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Voicing and aspiration in Swedish stops

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Abstract

This paper presents the results of an investigation of voicing and aspiration in the speech of six Central Standard Swedish speakers with a view to providing an account of Swedish stop production. The data show that in utterance-initial position the two-way stop contrast is almost always realized as a contrast between prevoiced stops and postaspirated ones. Word-medially and -finally, the contrast is that of a fully voiced stop and, variably, an unaspirated or preaspirated stop. The female speakers show a greater tendency to preaspirate than the male speakers, and the male speakers have a greater tendency for prevoicing than the females. The commonly observed k > t > p ranking of aspiration duration is found for both preaspiration and postaspiration. Possible articulatory and aerodynamic reasons for these findings are discussed. The voicing vs. aspiration contrast that we observe in Swedish is one that has generally been considered to be typologically unusual. It is suggested that, in fact, such languages may not be as unusual as has been claimed in the literature, and that by increasing the level of phonetic detail in the description of stop contrasts in individual languages, the accuracy of typological statements concerning stop production can be improved.

1. Introduction

In spite of the number of studies dealing with Swedish in the phonetics and phonological literature, it is surprisingly difficult to find accurate information about Swedish stops and voice assimilation. In this paper we present the results of our investigations of voice, aspiration and assimilation in stops in (Central Standard) Swedish.[2] Our findings have a bearing on a number of wider issues, such as male–female differences in voicing patterns, place-dependent differences in aspiration duration, laryngeal features and the typological characterization of stop systems in general.

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[2]We do not consider other correlates of the stop contrast, such as duration, F0 and other factors such as those listed in Diehl and Kluender (1987).

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Most Germanic languages, including Danish, English and German, contrast voiceless unaspirated and voiceless aspirated stops in initial position (Keating, 1984).[3] Dutch, Afrikaans, and Yiddish are usually cited as exceptions in that these Germanic languages exhibit no aspiration and have prevoicing in initial stops like "true voice" languages such as Russian, Spanish, and Polish (Iverson & Salmons, 1995; Keating, 1984; Lisker & Abramson, 1964). Swedish is often described as if it is like most other Germanic languages (Iverson & Salmons, 1995; Jessen, 1998; Keating, Linker, & Huffman, 1983) in having an aspiration contrast and no prevoicing in initial stops.

Both types of languages, that is, those with prevoicing and those with aspiration, have usually been described as involving a contrast of the feature [voice], apparently following the suggestions of Keating (1984, 1990). This leads to some ambiguity about the phonetic nature of the stops that are referred to as "voiced" and "voiceless". In German, for example, so-called "voiced" stops do not involve vocal fold vibration except (variably) in intersonorant position (Jessen & Ringen, 2002) and the "voiceless" stops are aspirated. In contrast, in Yiddish the so-called "voiced" stops do involve vocal fold vibration, even in word-initial position following a pause, and the so-called "voiceless" stops are not aspirated (Katz, 1987). To avoid confusion, we will refer to the two series as fortis and lenis, using these terms merely to indicate that there is a contrast between two stop series without indicating the nature of the stop contrast.

In *The Sound Pattern of English*, Chomsky and Halle (1968) proposed the features [±voice], [±tense], [±heightened subglottal pressure] and [±glottal constriction] to account for laryngeal contrasts found in the world's languages. For them, the feature [voice] does not indicate vocal fold vibration, rather it indicates a vocal fold configuration in which vibration will occur when there is sufficient airflow. As noted by Keating (1988) and Sommerstein (1977), these features have not been widely adopted. Keating (1984), building on Lisker and Abramson (1964) and Lieberman (1970, 1977), proposed that the phonological feature [±voice] should be used for contrasts that, phonetically, involve voiced vs. voiceless unaspirated stops as well as those that involve voiceless unaspirated vs. voiceless aspirated stops. For her, [+voice] does indicate vocal fold vibration. Halle and Stevens (1971) propose the features [±stiff vocal cords], [±slack vocal cords], [±spread glottis], [±constricted glottis]. Their claims about the features [stiff vc] and [slack vc] have not been supported by empirical evidence (see Keating, 1988 for discussion). Keating (1990), following a proposal by Steriade (1993), suggests that the phonetic representation of stops which vary along the VOT continuum consist of a closure node and a release node and that this system, unlike that proposed in her earlier paper, provides a representation for voiced aspirates as found in Hindi. She suggests that the closure node may be [+voice] or [−voice] and the release node may be [+spread glotts] ([+sg]) or [−sg] (cf. Halle & Stevens, 1971). According to this proposal, voiced stops are represented with a closure node that is specified as [+voice], and a release node that is [−sg] in the case of plain voiced stops, and [+sg] in the case of voiced aspirates. Both voiceless unaspirated and voiceless aspirated stops have a closure node that is specified as [−voice], but release nodes specified as [−sg] and [+sg], respectively. However, as Keating herself notes, such a system cannot easily express preaspiration (but see Steriade,1993).

Jansen (2004) notes that Keating's (1984, 1990) proposals seem to be problematic because her implementation of English intervocalic lenis stops with [+voice] or as having a [+voice] closure and a [−sg] release suggests that the voicing is *active*, whereas Jansen claims that all the indications are that voicing of intervocalic stops in English is *passive*. Our present findings for Swedish suggest that a single feature like [voice] can not adequately represent the Swedish stop contrast, and that Swedish appears to make use of both [voice] and [sg]. This is discussed further in Section 4.7.

In recent years, phonologists have been interested in identifying the laryngeal features that are found in various languages and in the types of assimilation that occur in consonant clusters (e.g., Cho, 1990, 1994; Lombardi, 1991, 1995, 1999). For Swedish, these works cite a number of sources, some of which are decades old,[4] in which the phonetic nature of the voiced stops is unclear. The data in these sources are based on impressionistic observations, so it is impossible to know whether the "voiced stops" exhibit prevoicing in utterance-initial position (like Yiddish) or have no prevoicing in this environment (like German).

[3]Prevoiced variants have also been noted, for example in English (Docherty, 1992, p. 92ff). However, the predominant phonetic pattern for the contrast in these languages seems to be voiceless unaspirated vs. voiceless aspirated.

[4]For example Cho (1990, 1994) cites Hellberg (1974) and Lyttkens and Wulff (1885), Lombardi (1999) cites Hellberg (1974).

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Keating et al. (1983) do present phonetic data, measuring VOT for both utterance-initial and intervocalic stops in Swedish. They report that their subjects did not produce initial stops with prevoicing and suggest that their results are like those of Löfqvist (1976). Yet, since Löfqvist's target lenis stops are all post-sonorant, he presents no data on the closure voicing of word-initial, post-pausal (or post-voiceless) lenis stops in Swedish. In contrast, other sources report prevoicing of word-initial stops in Swedish. For example, Fant (1973) presents a limited set of data using a Swedish speaker uttering nonsense words; in all nine spectrograms used for illustration of these words, it is clear that the stops are being produced with robust prevoicing. In addition, Karlsson, Zetterholm, and Sullivan (2004) present data on voicing and aspiration for eight speakers of Umeå Swedish. These data also show prevoicing of utterance-initial lenis stops in this dialect. Karlsson et al. do not present exact numbers for their means or medians, but their box-and-whisker plots suggest that prevoicing does occur for most or all of their subjects.

Although neither Löfqvist nor Keating et al. measured preaspiration, others report that postvocalic fortis stops are produced with preaspiration in the speech of many Swedish speakers (Fant, Kruckenberg, & Nord, 1991; Gobl & Ní Chasaide, 1988; Helgason, 2002; Tronnier, 2002; Wretling, Strangert, & Schaeffler, 2002).

The literature contains other conflicting claims as well: Cho (1994) claims that the devoicing of stops in certain clusters is only partial (e.g. she claims that the first stop in *vägt* 'weighed SUP' is partially devoiced), whereas others claim that the clusters are entirely voiceless (e.g. Lombardi, 1999). Recent work (Jessen & Ringen, 2002; Van Alphen & Smits, 2004) found that men have more closure voicing than do women in the production of lenis stops in German and Dutch, respectively, but Karlsson et al. (2004) found the opposite for Umeå Swedish.

The purpose of this paper is to determine which of these conflicting claims are correct and to provide a general description of the phonetics of (Central Standard) Swedish stop production. We present and discuss our findings about closure voicing (including prevoicing), pre- and postaspiration, differences in closure voicing and aspiration for men and women, voice assimilation in stop clusters, and place-dependent differences in pre- and postaspiration. Finally, we consider the implications of our findings for the representation of stops in terms of laryngeal features, for the typology of two-way stop contrast systems and for explanations of place-dependent differences in aspiration.

2. Method

Six subjects, three male and three female, were recruited for the experiment. The male subjects were DH (in his late twenties), MP (mid thirties) and PL (late twenties). The female subjects were AE (in her mid twenties), GT (late forties) and JR (early thirties). The subjects were all speakers of the Central Standard variety of Swedish, and have lived in Stockholm for most or all of their lives. All subjects reported having normal hearing. The subjects were paid for participating in the experiment.

