Appendix A
Velar and Glottal activity in Icelandic

Preface

The following contribution is an expanded version of the paper that appeared as Hoole (1987) in the Proceedings of the International Congress of Phonetic Sciences held in Tallinn. This expanded version was prepared immediately after the conference, but I then became distracted by other more urgent projects and never submitted it for publication, and I have not worked actively on Icelandic since then. However, I remain as convinced as I was then that the consonants of Icelandic are interesting for our understanding of laryngeal-oral coordination in general, and that the specific Icelandic question of a possible relationship between pre-aspiration and voiceless sonorants remains intriguing. As there is still very little instrumental data on Icelandic (and as the conference proceedings are probably of somewhat limited accessibility) it seemed worthwhile bringing the expanded version into suitable shape for making available electronically. Obviously, if I were writing this article from scratch today there would be a fair number of changes. However, as it did not seem appropriate after so many years to consider submitting it for normal journal publication I decided to adopt the following arrangement for the text: The bulk of the text simply remains as written almost 20 years ago, except for minor corrections to the text and improvements in the readability of the figures. The original discussion is then followed by a postscript that takes into account some of the relevant material that has been published in the intervening years, and thus hopefully provides readers with sufficient background to form their own opinion as to the most fruitful approach to this topic.

1 Introduction

In 1958 Haugen declared that “there is probably little to be added of purely phonetic detail” to the description of Icelandic. Undeterred by this, a number of investigators have in recent years looked closely at various aspects of Icelandic phonetics (e.g. Pétursson (1972, 1973b, 1975, 1976), Garnes (1973), Löfqvist & Yoshioka (1980a)). Indeed, as the latter hase pointed out, Icelandic provides plenty of scope for investigations of the temporal organization of speech. Their work concentrated on glottal activity, the most interesting phenomenon in this respect being what we will refer to (*pace* Pétursson, see below) as the pre-aspirated plosives. A further noteworthy aspect of Icelandic is the existence of voiceless nasals (see Pétursson, 1973a, for phonological analysis), which thus involve the coordination of labial or lingual, velar and glottal gestures.

In this work I will be taking a fresh look at velar and glottal activity in pre-aspirated plosives and voiceless nasals from two points of view; firstly what their temporal organization can tell us about the motor control of speech more generally. Discussion of this point will be deferred until later, but a word of warning is probably in order now: we are not able to avoid that frequent danger in the field of physiological phonetics, namely that conclusions have to be based on the speech of only one speaker. The dangers of this approach have been pointed out very clearly in recent work by Al Bamerni (1984). This study of velar control shows how speakers’ motor strategies vary, both within and across languages. On the other hand, this work makes it clear that progress can only be made by accumulating careful studies of different speakers.

The second point of view involves the question of using phonetic analysis to throw new light on phonological problems. Here I will be attempting to show that pre-aspirated plosives and voiceless nasals are more closely related than has often been assumed to be the case. At this point the phonetic and phonological background to these sounds must be discussed in greater detail and the hypotheses forming the backbone of the experimental investigations expounded more fully. My debt to Pétursson's work will be clear, although I take issue with him on a number of points.

1.1 Preaspirated plosives

Let us start with the preaspirated plosives. Phonetically, it is firmly established that they are produced with glottal abduction well before implosion of the plosive itself, peak glottal opening (PGO) being reached at about the time of implosion. A hardy annual in the field of Icelandic phonology has been the question of quantity. Here we will be referring to it only in passing. It is of relevance to the pre-aspirated plosives, however, since these sounds have traditionally been described as long, the voiceless unaspirated as short, e.g. 'seppi' (pre-aspirated) vs. 'sepi' (unaspirated). Recent experimental evidence tends to show (Garnes, 1973) that there is not much to choose between these sounds as far as length of the *occlusion* is concerned (in fact, the occlusion for the pre-aspirated stop may even be shorter; Pétursson, 1972).

Pre-aspirated plosives occur only word-medially, e.g. 'seppi', and finally, e.g 'löpp'; in combination with other consonants only before /**l**/ and /**n**/, e.g. 'epli', 'opna'.

Pétursson adduces a number of arguments aiming to show that the pre-aspirated plosives are better regarded as combinations of /**h**/ + Plosive (abbreviated to 'P' below):

a) The duration of prevocalic /**h**/ and the pre-aspiration phase are roughly the same.
b) The duration of pre-aspiration and occlusion are much the same. Put another way, pre-aspiration is proportionately very long compared with post-aspiration in Icelandic or other languages. Pétursson seems to be awkward with the idea that an aspiration phase can be as long as the occlusion to which it 'belongs'. He also seems to expect pre-aspiration, if such it is, to be a kind of mirror-image of post-aspiration. It is difficult to see the force of this argument, since there may be psycho-acoustic reasons why aspiration sitting on the vowel offset needs to be longer for perceptual saliency than that preceding an upcoming vowel.
c) He observed a slight lowering of the velum both for instances of /**h**/ and pre-aspiration in his cineradiographic investigations.
d) The posited consonantal groups /**h**/ + P have a similar temporal structure to other groups of C + P.

While Pétursson was perfectly aware of the restricted number of examples on which his analysis was based, and forgetting for a moment the reservations already given, the analysis as a whole seems quite plausible. In particular it has the merit of fitting in with the prediction that plosive following voiceless C is unaspirated.

However I think it will be possible to show, following presentation of my own experiments that none of the arguments taken individually really hold water. This will be the first step in support of the hypothesis regarding voiceless nasals to which we will now turn.

1.2 The voiceless nasals

Icelandic is certainly remarkable for the large number of phonetically identifiable nasals (see Pétursson, 1973a, for review), generally being considered to include 4 voiced (**m, n, ŋ, ɲ**), and the corresponding 4 voiceless nasals (as well as 4 constrictives). (We leave aside the palatal and velars here, as their phonemic status is debatable). The occurrence of voiceless nasals is not the same in all parts of Iceland, although their distribution is severely restricted everywhere. In the north they occur only in word final position following another voiceless consonant, e.g. ‘lasm’ [**lasm̥**] (friend), and would appear to be allophones of the corresponding voiced nasals since they become voiced again if followed by another voiced sound, e.g. vatn (water) [**va**^{h}**tn̥** #] vs. vatni (dat. sing.)[**va**^{h}**tnɪ** #].

In the south the same situation obtains; however in addition voiceless nasals can occur before /**p, t, k**/ following a short vowel (for details again see Pétursson). They are thus restricted to positions in which the pre-aspirated plosives also occur. Apparent examples of minimal pairs contrasting voiced and voiceless nasals are easy enough to find in this position, e.g. ‘dempi’ [**dem̥pi**] vs. ‘dembi’ [**dɛmpɪ**], so there is a prima facie case for regarding the voiceless nasals as phonemes in Southern Icelandic. In the north the situation is different since ‘dempi’ etc. is realized as [**dɛmp**^{h}**ɪ**] - contrasting through the aspiration with 'dembi' ([**dɛmpɪ**]) .

