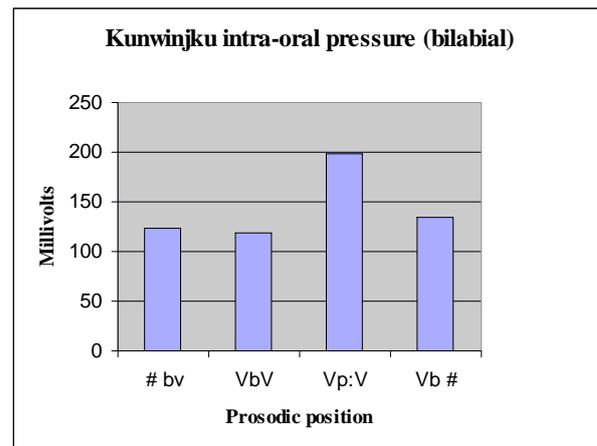


Figure 7. Mean Intra-oral pressure of bilabial segments in Kunwinjku for each position within a word.

5. Discussion

In Bininj Gun-Wok there are clear duration difference between *lenis* and *fortis* stops which correlates with previous finding in other Australian languages.

There are also articulatory differences which may be dependant or independent of timing. The different intra-oral pressure results show that the contrast in the stop series is realized in a variety of ways and is not based on duration alone. The *lenis* stop looks to be a rescaled version of a *fortis* stop but due to shorter durations, pressure targets cannot be achieved which in turn allows voicing to continue. Further quantitative investigation of the articulatory corpus will reveal whether this is in fact the case for all speakers.

Furthermore we are currently looking at the *lenis/fortis* contrast in relation to gemination. The *fortis* stops have a similar distribution to consonant clusters (e.g. /kb/) motivating a geminate phonological analysis that categorizes the long/fortis stop as a homorganic geminate cluster (e.g. /bb/) of two *lenis* segments. There is however, no evidence of long nasal segments, an argument against the geminate analysis. This is the subject of future investigation.

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Scicon (2006) *PCQuirerX.*, [computer program] Version 2.2.1
Los Angeles, California, retrieved 10 October 2006 from
<http://www.sciconrd.com>.

7. References

- Baker, B. J. (1999) Word Structure in Ngalakgan. PhD Thesis, Department of Linguistics, The University of Sydney
- Boersma, P. and D. Weenink (2006) *Praat: doing phonetics by computer*, [computer program] Version 4.4.07, Retrieved Feb. 2 from <http://www.praat.org>.
- Butcher, A. (1990) Phonetic correlates of contrasting stop series in Top End languages Australian National University Unpublished MS
- Butcher, A. (1992) Intraoral pressure as an independent parameter in oral stop contrasts Australian National University Unpublished MS
- Butcher, A. (1996) Phonetic correlates of contrasting stop-series in Non-Pama-Nyungan languages Course notes for the 3rd Australian Linguistic Institute. ANU Canberra.
- Butcher, A. (2004). 'Fortis/Lenis' revisited one more time: the aerodynamics of some oral stop contrasts in three continents. *Clinical Linguistics and Phonetics*, 18, 547-557.
- Cassidy, S. and J. Harrington (2005) *EMU Speech database.*, [computer program] Version 1.10.5sh Macquarie, Speech Hearing and Language Research Center, retrieved 5 June 2006 from: <http://sourceforge.net/projects/emu/>.
- Evans, B. and F. Merlan (2004). Stop Contrasts in Languages of Arnhem Land: From the perspective of Jawoyn, Southern Arnhem Land. *Australian Journal of Linguistics*, 24, 2, 185-224.
- Evans, N. (2003). *Bininj Gun-Wok: a pan-dialectal grammar of Mayali, Kunwinjku and Kune*. Canberra, Pacific Linguistics, Research School of Pacific and Asian Studies, Australian National University.
- Heath, J. (1978). *Ngandi Grammar, Texts and Dictionary*. Canberra, Australian Institute of Aboriginal Studies.
- Jaeger, J. J. (1983). The fortis/lenis question: evidence from Zapotec and Jawoñ. *Journal of Phonetics*, 11, 177-189.
- Ladefoged, P. and I. Maddieson (1996). *Sound of the World's Languages*. Oxford, Blackwell.
- Merlan, F. (1983). *Ngalakan grammar, texts and vocabulary*. Canberra, Pacific Linguistics.
- R (2006) *R: A Language and Environment for Statistical Computing.*, [computer program] Version 2.010 Vienna, Austria, R Foundation for Statistical Computing, retrieved 7 March 2006 from <http://cran.r-project.org/>.
- Scicon (2003) *PCQuirer.*, [computer program] Version 7.0 Los Angeles, California.