The subjects read a word list of 67 items which contained both fortis and lenis stops (see Appendix A). The aim was to obtain productions of words spoken in isolation, and therefore a carrier phrase was not used and the subjects were asked to pause briefly between words. However, they were not given specific instructions regarding style or manner of reading, nor was speaking rate controlled for. The words were chosen to provide examples of stops in word-initial (post-pausal) position, word-medial (intervocalic) position and word-final (pre-pausal) position. Three contrasting places of articulation for Swedish stops were considered: bilabial, dental and velar.[5] Words that were (subjectively) judged to be familiar to speakers were preferred over words that were perceived to be less familiar. These judgments were made by the first author in consultation with native speakers who did not participate in the experiment. Nonsense words were not used. In order to reduce the potential effects of a narrow vocal tract channel on voicing, low and low-mid vowels were preferred over mid-high and high ones. As a result there are more test words with low and mid-low vowels than with mid-high and high ones.

The complementarity of the Swedish quantity system was also taken into account in the data sample. Complementary length means that there is a relationship between the length of a vowel in a stressed syllable and the length of a following consonant: a consonant following a long, stressed vowel must be short and a consonant following a short, stressed vowel must be long—i.e. only -ˈVːC- or -ˈVCː- are possible, other length combinations are not allowed. Since the durational characteristics of these quantity types are so dissimilar,

[5]Retroflex stops, which are not underlyingly distinctive in Swedish, were not included.

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they were separated in the analyses of voicing and aspiration duration, and the data thus contain an equal number of words of each quantity type, 'V:C and 'VCː.

These different constraints on word selection made it difficult to construct a data set that was fully balanced in terms of the number of tokens for each parameter under consideration. In light of this, we decided that the data set should be balanced for word-medial and -final tokens, which meant we forfeited the balance in word-initial tokens. For this reason the data set for word-initial stops is not balanced (see Sections 3.1 and 3.2).

The recordings were made in an anechoic chamber at the Stockholm University phonetics laboratory. The microphone (Brüel & Kjær 4145) was placed directly in front of the speaker at a distance of approximately 35 cm. The signal was sent through a 30 Hz high pass filter and recorded directly to hard disk at 44.1 kHz. The data were subsequently downsampled to 16 kHz. The durational analysis of the data was carried out using the WaveSurfer software package (Sjölander & Beskow, 2000).

The duration of utterance-initial stop voicing, henceforth prevoicing, was measured as the interval from voice onset to stop release. Voicing duration in word-medial and -final stops (as well as in stop clusters) was measured as the interval between closure onset and the cessation of voicing during the closure phase. The onset of voicing was determined visually from spectrograms and oscillograms by identifying the onset of periodic oscillation taken to indicate vocal fold vibration. Likewise, the offset of voicing was determined by identifying the cessation of periodic oscillation.

Ladefoged and Maddieson (1996, p. 70) recommend that the interval from stop release to the onset of modal voicing (rather than voice onset proper) should be used to determine the extent of postaspiration. According to their definition, "aspiration is a period after the release of a stricture and before the start of regular voicing [...] in which the vocal folds are markedly further apart than they are in modally voiced sounds". This means that breathy voicing during aspiration is regarded as a part of the aspiration. We adopted this approach and measured postaspiration as the interval from stop release to modal voice onset. Therefore, our use of VOT actually refers to modal voice onset time rather than voice onset time proper. The

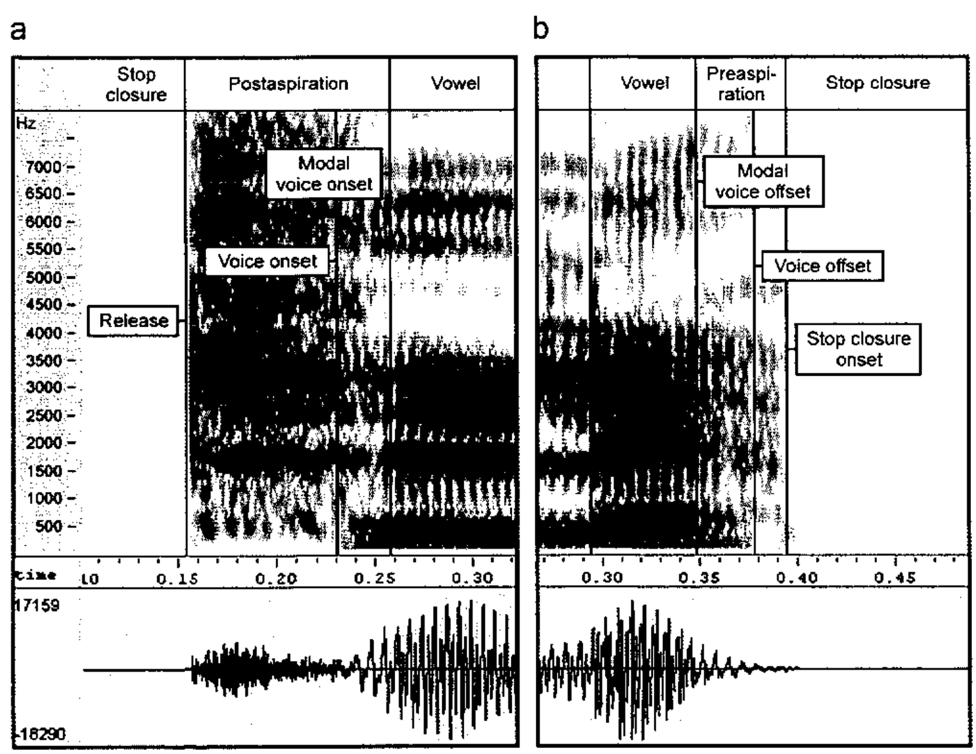

Fig. 1. (a and b) Examples showing the segmentation of postaspiration (a) and preaspiration (b). Postaspiration was measured as the interval from stop release to the onset of modal voicing. Preaspiration was measured as the interval from the offset of modal voicing to the onset of stop closure.

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onset of modal voicing (which marks the onset of the vowel in our measurements) was determined visually on a spectrogram as the cessation of aperiodicity in the mid-range of the spectrum, indicating that the vocal folds had been fully adducted. The labeling of a postaspirated stop is illustrated in Fig. 1a.

Frequently, intersonorant fortis stops in Swedish are produced so that voice offset is initiated before the stop closure is made. This results in preaspiration, i.e. a period of breathy voice and/or voiceless aspiration just before the stop closure silence (Helgason, 2002; Ladefoged & Maddieson, 1996, p. 70). The principles that were applied to postaspiration measurements were also applied to preaspiration measurements, i.e. modal voice offset time was used to determine the onset of preaspiration. The labeling of sequences in which such preaspiration occurred is illustrated in Fig. 1b. The onset of preaspiration was determined visually on a spectrogram by identifying the onset of aperiodicity in the mid-range of the spectrum indicating the onset of vocal fold spreading. The onset of the stop occlusion marked the end of preaspiration, and thus the interval between the onset of vocal fold spreading in the vowel and the oral occlusion for the stop is what we refer to as preaspiration. None of the subjects in the present data had markedly breathy voice types, and thus shifts from modal to breathy voicing and vice versa were usually easy to identify.

One result of this approach to measuring post- and preaspiration duration is that it does not indicate the degree of breathiness during aspiration. Thus we do not include a breakdown of preaspiration into breathiness and voicelessness when presenting our results. However, we do include a brief description of the extent of breathiness during aspiration in our discussion of preaspiration in Section 4.2. In any event, authors differ in the precise way they segment instances of pre- and postaspiration, so comparisons between different reports of aspiration (especially preaspiration) duration must take into account the measurement method used in each case.

3. Results

The first two sections of the Results, 3.1 and 3.2, are devoted to utterance-initial lenis and fortis stops, respectively. In Section 3.3 intervocalic and pre-pausal lenis stop are discussed and, finally, intervocalic and pre-pausal fortis stops are considered in Section 3.4.

3.1. Utterance-initial lenis stops

In total, 228 instances of utterance-initial lenis stops were analyzed, and thus 38 tokens per subject. Of the total of 228 lenis stops, 144 were bilabial, 36 were dental and 48 were velar.

The findings for the word-initial lenis stops can be summarized as follows: Utterance-initial lenis stops generally had robust prevoicing; the three males had longer prevoicing than did the females; there was less prevoicing for velar stops than for bilabials and dentals. These findings are discussed in more detail below.

All subjects showed a strong tendency for prevoicing (i.e. negative VOT). The spectrogram in Fig. 2 gives an example of a prevoiced initial stop. The VOT measurements for all 6 subjects are summarized in Table 1 and in Fig. 3. Mean prevoicing duration for the subjects ranged from 58 ms (AE) to 132 ms (MP). For all subjects pooled, 93% of the initial lenis stops had more than 10 ms of prevoicing. (Note that setting a boundary at 10 ms is purely arbitrary and does not reflect a perceptual difference limen of any kind). Subject AE had the shortest mean prevoicing duration, but still 31 of her 38 initial lenis had more than 10 ms of prevoicing. Each of the five remaining subjects had at most four instances of prevoicing shorter than 10 ms.

A one-way ANOVA (analysis of variance) indicated that subject was a significant factor in prevoicing duration ($F(5, 222) = 27.86$; $p < 0.001$). This suggests that there were significant between-subject differences in prevoicing duration. A Bonferroni comparison of means indicated that each subject differed significantly from at least two other subjects ($p < 0.002$). MP was the most divergent with a mean VOT that differed significantly ($p < 0.02$, at least) from all other subjects.

A clear difference in prevoicing duration between males and females was also observed. The female subjects had an average prevoicing duration of 66 ms as opposed to 109 ms for the males (see Table 1 and Fig. 3). A one-way ANOVA indicated that sex was a significant factor in prevoicing duration ($F(1, 226) = 77.52$; $p < 0.001$).

