# Velar and Glottal Activity in Icelandic*

**Philip Hoole**
**Lasse Bombien**

**Abstract:** Transillumination data was used to analyze laryngeal-oral coordination in Icelandic pre-aspirated plosives and groups of voiceless nasal plus plosive (together with comparison items with unaspirated plosive, and voiced nasal plus plosive). Analysis focussed firstly on whether pre-aspirated plosives are better regarded not as a counterpart to familiar (post)-aspirated plosives but rather as a sequence of /h/+plosive, and secondly on the phonemic status of voiceless nasals, given the existence of apparent minimal pairs of voiceless vs. voiced nasal followed by plosive (for one of the three subjects photoelectric data on velar movement supplemented the laryngeal data). Little evidence was found for regarding pre-aspirated plosives as /h/+plosive. This, in turn, makes it possible to closely link pre-aspirated plosives and voiceless nasals within a coarticulatory framework. The voiceless nasals are best regarded as not having phonemic status but rather as emerging from coarticulation with a following pre-aspirated plosive, thus forming a counterpart to the coarticulatory voicelessness of sonorants in sequences such as /pl/ in languages with post-aspirated plosives.

* The first author would like to thank Bernd Pompino-Marschall for awakening his interest in the topic of articulatory coordination in general, and, in particular, for recruiting the main subject. Both authors would like to thank him for the extensive opportunities they have enjoyed to acquire laryngeal fiberoptic and transillumination data at the phonetics lab of Zentrum für Allgemeine Sprachwissenschaft, Berlin. An acknowledgement is also in order to the Icelandic volcano Eyjafjallajökull ([ˈɛɪjaˌfjatlaˌjœkʏtl̥]) for raising public awareness of devoicing of sonorants, and, by disrupting air-traffic, for giving the first author the enforced leisure necessary to finalize the manuscript. Thanks also to Christine Mooshammer and an anonymous reviewer for constructive comments.

# 1 Introduction[1]

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 since then looked closely at various aspects of Icelandic phonetics (e.g. Pétursson, 1972, 1973a, 1975, 1976; Garnes, 1973; Löfqvist and Yoshioka, 1980). Indeed, as the latter have pointed out, Icelandic provides plenty of scope for investigations of the temporal organization of speech. Their work concentrated on glottal activity, including pre-aspirated plosives, which is a main focus of interest here. A further noteworthy aspect of Icelandic is the existence of voiceless nasals (see Pétursson, 1973b, for a phonological analysis), which thus involve the coordination of labial or lingual, velar and glottal gestures.

In this work we will consider velar and glottal activity in pre-aspirated plosives and voiceless nasals as part of the more general aim of using phonetic analysis to throw light on phonological problems. We will attempt to show that pre-aspirated plosives and voiceless nasals are more closely related than has often been assumed to be the case, particularly when these sounds are viewed from the perspective of coarticulatory processes. 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. Our debt to Pétursson's work will be clear, although we take issue with him on a number of points.

1 The work presented here has had a convoluted history: A preliminary version appeared many years ago as a conference presentation in Hoole (1987). A longer version was then prepared, but never submitted for publication. It eventually formed the appendix to an unpublished habilitation thesis on laryngeal articulation (Hoole, 2006a). The present version now supplements the single original speaker with more recent laryngeal data for two additional speakers (details in Bombien (2006)). Apart from these new data the introductory and results sections of the present paper still reflect the way in which the issues were formulated for the original paper. The results, the underlying questions, and the preliminary discussion in Section 4 are placed in the perspective of more recent literature in the concluding Section 5 ("General Discussion")

## 1.1 Pre-aspirated plosives

Let us start with the pre-aspirated plosives. Phonetically, it is firmly established that they are produced with glottal abduction starting well before implosion of the plosive itself (by implosion we mean the time-point at the onset of consonantal closure at which a sharp rise in intra-oral air-pressure begins). In fact, implosion corresponds roughly to the time at which peak glottal opening (PGO) occurs. A hardy annual in the field of Icelandic phonology has been the question of quantity, since Icelandic possesses quite a rich pattern of contrasting vowel and consonant durations. 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). Previous 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 than for the unaspirated case; Pétursson (1972)).

Pre-aspirated plosives occur only word-medially, e.g. 'seppi', and finally, e.g. 'löpp'. (leg) In combination with other consonants they occur only before /l/ and /n/, e.g. 'epli'(apple), 'opna' (open).

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 approximately 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 feel awkward about 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 linked to vowel offset needs to be longer for perceptual saliency than aspiration linked to vowel onset.

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 stated, the analysis as a whole seems quite plausible. In particular it has the merit of fitting in with the prediction that a plosive following a voiceless consonant is unaspirated.

However, we think it will be possible to show, on the basis of our own data, 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, 1973b, for a review), generally being considered to include four voiced ([m, n, ŋ, ɲ]), and the corresponding four voiceless nasals (as well as four 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' [dɛm̥pɪ] 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 post-aspiration with 'dembi' ([dɛmpi]).[2] The only experimental investigation, to our knowledge, 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) The difference in plosive duration following voiceless vs. voiced nasals is very small (any tendency was in the direction of shorter plosives after voiceless nasals).
c) Vowels preceding 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.[3]

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 pre-aspirated (authors' note)] *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

---

2 Pre-aspiration itself does also occur in Northern Icelandic in the words such as 'seppi' given in the previous section.

3 The more recent paper of Jessen and Pétursson (1998) also comes to the conclusion that there are no consistent differences in duration of the plosive following the different nasals. This paper is considered in more detail below in the General Discussion.

point of view, possibly as a result of a misunderstanding: "*Haugens Argumente sind wertlos, weil es aus physiologischen Gründen weder einen aspirierten noch einen stimmhaften Verschlusslaut nach stimmlosem Nasal geben kann*" (1975, p. 653)[4]. This is the more curious since Pétursson (1973a) has himself given a plausible account in coarticulatory terms of the genesis of pre-aspirates 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 pre-aspirates are phonemically /h/+P, and on this basis it is only consistent to regard the voiceless nasals as phonemes as well.
As already intimated at the beginning of the introduction, we believe that in fact it will be possible to argue that the most consistent picture of these sounds emerges if this coarticulatory perspective is retained for the synchronic analysis as well.
In short, the line of argument to be followed below is as follows:
First, the pre-aspirates must be examined. If no compelling reason is found for regarding them as sequences of /h/+plosive, then viewing voiceless nasals as a consequence of coarticulation with a following pre-aspirated plosive becomes a possible scenario. For the scenario to be not just possible but plausible we then need to show similarity in the glottal behaviour of the two classes of sounds. In addition, further articulatory and acoustic comparison of voiceless and voiced nasals also needs to be compatible with regarding them as allophones of the same phoneme.

# 2 Material, method, subjects

The recordings were carried out in two parts. The first part consisted of recordings of laryngeal movement, velar movement, and intraoral airpressure for a single subject (S1). These will be referred to as the main recordings. The second part consisted of recordings of laryngeal movement for a subset of the material for two additional subjects (S2 and S3). These will be referred to as supplementary recordings.

4 "Haugen's arguments have no value, because for physiological reasons it is not possible to have either an aspirated or voiced occlusive following a voiceless nasal".