The only experimental investigation, so far as I am aware, which has examined voiced and voiceless nasals in Southern Icelandic is also due to Pétursson (1975). His main findings were that in such minimal pairs:

a) voiceless nasals are longer than voiced
b) there is possibly a tendency to shorter plosives after voiceless nasals
c) vowels preceeding the different nasals are essentially the same length
d) there was no clear difference in velar opening

Pétursson was unable to give any measurements of the speed of the velar gesture, but he hypothesized that velar raising would be faster in the voiceless nasals.

He takes the view that since the plosives in pairs such as dempi/dembi are not reliably different in length, and since they are voiceless in both cases, the nasals are the bearers of the phonological contrast between such pairs and therefore belong to different phonemes.

We will be attempting to use experimental evidence to show that it is more elegant to regard the voiceless nasals as normal nasals coarticulated with pre-aspirated plosives.

This idea is not new. Haugen took the view that both “*pre- and post-aspiration are components of fortis stops*”, and that the voiceless continuants (i.e including nasals) are in complementary distribution with the voiced, since “*in the position before aspirated* (i.e also preaspirated (Ph. H)) *stops voicelessness is closely correlated to the aspiration of the stops and in general appears to be determined by it*” (1958, p.73).

The position of the aspiration would be stated in an allophonic rule.

The need for an allophonic rule of this kind has been a source of disquiet to some, e.g. Werner (1963), who plumps for the phonemicity of voiced and voiceless nasals in Faroese where a somewhat similar situation applies.

It is perhaps unfortunate that Haugen could not phrase his explanation in terms of coarticulation since Pétursson has consistently rejected his point of view, possibly as a result of a misunderstanding: "*Haugens Argumente sind wertlos, weil es aus physiologischen Grunden weder einen aspirierten noch einen stimmhaften Verschlusslaut nach stimmlosem Nasal geben kann*" (1975, p. 653). This is the more curious since Pétursson (1973b) has himself given a plausible account in coarticulatory terms of the genesis of preaspirates and voiceless nasals, in which the appearance of the two groups of sounds is closely linked, and attributed to the same process, namely a shift in the timing of a ballistic devoicing gesture.

However, Pétursson was already convinced for the reasons given above that preaspirates are phonemically /**h**/+P, and on this basis it is only consistent to regard the voiceless nasals as phonemes as well.

We will be trying to show the relevance of an examination of coarticulation for synchronic analysis.

2 Material, Method, Subject

A male speaker of Southern Icelandic ('linmæli') acted as subject. He had been studying in Germany for four years but visited Iceland regularly and was in constant contact with fellow Icelanders in Germany. The speech material was chosen to permit contrast of pre-aspirated plosives, unaspirated plosives, voiceless nasal plus plosive and voiced nasal plus plosive in as homogeneous an environment as possible. This led to the following basic list of 10 words, the sounds of interest all being in medial, post-stress position.

hitti	**hɪʰtɪ**	pre-asp	meet (1 sg. pret)
hiti	**hɪːtɪ**	unasp	heat (nom. Sg. m)
henti	**hɛn̥tɪ**	voiceless N	throw away (1 sg. pret)
hendi	**hɛntɪ**	voiced N	hand (dat. Sg. f)
seppi	**sɛʰpɪ**	pre-asp	dog (name)
sepi	**sɛːpɪ**	unasp	rag
dempi	**dɛm̥pɪ**	voiceless N	dampen(1. Sg. pres. Conj.)
dembi	**dɛmpɪ**	voiced N	throw (1 sg pres conj.)
hetta	**hɛʰta**	pre-asp	hood
sempinn	**sɛm̥pɪn**	voiceless N	base, common

The long vowels preceding the unaspirated plosives are generally somewhat diphthongized.

Back vowels and consonants were excluded from the material since they can cause artefacts in the photoelectroglottographic signal. In fact, for the purposes of the experiment this is not a very grave restriction since velar/palatal voiceless nasals are much rarer than their bilabial and alveolar counterparts. A further methodological word of warning is in order here: movement of the velum could also lead to artefacts in the PGG signal for the voiceless nasals, however the risk seemed worth taking.

This list was subjected to six different randomizations thus dividing the material into six blocks. To reduce list effects some dummy items were inserted at the beginning and end of each block. The words were embedded in the sentence frame "ég segi ____ þ á" ("*I say* ___ *then*")

The following procedure was followed for the recordings: Glottal activity was assessed using the transillumination technique (F-J electronics), the light source being applied between the thyroid and cricoid cartilages, and the light passing through the glottis being picked up by a catheter-mounted photo transistor inserted pernasally into the pharynx. Here the devoicing gesture was of principle interest, and for this the method is considered quite reliable (Hutters, 1976; Löfqvist & Yoshioka, 1980b), particularly for information on the timing of the gesture, while amplitude information should be interpreted with rather more caution.

Velar activity was monitored using the fiberoptic method developed by Künzel (1979). A fiberoptic bundle containing a light guide and photo transistor is inserted into the nasal cavity. The photo transistor picks up the light reflected from the upper surface of the velum. The relationship between velar height and amount of light reflected is considered to be basically linear (Künzel, 1979). Since the velograph also uses the photoelectroglottograph as light source and since we only had one instrument available velar and glottal activity had to be recorded separately. (Had two instruments been available it is still questionable whether simultaneous recording would have been possible because of interference between the light sources and catheters.)

To ensure that all recordings were spoken at roughly the same rate the first recording was recorded on tape, pauses were inserted, this tape was then played back to the subject over earphones in subsequent recordings, and he was asked to speak in the pause following the model. A total of three recordings was made. In each, the audio signal and the physiological signal were digitized and stored on magnetic tape on-line, the audio signal at a sample rate of 10 KHz, the physiological one at 5 KHz. The physiological signals were photoelectroglottgram in the first recording, velogram in the second and oral air-pressure in the third. The latter was registered via a Hanson Manometer and catheter also inserted through the nose into the pharynx. This last recording was used to fill in some of the details of plosive articulation and as a cross-check on the segmentation methods used in the first two. Following storage, a graphically-assisted segmentation program was used to measure the following parameters (for the words in the 'basic' list):

1. Length of the vowel preceding the consonant or consonant group
2. Length of the nasal or length of pre-aspiration, based on the audio signal
3. Length of the occlusion for the plosive
4. Size of PGO and its position relative to onset and offset of the preceding vowel
5. Maximum speed of glottal opening and its position
6. Maximum speed of glottal closing and its position
7. Maximum speed of velar lowering
8. Maximum speed of velar raising
9. Velar excursion
10. Interval between moment of maximum speed of glottal opening and closing
11. Interval between moment of maximum speed of velar lowering and raising.

For calculation of the parameters based on the physiological signals the signals were first smoothed and velocities were then determined by successive subtractions over 10 ms. steps.

Interest was also attached to determination of the onset of velar lowering and glottal abduction, the latter in particular because we have shown that in German the moment of glottal abduction is the same for plosives and fricatives if measured from onset of the preceding vowel and we were curious to see whether similar relationships obtain for other classes of sounds, and in other languages (see Hoole et al., 1984). However, these measurements presented some difficulties for reasons to be outlined below.

From the air-pressure curves only peak air-pressure in the occlusions was determined.

3 Results

3.1 Basic segment durations

I will begin presentation of the results by mentioning some of the grosser aspects of the temporal organisation of the material investigated - by this I mean effects that are still apparent when the results of all three recordings are lumped together. This should provide a framework for more precise discussion of the physiological parameters.