Prevoicing duration was observed to increase with frontness of stop place of articulation (see Table 2). Mean prevoicing duration was 61 ms for velar stops, 90 ms for dentals and 96 ms for bilabials. These differences were investigated with a General Linear Model analysis (which yields results similar to an ANOVA, but does not

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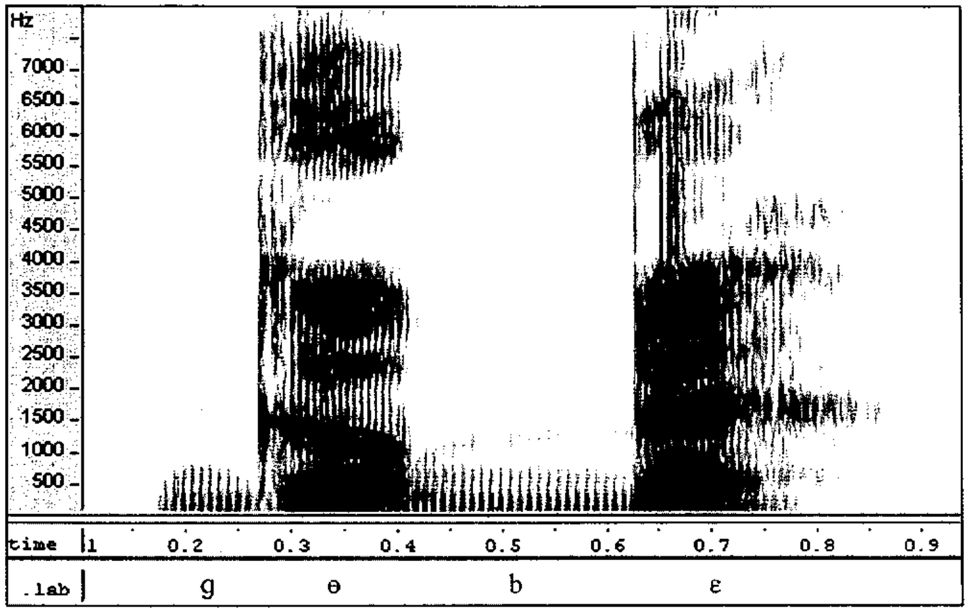

Fig. 2. Spectrogram of MP's production of the word *gubbe* "old man" showing prevoicing of the initial lenis stop and voicing of the intervocalic lenis stop.

Table 1
Mean VOT of utterance-initial lenis stops by subject and sex

	VOT	St dev	$n\% < -10$ ms
Females			
AE ($n = 38$)	−58	40	82
GT ($n = 38$)	−81	28	95
JR ($n = 38$)	−58	29	89
Mean total ($n = 114$)	−66	34	89
Males			
DH ($n = 38$)	−86	36	95
MP ($n = 38$)	−132	43	97
PL ($n = 38$)	−109	25	100
Mean total ($n = 114$)	−109	40	97

The number of tokens for each mean is indicated in parentheses in the leftmost column. In the rightmost column, $n\% < -10$ ms denotes the percentage of tokens in which prevoicing exceeded −10 ms.

require a balanced data set), using subject and place as factors. The analysis indicated that place was a significant factor in prevoicing duration ($F(2, 225) = 22.06$; $p < 0.001$). A Bonferroni comparison of the means indicated that mean prevoicing duration for velars was significantly shorter than for bilabials ($p < 0.001$) and dentals ($p < 0.001$). The difference between bilabials and dentals was not significant ($p = 1.000$).

3.2. *Utterance-initial fortis stops*

A total of 96 instances of utterance-initial, pre-vocalic fortis stops were analyzed (i.e. these stops occurred before a vowel, after a pause). Of the total of 96 stops, 24 were bilabial, 48 were dental and 24 were velar. For each subject there were a total of 24 tokens.

Measurements of voice onset time (VOT) for initial fortis stops are summarized in Table 3 and in Fig. 4. Mean VOT for the six subjects ranged from 54 to 70 ms. A one-way ANOVA did not indicate that subject was

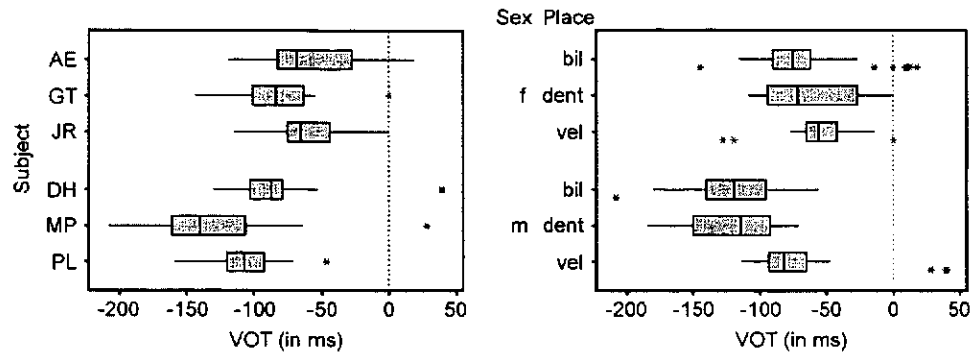

Fig. 3. Box-and-whisker plots of VOTs in utterance-initial lenis stops for each subject (left) and each place of articulation (right). The top three boxes in each plot represent the female subjects and the bottom three boxes the male subjects.

Table 2
Mean VOT in utterance-initial lenis stops by stop place of articulation

	VOT	St dev	$n\% < -10$ ms (%)
Bilabial ($n = 144$)	−96	41	96
Dental ($n = 36$)	−90	46	89
Velar ($n = 48$)	−61	38	88

The number of tokens for each mean is indicated in parentheses in the leftmost column. In the rightmost column, $n\% < -10$ ms denotes the percentage of tokens in which prevoicing exceeded −10 ms.

Table 3
Mean VOT in utterance-initial fortis stops by stop place of articulation

	VOT	St dev
Bilabial ($n = 24$)	49	12
Dental ($n = 48$)	65	18
Velar ($n = 24$)	78	14

The number of tokens for each mean is indicated in parentheses in the leftmost column.

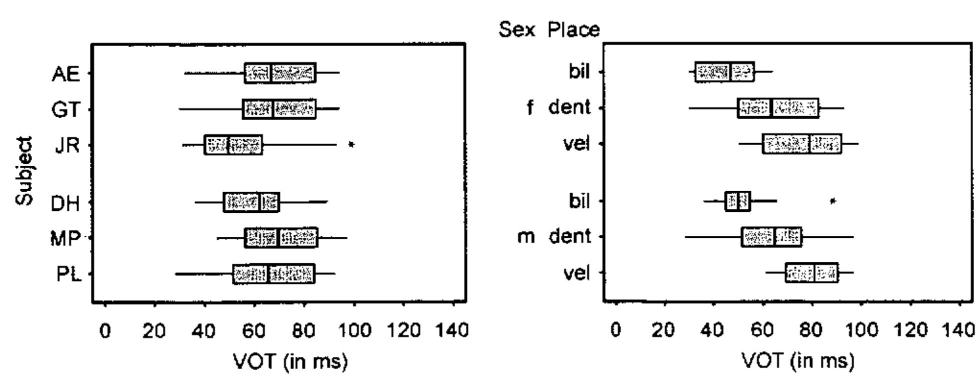

Fig. 4. Box-and-whisker plots of VOTs in word-initial fortis stops for each subject (left) and each place of articulation (right). The top three boxes in each plot represent the female subjects and the bottom three boxes the male subjects.

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a significant factor for VOT ($F(5, 90) = 1.72$; $p = 0.138$), which suggests that speaker-dependent differences in postaspiration duration are fairly small.

The difference in mean VOT between males and females was negligible, 63 ms for the females and 65 ms for the males. A one-way ANOVA did not indicate that this difference was significant ($F(1, 94) = 0.49$; $p = 0.486$).

Mean VOT was 49 ms for the bilabial stops, 65 ms for the dentals and 78 ms for the velars (see Table 3 and Fig. 4). A one-way ANOVA indicated significant differences with regard to place of articulation ($F(2, 93) = 21.59$; $p < 0.001$). Pair-wise Bonferroni comparisons of these means indicated that all three means differed significantly from one another ($p < 0.002$ at least).

3.3. *Intervocalic and postvocalic, pre-pausal lenis stops*

For all subjects pooled, 288 postvocalic lenis stops were analyzed, of which 144 were intervocalic and 144 were pre-pausal. The stops were equally divided between bilabial, dental and velar places of articulation, 96 of each. They were also equally divided according to quantity type, 'VːC vs. 'VCː, 144 of each.

The main findings for intervocalic and pre-pausal lenis stops were two-fold. First, both intervocalic and pre-pausal lenis stops were predominantly voiced for all subjects. And, second, sex appears to be a significant factor in the degree of voicing during stop closure. Additionally, a tendency to produce an epenthetic vocoid after the release of a pre-pausal lenis stop was observed. An example of such a vocoid can be seen in Fig. 5. These findings are discussed further below.

Both intervocalic and pre-pausal lenis stops were characterized by a strong tendency for voicing throughout the stop closure (see Figs. 2 and 5).

An overview of the degree of voicing in postvocalic lenis stops for each subject and for each of the four combinations of quantity type (VːC vs. VCː) and word position (pre-vocalic vs. pre-pausal) is given in Fig. 6. Voicing was robust for all subjects, and, in fact, all observed instances of stops were voiced to some degree, even for those subjects who had the most frequent occurrences of partial voicelessness (AE and GT).