## 2.1 Main recordings

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 list of two groups of four words each, the sounds of interest all being in medial, post-stress position.

| | | | |
|---|---|---|---|
| hitti | hɪ$^h$tɪ | pre-asp | *meet* (1 sg. pret) |
| hiti | hɪ:tɪ | unasp | *heat* (nom. Sg. m) |
| henti | hɛn̥tɪ | voiceless N | *throw away* (1 sg. pret) |
| hendi | hɛntɪ | voiced N | *hand* (dat. Sg. f) |
| | | | |
| seppi | sɛ$^h$pɪ | pre-asp | *dog* (name) |
| sepi | sɛ:pɪ | unasp | *rag* |
| dempi | dɛm̥pɪ | voiceless N | *dampen* (1. Sg. pres. Conj.) |
| dembi | dɛmpɪ | voiced N | *throw* (1 sg pres conj.) |

One additional word each for the pre-aspirate and voiceless nasal case were also included ('sempinn' is lexically somewhat marginal):

| | | | |
|---|---|---|---|
| hetta | hɛ$^h$ta | 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 of 10 words 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 ____ þá" (" *I say* ____ *then*").

The following procedure was followed for the recordings: Glottal activity was assessed using the transillumination technique (F-J Electronics' photoelectroglottograph), 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 phototransistor inserted nasally into the pharynx. Here the devoicing gesture was of principal interest, and for this the method is considered quite reliable (Hutters, 1976; Löfqvist and Yoshioka, 1980), 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 phototransistor 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, and 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 the photoelectroglottgram in the first recording, the velogram in the second and the intra-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 (peak glottal opening) 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 (i.e. parameters 4-11 in the above list) the raw signals were first smoothed and, for the sub-set based on velocities (i.e. parameters 5-8, 10, 11), velocities were then determined by successive subtractions over 10 ms. steps. As further timing parameters, interest was also attached to determination of the onset of velar lowering and glottal abduction. For the latter, we have shown that in German the time-point at which glottal abduction starts is the same for plosives and fricatives if measured from onset of the preceding vowel. 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 in the results below (in section 3.2.2 for glottal movements; in section 3.2.3 for velar movements). From the air-pressure curves only peak air-pressure in the occlusions was determined.

## 2.2 Supplementary recordings

These recordings were carried out nearly 20 years after the main recordings and used a different arrangement of the transillumination technique

for capturing laryngeal movements. Specifically, the larynx was filmed (video) using an Olympus ENF-P3 fiberscope.[5] The endoscopic light-source simultaneously provided the light for the transillumination signal, which was registered by means of phototransistors attached externally to the neck below the level of the glottis. Details of this technique, together with further discussion of methodological issues, can be found in Hoole (1999b, 2006b).
Two subjects (S2 and S3) recorded a corpus for the investigation of Icelandic sonorants that is presented in detail in Bombien (2006). It included four items that overlapped with the corpus of the main recordings, namely 'hitti', 'hiti', 'henti' and 'hendi',i.e. one item for each of the four consonant categories of interest. For both speakers 8-10 repetitions of these items were available for analysis. These data will be used to supplement the data from S1 for the analysis of acoustically based segment durations (principally section 3.1) and laryngeal kinematics (section 3.2.1 and 3.2.2).

# 3 Results

## 3.1 Basic segment durations

### 3.1.1 Main recordings

We will begin presentation of the results by mentioning some of the grosser aspects of the temporal organisation of the material investigated. By this are meant effects that are still apparent when the results of all three recordings for S1 are merged. This will then 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: 1. The vowel preceding the consonantal group; 2. The nasal or pre-aspiration section; 3. The occlusion phase of the plosive. Figure 1 shows the results for S1 in graphical form, averaging over all three recordings and over all word forms within each linguistic category. Table 1 shows a breakdown for each word form in the corpus and also includes the supplementary data from S2 and S3. On the basis of vowel length the

5 These recordings were carried out at ZAS, Berlin, with the kind assistance of Dr. Klaus Dahlmeier.

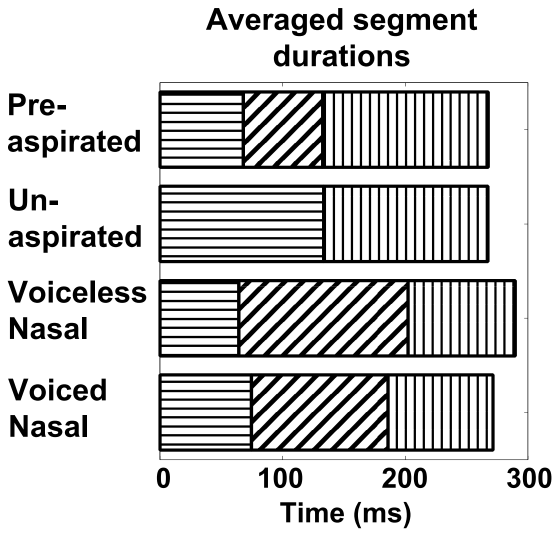


**Figure 1.** Average duration ofs the three basic segments for each of the main linguistic categories. Horizontal hatching: Vowel; Diagonal hatching: Pre-aspiration or Nasal (absent for the unaspirated category); Vertical hatching: Plosive occlusion.

material fell 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.

### 3.1.2 Supplementary recordings

The results of S2 and S3, given in Table 1, are comparable to those of S1 in all the following respects: 1. relative length of pre-aspiration and nasal segments, i.e. the pre-aspiration (in ‘hitti’) is clearly shorter than the nasal segments (in ‘henti’ and ‘hendi’); 2. the nasal segment is longer in the voiceless than voiced nasals; 3. the plosive occlusion durations are shorter in the words with nasals than in the pre-aspirated and unaspirated category. The only substantial difference from the temporal pat-

**Table 1.** Mean (in bold face) and sd of segment durations (in ms), For main subject (S1) averaged over all three reordings (n=18). For supplementary subjects (S2, S3), n=8-10.

| | | | Duration in (ms) | | |
|---|---|---|---|---|---|
| Word | Categ. | S | vowel | nasal/preasp. | occlusion |
| seppi | Pre- | 1 | **59** ± 5.7 | **76** ± 10.0 | **123** ± 14.9 |
| hetta | asp. | 1 | **70** ± 7.2 | **67** ± 8.4 | **136** ± 15.9 |
| hitti | | 1 | **75** ± 9.0 | **51** ± 12.5 | **146** ± 20.7 |
| hitti | | 2 | **80** ± 9.8 | **17** ± 4.8 | **73** ± 15.4 |
| hitti | | 3 | **85** ± 10.3 | **44** ± 20.0 | **115** ± 6.3 |
| sepi | Un- | 1 | **125** ± 14.4 | | **134** ± 16.1 |
| hiti | asp. | 1 | **142** ± 14.5 | | **134** ± 16.4 |
| hiti | | 2 | **86** ± 8.2 | | **71** ± 5.3 |
| hiti | | 3 | **88** ± 16.3 | | **131** ± 7.8 |
| dempi | Voice- | 1 | **68** ± 4.4 | **143** ± 10.5 | **87** ± 15.3 |
| sempinn | less | 1 | **62** ± 4.5 | **130** ± 10.6 | **83** ± 15.1 |
| henti | Nasal | 1 | **63** ± 10.4 | **141** ± 13.5 | **92** ± 11.2 |
| henti | | 2 | **57** ± 3.1 | **82** ± 8.2 | **42** ± 5.5 |
| henti | | 3 | **57** ± 8.0 | **116** ± 19.0 | **83** ± 11.1 |
| dembi | Voiced | 1 | **86** ± 5.2 | **108** ± 12.2 | **79** ± 20.8 |
| hendi | Nasal | 1 | **63** ± 6.0 | **115** ± 11.7 | **92** ± 12.7 |
| hendi | | 2 | **50** ± 10.5 | **65** ± 10.2 | **55** ± 11.4 |
| hendi | | 3 | **54** ± 12.5 | **78** ± 11.7 | **103** ± 18.8 |

terns of S1 involves a less central concern of the present investigation, namely the fact that the newer subjects show no evidence of longer vowels in unaspirated ‘hiti’. A further less striking difference is that the new subjects show rather shorter vowels for words with nasals than those without. The main difference between the new subjects is that S2 has shorter occlusion (and also pre-aspiration) durations than S3, despite having very similar vowel durations.

