

‘Fortis/Lenis’ revisited one more time: the
aerodynamics of some oral stop contrasts in
three continents

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Abstract

The terms *fortis* and *lenis* are variously regarded as having one single underlying phonetic correlate or many. An exploratory analysis of acoustic and aerodynamic data on contrasting stop series in a number of European and non-European languages confirms that a significant variation in peak intraoral pressure and in articulatory stricture duration are two of the main factors differentiating these series. Two central questions are: (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? A more detailed examination of the data from the non-European languages suggests that glottal aperture, rather than respiratory effort is the main physiological parameter underlying the pressure variation, and that each member of the opposition has a specific target peak pressure, rather than the *lenis* peak pressure being truncated by the early release of the articulatory closure.

Keywords: Fortis, lenis; intraoral pressure; Australian Aboriginal languages

Introduction

One correlate or many?

The phonetic basis of the phonological feature pair *fortis* versus *lenis* has continued to be a subject of some debate over the years. One of the central questions of this debate is whether such a feature distinction can be shown to have a single, language-universal phonetic correlate: is it possible to identify a specific physiological or acoustic reflex of ‘*fortisness*’ which can vary independently of other parameters – such as voicing, aspiration, and duration of the articulatory constriction – or is the contrast realised by a complex combination of such parameters, the contribution of each varying from language to language and from context to context?

At the ‘single correlate’ end of the spectrum of possible answers, the two most favoured candidates are *muscular tension* and *respiratory effort voice*. In a paper published exactly 30 years ago, Bill Hardcastle argues in support of the first of these in the case of Korean initial stops (Hardcastle, 1973). On the basis of acoustic and aerodynamic data, Hardcastle proposes that the most important correlate of the *fortis-lenis* distinction in this language is the degree of isometric muscular tension in the vocal folds and pharynx.

Ladefoged and colleagues (e.g. Ladefoged, 1971: 24-25, 29; Ladefoged, 1989: 65; Henton, Ladefoged and Maddieson, 1992: 89-90), on the other hand, strictly limit the use of the term *fortis* to indicate ‘increased respiratory effort in the production of a segment’, which, they say, is ‘comparatively rare’ in the world’s languages. In fact Korean is now the only example cited by the UCLA group (Henton et al 1992: 89) as having a true *fortis/lenis* distinction, whereby ‘heightened subglottal pressure accompanies the more constricted glottis and tensor walls of the vocal tract’. Dart’s (1987) model suggests that this increase in pressure is due to an increase in respiratory effort. Accordingly, this feature comes under the *pulmonic* node of Ladefoged’s (1989: 42) *airstream* ‘hyperfeature’ in his hierarchy of phonological features. He regards heightened subglottal pressure in itself as a necessary but not sufficient correlate of such increased effort. More recently Cho, Sun and Ladefoged (2002) have presented data on the Korean contrasts which suggest a rather more complex

picture, involving differences in both aerodynamics and vocal fold tension. Ladefoged and Maddieson (1996: 95-96) have also discussed the possibility that ‘articulatory strength’ may be a sole underlying correlate of *fortis*ness in a small number of languages. They conclude, however, in the case of the Dagestanian language Archi, ‘that length should be given the primary role’ in signalling the distinction between *fortis* and *lenis* obstruents.

Somewhere in the middle of the spectrum lies the approach of Malécot (1955; 1966a; b; 1968; 1969; 1970), working mainly on American English, who, following Stetson (1951), views ‘force of articulation’ (1970: 1588) as ‘a synesthetic interpretation of magnitudes of intrabuccal air-pressure.... conveyed variously in different contexts by the durations of the consonant closure and of the preceding vowel’. Thus for Malécot the phonological distinction corresponds to a single *gestalt* percept for the speaker, and this percept has as its ‘most consistent and powerful indicator’ the magnitude of the ‘pressure impulse’ – i.e. the product of intraoral pressure over time. However, he allows for a number of physiological parameters to underlie the percept, chief among them being ‘the air-valving action of the glottis, plus buccal and velopharyngeal apertures’.

Also in the ‘middle of the road’ is Jaeger (1983: 186), who doubts the validity of ‘force of articulation as an independently controlled variable’. She distinguishes between ‘VOT languages’ and ‘*fortis/lenis* languages’, thus excluding glottal timing (but not apparently glottal width) from the cluster of parameters said to underlie the latter contrast. On the basis of her data from Zapotec and Jawoyn, Jaeger regards articulatory closure duration as being the most important of these parameters, others being glottal width (deduced from the informal observation of burst intensity differences) and muscular tension (deduced from the informal observation of a greater tendency for fricative/glide allophony in *lenis* tokens).

