INTRAORAL PRESSURE AS AN INDEPENDENT PARAMETER IN ORAL STOP CONTRASTS

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ABSTRACT - An analysis of acoustic and aerodynamic data on contrasting stop series in a number of European and Australian languages confirms that a significant variation in peak intraoral pressure is one of the main factors differentiating many such series. A more detailed examination of the intraoral pressure data from the Australian languages suggests that glottal aperture is the main physiological parameter underlying this pressure variation, and there is no evidence to support the notion of a single independent phonetic correlate of the *fortis/lenis* distinction.

INTRODUCTION

The status of the phonological feature *fortis/lenis* continues to be a matter of some debate (see e.g. Malécot, 1970; Kohler, 1984). The central question is whether such a feature can be shown to have specific phonetic correlates which vary independently of other parameters such as voicing, aspiration, and duration of the articulatory constriction. Three of the main candidates as physiological correlates are pulmonic pressure, and the extent and timing of peak glottal opening. Variation in these parameters can conveniently be inferred from oral air flow and intraoral pressure records. This preliminary report presents some of the findings of an analysis of aerodynamic and acoustic data on contrasting stop series in a number of European and Australian languages.

European languages generally have two series of stops, which are differentiated from one another phonetically in one of two ways. In the one case one series is characterized by the presence of glottal pulsing during the articulatory closure and the other by its absence. In the other case one series is characterized by a period of aspiration following the release of the oral closure and the other is unaspirated. No matter which of these phonetic mechanisms is used, we tend to refer to these contrasting series as *voiced* and *voiceless*. The terms *fortis* and *lenis* are less often used, but when they are, they are generally applied to the *voiceless* and *voiced* series respectively, as if the terms were synonymous. A much smaller group of European languages distinguish between *short* and *long* or *single* and *geminate* consonants. A few languages make this distinction in both *voiced* and *voiceless* series. Only a minority of Australian languages have more than one series of oral obstruents. In those languages which do have two contrasting stop series, the opposition has often been labelled as *fortis* versus *lenis*. It is clear, however, that not all these languages realise the contrast in a phonetically similar fashion (Butcher, forthcoming). One group of languages, in Arnhem Land, south and east of Darwin, has a stop contrast in word-medial position only (intervocalically and, in most cases, also following liquids and nasals). Voice onset times in these languages tend to be short-lag and variable (in both series), and not a reliable cue to the stop contrast. The most consistent cue appears to be the duration of the articulatory stricture, and indeed the contrast in these languages has also been analysed as one of *single* versus *geminate* stops. A second group, in the Daly River area, south-west of Darwin, has a contrast in medial and initial position (and also has contrasting fricatives at some places of articulation). These languages have a 'true' voicing distinction, with a contrast between presence and absence of glottal pulsing during the articulatory closure.

METHOD

In this paper data is presented on two of the parameters which are said to correlate highly with the *fortis/lenis* distinction - articulatory closure duration and peak intraoral pressure (Malécot, 1970; Jaeger, 1983). These parameters were measured in intervocalic bilabial stops in five languages: Burarra (a typical Arnhem Land language), Murrinh-Patha (a typical Daly language), French (a language with *voiced* and *voiceless* series), English (a language with *aspirated* and *unaspirated* series), and Italian (a language with *single* and*geminate voiced* and *voiceless* series). A single speaker of each language read a list of between 8 and 12 polysyllabic words, containing an equal number of *fortis* and *lenis* stops in comparable environments (the list for Italian also included examples of geminates in both series). Each word was repeated 3 times, giving a total of 24 to 36 tokens for each language. An