## 3.2 Glottal and velar activity in detail

Continuing on from the overview of the temporal structure of the utterances given in the previous section we will now discuss in detail the relevant laryngeal and velar kinematics. Figures 2 and 3 show ensemble averages for the glottal and velar signals, together with the audio amplitude envelope, of 8 of the 10 words examined for S1 (i.e. two words for each of the four linguistic categories). Table 2 gives the magnitude of peak glottal opening for S2 and S3. These serve to indicate that all three subjects agreed in the gross features of laryngeal behaviour, i.e. no glottal opening for the voiced nasal category, weak abduction for the unaspirated, and substantial abduction for the pre-aspirated and voiceless nasals. Whether the latter two categories nevertheless differ in their laryngeal kinematics will be considered in detail below.

**Table 2.** Mean peak glottal opening amplitude for the supplementary subjects (n=9)

| | Mean Peak Glottal Opening in Volt | |
|---|---|---|
| Word | S2 | S3 |
| hitti | 1.91 | 1.85 |
| hiti | 0.25 | 0.53 |
| henti | 1.94 | 2.01 |
| hendi | -0.01 | -0.02 |

Quantitative analysis for S1 was supported, where appropriate, by 2 x 2 analyses of variance 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 in each block of repetitions to zero mean and unit standard deviation. For S2 and S3 (where only glottal kinematics are relevant) there was an insufficient range of material in the word-medial position for the kind of normalization just mentioned to be appropriate. Accordingly, statistical testing was based on Wilcoxon signed rank tests with word pairs (e.g. a pre-aspirated and a voiceless nasal pair) matched by block (repetition number). This non-parametric procedure (apart from being insensitive to outliers in general) can be assumed to be relatively insensitive to changes in the gain in the transillumination signal, caused, for example, by changes in the position of the fiberscope, over the course of the recording (such changes were indeed clearly present). We turn first to the results bearing on the phonological analysis of the pre-aspirates and nasals.

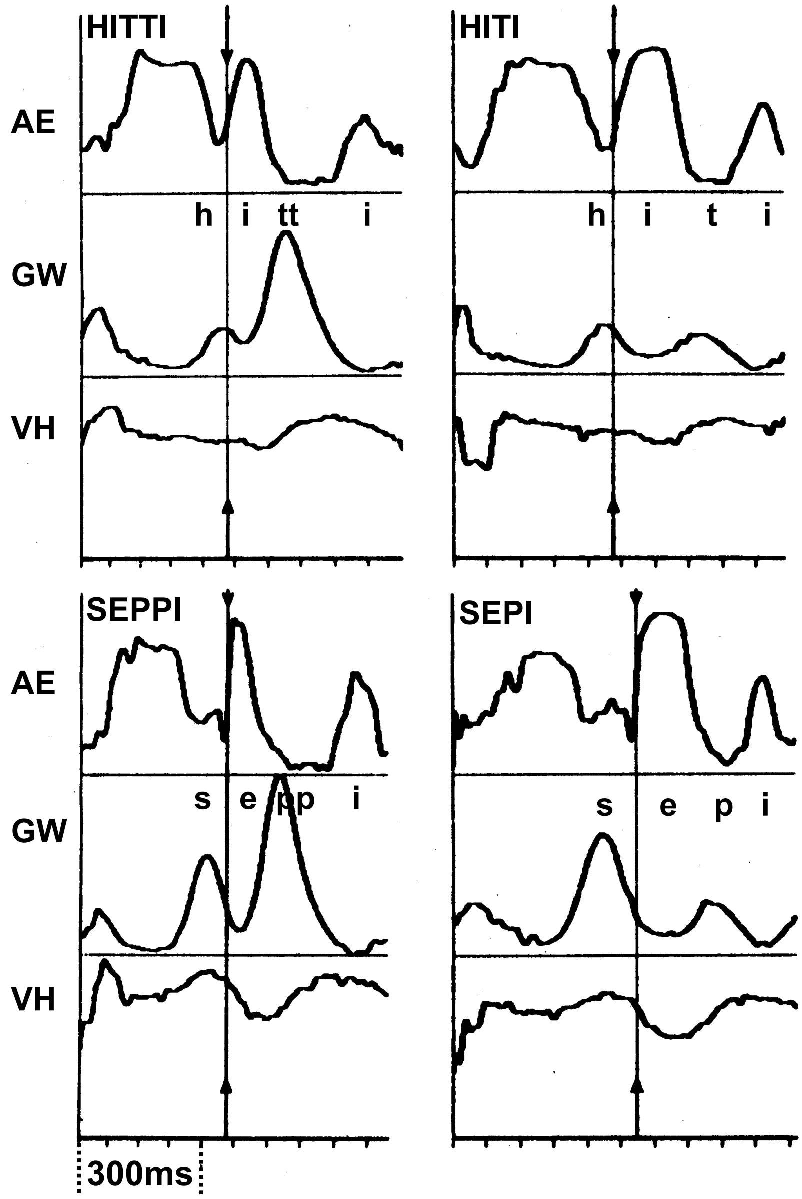


**Figure 2.** Ensemble averages for pre-aspirated and unaspirated consonants of S1. From top to bottom: Audio Envelope (AE); Glottal Width (GW) from the photoglottographic signal; Velar Height (VH) from the velograph signal. Line-up point (line with arrow) at onset of vowel preceding target consonant. Lower-case transliteration in GW panels indicates rough alignment of segments. No units are shown for the glottal and velar movement signals because the signals from the phototransistors cannot be calibrated. However, across Figures 2 and 3 all sub-panels for a given signal are shown with the same scaling.