The words will be treated as consisting of a maximum of three basic segments (see Table 1 and Fig. 1):

1. The vowel preceding the consonantal group;
2. The nasal or pre-aspiration section;
3. The occlusion phase of the plosive.

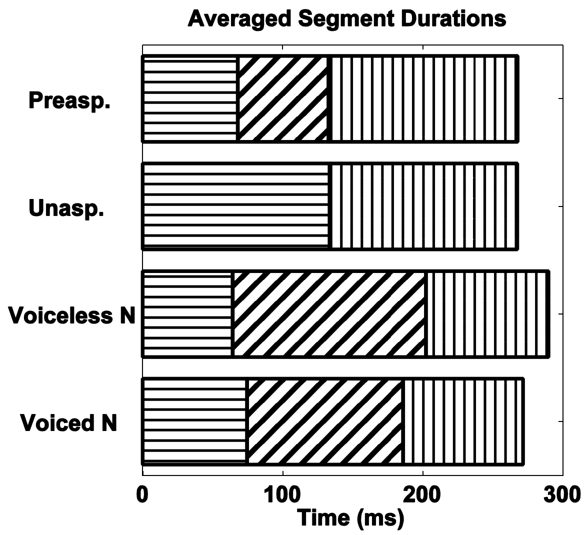


Fig.1:Average durations of the three basic segments for each of the main linguistic categories. Horizontal hatching: Vowel; Diagonal hatching: Preaspiration or Nasal (absent for the unaspirated category); Vertical hatching: Plosive occlusion

Vowel length divided the material into two groups, one group consisting only of sepi, and hiti, in which the (diphthongized) vowel was 120-140 ms in length (segment 2 being completely lacking here of course) and a second group containing all other words, in which the length of the vowel was roughly 60-85 ms. As far as segment 2 is concerned, the length of pre-aspiration was clearly shorter than that of the nasals - 50-70 ms vs. 110-150 ms. Within the nasals the voiceless sounds tended to be longer than the voiced counterparts (see below for more precise evaluation).

The length of segment 3, the plosive occlusion, tended to counterbalance the length of segment 2 with much shorter plosives following the nasals than in the pre-aspirated or unaspirated conditions - ca. 80 ms vs. ca. 120-140 ms.

Table 1. Main segment durations averaged over all three recordings (n=18)

	vowel		nasal or preaspiration		occlusion	
	mean	sd	mean	sd	mean	sd
PREASPIRATED						
hitti	75	9.0	51	12.5	146	20.7
seppi	59	5.7	76	10.0	123	14.9
hetta	70	7.2	67	8.4	136	15.9
UNASPIRATED						
hiti	142	14.5			134	16.4
sepi	125	14.4			134	16.1
VOICELESS NASAL						
henti	63	10.4	141	13.5	92	11.2
dempi	68	4.4	143	10.5	87	15.3
sempinn	62	4.5	130	10.6	83	15.1
VOICED NASAL						
hendi	63	6.0	115	11.7	92	12.7
dembi	86	5.2	108	12.2	79	20.8

3.2 Glottal and velar activity in detail

The results will now be presented and discussed in more detail. Where appropriate 2 x 2 analyses of variance were carried out on the relevant pairs from the basic word list. In order to counter to some extent such problems as zero drift and variations in gain in the physiological signals the raw data were normalized by converting the data of each block in the complete word list to a N(0,l) distribution.

We turn first to the results bearing on the phonological analysis of the pre-aspirates and nasals.

3.2.1 Pre-aspiration or /h/

Regarding the duration of pre-aspiration, it has already been pointed out that the length of pre-aspiration and the length of nasals preceding the plosive is quite different and that, in general, sequences of nasal plus plosive are structured differently from sequences (if this is the right word) of pre-aspiration plus plosive. Furthermore, the length of pre-aspiration, while appreciable, was never as long as the subsequent occlusion (see Table 1 again). Thus in Pétursson's terms the results for this speaker do not offer much support for his hypothesis.

The main point in this subsection is whether the relevant glottal activity suggests a rapprochement between pre-aspiration and /**h**/. Fig. 2 gives ensemble averages for the glottal and velar signals, together with the audio amplitude envelope, of the words examined.