At the ‘multiple correlate’ end of the scale, in their classic cross-language study of voice onset time Lisker & Abramson (1964: 387) are adamant that ‘none of the acoustic features which have been suggested as correlates of a *fortis/lenis* dimension is demonstrably independent of voicing’. They show that even in languages with three categories of stops, these categories can be distinguished, in initial position at least, on the basis of voice onset time alone (although in the case of Korean ‘the resolution between the two lower-valued

categories is not very good'). In the case of four-category languages, however, the feature of breathy voice ('low amplitude buzz mixed with noise') needs to be recruited to distinguish between the two voiced categories. The validity of intraoral pressure as the sole basis of a *fortis/lenis* distinction in English is further questioned by Lisker (1970: 215), who notes that 'Both initially and medially before a stressed vowel the two categories show peak pressures that overlap very extensively'.

Kohler (1984: 168) sees the *fortis/lenis* contrast as realised through both 'an articulatory timing and ... a laryngeal power/tension component. The former relates to the speed of stricture formation and release, and is probably a language universal, the manifestation of the latter (aspiration, voicing, glottalization) is language-specific.' Thus Kohler's concept of the feature [\pm fortis] potentially subsumes a whole range of parameters often thought of as underlying separate phonological features such as [\pm long], [\pm voiced], [\pm aspirated], [\pm tense/stiff]. A consequence of this approach is that the [\pm fortis] feature is only sufficient to categorise systems with two stop series. For phonological systems distinguishing three or four series other features must be invoked, e.g. [\pm aspirated][\pm tense] for Korean and [\pm voiced][\pm aspirated] for Hindi (Kohler 1984:170).

Thus, to summarise, the recent literature reveals three basic views of the phonetics of [\pm fortis]:

- 1 [\pm fortis] is a comparatively rare feature – either airstream or articulatory – with a single underlying phonetic parameter of physical effort.
- 2 [\pm 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 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.

Languages of interest

Most European languages have only two series of stops, which are differentiated from one another phonetically either through the presence or absence of glottal pulsing during the articulatory closure (typical of most Romance languages), or through the presence or absence of aspiration following the release of the oral closure (typical of most Germanic languages). The terms *fortis* and *lenis*, when used, are generally applied to the *voiceless* or *aspirated* and *voiced* or *unaspirated* series respectively, just as Kohler's model predicts. A much smaller group of European languages (exemplified by Finnish and Estonian) distinguish between *short* and *long* or *single* and *geminate* consonants. In these cases the *fortis/lenis* label as suggested by Kohler (1984:170) is traditionally less often applied. A few languages, such as Italian, make this distinction in both *voiced* and *voiceless* series, which in some analyses would necessitate the use of an additional [±long] feature. In this paper I shall compare aspects of the aerodynamics of stop contrasts in some European languages with four non-European languages that have not traditionally been associated with either [±voiced] or [±aspirated] features (indeed two of these languages have not previously been the subject of any instrumental phonetic study). The aim here is to ascertain which, if any, of the phonetic parameters reviewed above underlie these contrasts, and whether a single parameter or a multiple parameter view of [±fortis] is supported by the data from these languages.

Australian languages are generally well known for having only one series of oral obstruents. However, a number of them – perhaps as many as 30% – do have two contrasting stop series, which have been given a variety of labels by linguists, the most frequent in fact being *fortis* versus *lenis*. It seems clear that not all of these languages realise the contrast in a phonetically similar fashion, although there appears to be little correlation between phonological labels and phonetic mechanisms (Butcher, forthcoming). One group of such languages, to the south and east of Darwin, has a stop contrast in word-medial position only (intervocally 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 to the contrast appears to be the duration of the articulatory stricture, and indeed the two series in some of these languages have been labelled *short* versus *long* or *single* versus *geminate*. This group is represented in the present study by Burarra, a non-Pama-Nyungan language spoken by some 500-600 people living within and to the south and east of Maningrida in north central Arnhem Land. A second group of languages, in the Daly River area, south-west of Darwin, has a contrast in medial and initial position (and also, unusually for Australian languages, contrasting fricatives at some places of articulation). These languages too have been said to have a *fortis/lenis* contrast, although phonetically they appear to have a ‘true’ voicing distinction, with a contrast between presence and absence of glottal pulsing during the articulatory closure. This group is here represented by Murrinh-Patha, a non-Pama-Nyungan language spoken by about 1000 people, the largest group being based at Wadeye (Port Keats), where it has become the local *lingua franca*.