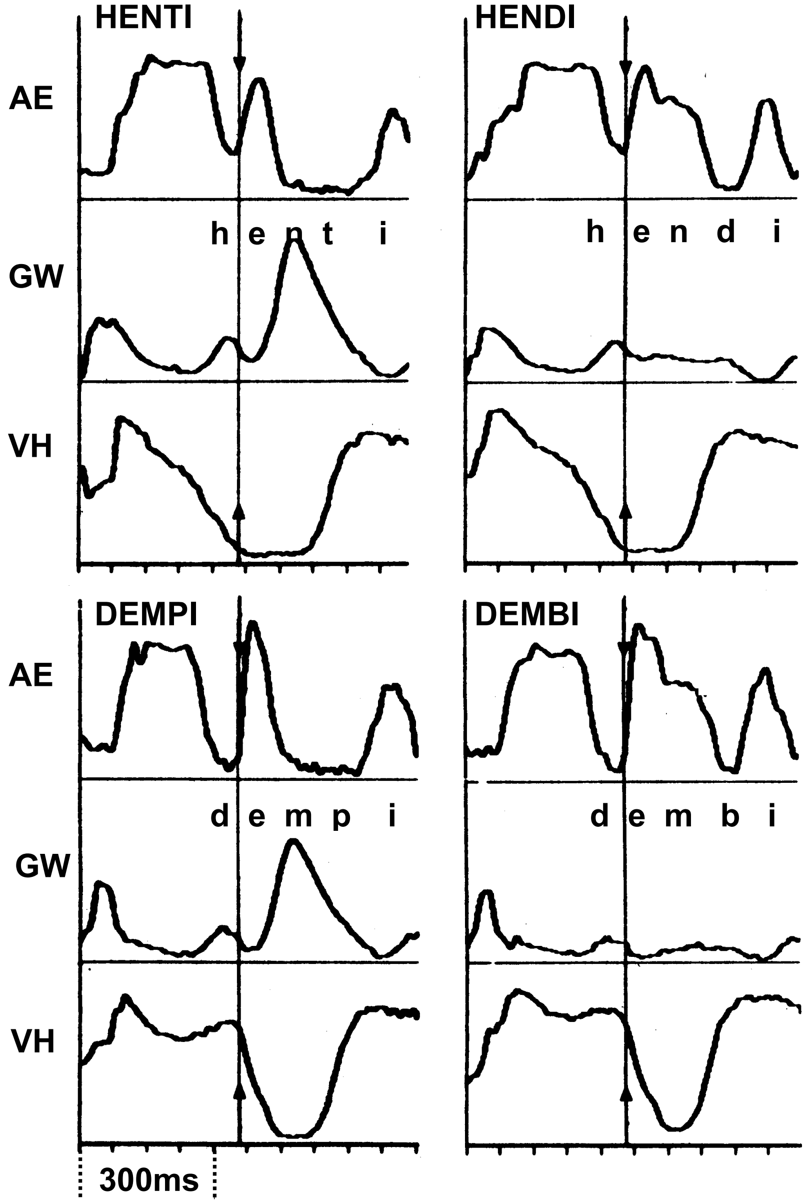


**Figure 3.** Ensemble averages for voiceless and voiced nasals of S1. Other details as in Figure 2.

### 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, even for subjects S1 and S2 with the longest pre-aspiration segments, was never anywhere near as long as the subsequent occlusion (see Table 1). Thus in Pétursson's terms the results for these speakers do not offer much support for his hypothesis.

The main point in this subsection is whether the relevant glottal activity suggests a close connection between pre-aspiration and /h/. 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' for S1 in Figure 2 it is quite clear that activity for /h/ is rather restrained compared with the pre-aspirates (the same applies to 'hetta', which is not shown in the ensemble averages; note also the clearly smaller opening for /h/ than for the voiceless nasal in 'henti' in Figure 3). 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.

Of the supplementary speakers, the results for S3 were very similar to those of S1: the magnitude of glottal opening was significantly larger for the pre-aspirate of 'hitti' than the initial /h/ ($p<0.01$). For S2 the pre-aspirate had only a marginally larger opening, and this did not approach significance ($p>0.6$). For both these speakers, just as for S1, the glottal opening for the voiceless nasal was significantly larger than the initial /h/ ($p<0.05$ for S2, $p<0.01$ for S3). We will see below that there is no strong evidence for differences in the glottal gesture of the pre-aspirates and the voiceless nasals. The present section thus indicates overall more vigorous glottal abduction for these medial consonantal articulations than for initial /h/.[6] Pétursson considers the extensive ges-

6 In view of the equivocal result for S2 (a significant difference from /h/ for voiceless nasals but not pre-aspirates) and the fact that in the next section he showed no trace of a difference between glottal activity for the pre-aspirates and voiceless nasals, we re-ran

ture 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/? We would suggest that arguments based on similarities or dissimilarities do not take us very far - at least 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/ (cf. Hutters, 1984, for similar findings in Danish fricatives). 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. Turning now from glottal to velar activity (for S1 only), the issue here is whether Pétursson's observation can be replicated that both phonemic /h/ as well as pre-aspiration may show slight lowering of the velum. The recording of velar activity (bottom panels of Figures 2 and 3) 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, i.e. moving from the slightly lowered position for the preceding vowel

---

the statistical test for comparing with /h/ after pooling the pre-aspirates and voiceless nasals, thus increasing n from 9 to 18. This gave a significant difference between the pooled medial consonants and initial /h/ at $p<0.05$.

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 for three kinematic parameters are given for S1 in Figure 4: 1. peak glottal opening amplitude; 2. peak abduction velocity; 3. peak adduction velocity (timing parameters are considered afterwards). 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 Figures 2 and 3 suggest 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 Figure 4) shows that PGO, maximum abduction velocity and maximum adduction velocity are all significantly higher in the pre-aspirates than in the nasals ($p<0.01$).[7] Amplitude and velocity information of the transillumination technique should be treated with caution, however. This is underlined by the values for the third pair 'hitti, sempinn' in Figure 4. 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.[8] Moreover, for both of the supplementary subjects PGO

7 Note that 'hetta', the item with the largest opening amplitude, is not shown in the ensemble averages of Figures 2 and 3.

8 Caution is probably particularly in order for the third of the kinematic parameters shown in Figure 4 (maximum adduction velocity): There is some evidence in the ensemble averages of Figures 2 and 3 for velum-induced artefacts in the PGG curves (velar raising occurs roughly during glottal adduction, whereas velar lowering takes