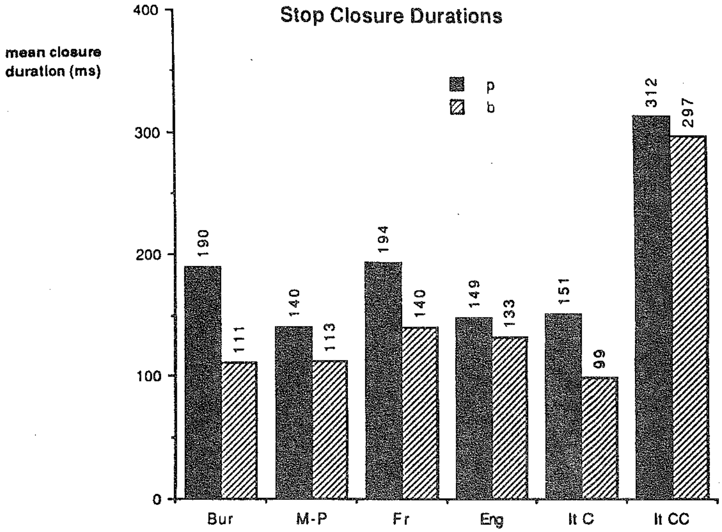


Figure 1. Mean durations of bilabial stop closures in five languages.

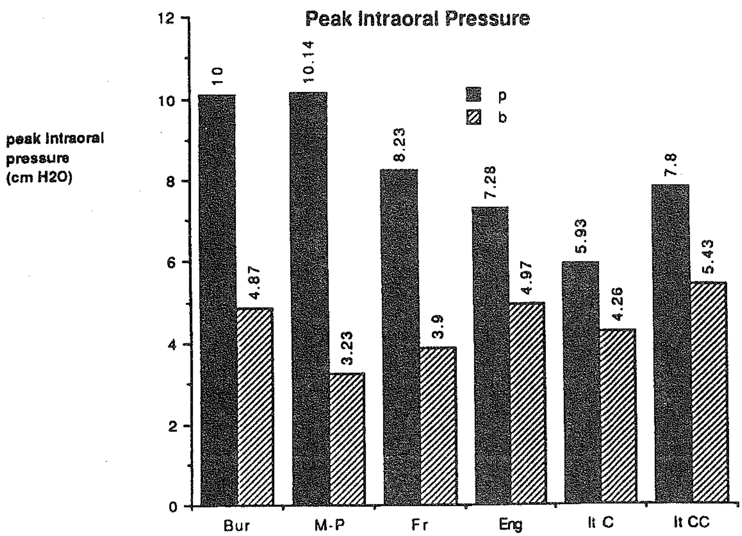


Figure 2. Mean peak intraoral pressures during bilabial stop closures in five languages.

Bur = Burarra, M-P = Murrinh-Patha, Fr = French, Eng = English, It C = Italian (single stops), It CC = Italian (geminate stops) analogue audio recording was made of each session. Duration measurements were made from the audio signal after digitizing at 10 kHz. Pressure measurements were made by means of a variable reluctance differential pressure transducer connected to a catheter inserted between the lips of the speaker. After demodulation of the carrier signal, the resulting DC output was digitized at 100 Hz and stored directly to disk. A great number of other measurements were also carried out at the same time, including duration of the preceding vowel, duration of glottal pulsing into the closure, and voice onset time. The results of these measurements were rather less central to the present topic, however, and, in view of spatial constraints, are not discussed in detail here.