Two of the male subjects, DH and PL, had full voicing in nearly all instances of both intervocalic and pre-pausal stops. Two of the female subjects, AE and GT, had the greatest (albeit modest) tendency for voicelessness, most notably in word types that had a VCːV structure (i.e., words like *slägga* 'sledgehammer'). The subjects JR (female) and MP (male) were intermediate with regard to the tendency for voicelessness.

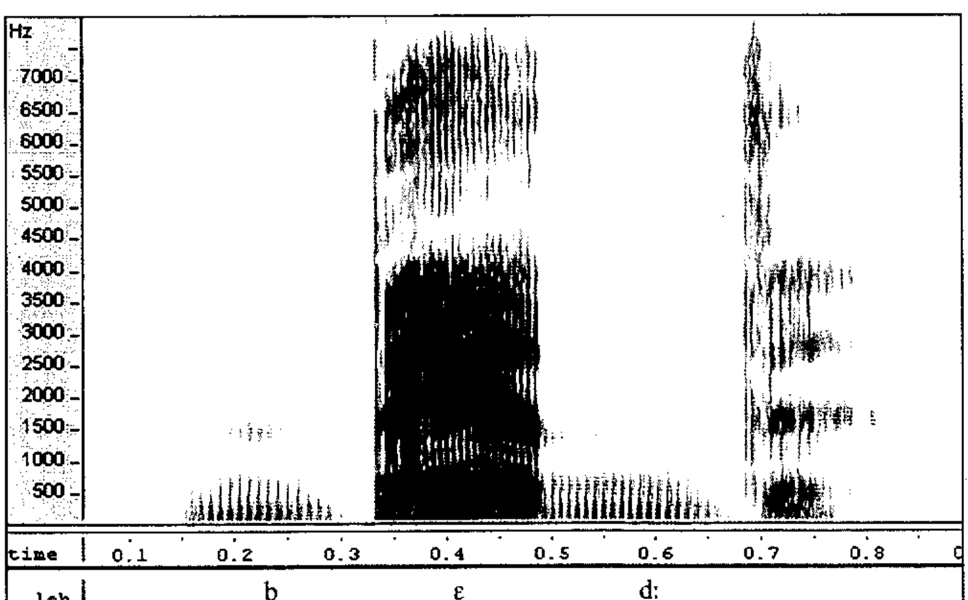

Fig. 5. Spectrogram of MP's production of the word *bädd* "bed" showing prevoicing of the initial lenis stop and an epenthetic vocoid following the pre-pausal lenis stop release.

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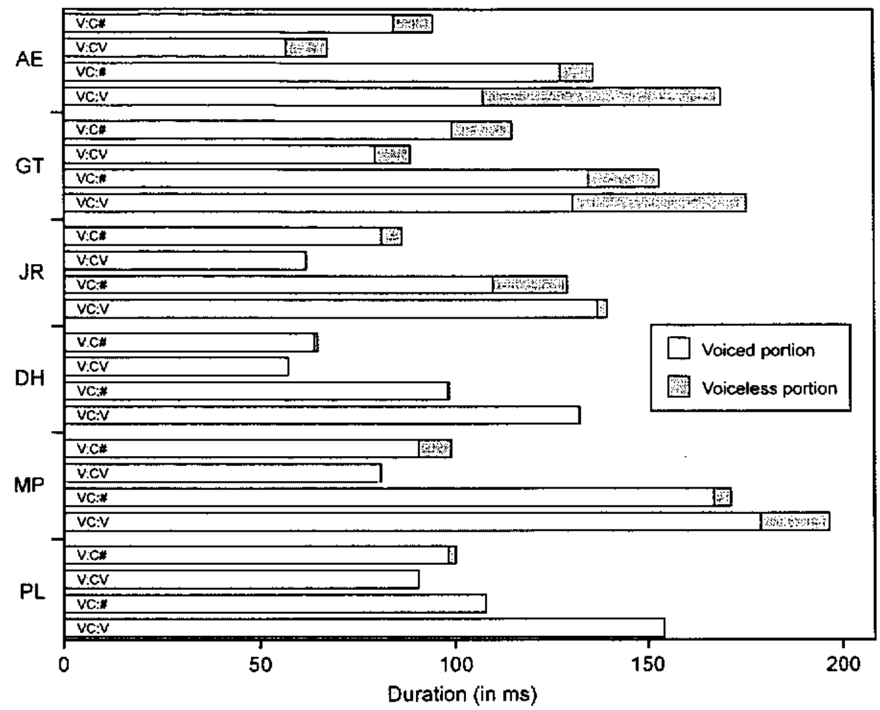

Fig. 6. Mean closure and voicing durations for each subject and for all four combinations of quantity (V:C vs. VC:) and word position (pre-vocalic vs. pre-pausal). The mean duration of the voiced stop portion is indicated by a white bar, and the voiceless portion is indicated by a light gray bar. Each bar represents the mean for 12 measurements.

For each stop closure, the duration of stop voicing during closure divided by the stop closure duration (which yielded the proportion of the stop closure that was voiced) was used as a measure of the degree of voicing. A four-way ANOVA was performed on this measure, with sex, place of articulation, quantity type, and position in the word as factors, as well as the interaction of quantity type and position. The ANOVA indicated a significant main effect for sex in the degree of voicing ($F(1,281) = 49.05$; $p<0.001$), and an interaction effect for quantity type and position ($F(1,281) = 8.27$; $p<0.005$). Place of articulation, quantity, and word position were not significant ($F(2,281) = 0.65$; $p = 0.521$; $F(1,281) = 3.86$; $p = 0.051$; and $F(1,281) = 1.15$; $p = 0.284$, respectively). These results indicate that there are substantial male–female differences in the degree of voicing in our data, but that place of articulation, quantity and word position do not, as such, significantly affect the degree of voicing. However, the interaction effect between quantity type and position suggested that one or more of the four possible combinations of quantity type and position (V:C#, V:CV, VC:#, and VC:V) was divergent with respect to degree of voicing. A Bonferroni comparison of means suggested that the degree of voicing in words with a VC:V structure was significantly different from both VC:# ($p<0.05$) and V:CV ($p<0.005$) while other comparisons were not significant ($p = 0.1953$ for VC:V vs. V:C#, and $p = 1.000$ for the remaining comparisons). The fact that VC:V has the longest stop closure durations for all subjects suggests that there is a tendency for voicelessness to increase with increased stop closure duration.

3.4. Intervocalic and postvocalic, pre-pausal fortis stops

For all subjects pooled, a total of 288 postvocalic fortis stops were analyzed, 144 intervocalic and 144 pre-pausal. They were divided equally between bilabial, dental and velar places of articulation, 96 tokens for each. They were also divided equally with respect to quantity type, 'V:C vs. 'VC:, 144 tokens of each. The findings indicate that preaspiration duration is affected by both sex and place of articulation (see Section 3.4.1).

Postaspiration duration was found to increase with backness of stop place of articulation, but was still very short for all six speakers (see Section 3.4.2).

3.4.1. *Preaspiration—VOffT*

A tendency for some of our subjects to produce postvocalic stops with preaspiration, measured as VOffT, is reflected in the present data. Two of the subjects, both female, had a mean preaspiration duration exceeding 55 ms (see Table 4). Two speakers, both male, did not have substantial preaspirations (less than 35 ms). The remaining two speakers had intermediate preaspiration tendencies. For all subjects pooled, mean preaspiration duration was 44 ms. The mean duration of preaspiration for the female subjects was 52 ms, and for the males 35 ms, a difference of 17 ms. Fig. 7 shows preaspiration in MP's production of the word *däck* 'deck'.

Mean preaspiration duration was observed to increase with the backness of stop articulation. For the females, mean preaspiration duration was 19 ms longer before velars than before bilabials, and for the males the difference was 14 ms (see Table 5). Mean preaspiration duration for dentals was intermediate for both, although there was little difference in duration between dental and velar closures for the female speakers.

A four-way ANOVA was performed on the preaspiration duration data, with sex, place, quantity type and word position (intervocalic vs. pre-pausal) as factors. The ANOVA indicated a significant main effect for sex

Table 4
Preaspiration duration (PrA) in word-medial, postvocalic fortis stops by subject and sex (collapsed over place of articulation and word position)

Females	PrA	St dev	Males	PrA	St dev
AE ($n = 48$)	56	26	DH ($n = 48$)	34	14
GT ($n = 48$)	44	19	MP ($n = 48$)	45	20
JR ($n = 48$)	57	18	PL ($n = 48$)	27	16
Mean total ($n = 144$)	52	21	Mean total ($n = 144$)	35	17

The number of tokens for each mean is indicated in parentheses in the leftmost column.