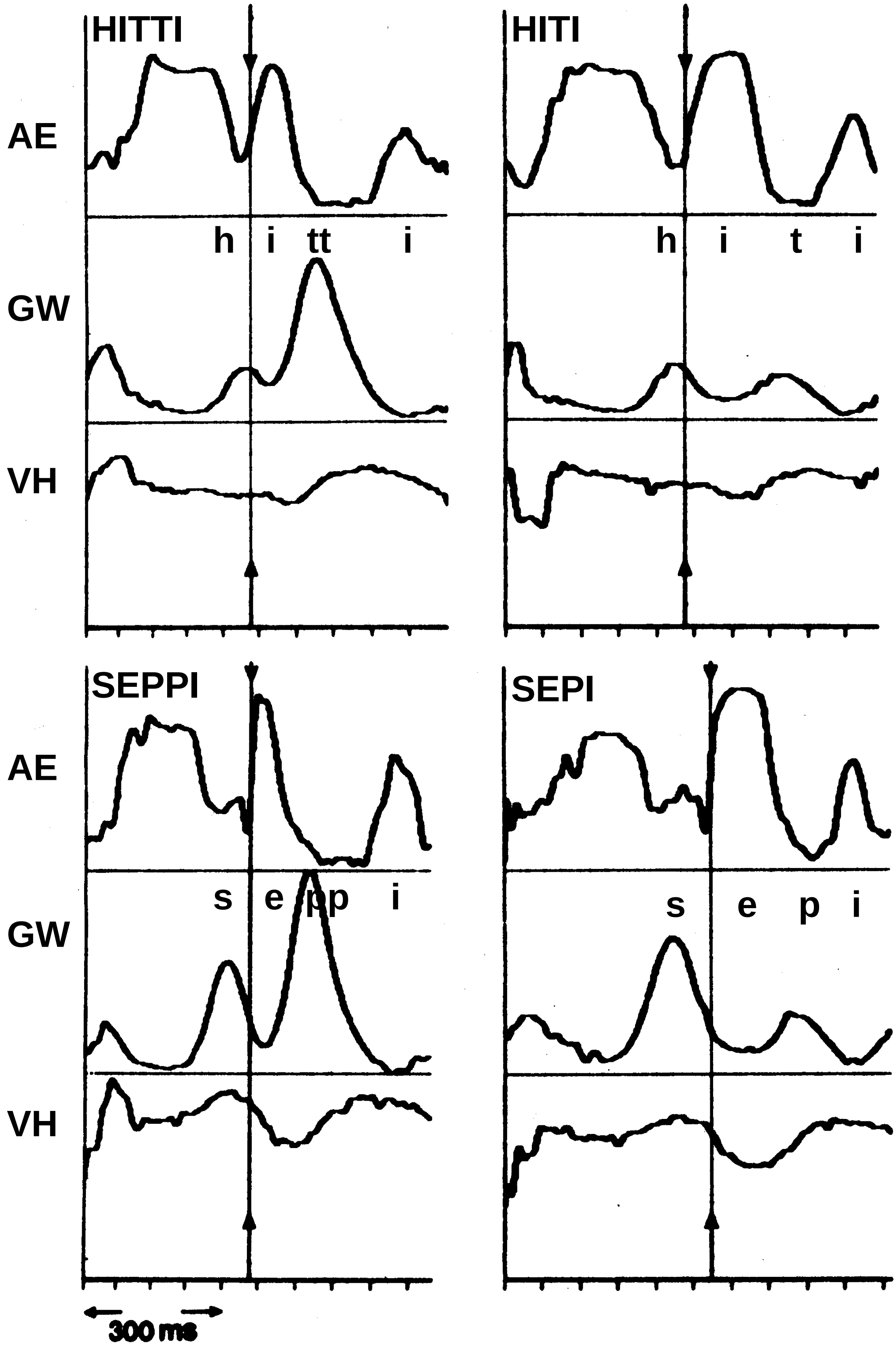


Fig.2a:Ensemble averages (from top to bottom) of audio envelope (AE), Glottal Width (GW) from the photoglottographic signal, and Velar Height (VH) from the velograph signal. Line-up point (line with arrow) at onset of vowel preceding target consonant. Preaspirated and unaspirated consonants.

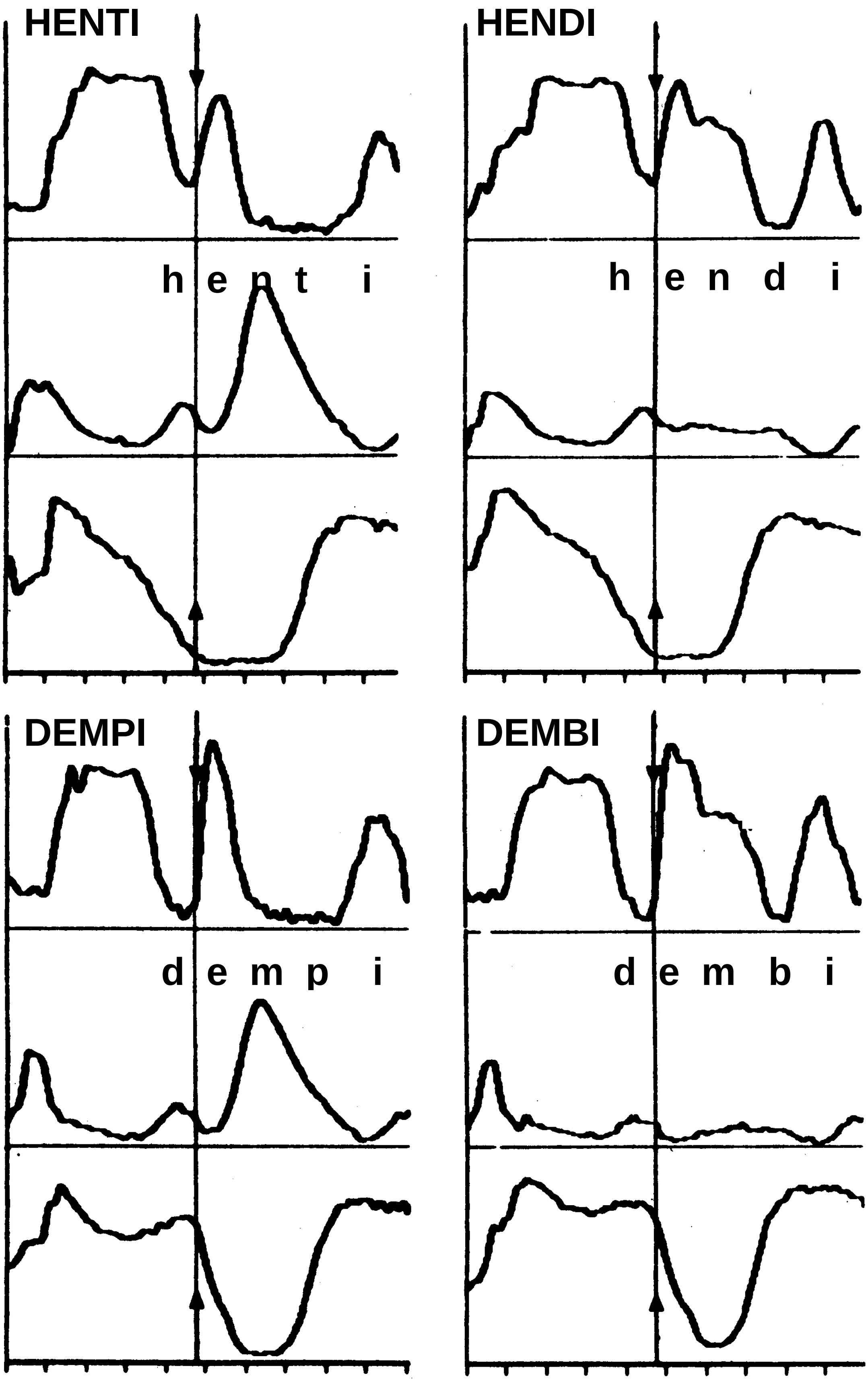


Fig.2b:Ensemble averages for voiceless and voiced nasals. Other details as in Fig. 2a.

The material gives a wealth of examples of /**h**/ in prevocalic, word-initial, pre-stress position. Comparing in particular glottal activity for /**h**/ and for the occlusive in 'hitti' and 'hetta' it is quite clear that activity for /**h**/ is rather restrained compared with the pre-aspirates. The differences are large enough to make any non-linearities in the PGG signal negligible. The differences are the more striking since the pre-stress position for /**h**/ might have been expected to support a more vigorous glottal gesture. In fact, the gesture for the pre-aspirates seems to be even bigger than that for fricatives (cf. 'seppi' etc.). This agrees with Pétursson's results, while Löfqvist & Yoshioka generally noted rather smaller glottal openings for the pre-aspirates. Pétursson considers the extensive gesture for pre-aspirates to be essentially similar to that of other combinations of two voiceless consonants, and this as support for the position that two consonants are in fact present here. What is the basis for deciding which aspect should carry more weight - the similarity in gesture for supposed two-consonant-clusters, or the dissimilarity beween the gesture for pre-vocalic and pre-consonantal /**h**/? It seems to me that arguments based on similarities or dissimilarities do not lead very far - at least not if the aerodynamic and physiological setting in which the language's phonological contrasts have to be produced is not taken into account. The following remarks could be made here: It is conceivable that a larger amplitude of glottal opening is necessary for audible aspiration when this is to be superimposed on a closing movement of the vocal tract (i.e.pre-aspiration) than on an opening movement. And the amount of abduction required is perhaps even less when the voiceless segment is superimposed on a relatively unconstricted vocal tract as in intervocalic /**h**/. The fact that in combinations of two voiceless segments a fairly large gesture occurs is also not surprising since the temporal constraints on the abductory/ adductory cycle are slackened. This slackening of constraints is particularly to be seen in the adductory phase which has often been observed to be more variable in form than the abductory phase. The abductory phase has a particular aerodynamic task to fulfil, whereas the adductory phase does not. In the light of observations of this kind it is probably arbitrary at this level of analysis whether a particular type of voiceless segment is described as /**h**/ or as pre-aspiration.