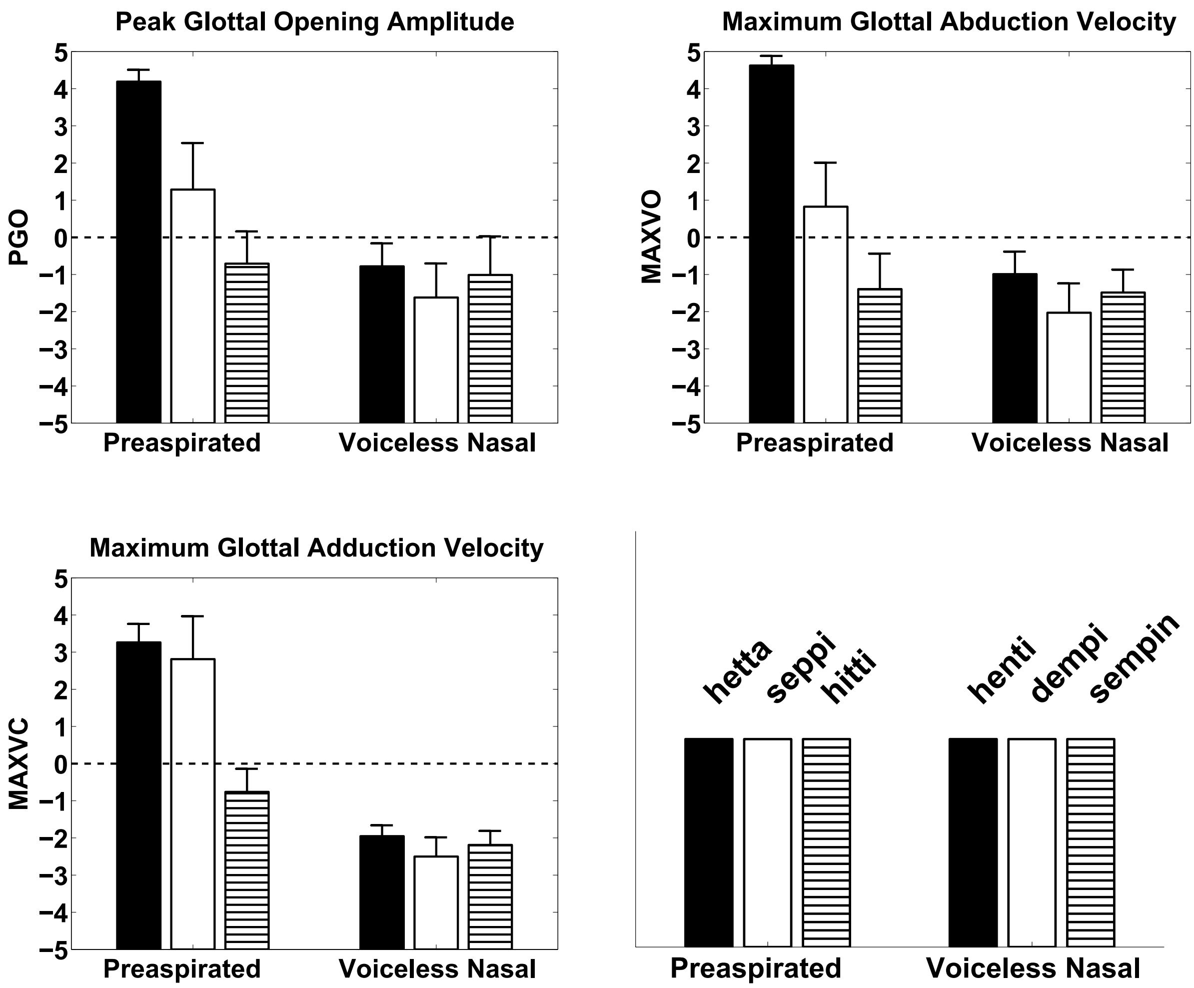


**Figure 4.** Means of glottal amplitude and velocity parameters for words with preaspirated plosives and voiceless nasals. Data normalized to zero mean and unit standard deviation in each block of repetitions. Bottom right panel indicates identity of each word in the three main panels. Error bars indicate standard error of mean (n=6).

amplitudes are marginally higher for the voiceless nasal 'henti' rather than the pre-aspirate 'hitti'. But these differences are nowhere near being significant in the signed rank test over 9 matched pairs (p-values of approx. 0.8 for both subjects).[9] And similarly for both the velocity parameters neither of these subjects showed any evidence at all of significant differences. The relationships in the *timing* of glottal activity can be approached with more confidence, however. Average results for the timing parameters are shown for S1 in Figure 5. There is one clear dif-

place sometime before glottal abduction).

9 As can be seen from Table 2 the mean amplitude differences do not exceed 0.2V for either subject. To put this in perspective, the standard deviation of the pairwise differences amounted to 0.8 (S2) and 0.9 (S3).

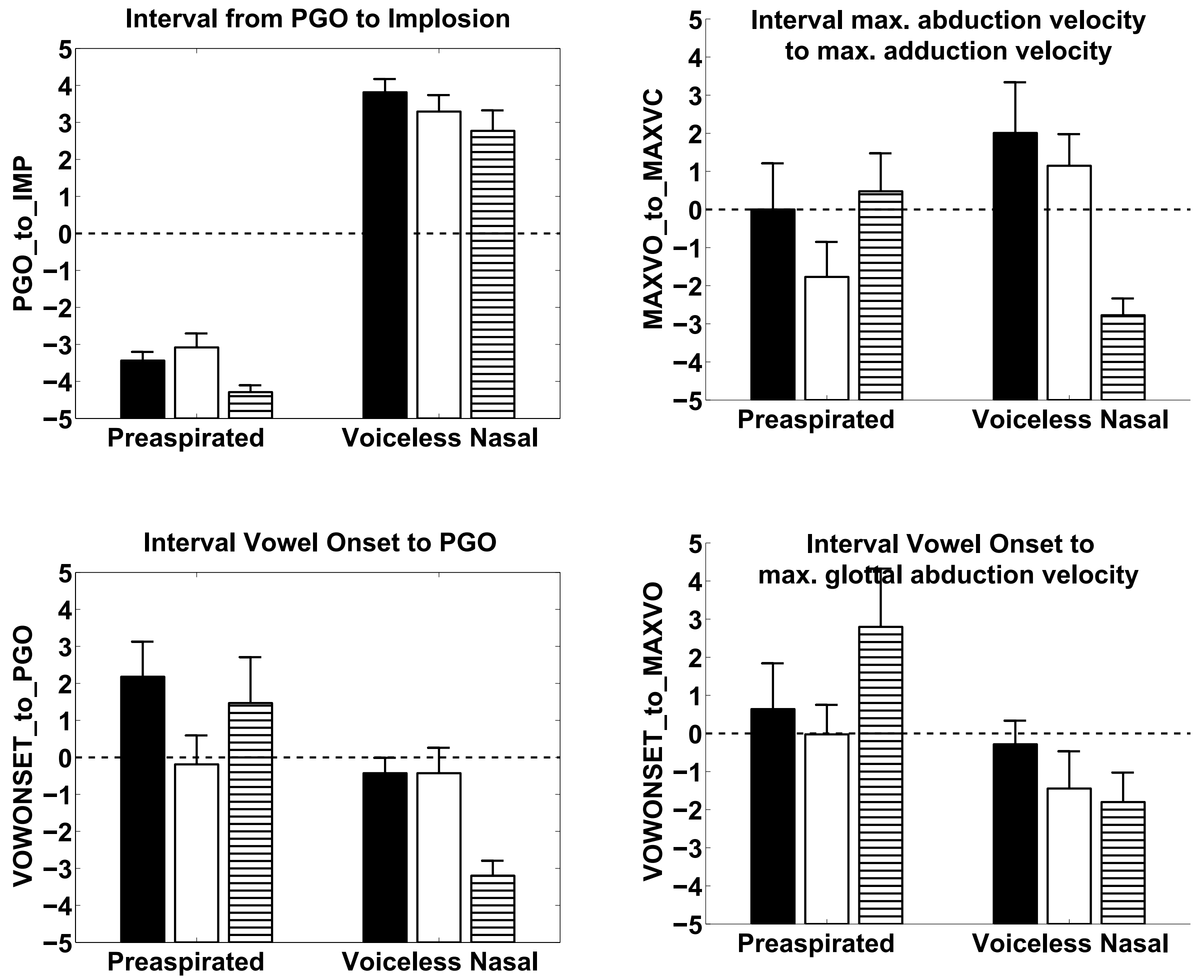


**Figure 5.** Means of glottal timing parameters for words with pre-aspirated plosives and voiceless nasals (normalized data). Other details as Figure 4 (i.e. from left to right bars are 'hetta, seppi, hitti, henti, dempi, sempinn')

ference, but also some interesting similarities between pre-aspirates and nasals.

Firstly, there is similarity with respect to the most basic durational parameter, namely the overall duration of the gesture. This was estimated by the interval from instant of maximum abduction velocity to instant of maximum adduction velocity (Figure 5, top right panel, for S1). This measure of the gesture duration was preferred to one based on onset and offset of the abduction movement because it appeared more stable with respect to fluctuation in the baseline of the transillumination signal. For none of the subjects did this measure show a significant difference between pre-aspirates and voiceless nasals.