RESULTS

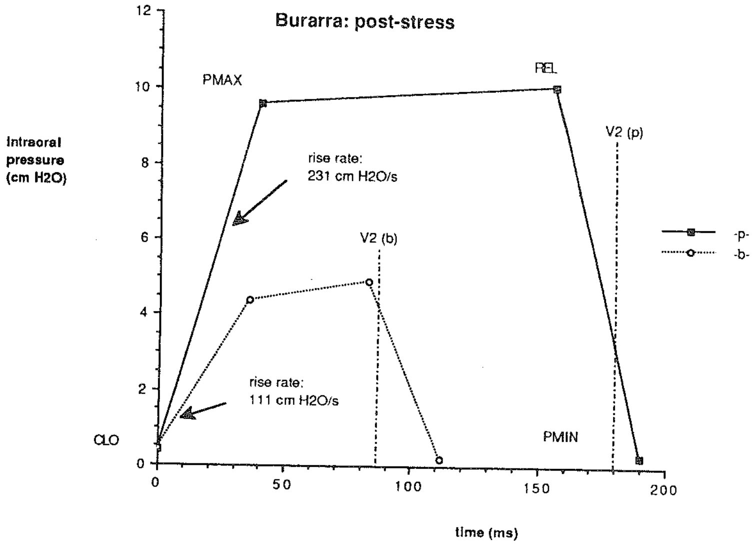
Figure 1 shows mean values of intervocalic bilabial closure durations following a stressed vowel in these five languages. It is clear that three languages make significant use of differences in closure duration to signal the contrast between /p/ and /b/: French and Italian (with single consonants), both of which have a phonetic voicing distinction, and Burarra, which does not. Note also that Italian makes a very significant difference in duration between *single* (C) and *geminate* (CC) stops, with a ratio of over 2:1 in the case of voiceless stops and almost 3:1 in the case of the voiced cognates. This is somewhat greater than the difference between *fortis* and *lenis* stops in most Australian languages.

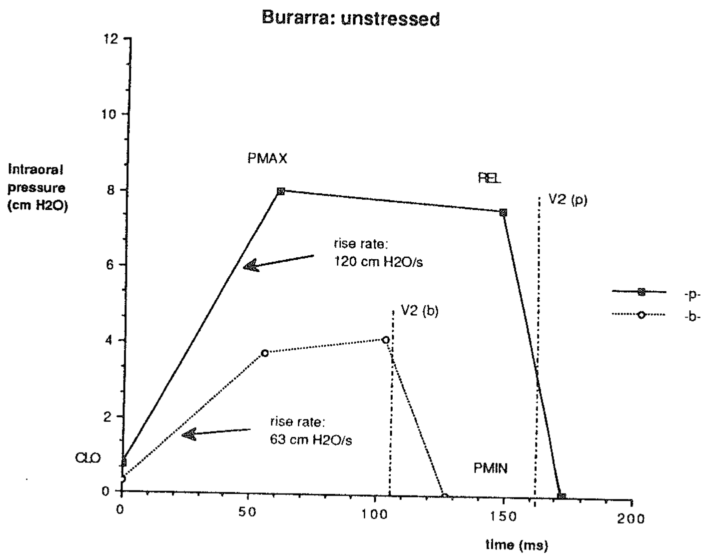
Figure 2 shows that all languages in the sample have consistent differences in peak intraoral pressure between the two stop categories. Once again, French and Burarra have amongst the most striking differences, with ratios greater than 2:1. In this parameter, however, they are overshadowed by Murrinh-Patha, where mean pressure for the /p/ is more than three times that for the /b/.

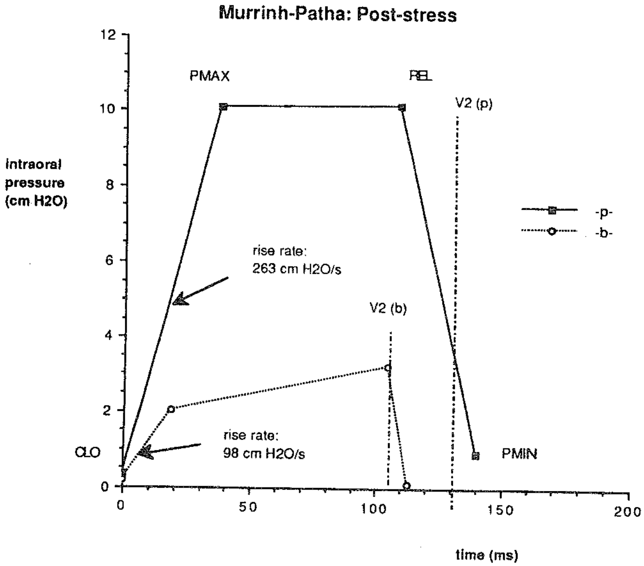
Figures 3, 4, 5 and 6 show the averaged intraoral pressure curves for intervocalic /p/s and /b/s following stressed and unstressed vowels in the two Australian languages. Each curve represents the average of nine tokens in each of three different contexts, drawn on the basis of means of pressure and duration values measured at four critical points in the raw data: CLO is the point at which a sharp rise in pressure begins (normally from zero) - this is assumed to be the point at which bilabial closure is completed; PMAX is the point at which the initial rise decreases sharply in steepness (and usually levels off completely); REL is the point at which pressure begins to decrease sharply - this is assumed to be the point of release of the articulatory closure; PMIN is the point at which the rapid decrease in pressure levels off (normally zero). V_2 marks the point at which a sharp rise in the intensity of the acoustic waveform indicates the onset of the following vowel.