The recording of velar activity (bottom panels of Fig. 2) failed to reveal any peculiarities in the pre-aspiration phase. No evidence for lowering in the pre-aspiration phase was found. True, the soft palate was often lower during the pre-aspiration phase than during the subsequent occlusion but was in fact usually being raised during this phase moving from the slightly lowered position for the preceding vowel towards the high position for the plosive - all much as one might expect (e.g Bell-Berti, 1980). In other words there is no difference between seppi/sepi etc. in velar activity. Examination of word-initial /**h**/ revealed quite clearly that /**h**/ does not have a characteristic velar position. When a nasal is upcoming, as in 'hendi' velar position is already quite low in the /**h**/ (compare the position for word-initial /**d**/ in 'dembi') while when no nasal is in sight, the position is high, showing at the most some coarticulatory influence of the surrounding vowel.

Thus it is difficult to find support for the identity of /**h**/ and pre-aspiration in velar behaviour.

3.2.2 Pre-aspirates vs. voiceless nasals

We now turn to a direct comparison of glottal activity in the pre-aspirates and the voiceless nasals. Means and standard errors of amplitude and velocity parameters are given in Fig. 3. Both our hypothesis and Pétursson's would lead one to expect the activity to be quite similar in the two (groups of) sounds. Inspection of the ensemble averages in Fig. 2 suggests that this is indeed the case, as far as form and size of the glottal gesture is concerned. However a two-way analysis of variance on hetta,seppi,henti,dempi (i.e. the two leftmost pairs in each panel of Fig. 3) shows that PGO, maximum abduction velocity and maximum adduction velocity are all significantly higher in the pre-aspirates than in the nasals ($p<0.01$).

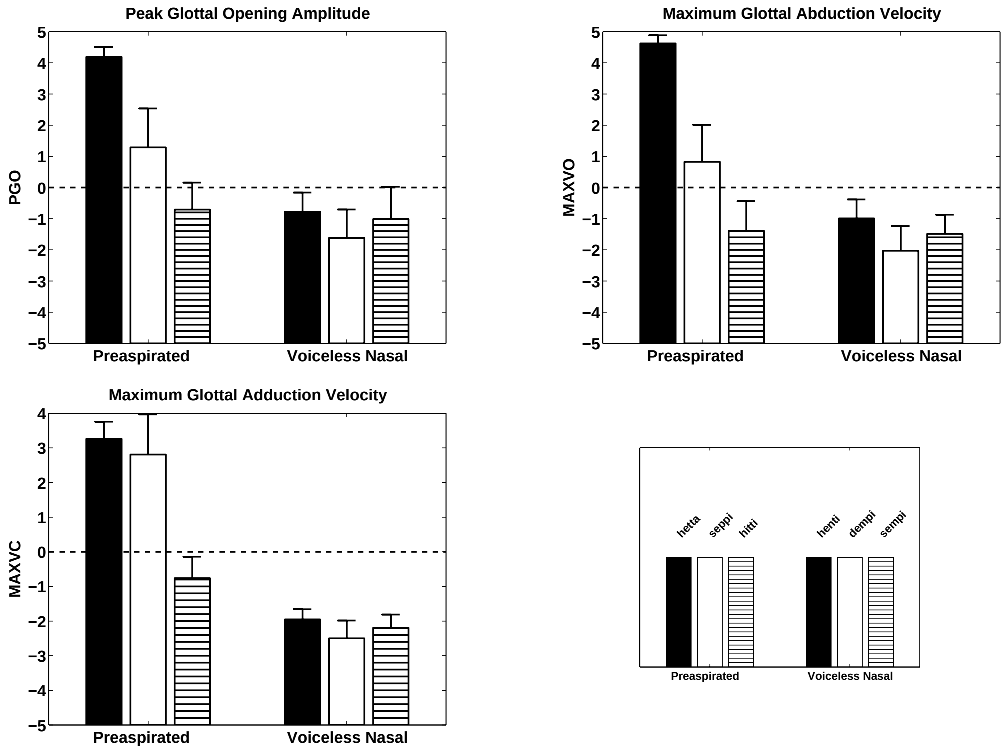


Fig.3: Means of glottal amplitude and velocity parameters for words with preaspirated plosives and voiceless nasals. Data normalized to zero mean and unit standard deviation in each block of repetitions. Bottom right panel indicates identity of each word in the three main panels. Error bars indicate standard error of mean (n=6).

Amplitude information of the transillumination technique should be treated with caution, however. This is underlined by the values for the third pair hitti,sempi in Fig. 3. They were excluded from the analysis of variance as being less directly comparable than the other two pairs, but it is still noticeable that their values are virtually indistinguishable.

Particularly with the third of the parameters just mentioned (maximal adduction velocity) there is some evidence in the ensemble averages for velum-induced artefacts in the PGG curves (velar raising occurs roughly during glottal adduction, whereas velar lowering takes place sometime before glottal abduction).

The relationships in the timing of glottal activity can be approached with more confidence, however. Average results for the timing parameters are shown in Fig. 4. There are some clear differences, but also some interesting similarities between pre-aspirates and nasals. Firstly, it should come as no surprise that the interval from PGO to formation of the occlusion for the plosive is completely different for the NP and HP sounds (top left panel of Fig. 4).

Lumping the raw data for nasals and preaspirates gives:

x = 85.4 ms. +/- 13.5 for the nasals
x = 10.4 ms. +/- 8.6 for the preasapirates

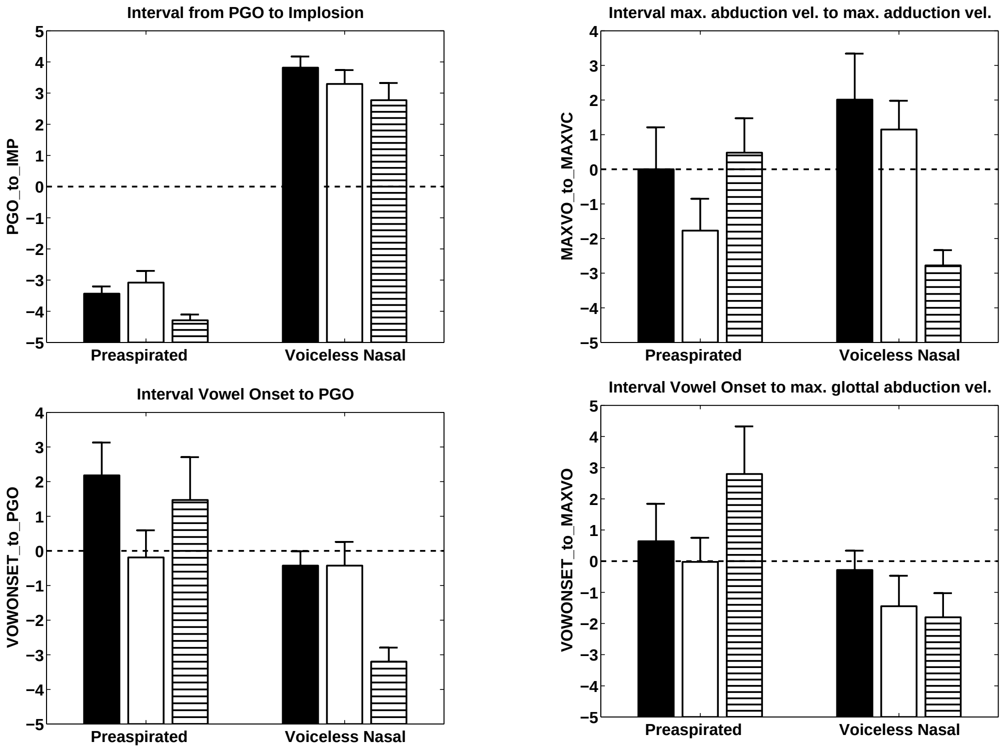


Fig.4: Means of glottal timing parameters for words with preaspirated plosives and voiceless nasals (normalized data). Other details as Fig. 3

This is a natural consequence of the broad similarity in the glottal gesture and the different structuring of the cluster outlined above. However, it does mean that our hypothesis cannot simply claim that a voiceless nasal results from placing a nasal in front of a pre-aspirate which remains otherwise unchanged (see discussion).