The most striking difference on the other hand involves the interval from PGO to formation of the occlusion for the plosive. The top left panel of

Figure 5 gives a complete breakdown of all word-types for S1. Table 3 summarizes the results for all three subjects. While PGO more or less

**Table 3.** Means (in bold face) and sds of interval from Peak Glottal Opening to Implosion in ms. For S1 averaged over all three word-types per category (n=18). For S2 and S3 data only for 'hitti' and 'henti' (n=9).

| | Duration | | |
|---|---|---|---|
| Subject | S1 | S2 | S3 |
| pre-aspirated | **10** ± 8.6 | **-3** ± 4.5 | **8** ± 13.6 |
| voiceless nasal | **85** ± 13.5 | **47** ± 9.2 | **58** ± 22.7 |

coincides with the start of the oral occlusion phase in the pre-aspirates it is timed much earlier relative to this point in the voiceless nasal. The difference amounts to 50ms for S2 and S3, and 75ms for S1.

This is a natural consequence of the similarity in the overall duration of the glottal gesture in conjunction with the different structuring of the cluster outlined at the start of the results section, i.e. shorter occlusion duration for the voiceless nasal than for the pre-aspirate word-forms, and, conversely, longer duration of the voiceless nasal phase itself compared to the pre-aspiration phase. 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).

We were also particularly interested in determining whether our finding for German (referred to briefly at the end of section 2.1 above) 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 reliably measure the point at which glottal abduction started due to the fluctuations in the baseline of the transillumination signal mentioned above. Nonetheless, for S1 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 Figure 5, bottom panels), again excluding the rightmost pair for the reasons given above. For S3, too, no significant differences were found for either of these durational measures. S2, by contrast, did show significant differences (at $p<0.05$ for both parameters). Nevertheless, the differences between pre-aspirates and voiceless nasals amounted to less than 10ms for both parameters (which contrasts markedly with the just-mentioned 50ms difference in the timing of PGO relative to the start of the oral occlusion). Thus, it still seems possible to state, as for the earlier German results, that differently structured oral articulations are superimposed on rather 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 segmental duration. As already indicated in the discussion of the acoustic segment durations this was not borne out in the results. The voiceless nasals as measured from the audio signal (refer back to Table 1 and Figure 1) were clearly longer than the voiced ones ($p<0.01$ for all subjects). This agrees with the earlier acoustic measurements of Pétursson. An important further component in Pétursson's argument for the phonemicity of the voiceless nasals is that any opposition in the plosives following voiceless vs. voiced nasals is neutralized. The occlusion phases of the plosives are clearly voiceless in both cases, so the main interest attaches to the duration of the occlusion. Pétursson (1975) and, more recently, Jessen and Pétursson (1998) concluded that there was no consistent difference in the occlusion durations. This is not completely borne out by the present results. For S1 there is indeed no significant difference in the durations, but both S2 and S3 showed significantly shorter occlusion durations following the voiceless nasals ($p<0.01$ and $p<0.05$, respectively), i.e. a reciprocal adjustment almost compensating for the longer duration of the voiceless nasal segment itself (see Table 1 for details). Clearly the limited data for S2 and S3 do not provide strong grounds for rejecting the contention that the occlusion durations do not differ, but it might be interesting to follow up this issue with a much larger scale acoustic investigation of young speakers. Moreover, we will argue in the discussion section that even if the occlusion durations do not differ, this still does not necessarily need to imply the plosive opposition as a whole is completely neutralized. We now turn to the kinematic parameters of the velar gesture. These are

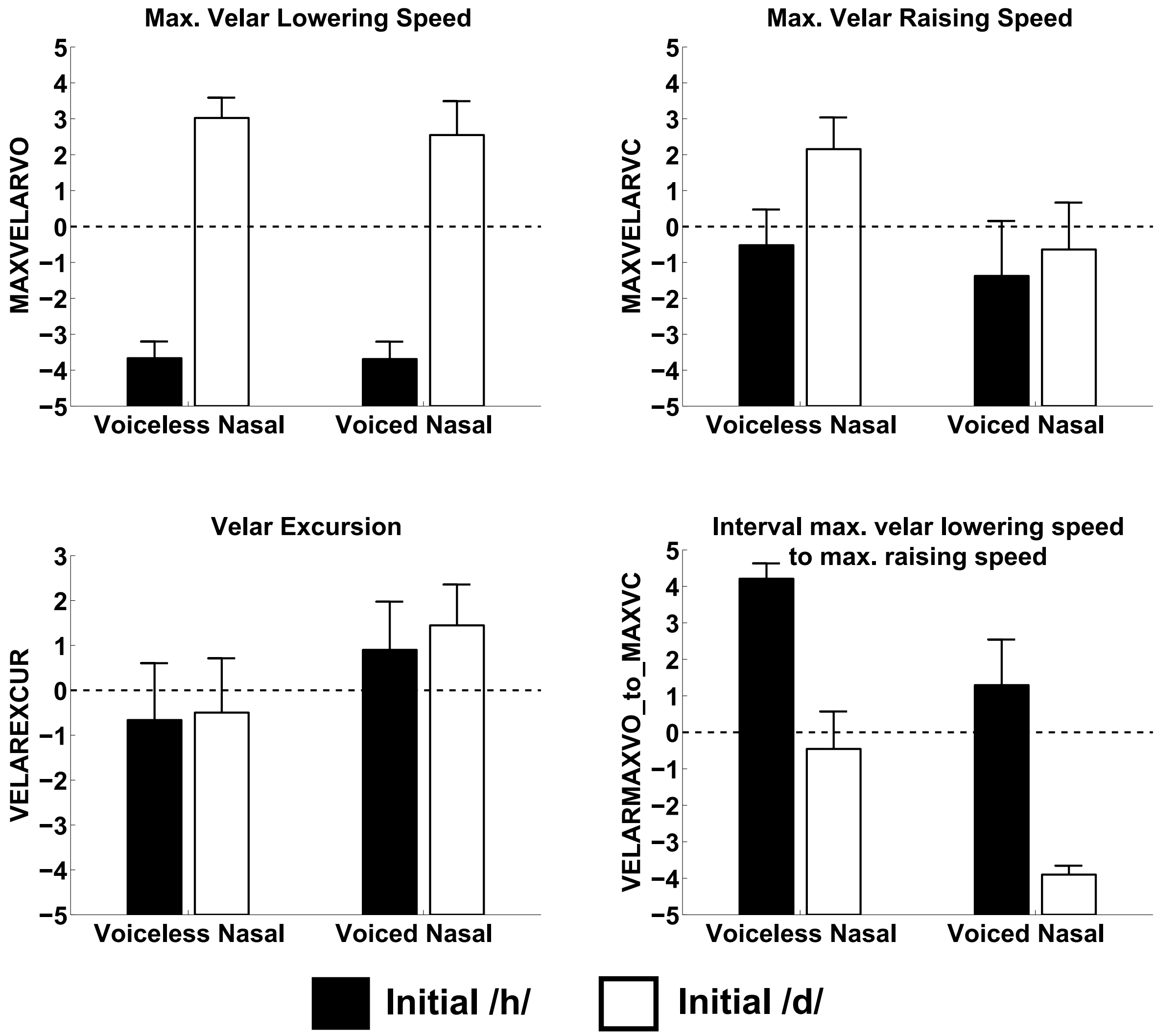


**Figure 6.** Means of kinematic parameters of velar activity for words with voiced and voiceless nasals (normalized data). In each panel from left to right the black bars (initial /h/) correspond to 'henti, hendi', the white bars (initial /d/) to 'dempi, dembi'. Other details as Figure 4

shown in Figure 6. 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 (thus the patterns in the top left and bottom right panels are dominated by the difference between /h/-initial (black bars) and /d/-initial (white bars) words). 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

In this final section of the results we consider two remaining characteristics of the plosive occlusions that have not been dealt with above.