LuGanda is a Niger-Congo language spoken by over 3 million people in central and southern Uganda. The phonology is usually considered to have a *single/geminate* contrast as well as a voicing contrast. In fact voiced geminate consonants occur mainly in syllable-initial position as the result of the historical loss of an intervening high vowel (and voiceless geminates occur only in loan words). The LuGanda *single/geminate* stop opposition was originally cited by Ladefoged (1971:24) as an example of a true *fortis/lenis* contrast. More recently Henton et al (1992:89) and Ladefoged and Maddieson (1996:95) have expressed doubts as to whether the pressure differences are in fact due to respiratory effort and raised the possibility that, with steady lung volume decrement, differences in articulatory closure duration alone may be sufficient to produce higher pressures in the long stops of this language. There are over 75 million speakers of Javanese, mainly concentrated in central Java. This Western Malayo-Polynesian (Sundic) language has two series of stops which are sometimes referred to as *fortis* and *lenis*, but more often as *light* and *heavy*. An acoustic study by Fagan (1988) strongly suggests that the distinction is based on a difference in phonation type at release - the *light* stops being voiceless unaspirated and the *heavy* cognates being also voiceless but with breathy or ‘slack’ voice at release.

3 Method

In this paper some preliminary data are presented on two of the parameters which are said to underlie the *fortis/lenis* distinction – articulatory closure duration and peak intraoral pressure. These parameters were measured in intervocalic bilabial stops in seven languages: Burarra, Murrinh-Patha, French, English, Italian, Javanese, and LuGanda. 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 intervocalic and (where appropriate) initial environments. The lists for Italian and LuGanda also included examples of geminates. Each word was repeated 3 times, giving a total of 24 to 36 tokens for each language. An analogue audio tape recording was made of each session. Duration measurements were made from the audio signal after digitising at 20.05 kHz with 16 bit resolution. Pressure measurements of bilabial stops were made by means of a variable reluctance differential pressure transducer connected to a 2 mm (inner diameter) plastic catheter inserted between the lips of the speaker. After demodulation of the carrier signal, the resulting DC output was low-pass filtered with a cut-off frequency of 50 Hz, before being digitised at 100 Hz and stored directly to disk. A 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, voice onset time, and fundamental and first and second formant frequencies of the following vowel. The results of these measurements were rather less central to the present topic, however, and are not discussed in detail here.

[Insert Figure 1 about here]

Results

Figure 1 shows mean values of intervocalic bilabial closure durations following a stressed vowel in these seven languages. Four of the speakers make significant use of differences in closure duration to signal the contrast between /p/ and /b/: the LuGanda and Burarra speakers both have *fortis* stops which are just over 70% longer than their *lenis* counterparts; Italian

single *fortis* stops are some 53% longer than the *lenis*, and French *fortis* stops are just under 40% longer. In the case of the three other languages the difference is 25% or less. As far as the geminates are concerned, *lenis* geminates are no less than three times as long as their single equivalents in both Italian and LuGanda, whilst in Italian /pp/ closures are twice as long as /p/ closures. Thus there seems to be a clear difference between the magnitude of duration difference used to signal *fortis/lenis* distinctions and that used to signal the distinction between single and geminate stops.

[Insert Figure 2 about here]

Figure 2 shows that most languages in the sample have consistent differences in peak intraoral pressure between the two stop categories – the possible exceptions are English and Javanese. Once again the Burarra and French speakers both have striking differences, with ratios greater than 2:1. In this parameter, however, they are overshadowed by LuGanda and Murrinh-Patha, where in both cases mean pressure for the /p/ is more than three times that for the /b/. Note that peak pressures for the Murrinh-Patha *fortis* tokens are of similar magnitude to those measured in the Burarra speaker, at around 1,000 Pa, 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 (in the case of this speaker's initial *lenis* stops, more than half the tokens were fully implosive). It is also worth noting that geminates in Italian have only about 30% more pressure than the corresponding single stops, whereas in LuGanda the ratio is 2:1, resulting in a neat pattern of pressure differentials in that language of 1:2:3 between the three categories /b/~/bb/~/p/.

[Insert Figures 3, 4, 5 and 6 about here]

Figures 3, 4, 5 and 6 show the averaged intraoral pressure/time curves for intervocalic /p/s and /p/s following stressed vowels in the four non-European 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; P_{MAX} is the point at which the initial rise decreases sharply in steepness (and often 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; P_{MIN} is the point at which the rapid decrease in pressure levels off (normally zero). V_2 marks the point (in [-voice] types) at which the onset of periodicity in the acoustic waveform indicates the beginning of the following vowel.