Regarding similarities in timing the first point to be made is that there is no difference in the overall duration of the gesture as estimated by the interval from instant of maximum opening speed to instant of maximum closing speed (Fig. 4, top right panel).

We were also particularly interested in determining whether our finding for German that the interval from vowel onset to glottal abduction remained the same for an /**st**/ cluster and a single /**t**/ could be replicated in another language with different material (cf. Hoole et al., 1984). In this case it unfortunately proved impossible to measure the point of glottal abduction reliably due to fluctuations in the baseline of the transillumination signal. Nonetheless, the interval from vowel onset to the moment of maximal abduction velocity, and the interval from vowel onset to PGO were not significantly different in the two classes of sounds (see Fig.4, bottom panels), again excluding the rightmost pair for the reasons given above. Thus, as in the German results, differently structured oral articulations are superimposed on similar glottal activity when viewed from the onset of the preceding vowel.

3.2.3 Voiced vs. voiceless nasals

The next group of results to be presented concerns velar and oral activity in the voiced and voiceless nasals. Under the hypothesis that the voiceless nasals are not themselves voiceless one might expect the nasals to be similar in velar activity and length. As intimated at the beginning of the section this was not borne out in the results. The voiceless nasals as measured from the audio signal (refer back to Table 1 and Fig. 1) were clearly longer ($p < 0.01$), yet there was no reciprocal adjustment in the length of the following plosive, thus replicating Péturssons's earlier results quite closely.

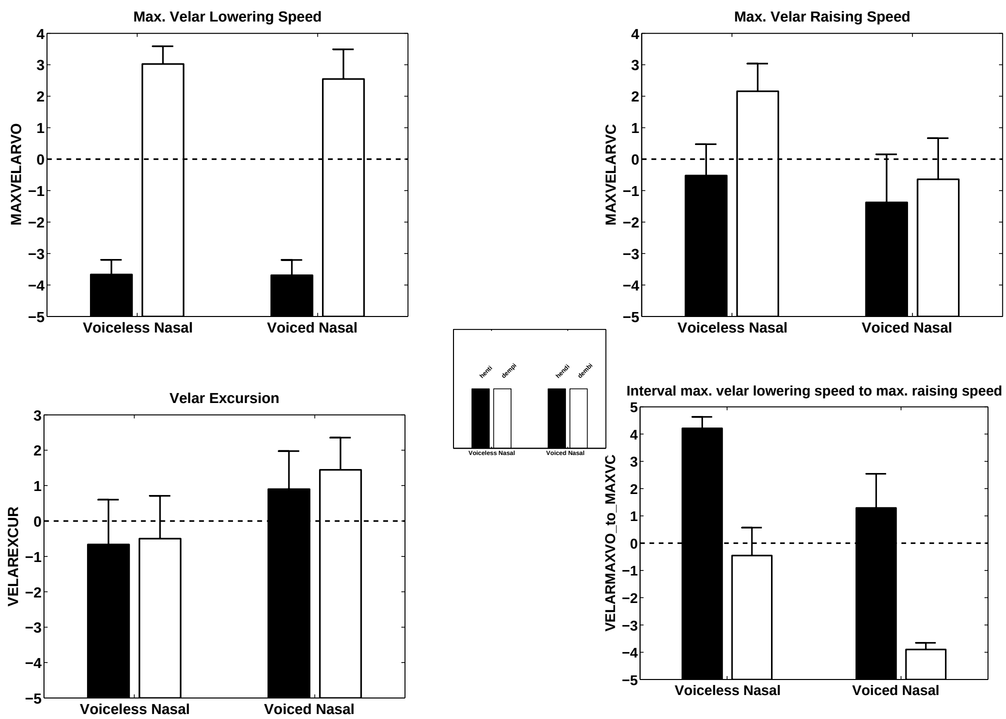


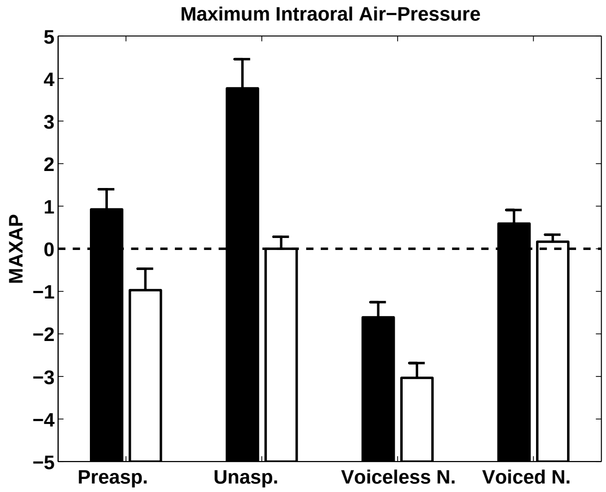
Fig.5: Means of kinematic parameters of velar activity for words with voiced and voiceless nasals (normalized data). In each panel the bars correspond from left to right to 'henti', 'dempi', 'hendi', and 'dembi'. Other details as Fig. 3

Kinematic parameters of the velar gesture itself are shown in Fig. 5. There were no significant differences in maximum raising or lowering speed or in overall excursion based on a two-way analysis of variance of henti, dempi, hendi, dembi. Taking the length of the interval between the positions of maximum lowering and raising speed as a measure of the length of the velar gesture there was also no significant difference in the analysis of variance performed on the raw data - slightly unexpectedly in view of the result obtained from the audio signal. Based on the normalized data, however, the difference was significant ($p<0.0l$). This slightly equivocal result was probably due to the considerable anticipatory coarticulation in hendi/henti which resulted in a slow lowering speed and rather inaccurate determination of the position of maximum lowering velocity. A straight t-test on the raw- data of dempi/dembi turned out to be significant ($p<0.05$).

3.2.4 Plosive occlusions: Duration and air-pressure

The final group of results to be presented here involves the occlusion phase of pre-aspirated and non-aspirated plosives. Lumping the length of the occlusion from all three recordings for the pairs hitti/hiti and seppi/sepi no evidence for longer occlusions in the pre-aspirates could be found since both pairs differ by about 10ms, but in different directions (refer back to Table 1). This is in line with other recent investigations.