**Durations of pre-aspirated vs. unaspirated plosives:** As mentioned in the introduction the duration of the occlusion phase of pre-aspirated and non-aspirated plosives has been of some interest with respect to the syllable-structure and quantity system of Icelandic. Accordingly, although not of central concern to our analysis of the pre-aspirates and voiceless nasal, we summarize the results here for the sake of completeness. Pooling the length of the occlusion from all three recordings for S1 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). For the supplementary speakers only the 'hitti/hiti' pair is available. For S2 the difference is clearly negligible. For S3 the pre-aspirate is actually about 16ms shorter (significant at $p<0.01$). Thus the results are in agreement with the other investigations quoted in the introduction since despite the traditional association of the pre-aspirates with long consonants there is no evidence that they actually have longer occlusions.

**Intraoral air-pressure:** From the air-pressure recording we measured the peak air pressure in the occlusion (see Figure 7). Dividing the words into four matched pairs differing in the presence vs. absence of a strong glottal abduction gesture a 2 x 4 analysis of variance on 'hitti, henti, seppi, dempi' vs. 'hiti, hendi, sepi, dembi' showed that the latter, i.e.

those without a large magnitude of glottal abduction have significantly higher peak air-pressures ($p<0.0l$). Note that it is thus the plosives that would traditionally be regarded as fortis that have the lower pressures. The most plausible explanation for this result is that the expenditure of air before the oral occlusion in the pre-aspiration or voiceless nasal phases causes a temporary drop in sub-glottal pressure. Note that the effect may be somewhat stronger (i.e. lowest air-pressure of all) in the voiceless nasals because these have a longer period than the pre-aspirates in which glottal opening is combined with an unoccluded vocal tract.

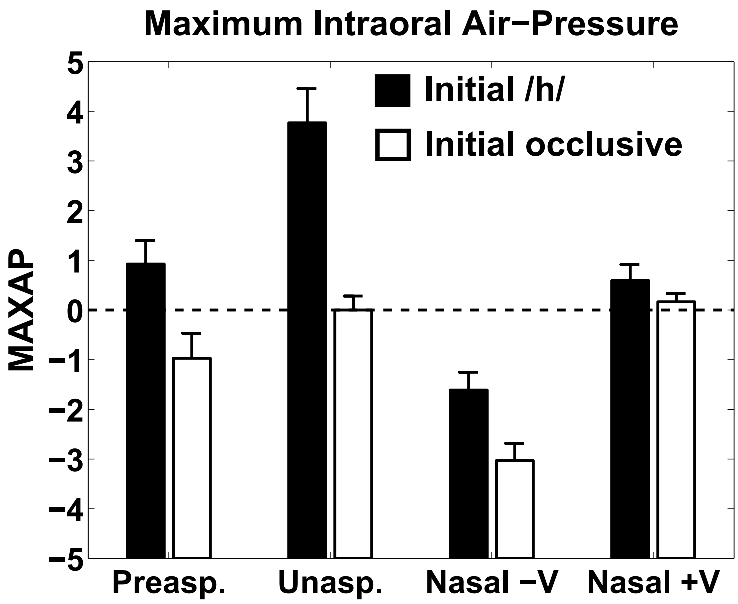


**Figure 7.** Means of maximum intraoral air-pressure in the occlusion phase (normalized data). From left to right, black bars (initial /h/) are 'hitti, hiti, henti, hendi', white bars (initial occlusive) are 'seppi, sepi, dempi, dembi'. Other details as Figure 4

# 4 Discussion of the results

The main points in the results can be summarized as follows:

- Pre-aspirated plosives and voiceless nasals have a very similar glottal gesture in terms of overall duration, and in the timing of its onset relative to the preceding vowel.
- No clear differences in magnitude of glottal abduction were found between these categories; they both tended to be larger than e.g.

prevocalic /h/ and unaspirated plosives.
- Duration of plosive occlusions was longer in the pre-aspirates than in the plosive following nasals.
- Duration of pre-aspiration was shorter than the duration of the voiceless nasal.
- Pre-aspirates and voiceless nasals differed radically in the timing of PGO relative to the start of the plosive occlusion (PGO timed earlier for voiceless nasals)
- Voiceless nasals were somewhat longer than the voiced nasals (both in terms of oral occlusion and duration of the velar gesture)

We will now review the immediate implications of the results for the original questions and hypotheses. In the following section the perspective is widened to take more recent literature into account.

Pétursson's arguments for analysing pre-aspirates as /h/+P received little support. Arguments in favour of the nasal hypothesis (voiceless nasals are not phonemic, but are a coarticulatory consequence of pre-aspiration) 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, for example, obviously does not prevent them from being allophones of the same phoneme.

The fact that glottal behaviour was very similar in the pre-aspirate and voiceless nasal cases does not necessarily mean that both cases must have the same number of phonemic segments, i.e. two in Pétursson's view. This is particularly the case if the voiceless nasal is accepted as underlying voiced, with [$^{h}$p] and [m̥p] thus qualitatively similar to cases such as [p$^{h}$] and [pl̥] in English and other languages (see below for further discussion of this possible analogy; see e.g. Ridouane et al. (2007) for recent discussion of an extensive range of cases illustrating the relationship between the number of segments and the number of observable glottal abduction gestures).

The probably more crucial issue 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). 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? Not necessarily, if one accepts the point of view we developed on the basis of the German material (Hoole et al., 1984), namely that the speech mechanism reorganizes oral articulations more readily than glottal ones. Moreover, analysis of the laryngeal gesture associated with onset clusters (Hoole, 2006b) suggests that the gesture is organized to reflect the aerodynamic demands of the onset as a whole. A somewhat similar account may be appropriate here. The fact that oral activity was rearranged while glottal activity was not, could, at some level, represent 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 (see Lodge, 2007, for a non-segmental perspective on aspiration in Icelandic).

Our proposed account does, however, leave open at least one perspective that would warrant further exploration: In the present experiments the pre-aspirates and voiceless nasals never showed more than one glottal opening peak. However, it cannot be completely ruled out that either or both of these sound categories underlyingly consist of two strongly overlapped glottal gestures (Munhall and Löfqvist, 1992), that may only become visible individually at very slow speech rates. Here we are arguing for a basic similarity in the glottal gesture for pre-aspirates and voiceless nasals, so it would constitute evidence against this hypothesis if it turned out that these sound categories behave differently over variation in speech rate with respect to the glottal movement patterns.

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. In English, in such pairs as 'plead/bleed', 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 one could 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.[10] 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.[11]

To conclude this discussion of the results, we would like to consider briefly the patterns of anticipatory velar coarticulation observable in our data.

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

10 This issue has now been looked at in detail for German material in Hoole, 2006b. The patterns of reorganization were actually somewhat more complex than the one originally assumed here. But it was possible to unify them under the assumption that the speaker actively plans to generate a longer period of voicelessness following release of /p/ in /pl/, than following the release of singleton /p/.