Discussion

Clearly in three of these languages there are substantial and consistent differences in the magnitude of the ‘pressure impulse’ (Malécot 1970:1588) – i.e. the product of intraoral pressure over time. In the case of Burarra and LuGanda, this is achieved through differences in both peak pressure and stricture duration, in the case of Murrinh-Patha the difference resides almost entirely in the peak pressure. The stop contrast in Javanese, on the other hand could only be considered to be one of *fortis* versus *lenis* in one of the models discussed above. There is no evidence of substantial differences in timing or in peak intraoral pressures, as required by Ladefoged’s and Malécot’s models. The contrast appears to be based entirely on differences in the mode of glottal vibration following the release and could be accounted for only in Hardcastle’s single feature model or Kohler’s multi-feature model model (in both cases, as a difference in vocal fold tension).

As far as the three ‘pressure difference’ languages are concerned, there are three ways in which the contrast might be achieved. The first two possibilities assume a ‘rescaling’ model (Harrington, Fletcher & Roberts 1995) – i.e. an active attempt is made by the speaker to achieve a certain target pressure for each member of the opposition, the *lenis* target being a reduced or rescaled version of the *fortis* one. This could be done either by varying pulmonic pressure or by maintaining a constant pulmonic pressure and varying the peak glottal width and speed of stricture formation. Both Malécot’s and Kohler’s model’s would allow for the

latter mechanism; Ladefoged, as we have seen, would only count as true [\pm fortis] contrasts those rare cases where the former mechanism is employed (Dart 1987). The third possibility is the ‘truncation’ type approach (Beckman & Edwards 1995) suggested by Ladefoged for LuGanda, whereby the glottal area and pulmonic pressure are much the same for both members of the opposition, 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 - i.e the *lenis* member is a truncated version of the *fortis* one.

Let us examine these hypotheses in reverse order. In order for the truncation hypothesis to be supported, 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 across stop types for a given speaker at a given tempo. Neither of these things appears to be happening in the case of these three languages, 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 (Butcher, forthcoming). Secondly, as can be seen in Figures 3 to 5, there are clear and consistent differences between *fortis* and *lenis* categories in all three languages in the rate of rise of intraoral pressure. Pressure rises in the Australian languages in *fortis* stops at twice the rate it does in *lenis* stops (regardless of stress position) and in LuGanda the difference is a massive five-fold.

This strongly supports a rescaling hypothesis, whereby 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/articulatory, is used to vary the target pressure? Since both Burarra stop categories are voiceless, a clue may be gleaned from this language, by observing at what level glottal pulsing commences for the following vowel. As

can be seen from figure 3, voicing begins with both categories of stop at a point where intraoral pressure has decreased to between 3,000 and 4,000 Pa (as it does for the fortis stops of Murrinh-Patha and LuGanda also). Since this value remains constant and the transglottal pressure differential necessary for voicing to begin must also be more or less constant, we can infer that pulmonic pressure does not vary greatly across the two categories. This would seem to indicate that, in Burarra at least, control of glottal aperture and articulatory stricture formation are the main parameters underlying the distinctive variation in peak intraoral pressure.

Thus there is no evidence from these preliminary data to support the notion of a single independent phonetic correlate of the *fortis/lenis* distinction in these languages. However, the results for LuGanda and the two Australian languages seem to support a ‘middle-of-the-road’ two-feature model of the contrast – i.e. one based on closure duration and intraoral pressure – or, if one prefers, the ‘pressure impulse’ concept of Malécot.