From the air-pressure recording we measured the peak air pressure in the occlusion (see Fig 6). Dividing the words into those with a devoicing gesture and those without, a 2 x 4 analysis of variance on /hitti, henti, seppi, dempi/ vs. / hiti, hendi, sepi, dembi/ showed that those without devoicing have significantly higher peak air-pressures ($p<0.0l$), assuming that it is legitimate to arrange the data in this way. The only explanation I can offer for this result is that the expenditure of air in the pre-aspiration phase causes a temporary drop in sub-glottal pressure.



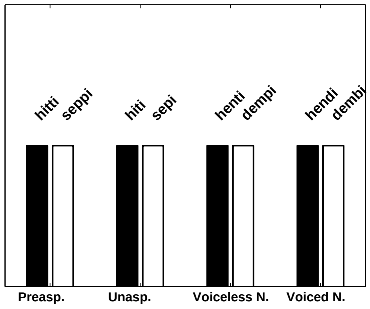


Fig.6:Means of maximum intraoral air-pressure in the occlusion phase. Other details as Fig. 3

4 Discussion

Pétursson’s arguments for analysing pre-aspirates as /**h**/+P received little support. Arguments in favour of the nasal hypothesis remain more equivocal. It might have simplified matters if the different nasals had proved identical in every respect except coarticulatory voicelessness. However the fact that they differ clearly in length obviously does not prevent them being allophones of the same phoneme.

The fact that glottal behaviour was very similar in both cases does not necessarily mean that both cases must have the same number of phonemic segments, i.e. two in Pétursson's view. There are plenty of examples available in the literature.

A more important question, though perhaps pre-destined for an inconclusive answer, involves the changing relationships between glottal and oral activity: When the plosive is preceded by a nasal it becomes shorter - this is in itself a trivial observation yet the effect is the same on both pre-aspirated and unaspirated plosives (see Table 1 again). Should one then expect the glottal gesture in the pre-aspirates to undergo similar modification i.e. should in particular the position of PGO relative to acoustic onset of the plosive remain (relatively) the same? Perhaps so if one adheres to a strict interpretation of a coordinative structure approach - not necessarily if one accepts the point of view we developed on the basis of the German material, namely that the speech mechanism reorganizes oral articulations more readily than glottal ones. However, for the moment, this is no more than a point of view. Nonetheless, the fact remains that glottal activity was not rearranged while oral activity was. At some level this represents an economy of effort; linguistically, the job of the motor system is to maintain the distinction between e.g ‘dempi’ and ‘dembi’. This can be accomplished more reliably by devoicing the nasal completely, and at the same time perhaps more economically by using the glottal activity pattern for normal pre-aspirates. In a sense, it may simply not be appropriate to ask which segment the devoicing gesture ‘belongs’ to.

A last argument in favour of the plausibility of our view of the voiceless nasals is that the same phenomenon, i.e. one of coarticulation, in a different context has traditionally led to an analysis equivalent to the one we are proposing, namely in English such pairs as plead/bleed where one could also assert that the phonological contrast is carried by the voicing of the liquid. Yet few voices have been raised in favour of voiceless /**l**/ as a phoneme of English.

Here I would also venture the hypothesis that in English ‘pea’ vs. ‘plea’ a constant glottal articulation is combined with reorganized oral articulation, so that for example peak glottal opening occurs at a different time relative to the release of the /**p**/ occlusion in the two words.

If our approach is accepted a considerable simplification of the Icelandic sound system results. To be completely coherent however the analysis would have to be extended to the voiceless liquids, which are distributed similarly to the voiceless nasals. The Icelandic sound-system also becomes more typically European (cf. again Werner's (1963) reservations when proposing a rather “uneuropean” system for Faroese) since, in addition to the absence of voiceless continuants, we now have two series of stops with a fairly free distribution if we accept an allophonic rule for place of aspiration. Previously the aspirated stops were restricted to word-initial position, being here post-aspirated.

Finally, we would like to devote a few more words to the topics of coordinative structures and anticipatory velar coarticulation.

Assuming that the production of the voiceless nasal segments requires coordination of velar, laryngeal and oral activity it might be natural to expect these three systems to be constrained to act as a unit. Since we were unable to record velar and laryngeal activity simultaneously in this experiment we cannot attack this question as directly as we would wish. However it is quite apparent from our recordings that the factor most strongly influencing velar activity is the presence or absence of an /**h**/ at the beginning of the word containing the nasal. Bell-Berti (1980) has pointed out that some attempts to demonstrate a feature-spreading model of anticipatory velar coarticulation have failed to take into account the different intrinsic velar heights of purely oral sounds, particularly vowels. There is a great deal of merit in this observation. However, even when this is taken into account, the amount of velar depression by the time the /**h**/ is reached appears so large that it is tempting to think that its specification for velar position is so weak that some feature-spreading is occurring. This experiment was not designed to investigate the viability of feature-spreading as such. For the moment we would simply join Al-Bamerni in suspecting that compared to other articulatory systems velar activity is subject to fewer (or different) constraints.

5 Postscript

The discussion throughout the work presented above centered very much on the ideas presented in Pétursson's many papers, this being the only body of work giving a comprehensive experimental perspective on the relevant phenomena.

However, with hindsight, for the majority of those who have worked on Icelandic sound structure our basic contention is probably neither particularly radical nor controversial, namely that the voicelessness of the nasals in the contexts examined here does not motivate the assumption of nasal phonemes in Icelandic.

Thus, in a more recent paper arguing for voiceless nasal phonemes in Icelandic, Jessen & Pétursson (1998) clearly regard themselves as swimming against the current when they state (p. 43) that "*despite the mainstream opinion it is possible and in several ways desirable to ascribe distinctive status to the voiceless nasals of Icelandic*", and that the majority view favours a derivational account of nasal devoicing that is closely related to analysis of preaspiration. Where our account still differs from the so-called mainstream phonological approach is in the role assigned to coarticulatory processes. It strikes me that this still has the potential to short-circuit much of the discussion since in this perspective nasal devoicing simply does not need accounting for in the phonology, once one has a laryngeal-oral coordination relation for pre-aspirated plosives as a point of departure. This is essentially identical to Browman & Goldstein's original (1986) motivation for a gestural account of laryngeal contrasts. Thus, just by way of example, in a recent analysis within the framework of Optimality Theory Ringen (1999) needs to arrive at a representation that associates [spread glottis] with both the plosive and the preceding sonorant. The wider point is that this may be unnecessary if phonological representations incorporate a concept of time that goes beyond what Gafos (2002) has recently referred to as the 'trivial' concept of time, i.e one restricted to serial order (see also Gafos et al., under review), though admittedly we are not going to resolve such an issue here with limited data on one speaker of Icelandic.

To round off this update of the discussion, it is important to come back to the above-mentioned paper of Jessen and Pétursson, since they raise a number of cogent points that deserve detailed consideration.