11 Note that Northern Icelandic also has post-aspirated stops where the present corpus has unaspirated ones, e.g. in 'hiti'.

simply join Al Bamerni (1984) in suspecting that compared to other articulatory systems velar activity is subject to fewer (or different) constraints.

## 5 General discussion

The discussion throughout the introduction and the presentation of the results has 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, in more recent years, 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 and 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 pre-aspiration. Where our account still differs from the so-called mainstream phonological approach is in the role assigned to coarticulatory processes. We contend 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 and Goldstein's (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., 2010), though admit-

tedly we are not going to resolve such an issue here with limited data on just a few speakers of Icelandic.

To round off this review of the more recent discussion, it is important to come back to the above-mentioned paper of Jessen and Pétursson (1998), 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[12]. This is certainly an objection that can be applied to our own work here. These sounds are undoubtedly phonetically interesting. Although often referred to as voiceless, it appears from a recent study (based on further material from the recordings of S2 and S3 used here) that they often involve only a rather small amount of glottal abduction and may actually show uninterrupted - but non-modal - voicing (Bombien, 2006, see there for further references). This is a rather 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 and Pétursson note, such sequences would, if adopted, sit rather awkwardly in the rest of the Icelandic sound system. It might prove interesting to follow these sounds over the next few decades, because the non-modal voicing could be a hint of a change in progress in their realization.

The other major point raised by Jessen and Pétursson 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 (Hoole, 1987, 1999a, 2006b).

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. However, the strength of this argument is diffi-

12 A contrastive example: ‘ný́ta’ [ni:ta] (to use) ‘hný́ta’ [n̥i:ta] (to knot), from Bombien (2006)

cult to judge, 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 made by them 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 very similar (though note that the latter assumption is qualified somewhat by our findings for S2 and S3; cf. section 3.2.3 above), 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*" (Jessen and Pétursson, 1998, 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.

# References


Al Bamerni, A. (1984). Speech rate and velar control. In Cohen, A. and van den Broecke, M. P. R., editors, *Abstracts of the 10th International Congress of Phonetic Sciences*, page 464.

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

Bombien, L. (2006). Voicing alterations in Icelandic - a photoglottographic and acoustic investigation. *AIPUK*, 37:63–82.

Browman, C. and Goldstein, L. (1986). Towards an articulatory phonology. *Phonology Yearbook*, 3:219–252.

Gafos, A. (2002). A grammar of gestural coordination. *Natural Language and Lingustic Theory*, 20(1):169–337.

Gafos, A., Hoole, P., Roon, K., and Zeroual, C. (2010). Variation in timing and phonological grammar in Moroccan Arabic clusters. In Fougeron, C., Kühnert, B., d'Imperio, M., and Vallé, N., editors, *Laboratory Phonology 10: Variation, Detail and Representation*. Mouton de Gruyter, Berlin/New York.

Garnes, S. (1973). Phonetic evidence supporting a phonological analysis. *Journal of Phonetics*, 1:273–283.

Haugen, E. (1958). The phonemics of modern Icelandic. *Language*, 34:55–88.

Hoole, P. (1987). Velar and glottal activity in a speaker of Icelandic. In *Proceedings of the 11th International Congress of Phonetic Sciences*, volume 3, pages 31–34, Tallinn, Estonia. Academy of Sciences of the ESSR.

Hoole, P. (1999a). Laryngeal Coarticulation. Section A: Coarticulatory investigations of the devoicing gesture. In Hardcastle, W. J. and Hewlett, N., editors, *Coarticulation: Theory, Data and Techniques*, pages 105–121. Cambridge University Press, Cambridge.

Hoole, P. (1999b). Techniques for investigating laryngeal articulation and the voice-source. Section A: Investigation of the devoicing gesture. In Hardcastle, W. J. and Hewlett, N., editors, *Coarticulation: Theory, Data and Techniques*, pages 294–300. Cambridge University Press, Cambridge.

Hoole, P. (2006a). *Experimental studies of laryngeal articulation. Appendix: Velar and glottal activity in Icelandic*. Unpublished habilitation thesis, Ludwig-Maximilians-Universität, Munich. http://www.phonetik.uni-muenchen.de/~hoole/pdf/habilicelandic.pdf [accessed May 1, 2010].

Hoole, P. (2006b). *Experimental studies of laryngeal articulation. Part 2: Larygeal-Oral coordination in consonant sequences*. Unpublished habilitation thesis, Ludwig-Maximilians-Universität, Munich. http://www.phonetik.uni-muenchen.de/~hoole/pdf/habilpgg_chap_all.pdf [accessed May 1, 2010].

Hoole, P., Pompino-Marschall, B., and Dames, M. (1984). Glottal timing in German voiceless occlusives. In Van der Broecke, M. and Cohen, A., editors, *Prooceedings of the 10th International Congress of Phonetic Sciences*, pages 309–403, Utrecht, The Netherlands.

Hutters, B. (1976). Problems in the use of the photoelectric glottograph. *Annual Report of the Institute of Phonetics of the University of Copenhagen*, 10:274–312.

Hutters, B. (1984). Vocal fold adjustments in Danish voiceless obstruent production. *Annual Reports of the Institute of Phonetics, University of Copenhagen*, 18:293–385.

Jessen, M. and Pétursson, M. (1998). Voiceless nasal phonemes in Icelandic. *Journal of the International Phonetic Association*, 28:43–53.

Künzel, H. (1979). Röntgenvideographische Evaluierung eines Photoelektrischen Verfahrens zur Messung der Velumhöhe beim Sprechen. *Folia Phoneatrica*, 31:153–166.

Lodge, K. (2007). Timing, segmental status and aspiration in Icelandic. *Transactions of the Philological Society*, 105(1):66–104.

Löfqvist, A. and Yoshioka, H. (1980). Laryngeal activity in Icelandic obstruent production. *Haskins SR*, 63:275–292.

Löfqvist, A. and Yoshioka, H. (1980). Laryngeal activity in Swedish obstruent clusters. *Journal of the Acoustical Society of America*, 63:792–801.

Munhall, K. and Löfqvist, A. (1992). Gestural aggregation in speech: laryngeal gestures. *Journal of Phonetics*, 20:111–126.

Pétursson, M. (1972). La préaspiration en islandaise moderne. Examen de sa réalisation phonétique chez deux sujets. *Studia Linguistica*, 26:61–80.

Pétursson, M. (1973a). L'origine des phonèmes nasals et liquides sourds et du [h] postvocalique de l'islandaise moderne. *Orbis*, 22:335–342.

Pétursson, M. (1973b). Phonologie des consonnes nasales en islandais moderne. *La Linguistique*, 9:115–138.

Pétursson, M. (1975). Examen expérimental de la réalistion phonétique des nasales sourdes de l'islandaise moderne. In Dahlstedt, K.-H., editor, *The Nordic Languages and Modern Linguistics*, volume 2, pages 634–653. Almqvist & Wiksell, Stockholm.

Pétursson, M. (1976). Aspiration et activité glottale. Examen expérimental à partir de consones islandaises. *Phonetica*, 33:169–198.

Ridouane, R., Hoole, P., and Fuchs, S. (2007). Laryngeal behavior in voiceless words and sentences: a photoelectroglottographic study. In Trouvain, J. and Barry, W., editors, *Proceedings of the 16th International Congress of Phonetic Sciences [ICPhS XVI]*, pages 2049–2052, August.

Ringen, C. O. (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.