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References

- BECKMAN, M.E. and EDWARDS, J., 1995, Articulatory evidence for differentiating stress categories. In P. Keating (ed.) *Phonological Structure and Phonetic Form: Papers in Laboratory Phonology III* (Cambridge: Cambridge University Press), pp 7-33.
- BUTCHER, A.R., forthcoming, *The Sounds of Australian Languages* (Oxford: Oxford University Press).
- CHO, T., JUN, S.-A. and LADEFOGED, P., 2002, Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of Phonetics* **30**, 193-228.
- DART, S., 1987, An aerodynamic study of Korean stop consonants: measurements and modeling. *Journal of the Acoustic Society of America* **81**, 138-147.
- FAGAN, J.L., 1988, Javanese intervocalic stop phonemes: the light/heavy distinction. In R. McGinn (ed.), *Studies in Austronesian Linguistics* (Athens, OH: Center for International Studies), pp 173-200.
- HARDCASTLE, W.J., 1973, Some observations on the *tense-lax* distinction in initial stops in Korean. *Journal of Phonetics* **1**, 263-272.
- HARRINGTON, J., FLETCHER, J. and ROBERTS, C., 1995, Coarticulation and the accented/unaccented distinction: evidence from jaw movement data. *Journal of Phonetics* **23**, 305-322.
- HENTON, C., LADEFOGED, P. and MADDIESON, I., 1992, Stops in the world's languages. *Phonetica* **49**, 65-101.
- JAEGER, J.J., 1983, The fortis/lenis question: evidence from Zapotec and Jawoñ. *Journal of Phonetics* **11**, 177-189.
- KOHLER, K.J., 1984, Phonetic explanations in phonology: the feature fortis/lenis. *Phonetica* **41**, 150-174.
- LADEFOGED, P., 1971, *Preliminaries to Linguistic Phonetics* (Chicago IL: The University of Chicago Press).
- LADEFOGED, P., 1989, Representing Phonetic Structure. *UCLA Working Papers in Phonetics* **73**.

- LADEFOGED, P. and MADDIESON, I., 1996, *The Sounds of the World's Languages*. (Oxford: Blackwell).
- LISKER, L., 1970, Supraglottal air pressure in the production of English stops. *Language & Speech* **13**, 215-230.
- LISKER, L. and ABRAMSON, A.S., 1964, A cross-language study of voicing in initial stops: acoustical measurements. *Word* **20**, 384-422.
- MALÉCOT, A., 1955, An experimental study of force of articulation. *Studia Linguistica* **9**, 35-44.
- MALÉCOT, A., 1966a, The effectiveness of intra-oral air-pressure-pulse parameters in distinguishing between stop cognates. *Phonetica* **14**, 65-81.
- MALÉCOT, A., 1966b, Mechanical pressure as an index of 'force of articulation'. *Phonetica* **14**, 169-180.
- MALÉCOT, A., 1968, The force of articulation of American stops and fricatives as a function of position. *Phonetica* **18**, 95-102.
- MALÉCOT, A., 1969, The effect of syllable rate and loudness on the force of articulation of American stops and fricatives. *Phonetica* **19**, 205-216.
- MALÉCOT, A., 1970, The lenis/fortis opposition: its physiological parameters. *Journal of the Acoustic Society of America* **47**, 1588-1592.
- STETSON, R.H., 1951, *Motor Phonetics* (Amsterdam: North Holland).

Figures

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

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

Figure 3. Intraoral pressure changes over time during Burarra bilabial stops following a stressed vowel. Averaged over nine tokens.

Figure 4. Intraoral pressure changes over time during Murrinh-Patha bilabial stops following a stressed vowel. Averaged over nine tokens.

Figure 5. Intraoral pressure changes over time during Javanese bilabial stops following a stressed vowel. Averaged over nine tokens.

Figure 6. Intraoral pressure changes over time during LuGanda bilabial stops following a stressed vowel. Averaged over nine tokens.