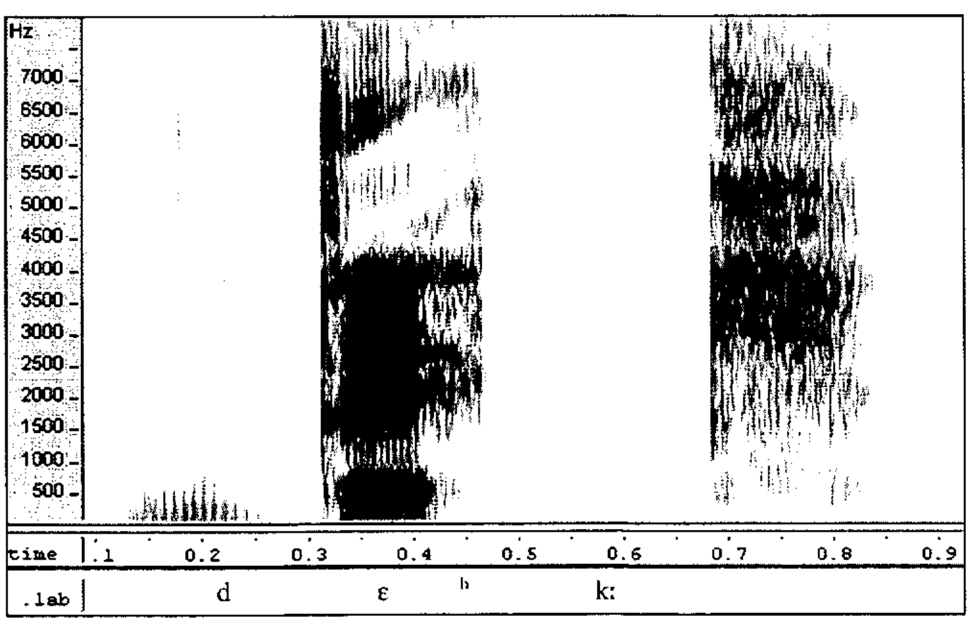

Fig. 7. Spectrogram of MP's production of the word *däck* "deck" showing preaspiration of the postvocalic fortis stop.

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Table 5
Preaspiration duration (PrA) in word-medial, postvocalic fortis stops by sex and stop place of articulation (collapsed over word position)

	Females		Males	
	PrA	St dev	PrA	St dev
Bilabial	40	17	28	16
Dental	57	20	36	16
Velar	59	23	42	20

Each mean represents 48 tokens.

Table 6
Postaspiration duration in word-medial, intervocalic fortis stops by sex and stop place of articulation

Females	VOT	St dev	Males	VOT	St dev
Bilabial ($n = 24$)	14	3	Bilabial ($n = 24$)	13	4
Dental ($n = 24$)	22	8	Dental ($n = 24$)	24	7
Velar ($n = 24$)	27	6	Velar ($n = 24$)	35	9
Mean total ($n = 72$)	21	8	Mean total ($n = 72$)	24	12

The number of tokens for each mean is indicated in parentheses in the leftmost column.

in preaspiration duration ($F(1, 282) = 55.67$; $p<0.001$) as well as place ($F(2, 282) = 20.48$; $p<0.001$). A Bonferroni comparison of means indicates that preaspiration before bilabials is significantly shorter than before dentals and velars ($p<0.0001$ in both cases), but that there is not a significant difference between dentals and velars ($p = 0.479$). Neither quantity type nor position were found to be significant ($F(1, 282) = 0.32$; $p = 0.575$; and $F(1, 282) = 3.46$; $p = 0.064$, respectively). To summarize, male speakers seem to have significantly shorter preaspiration than females in our data. Also, bilabial stops have shorter preaspiration than do dentals and velars. However, phonological quantity and word position do not seem to have a significant effect on preaspiration duration.

3.4.2. *Postaspiration—VOT*

Postaspiration (measured as VOT) was measured for the 144 intervocalic fortis stops, 48 for each place of articulation (see Table 6). (Postaspiration duration for pre-pausal stops was not measured since it was, in many cases, difficult to distinguish aspiration from exhalation). For all subjects pooled, the mean duration of postaspiration was 23 ms, 21 ms for the females and 24 ms for the males. Mean postaspiration duration was observed to increase slightly with backness. For the female speakers, mean postaspiration duration was 13 ms longer for velars than for bilabials, and for the males it was 22 ms longer.

A three-way ANOVA was performed on the postaspiration data with sex, place of articulation and quantity type as factors. The ANOVA indicated a significant main effect for place of articulation ($F(2, 139) = 79.16$; $p<0.001$) as well as sex ($F(1, 139) = 7.35$; $p<0.01$). Quantity type, however, was not significant ($F(1, 139) = 2.66$; $p = 0.105$). Thus, just as with preaspiration duration, there appear to be significant male–female differences in postaspiration duration, as well as place-dependent differences. However, the quantity structure ('V:C vs. 'VC:) does not seem to have a significant effect on postaspiration duration.

3.5. *Voicing in clusters*

Several types of stop clusters were recorded and examined with regard to voicing properties. First, 24 intervocalic /gd/ clusters were analyzed, four for each subject. Such clusters occur in words like *vägde* 'weighed' and *byggde* 'built', and are henceforth referred to as lenis clusters. Second, for each subject, eight pre-pausal (and postvocalic) /pt/ and /kt/ clusters were analyzed (four of each), making a total of 48 tokens. These occur in words such as *köpt* 'bought (past ppl.)' and *läkt* 'healed (past ppl.) and are henceforth referred

Table 7
Mean VOffT and stop cluster duration (CC dur) for each of the four stop cluster types considered

Cluster type	VOffT	St dev	CC dur	St dev
Fortis-fortis ($n = 48$)	−26	19	257	52
Fortis-lenis ($n = 48$)	−31	16	224	40
Lenis-fortis ($n = 36$)	−20	17	249	43
Lenis-lenis ($n = 24$)	160	43	170	37

The number of tokens for each mean is indicated in parentheses in the leftmost column.

to as fortis clusters. The third cluster type examined is one that is generally described as phonetically voiceless, but in a generative phonological analysis can be derived from a sequence of a fortis and a lenis stop through progressive voice assimilation. These occur in the past tense forms of verbs, e.g. *köpte* 'bought' (< *kö*/p + d/*e*) and *väckte* 'awakened (trans.)' (< *vä*/k + d/*e*). We refer to these as fortis-lenis clusters. For each subject, we examined four tokens of each cluster, /pd/ and /kd/, making a total of 48 tokens. Fourth, for each subject, six instances of lenis-fortis clusters were examined, i.e. clusters in which the first element can be derived from a lenis stop and the second one from a fortis stop. All instances involved the cluster /gt/ in postvocalic, pre-pausal position. These occur in words such as *byggt* 'built (past ppl.)' and *vägt* 'weighed (past ppl.)'. For all subjects pooled, there were a total of 36 tokens of lenis-fortis clusters.[6]

The purpose of these cluster observations was to ascertain whether the mixed clusters (fortis-lenis and lenis-fortis) aligned more with fortis or with lenis clusters, or whether they exhibited some intermediate voicing pattern.

Table 7 gives the mean voice offset time (VOffT) for all stop clusters considered as well as the mean duration of the four stop cluster types (CC dur). The cluster, CC, comprises the occlusion phase of the first stop, the release of the first stop and the occlusion phase of the second stop. In the case of lenis clusters (/g + d/) voicing was usually present throughout the CC phase and voice offset time in these cases was therefore set as equal to the duration of the CC phase.

For lenis clusters it was found that in 23 out of 24 instances the first stop in the cluster was voiced throughout the stop closure. The second stop in the cluster was fully voiced in 18 out of 24 instances. Of the remaining instances, 5 had voicing during more than half of the stop closure, and 1 had no voicing. Also, the production of the lenis clusters was generally characterized by the occurrence of a vocoid between the two stops. The release phase of the first stop in the cluster was therefore usually produced with a voicing accompaniment. An example of this is provided in the spectrogram in Fig. 8. The vocoid was present to some degree in 22 out of 24 instances. The mean duration of the vocoid was 31 ms.

All 48 instances of fortis clusters (/p + t/ and /k + t/) were produced without voicing and with both stops released. These clusters tended to be produced with a slightly negative VOffT, indicating a short period of preaspiration. The mean duration of this preaspiration was 26 ms for all subjects pooled.

Likewise, all the fortis-lenis (/p + d/ and /k + d/) clusters were produced without voicing in either stop element and with both stop elements released. These clusters also tended to be preceded by a short period of preaspiration, the mean duration of which was 31 ms for all subjects pooled. (Since the fortis-lenis clusters were followed by a vowel, it was also possible to estimate the degree of postaspiration, which was 26 ms for all subjects pooled). An example of an intervocalic fortis stop cluster is given in Fig. 9.

The lenis-fortis clusters (/gt/) were generally produced without voicing in either stop and with a slight preaspiration (mean duration = 21 ms). In all 36 cases both stop elements were released. Postaspiration duration in pre-pausal position was not measured because of the problems involved with distinguishing exhalation from aspiration. Fig. 10 provides an example of a typical production of a /gt/ cluster.

To investigate these differences further, a General Linear Model analysis of VOffT was performed with cluster type and subject as factors. This analysis indicated that cluster type was a highly significant factor in

[6]Since statements in the literature (e.g. Cho, 1994; Lombardi, 1999) consider such clusters from a generative linguistic perspective, we present our data from the point of view of a generative analysis.