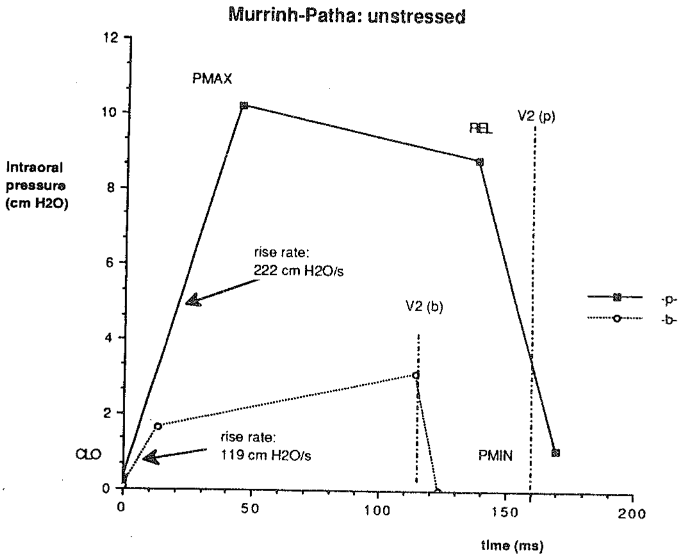
Peak glottal width appears to be achieved early on in the closure, with maximum pressure maintained for well over 100 ms in most *fortis* tokens. This is usually thought of as characteristic of 'plain' - i.e. unaspirated - voiceless stops such as are found in French, as opposed to aspirated voiceless stops, of the kind found in English. The latter type of sounds require peak glottal opening to coincide with the moment of articulatory release, whereas the former require peak opening to occur within the articulatory closure.

Clearly there are large and consistent differences in peak intraoral pressure. In Burarra following stressed vowels *fortis* closures are 70% longer than *lenis* closures and have just over twice the pressure behind them. Between unstressed vowels the duration difference is halved: *fortis* closures are only 36% longer, but are still produced with 95% more pressure than their *lenis* counterparts. In Murrinh-Patha, as we have seen, there is comparatively little difference in duration between *fortis* and *lenis* realisations (*fortis* closures are 24% longer). On the other hand, there is a very striking difference in peak pressure, which is maintained regardless of stress position. *Fortis* stops have on average more than three times the peak pressure of *lenis* stops. Peak pressures for the *fortis* tokens are of similar magnitude to those measured in the Burarra speaker, at around 10 cm H_2O, but pressures for the *lenis* realisations are very much lower. Visual observation of the Murrinh-Patha speaker at the time of recording confirmed that the larynx is lowered quite substantially during the *lenis* articulations, presumably to facilitate the prolongation of glottal pulsing into the stop closure. This is clearly the reason for the low, fluctuating, and sometimes negative intraoral pressure values recorded during these fully voiced stops, a phenomenon which also occurs consistently in speakers of other Daly languages (in the case of this speaker's initial *lenis* stops, more than half the tokens were fully implosive).