First of all, they point out that discussion of the existence of voiceless nasals (and other sonorants) has tended to neglect their occurrence in syllable-initial position[1]. This is certainly an objection that can be made to our own work here. These sounds are undoubtedly phonetically interesting. Although often referred to as voiceless, it appears from a recent study (also including photoelectroglottographic recordings) that they often involve only a rather small amount of glottal abduction and may actually show uninterrupted - but non-modal - voicing (Bombien, in

[1]A contrastive example: nýta [**niːta**] (to use) hnýta [**n̥iːta**] (to knot), from Bombien (in press)

press; see there for further references). This is rather a different situation from the voiceless sonorants before plosives, which appear to be really completely voiceless, and where the amplitude of glottal opening (extending of course into the following plosive) is clearly extensive. We will leave as an open question here whether they should be given phonemic status or analyzed as /**h**/+sonorant. The latter analysis has a tradition extending back to Haugen, but, as Jessen & Petursson note, such sequences would, if adopted, sit rather awkwardly in the rest of the Icelandic sound system.

The other major point they raise concerns the appositeness of regarding voiceless sonorants before plosives as a parallel phenomenon to devoicing of sonorants after voiceless sounds in languages such as English, German and in fact Icelandic itself (cf. Hoole, 1987, 1999).

The first argument they use in this connection is that sonorant devoicing is a gradient phenomenon in English etc. since the the amount of devoicing varies with the preceding sound, e.g plosive, fricative, fricative-plosive cluster, whereas the sounds are categorically and completely voiceless in Icelandic. I am not sure how strong this argument is, since there is probably simply not a comparable range of contexts in Icelandic that could allow gradient behaviour to be revealed.

A rather interesting further observation is that native speakers of Icelandic are not aware of devoicing of sonorants in cases like /**pl**/ any more than phonetically naive English speakers are, but that they are aware of something like voicelessness in the reverse case - which hence should perhaps be regarded as having a different status.

Finally, they raise a point that we would prefer to see from a completely different perspective, but where, paradoxically, we are actually very much in sympathy with the underlying motivation for the direction they are trying to take. In their view, the plosive opposition in pairs like henti/hendi is completely neutralized, i.e both are voiceless unaspirated, and show an occlusion duration that is virtually identical (see Table 1 above, for confirmation of this), whereas this complete neutralization is probably not present in the more familiar cases such as /**pl**/ vs. /**bl**/ etc. Their point of view must assign the glottal gesture exclusively to the nasal (or other sonorant), whereas we are taking the perspective that the basic coordination relation at issue here is the one for a pre-aspirated plosive - even if it does become modified for the cluster compared to the pre-aspirated case. In our view, then, the plosives are, of course, radically different. This is where resolution is difficult: “You pays your money and takes your choice”. Why did we nonetheless just indicate that we were in sympathy with the more general motivation of their argument? Part of their motivation for favouring the phonemicity of the voiceless nasals is that it avoids the necessity for, in their view, an unduly abstract phonological representation, i.e one involving “*the assumption that the voicelessness of sonorants is derived by characteristics of the following stop that are accessible not in concrete phonetic, but only abstract phonological terms*” (p.43).

This is in fact precisely the motivation for the coarticulatory perspective put forward here: we assume that we do indeed have a very concrete difference between the stops, and obtain the voiceless nasals by getting as much mileage as possible from the application of very general and unabstract principles of coordinated behaviour.

Nobody would deny that the temporal dimension is crucial to speech. In fact, all human behaviour is probably built up on principles of temporal coordination. The widely diverging views for the small problem discussed here may simply reflect the fact that principles of temporal coordination have not yet been well integrated into phonological representations, and, more surprisingly, often not even into phonetic accounts.

6 References

Al Bamerni, A. (1984). "Speech rate and velar control". In: Cohen, A. & van den Broecke, M.P.R. (Eds.), Abstracts of the 10th Int. Cong. Phon. Sci., p. 464.

Bell-Berti, F. (1980). "Velopharyngeal function: A spatio-temporal model". Haskins SR 63/4, 41ff..

Bombien, L. (In press). "Voicing alternations in Icelandic sonorants – a photoglottographic and acoustic analysis". ARIPUC, IPDS, Kiel.

Browman, C.P. & Goldstein, L. (1986). "Towards an articulatory phonology". Phonology Yearbook, 3, 219-252.

Gafos, A., Hoole, P., Roon, K. & Zeroual, C. (Under review). "Variation in timing and phonological grammar in Moroccan Arabic clusters". Papers from LabPhon 10, Paris, June 2006.

Gafos,A. (2002). "A grammar of gestural coordination". Natural Language and Linguistic Theory, 20 (2), 269-337.

Garnes, S. (1973). "Phonetic evidence supporting a phonological analysis". J. Phonetics 1, 273-283.

Haugen, E. (1958). "The phonemics of modern Icelandic". Language 34, 55-88.

Hoole, P., Pompino-Marschall, B. & Dames, M. (1984). "Glottal timing in German voiceless occlusives". In Van den Broecke, M.P.R & Cohen, A. (Eds.) Proc. 10th Int. Cong. Phonetic Sciences, 309-403.

Hoole, P. (1987). "Velar and glottal activity in a speaker of Icelandic". Proc. 11th Int. Cong. Phonetic Sciences, 3, 31-34..

Hoole, P. (1999). "Laryngeal Coarticulation. Section A: Coarticulatory investigations of the devoicing gesture". In: W.H Hardcastle and N. Hewlett (eds.), Coarticulation: Theory, Data and Techniques, pp. 105-121. Cambridge University Press.

Hutters, B. (1976). "Problems in the use of the photoelectric glottograph". ARIPUC, 10, 274-312.

Jessen, M. & Pétursson, M. (1998). "Voiceless nasal phonemes in Icelandic". J. Int. Phon. Assoc., 28, 42-53.

Künzel, H. J. (1979). "Röntgenvideographische Evaluierung eines photoelektrischen Verfahrens zur Registrierung der Velumhöhe beim Sprechen". Folia Phoniatrica, 31, 153-166.

Löfqvist, A. & Yoshioka, H. (1980a). "Laryngeal activity in Icelandic obstruent production". Haskins SR 63/4, 275ff ; also in Nordic Journal of Linguistics, 4, 1-18 (1981).

Löfqvist, A. & Yoshioka, H. (1980b). "Laryngeal activity in Swedish obstruent clusters". JASA, 63, 792-801.

Pétursson, M. (1972). "La préaspiration en islandais moderne. Examen de sa réalisation phonétique chez deux sujets". Studia Linguistica, 26, 61-80.

Pétursson, M. (1973a). "Phonologie des consonnes nasales en islandais moderne". La Linguistique, 9, 115-138.

Pétursson, M. (1973b). "L'origine des phonèmes nasals et liquides sourds et du h postvocalique de l'islandais moderne". Orbis, 22, 335-342.

Pétursson, M. (1975). "Examen expérimental de la réalisation phonétique des nasales sourdes de l'islandais moderne". In K.-H.. Dahlstedt (ed.) The Nordic Languages and Modern Linguistics, 2, 634-653.

Pétursson, M. (1976). "Aspiration et activité glottale. Examen expérimental à partir de consonnes islandaises". Phonetica, 33, 169-198.

Ringen, C. (1999). "Aspiration, preaspiration, deaspiration, sonorant devoicing and spirantization in Icelandic". Nordic Journal of Linguistics, 22, 137-156.

Werner, O. (1963). "Aspiration und stimmlose Nasale/Liquide im phonologischen System des Färingischen". Phonetica, 9, 79-107.