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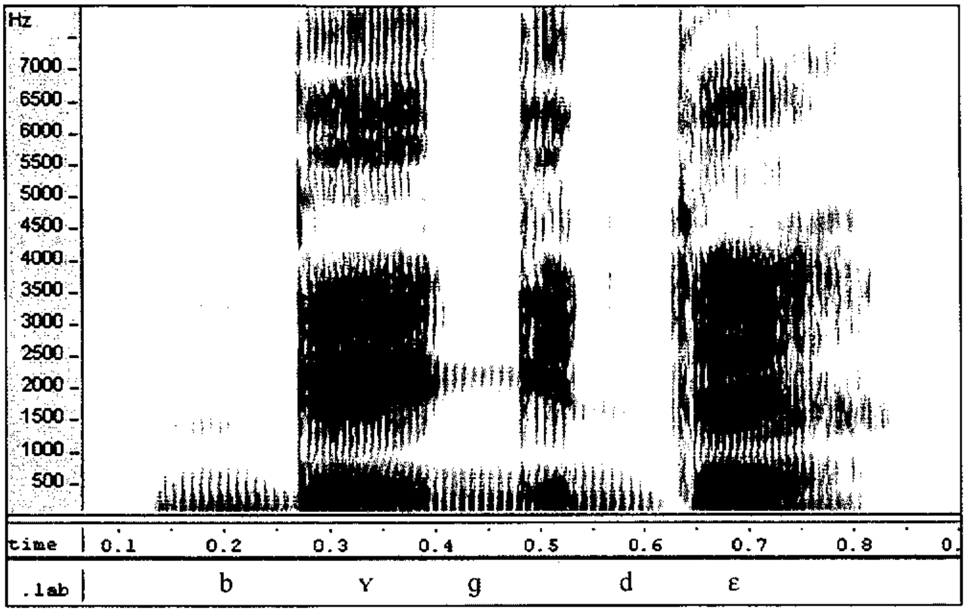

Fig. 8. Spectrogram of MP's production of the word *byggde* "built (past tense)" showing voicing in both elements of the lenis stop cluster as well as an epenthetic vocoid.

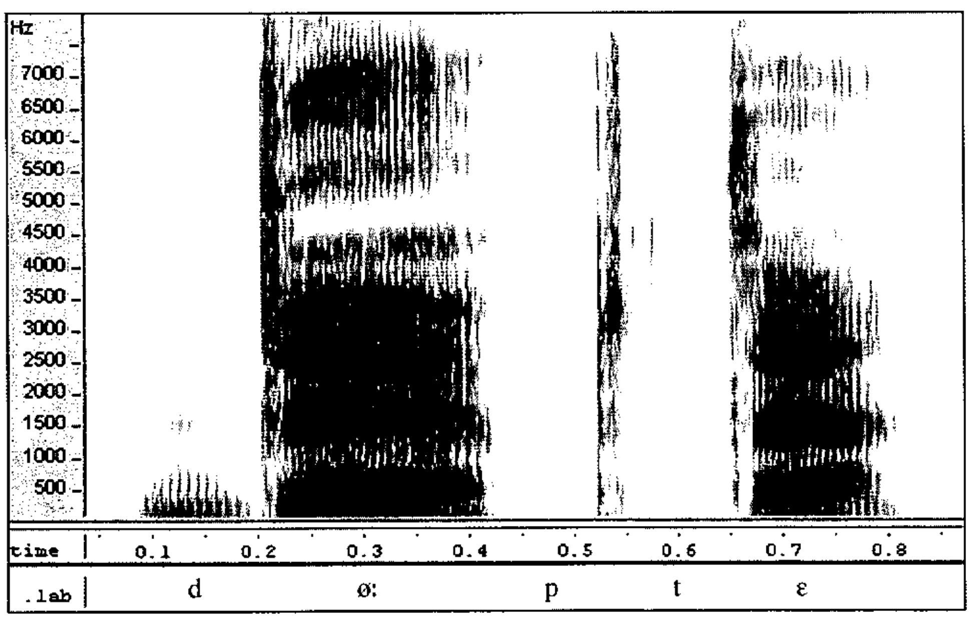

Fig. 9. Spectrogram of MP's production of the word *döpte* "baptized" showing voicelessness in both stop cluster elements. Both stop elements are released.

VOffT duration ($F(3, 147) = 468.30$; $p<0.001$). Subject was significant at the 5% level ($F(5, 147) = 2.83$; $p<0.05$). A Bonferroni comparison of means suggested that VOffT in lenis clusters was significantly different from that in all other cluster types ($p<0.0001$ in all cases). Differences between the remaining three cluster types were not significant ($p = 0.143$ for lenis-fortis clusters vs. fortis clusters, and $p = 1.000$ for the remaining comparisons).

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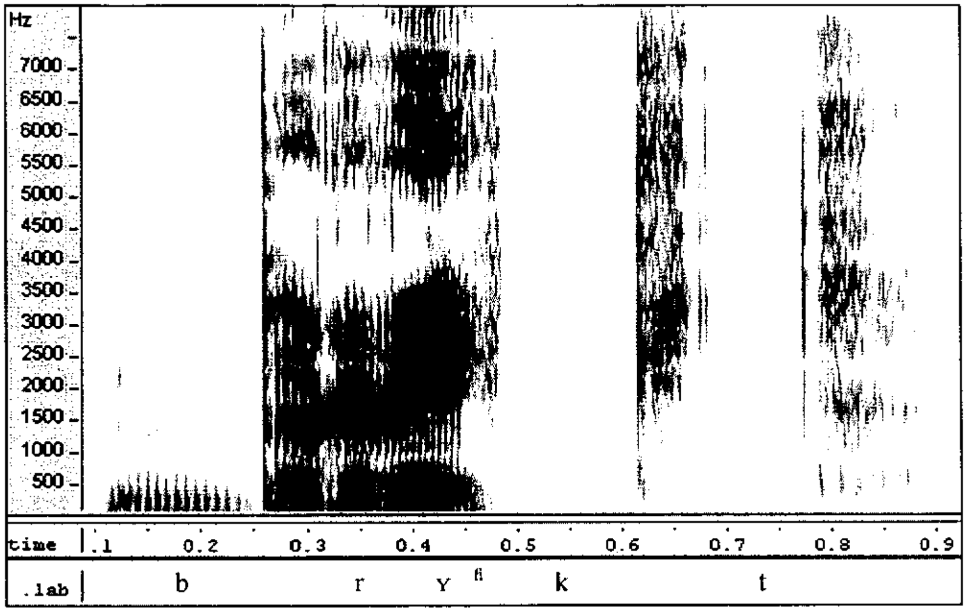

Fig. 10. Spectrogram of MP's production of the word *bryggt* "brewed (sup.)" showing voicelessness in both stop cluster elements as well as a very short period of breathy voice before the first stop closure. Both stop elements are released.

4. Discussion

4.1. Prevoicing

All six subjects in our experiment have considerable prevoicing of initial lenis stops. This differs from the results reported by Keating et al. (1983) who found no prevoicing for such stops. Since the recordings for the experiment of Keating et al. (1983) were made in the US (Keating, p.c.), it is possible that the VOT patterns of their subjects were influenced by English. Specifically, one might expect that if Swedish stop production were influenced by English, it would primarily affect prevoicing. It should be noted that the difference between our subjects, who all speak English, and those for the study of Keating et al. is that their speakers were living in an English speaking environment, whereas ours were living in an environment where Swedish is the dominant language. Recent work has shown that subjects are influenced by fine phonetic detail in imitation tasks (Goldinger, 1998). An experiment by Nielsen (2006) showed that subjects produced significantly longer VOTs after exposure to speech with longer VOTs. They generalized the increased aspiration to new instances of /p/ in unheard words as well as to a new segment (/k/). This suggests that native speakers of one language may change the VOTs in their native language as a result of VOTs in the language that is spoken around them. That such changes can occur in the first language (L1) as a function of the ambient language has been shown by Sancier and Fowler (1997). Brazilian Portuguese contrasts stops with prevoicing with stops with short-lag VOT. Sancier & Fowler found that the positive VOTs in a speaker's L1 (Brazilian Portuguese) were longer after an extended stay in the United States and shorter after an extended stay in Brazil. They conclude that the English long-lag stops influenced the amount of positive VOT in the L1, Brazilian Portuguese.

Examples of such influence that pertain specifically to prevoicing include Caramazza and Yeni-Komshian (1974) who suggested that the lack of prevoicing in Canadian French was due to the historical influence from Canadian English. Also, Heselwood and McChrystal (1999) studied the speech of Panjabi speakers living in Bradford, England. Panjabi has a three-way distinction in post-pausal stops, prevoiced, voiceless unaspirated and aspirated. For the older age groups in their study, the expected voicing contrasts between the three categories were upheld. For the younger age group, the frequency of occurrence of prevoicing was radically reduced, and there was apparently no distinction between the prevoiced and voiceless unaspirated stops. Their stop system had thus come to closely resemble the two-way stop system of English. Obviously, this is an area that deserves further attention and the apparent discrepancy between the data in Keating et al. (1983) and our own may have other causes.

It is worth noting that the occurrence of prevoicing in Swedish is not limited to word list reading. Helgason (2002, p. 139ff) reported prevoicing in unscripted speech (elicited through map tasks) and determined that prevoicing occurred in most content words, but more infrequently in function words. Thus approximately 9 out of 10 content words had some degree of prevoicing, whereas it was found in only about a third of function words. Since function words are more likely to be unstressed in a sentence context than are content words, it seems plausible that the difference observed is a direct function of stress. Possibly, those function words that do have prevoicing simply have more stress than those without prevoicing.

4.2. *Preaspiration*

Gobl and Ní Chasaide (1988) and Fant et al. (1991) both note the occurrence of preaspiration in Swedish fortis stops. This preaspiration is not an obligatory attribute of fortis stop production in most varieties of Swedish, but there are speakers who preaspirate regularly and consistently (Helgason, 2002). For such speakers, there are striking durational similarities between their non-obligatory preaspiration and the obligatory preaspiration one finds in, e.g., Faroese (Helgason, 2002). Preaspiration has been shown to occur in both southern (Tronnier, 2002) and northern (Wretling et al., 2002) Swedish dialects, as well as in at least one variety of Norwegian (Van Dommelen, 2000).