Burarra: post-stress
Intraoral pressure (cm H2O)
time (ms)
PMAX
REL
V2 (p)
V2 (b)
rise rate:
231 cm H2O/s
rise rate:
111 cm H2O/s
CLO
PMIN
-p-
-b-
0
2
4
6
8
10
12
0
50
100
150
200


Burarra: unstressed
Intraoral pressure (cm H2O)
time (ms)
PMAX
REL
V2 (p)
V2 (b)
rise rate:
120 cm H2O/s
rise rate:
63 cm H2O/s
CLO
PMIN
-p-
-b-
0
2
4
6
8
10
12
0
50
100
150
200


Murrinh-Patha: Post-stress
Intraoral pressure (cm H2O)
time (ms)
PMAX
REL
V2 (p)
V2 (b)
CLO
PMIN
rise rate:
263 cm H2O/s
rise rate:
98 cm H2O/s
-p-
-b-


Murrinh-Patha: unstressed
Intraoral pressure (cm H2O)
time (ms)
PMAX
REL
V2 (p)
V2 (b)
CLO
PMIN
rise rate:
222 cm H2O/s
rise rate:
119 cm H2O/s
-p-
-b-

DISCUSSION

There are three ways in which such a contrast in intraoral pressure might arise. The first two possibilities assume an active attempt is made by the speaker to acieve a certain target pressure for each member of the opposition. This could be done either by varying pulmonic pressure or by maintaining a constant pulmonic pressure and varying the glottal area. Both Malécot (1970:1589) and Kohler (1984:153) emphasize the importance of the latter mechanism; Ladefoged (1971:24) has suggested that the former mechanism must be resorted to for some languages. The third possibility is that the glottal area and pulmonic pressure are much the same for both phonemes, the differences in peak intraoral pressure being solely a function of the differences in duration of the articulatory stricture. Thus *fortis* stops would only have greater peak pressures than *lenis* stops by virtue of the fact that the pressure has more time in which to build up. This seems to be the assumption made by Jaeger (1983:185).

In order for this last hypothesis to be supported, however, we would expect to find (1) that there would be a close correlation between closure duration and peak pressure, and (2) that the rate of rise of intraoral pressure would be more or less constant for a given speaker at a given tempo. Neither of these things appears to be happening in the Australian cases, however. Firstly, as we have seen, the difference in pressure between *fortis* and *lenis* stops is in fact greater in Murrinh-Patha than in Burarra, although the length difference is much smaller. Furthermore, within each language the pressure difference is almost as great between unstressed vowels as it is following a stressed vowel, although the difference in duration becomes much less. Secondly, there are clear and consistent differences between *fortis* and *lenis* categories in the rate of rise of intraoral pressure. Pressure rises in *fortis* stops at twice the rate it does in *lenis* stops, regardless of stress position.

All of this strongly suggests that speakers consistently aim to achieve a different target peak pressure for each stop category, rather than maintaining a more or less constant subglottal pressure and leaving the peak intraoral pressure to be determined by the duration of the articulatory closure. If this is the case, which of the two possible control mechanisms, pulmonic or glottal, is used to vary the target pressure? A clue can be gleaned from the fact that, as shown in figures 3 to 6, glottal pulsing for the following vowel invariably commences at a point where intraoral pressure has decreased to between 3 and 4 cm H_2O. Since this value remains fairly constant and the transglottal pressure differential necessary for voicing to begin must also be more or less constant, we can infer that subglottal pressure does not vary greatly across categories. This would seem to indicate that control of glottal aperture is the main parameter underlying the distinctive variation in intraoral pressure in these two languages.

Since the degree and timing of glottal opening are known to be the variables underlying the other main features by which languages distinguish stop series, namely voicing and aspiration, there would appear to be no evidence from these data to support the notion of a single independent phonetic correlate of the *fortis/lenis* distinction. True *gemination* appears to be independent of the various components of *fortisness*.

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