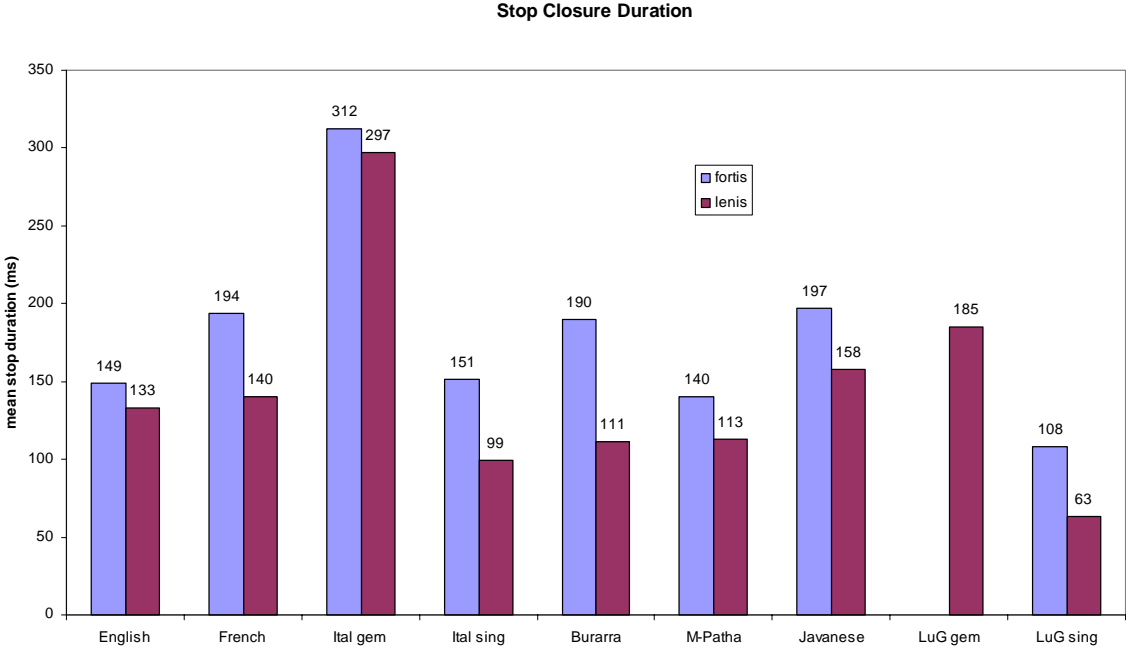


Figure 1

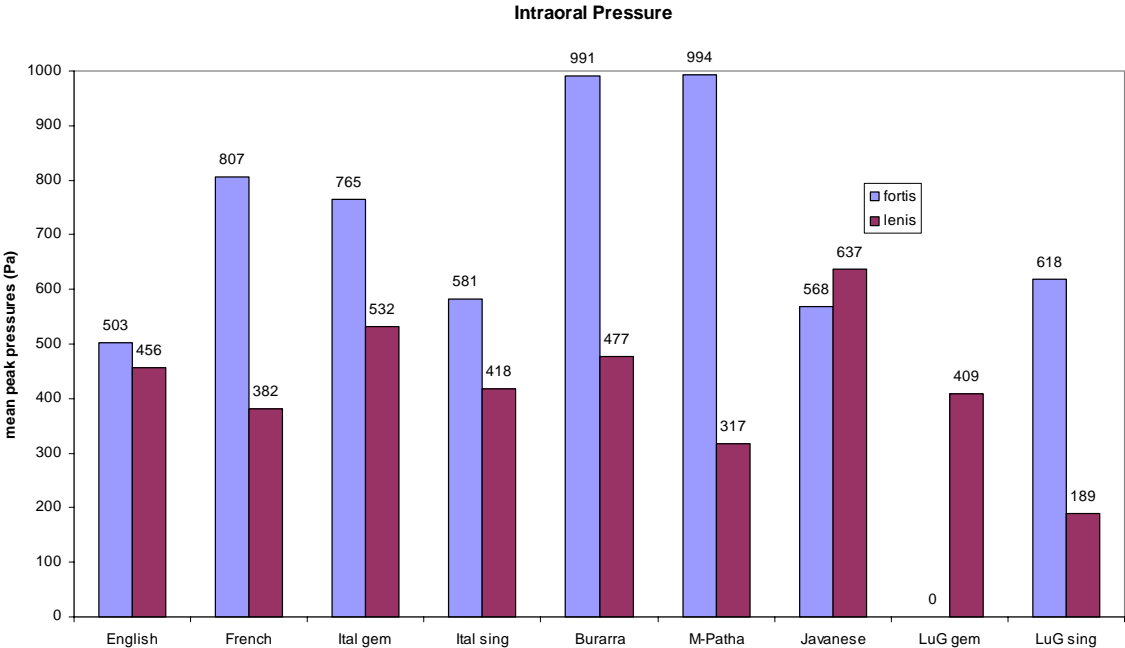


Figure 2