Helgason (2002, p. 120ff) showed that preaspiration in Swedish is not specific to word list reading, but is found in unscripted speech as well. In his unscripted speech data, mean preaspiration duration in content words ranged from 6 ms to 45 ms, depending on speaker and stop quantity. In our read speech data, mean preaspiration duration was considerably longer, ranging from 27 to 57 ms. Most likely, the longer durations in our read speech data reflect a slower speaking rate than in Helgason's unscripted data. Also, our data come from words spoken in isolation, while the relevant words in Helgason's data were seldom spoken in isolation. Coincidentally, two of our subjects, MP and GT, also participated in Helgason's study, enabling us to compare preaspiration durations for these two speakers in unscripted and read speech. In Helgason's study, MP and GT had a mean preaspiration duration of 8 and 14 ms, respectively. In our data, mean preaspiration duration for these speakers was 45 and 43 ms, respectively.

The perceptual salience of preaspiration has been studied by Pind (1993, 1998). His 1993 experiment indicated that given a vowel + stop sequence of 350 ms, a preaspiration duration exceeding 35–40 ms was needed to trigger a preaspiration percept for an Icelandic listener. For vowel + stop sequences of 297 ms, preaspiration had to exceed approximately 30 ms to trigger a preaspiration percept. From this we can infer that if preaspiration is longer than approximately 10% of the total vowel + stop sequence, it is likely to be perceptually salient. (Note that these findings for Icelandic do not provide an absolute threshold for the perceptual salience of preaspiration, i.e. preaspiration may be perceptually salient even if it is shorter than what is required for categorical perception of preaspiration in Icelandic.) With the exception of PL, all our subjects do, on average, have a mean preaspiration duration exceeding or approaching that which would trigger a preaspiration percept in an Icelandic listener (see Table 8). This strongly suggests that preaspiration in Swedish is perceptually salient.

It should be noted that there was a much stronger tendency for breathy voicing in preaspiration than in postaspiration in our data. Such a difference was also observed by Ní Chasaide and Gobl (1993), who noted that the duration of the breathy portion of preaspiration in their data tended to be much longer than that of postaspiration (see also Gobl & Ní Chasaide, 1999). The mean duration of preaspiration in our data ranged from 27 to 57 ms for the six subjects (see Section 3.4.1), and the proportion of breathiness within preaspiration ranged from 45% (for the subjects with the longest mean preaspiration duration) to 90% (for those with the shortest). Postaspiration of utterance-initial fortis stops yielded mean durations ranging from 53 to 70 ms, with a proportion of breathiness ranging from 16% to 31%.

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Table 8
Mean duration of vowel + closure sequences (V + C) and preaspiration (PrA) for each subject

Subject	V + C	PrA
AE	391	56
GT	392	43
JR	329	57
DH	314	34
MP	385	45
PL	379	27

Note that the preaspiration duration is also included as part of the V + C sequence.

4.3. *Clusters*

Swedish is often characterized as a language in which both progressive and regressive assimilation to voicelessness occurs in stop clusters (e.g. *köpte* with [pt] 'bought' (<*kö*/p + d/*e*) and *byggt* with [kt] 'build SUP' (<*by*/g + t/ (e.g. Lombardi, 1999). Cho (1994), however, claims that some devoicing in stop clusters is only partial and, for example, she claims that the first stop in *byggt* 'build SUP' is only partially devoiced.

Our data show both progressive and regressive assimilation in stop clusters: voicing is either present in both stops in a cluster, or in neither of them. Stop clusters that have underlying (or historically) mixed voicing are entirely voiceless. Only clusters in which both stops are lenis are voiced.[7]

4.4. *Male–female differences*

The female speakers generally tended to produce less voicing during closure than did the male speakers. For medial stops, females had more instances of partial voicelessness of the stop than did males; for initial stops, the females had shorter prevoicing than the males. Similarly, for German, Jessen and Ringen (2002) found that females had more instances of partial voicelessness in intervocalic lenis stops than did males. For Dutch, van Alphen and Smits (2004) found that male subjects produced utterance-initial lenis stops with prevoicing more often than did females. The observed differences may be due to the difference in size between male and female vocal tracts. It has been demonstrated that bilabial stops have a greater tendency for voicing than velars because the vocal tract volume for bilabials can be made far greater than the volume for velars (Ohala, 1983). A larger supraglottal volume allows for a longer period of voicing because the time during which transglottal air flow is sufficiently high for voicing to occur is longer. For the same reason, the larger male vocal tract should be more amenable to voicing during closure than the smaller female vocal tract.

In contrast, though, Karlsson et al. (2004) found that females had longer prevoicing than males in Umeå Swedish and, similarly, Ringen (2008) found that in both Russian and Hungarian women have longer prevoicing than do men. Ringen suggests that one possible explanation for this is that prevoicing in Russian and Hungarian is necessary to distinguish the two stop types and that the longer female prevoicing is an aspect of the tendency for clear speech often attributed to female speakers (see, e.g., Bradlow, Toretta, & Pisoni, 1996; Byrd, 1994; Hazan & Markham, 2004; Henton, 1992, 1983; Kramer, 1978). However, this explanation cannot be applied to Umeå Swedish, in which prevoicing is not essential to maintain a two-way distinction. Apparently, more research is needed in this area.

The female speakers had a greater tendency to preaspirate their postvocalic fortis stops than did the males. This agrees with several earlier observations of male–female differences for preaspiration. For example, Gobl and Ní Chasaide (1988, p. 37) note that 4 out of 4 of their female speakers preaspirated while only 4 out of 7 of their males speakers did. Fant et al. (1991) also note that females tend to preaspirate more than males, although they do not present data to this effect. For the Arjeplog dialect of Swedish, Stölten (2002) found that preaspiration duration was longer for females than for males. For the Tyneside dialect of English, Docherty

[7]A very different situation is found with fricative-stop clusters: here, as Cho (1994) suggests, the regressive assimilation is only partial (Helgason & Ringen, 2007) and in forms such as *bygds* 'district-GEN' and *hävds* 'custom-GEN' the stops are fully or nearly fully voiced.

and Foulkes (1999) and Docherty, Foulkes, Tillotson, and Watt (2006) found that children and adult females tended to preaspirate more than adult males (see also Foulkes, Docherty, & Watt, 1999).

Possibly, the tendency for female speakers to produce preaspirations more often, and with longer durations than males, is a consequence of a general tendency for breathiness in female voice sources. Investigating voice source characteristics in 22 female and 21 male subjects, Hanson (1997) and Hanson and Chuang (1999) observed that the female voice sources had a greater degree of spectral tilt than did the male voice sources, indicating that the voice quality of female speakers tends to be more breathy than that of male speakers. Such a difference also seems to exist between male and female speakers of Swedish (Fant et al., 1991). Titze (1989) proposes a possible explanation for the breathiness of female voice sources, suggesting that female speakers tend to spread their vocal processes to de-emphasize the power efficiency of their voices, which he estimates is approximately 25% greater than for males. Assuming that the change from modal voicing to breathy voicing and voiceless aspiration occurs more rapidly for speakers whose vocal folds are already partially spread during modal voicing, one would predict that females preaspirate more readily than males.

4.5. *Place-dependent differences*

Prevoicing durations in our Central Standard Swedish data were longer for bilabials and dentals than for velars. This agrees with observations from a number of other languages concerning place-dependent differences in the duration of voiced stops, both utterance-intial (van Alphen & Smits, 2004 for Dutch) and intersonorant (Jessen, 1998 for German; Stevens & Hajek, 2004 for Sienese Italian). This place-dependence can be explained in terms of differences in aerodynamic conditions in the vocal tract between back and front places of articulation (Ohala, 1983; Ohala & Riordan, 1979). Voicing requires that subglottal air pressure be higher than the pressure above the glottis. When a non-nasal stop closure is made in the vocal tract, air pressure above the glottis gradually becomes equal to the subglottal pressure and voicing cannot be maintained. The smaller the volume of the cavity above the glottis, the shorter the time that voicing can be maintained. For velars the volume between the glottis and the constriction is much smaller than for bilabials and, perhaps more crucially, the production of bilabials involves more compliant tissues that can expand passively and increase the available volume. Therefore one would expect less voicing in velars than in bilabials.

Postaspiration duration (VOT) of utterance-initial fortis stops in the Swedish data was observed to increase with the backness of stop articulation. This agrees with a large number of observations of VOT from other languages (Cho & Ladefoged, 1999). Interestingly, preaspiration (VOffT) of postvocalic stops in the Swedish data followed the same pattern, that is, they were longer before velar stops than before dentals, and longer before dentals than before bilabials. These findings mirror those of Indriðason, Eyþórsson, Halldórsson, Jónsson, and Bjarnadóttir (1991) for Icelandic, who report a mean preaspiration duration of 82 ms before bilabial stops, 95 ms before dento-alveolars, and 107 ms before velars (we obtained these means by pooling the results of speakers of both dialects that Indriðason et al. consider). Also, for Scots-Gaelic, Ladefoged, Ladefoged, Turk, Hind, and Skilton (1999) found that mean preaspiration duration before bilabial closures was 50 ms, 80 ms before palatals and approximately 105 ms before both dental and velar stops.