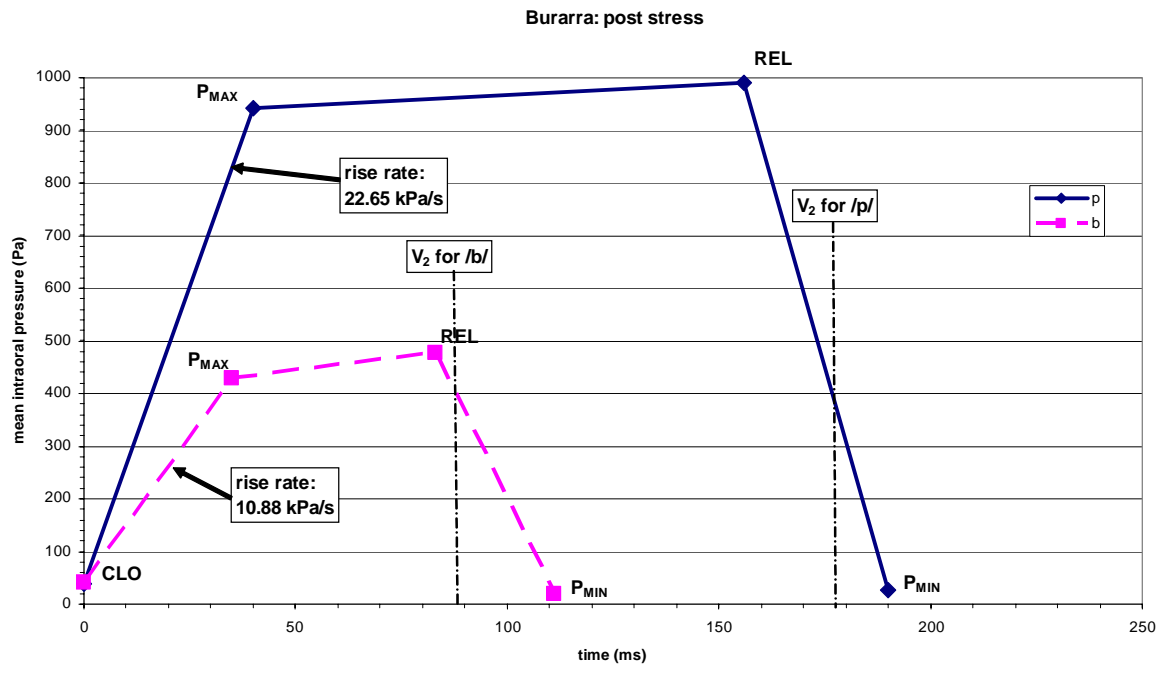


Figure 3

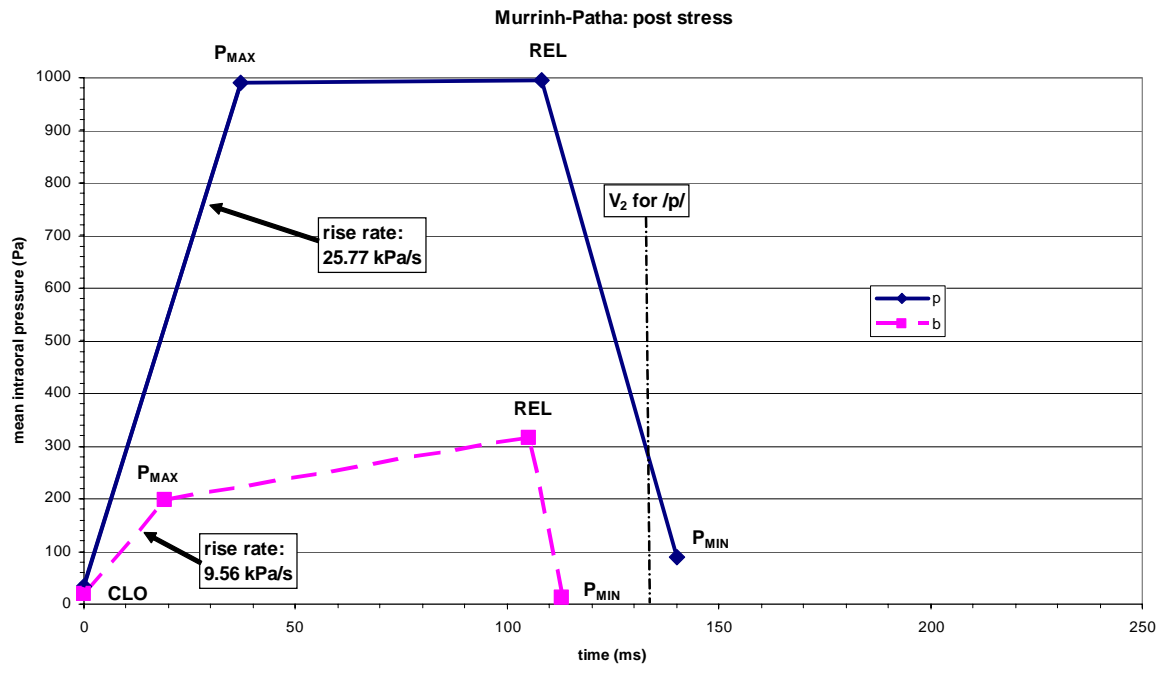


Figure 4

Javanese: post stress

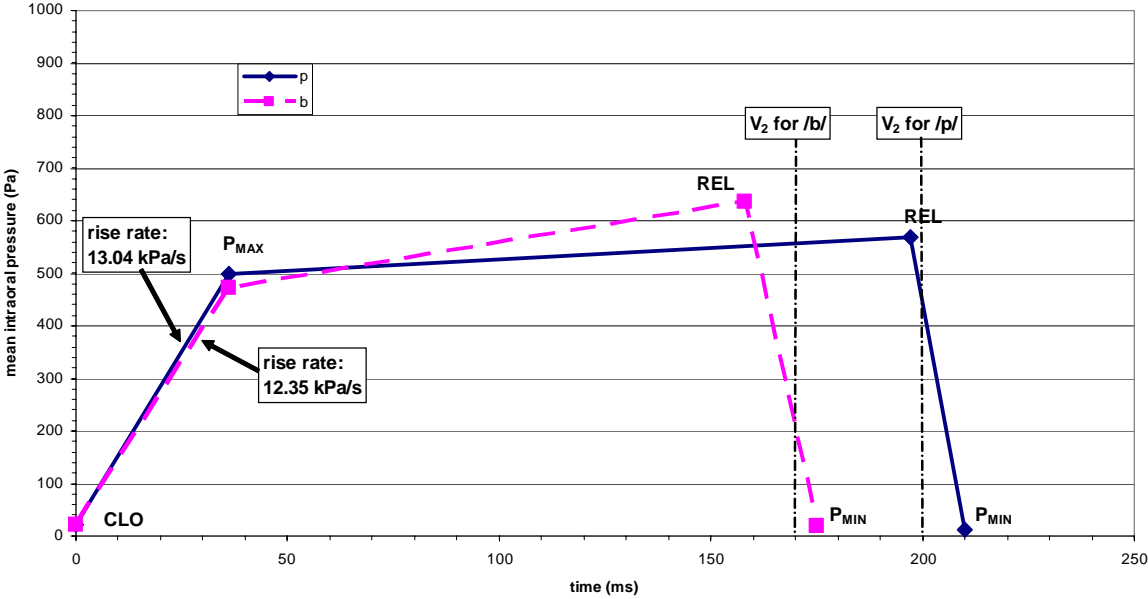


Figure 5

LuGanda: post stress

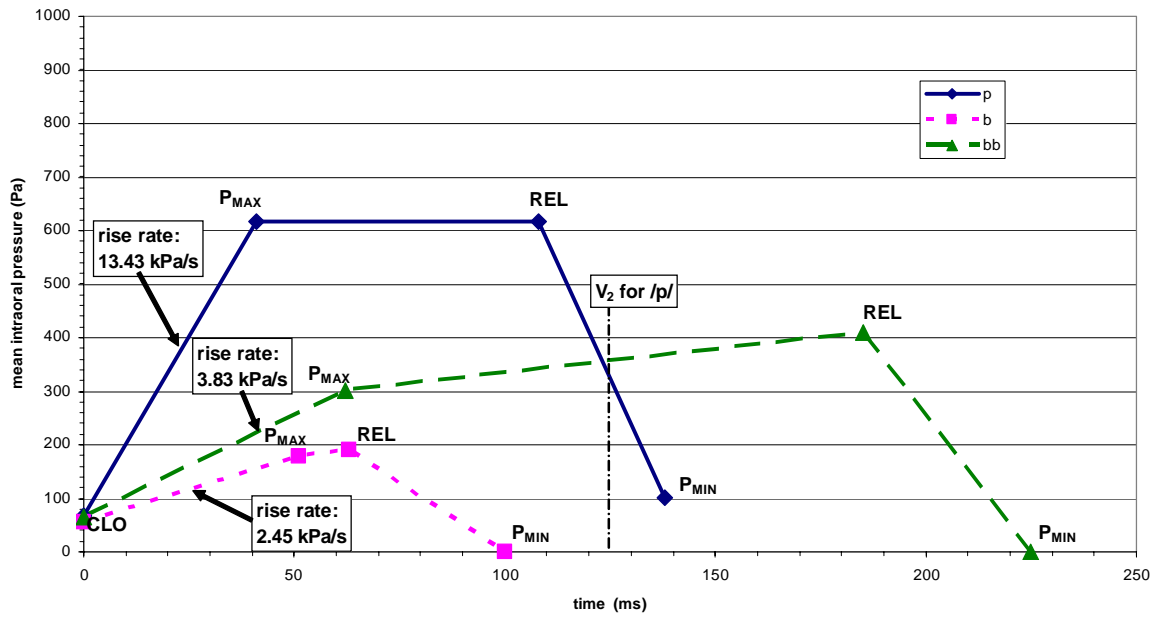


Figure 6