The consistent finding that preaspiration before bilabial stops is shorter than before dentals and, especially, velars has a bearing on the numerous theories put forth to explain away place-dependent VOT differences (see Cho & Ladefoged, 1999, for an overview). Most of these theories attribute the effect to "low-level" articulatory and/or aerodynamic factors, usually by incorporating the build-up and release of intra-oral pressure into an explanation of the causes of place-dependent VOT differences (e.g. Hardcastle, 1973; Maddieson, 1997; Stevens, 1999). However, most of these explanations do not account for place-dependent differences in VOffT, since there is little or no build-up of intra-oral pressure before or during the interval between voice offset and the onset of a stop closure. Still, one account by Hardcastle (1973) can be applied to both pre- and postaspiration. Hardcastle suggested that the relatively low velocity of movement of the tongue dorsum as compared to the tongue tip or lips might affect VOT. Kuehn and Moll (1976) provided support for the notion that velocity of movement for labials is faster than for coronals, and faster for coronals than for velars. For stops, the relatively rapid opening of the constriction leads to a rapid lowering of intra-oral pressure, and the more rapidly the intra-oral pressure falls, the sooner the transglottal pressure becomes appropriate for voicing. In contrast to most other explanations offered in the literature, this account may be applied to place-dependence in VOffT as well. If a velar closure takes longer to implement than, for instance, a bilabial one, this may result in a longer lag between voice offset and stop closure (i.e. preaspiration) for velars than for bilabials.

4.6. Utilizing the VOT continuum

Lisker and Abramson (1964) find no languages with both prevoicing and aspiration in their study. Indeed, they state that "not a single one of the two-category languages locates its categories where we might expect to find them, that is, at opposite ends of the continuum of voice onset time. This fact, if it is a reflection of the situation in languages generally, is evidence for the view that in the phonetic 'realization' of phonemic contrasts human beings fall considerably short of utilizing all the phonetic space available to them" (Lisker & Abramson, 1964, pp. 403–407). This is in line with later observations of the typology of consonant systems, in particular the "Size Principle" (Lindblom & Maddieson, 1988) which concerns the apparent avoidance of phonetically "complex" (but highly distinctive) segments in small phoneme inventories. As an explanation of these phenomena, Lindblom (1990) promotes the idea that speakers strive for a balance between effort on the one hand and intelligibility on the other. As a result, phonological systems evolve in which phonetic contrasts tend to be sufficiently, rather than maximally, distinctive.

Our investigation indicates that Swedish is an example of a language with a stop system that has been claimed to be typologically unusual or non-existent (Jansen, 2004; Keating, 1984; Lisker & Abramson, 1964). In utterance-initial position the "opposite ends" of the VOT continuum are utilized, postaspiration vs. prevoicing. Postvocalically, there is a tendency to contrast preaspirated stops with voiced ones. In pre-pausal position the contrast is that of a voiceless stop (with varying degrees of aspiration) and a voiced one. There is also a strong tendency to produce an epenthetic vocoid after the release of a voiced stop. Thus, the pre-pausal stop is often pre-vocalic from a phonetic point of view, which is likely to increase the perceptual salience of both its voicing and its stop place of articulation and provides additional cues for determining phonological quantity.

Swedish is one of a number of languages that does not comply with the prevailing notions of typological normalcy in stop systems. Vaux and Samuels (2005) list Swahili (Polomé, 1967), many Western dialects of Armenian (Vaux, 1998) and some idiolects of English (e.g. Scobbie, 2006) as being languages with two stop series that contrast fully voiced stops with aspirated ones. Turkish is another language with a two-way stop contrast in which lenis stops are prevoiced and fortis stops are aspirated in post-pausal position (see Kallestinova, 2004; Ringen, 2008). Although only 4.7% of the languages in the UPSID database (Maddieson, 1984; Maddieson & Precoda, 1989) are listed as having a two-way stop system in which fully voiced stops contrast with aspirated ones (i.e. 21 out of 451 languages),[8] both Turkish and the Eastern dialect of Armenian are part of the UPSID language sample, and are both listed as having a voiceless vs. aspirated contrast. Hence, there is some indication that the frequency of occurrence of the voiced vs. aspirated opposition may be underestimated in UPSID.

Possibly, the increasing body of cross-linguistic, phonetically detailed research into stop systems will reveal a more complex picture of stop contrast typology than has often been assumed. Existing descriptions of stop contrasts may have ignored too much phonetic detail. Data that more accurately reflect the phonetic detail involved in stop production should increase both the accuracy of phonological descriptions and the reliability of typological statements.

4.7. Laryngeal features in stop production

Keating (1990) suggests, following Kingston (1985), that preaspirates derive from geminates (as in Icelandic) and that there are no cases of single-segment preaspirates. Yet single-segment preaspirates are found in Faorese (see Helgason, 2002, p. 146ff) and in the Gräsö dialect of Swedish (Helgason, 2002, p. 169ff) as well as for some speakers of Swedish in our own data. Hence, Swedish presents another problem for

[8]The languages in question are: Norwegian, Farsi, Khalkha, Adzera, Lak, Rutul, Bats, Archi, Avar, Kota, Ewe, Akan, Ga, Kohumono, Bobo-Fing, Klamath, Kwakw'ala, Yana, Acoma, Tunica and Alamblak.

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Keating's (1990) proposal about phonetic representations of voicing contrasts, since preaspirated stops are not easily represented in her system.

Recently, many phonologists and phoneticians, including Anderson and Ewen (1987), Jessen (1989, 1996, 1998), Rice (1994), Iverson and Salmons (1995, 2003), Tsuchida, Cohn, and Kumada (2000), Petrova, Plapp, Ringen, and Szentgyörgyi (2000, 2006), Jessen and Ringen (2002), Ringen and Helgason (2004), Beckman, Jessen and Ringen (2006), among others, have rejected the idea that there is a single [voice] feature that underlies the two-way phonological contrasts in languages which contrast prevoiced stops and short-lag VOT stops as well as in languages that contrast short-lag and long-lag VOT stops. Rather, they claim that [voice] is the feature of contrast in languages with prevoicing, but [spread glottis] ([sg]) is the feature of contrast in languages with a short-lag vs. long-lag VOT contrast and that any voicing of stops that occurs in languages with a [sg] contrast is due to passive voicing. If prevoicing implicates the feature [voice] in phonetic representations and aspiration implicates [sg], then Swedish would appear to have both (cf. Beckman & Ringen, 2004; Ringen & Helgason, 2004).

Discussions of appropriate phonetic representations in languages with two-way VOT contrasts have not considered languages such as Swedish. Hence it would appear that discussions of the phonetics-phonology interface will need to be revisited in light of the findings reported here.

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Appendix A. Word list with broad transcriptions

1.	sladd ['slad:]	24.	bebis ['be:bɪs]	47.	fött ['fœt:]
2.	svept ['sve:pt]	25.	byggt ['bʏgt]	48.	lånade ['lo:nadɛ]
3.	köpte ['ʃø:ptɛ]	26.	baka ['bɑ:ka]	49.	labb ['lab:]
4.	läka ['lɛ:ka]	27.	byggde ['bʏgdɛ]	50.	gubbe ['gɵb:ɛ]
5.	däck ['dɛk:]	28.	puck ['pʰɵk:]	51.	ledde ['lɛd:ɛ]
6.	fat ['fɑ:t]	29.	köpt ['ʃø:pt]	52.	vägt ['vɛ:gt]
7.	läkte ['lɛ:ktɛ]	30.	gap ['gɑ:p]	53.	dagg ['dag:]
8.	rep ['ɾe:p]	31.	glapp ['glap:]	54.	klubb ['kl̥ɵb:]
9.	kub ['kʰʉ:b]	32.	väga ['vɛ:ga]	55.	sköta ['ɧø:ta]
10.	ägg ['ɛg:]	33.	byta ['by:ta]	56.	bibel ['bi:bɛl]
11.	bryggt ['bɾʏgt]	34.	skötte ['ɧœt:ɛ]	57.	gapade ['gɑ:padɛ]
12.	att leda [at 'le:da]	35.	tabbe ['tʰab:ɛ]	58.	bad ['bɑ:d]
13.	lett ['lɛt:]	36.	döpte ['dø:ptɛ]	59.	tappa ['tʰap:a]
14.	öga ['ø:ga]	37.	lag ['lɑ:g]	60.	bytt ['bʏt:]
15.	släppa ['slɛp:a]	38.	skällde ['ɧɛldɛ]	61.	kläckte ['kl̥ɛktɛ]
16.	vägde ['vɛ:gdɛ]	39.	skött ['ɧœt:]	62.	bädd ['bɛd:]
17.	att föda [at 'fø:da]	40.	bygga ['bʏg:a]	63.	bytte ['bʏt:ɛ]
18.	läpp ['lɛp:]	41.	vrak ['vɾɑ:k]	64.	tub ['tʰʉ:b]
19.	packa ['pʰak:a]	42.	födde ['fœd:ɛ]	65.	prat ['pɾ̥ɑ:t]
20.	läkt ['lɛ:kt]	43.	tak ['tʰɑ:k]	66.	räd ['ɾɛ:d]
21.	kapa ['kʰɑ:pa]	44.	kläckt ['kl̥ɛkt]	67.	skrämde ['skɾɛmdɛ]
22.	slägga ['slɛg:a]	45.	kläcka ['kl̥ɛk:a]		
23.	väg ['vɛ:g]	46.	köpa ['ʃø:pa]		

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