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A PHONETIC STUDY OF THE STØD IN STANDARD DANISH

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Abstract

Chapter I gives a brief survey of phonological interpretations of the Danish stød, the dialectal and historical background, and previous phonetic investigations.

Chapter II gives an account of the material, subjects and procedures used in the present investigation.

Chapter III contains the results. In accordance with Svend Smith a distinction is made between the first and the second phase of the stød.

The first phase is characterized acoustically by a higher pitch level and often a higher intensity level than syllables without stød, and by a relatively high subglottal pressure and airflow, thus generally by a relatively high expenditure of energy. In the second phase, the stød phase proper, there is a strong decrease in intensity, particularly in the lower part of the spectrum and, for the majority of the speakers, a noticeable decrease in fundamental frequency and/or aperiodicity. Moreover the airflow is low, and inverse filtering shows a decreasing amplitude of glottal flow peaks. There is also a slight decrease in subglottal pressure, and all speakers have a constriction of the vocal folds and often of the ventricular folds as well, but with large interindividual variation as to the degree of constriction. On the boundary between the first and the second phase most speakers have a strong contraction of the vocalis and lateralis muscles, obviously preparing for the glottis constriction of the second phase.

Chapter IV discusses the stød in relation to phonation types and concludes that the stød is closely related to creaky voice though without sharing all of its characteristic features.

Moreover the causal relations among the various properties of the Danish stød are discussed. The author cannot follow Svend Smith in assuming that a sudden contraction and relaxation of the respiratory muscles resulting in a quick rise and fall in subglottal pressure, constitute the primary factor. There is rather an independent contraction of a number of muscles, and neither the high pitch in the start nor the fall in pitch and intensity in the second phase can be explained by the subglottal pressure contour. The high pitch level in the start may be explained by activity in the cricothyroid, and the decrease in pitch and the low intensity in the second phase is probably *due to the glottis constriction, although the fact that the decrease in intensity starts rather early, raises some problems.*

Finally the question of the origin of the stød is taken up again. It is suggested that the stød in Danish perhaps originated from a reinforcement of the first syllable due to reduction and loss of a following syllable in common Scandinavian. The reinforcement may have been accompanied by a rise in pitch so that developments in different directions (involving stød or tonal accents) were possible.

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I. INTRODUCTION

A. PHONOLOGICAL ASPECTS OF THE STØD

1. STØD AS A PROSODY

The Danish stød is a prosodic phenomenon connected with certain syllables. It generally shows up as a decrease in intensity and (often) pitch, in distinct speech ending in irregular vibrations (creaky voice), in very emphatic speech probably sometimes in a complete glottal closure. A distinction is often made between "stød in the vowel" and "stød in the consonant". But the stød is not, primarily, connected with specific segments. The irregularities (or dip of the Fo- or intensity curves) are generally found about 10-15 cs after the start of the vowel; therefore, if the vowel is long they will coincide with the end of the vowel, and if the vowel is short with the beginning of a following sonorant consonant. The stød requires for its manifestation a certain stretch of voicing. Therefore, syllables ending in a short vowel or in a short vowel plus voiceless consonant(s) cannot have stød in Standard Danish. They are said to lack "stød-basis". As Danish syllables do not have voiced obstruents after short vowels (phonetically Danish [ð] is a sonorant, not an obstruent), only syllables with short vowel plus sonorant consonant can have stød. Moreover, the stød requires a certain degree of stress (primary or secondary stress) and disappears if the syllable loses its stress in the sentence. It also disappears in song (at least in traditional higher style singing). These facts show that it is not a segment but a prosody. In phonetic transcription it is traditionally indicated by a raised comma (’) or sometimes by the symbol for a glottal stop (ˀ) placed after a long vowel or after a sonorant consonant following a short vowel (see Note 1 on phonetic transcription).

2. STØD IN DIFFERENT WORD TYPES

The presence or absence of stød can often be predicted. This is, however, not always the case; and there is quite a number of minimal pairs (see below).

As far as native monomorphemic words are concerned, the presence of stød is characteristic of monosyllables (provided that they have stød-basis) in contradistinction to disyllables. (1) Almost all monosyllables with long vowel have stød, e.g. *pil* [pʰi:’l]'arrow', *hus* [hu:’s] 'house', *bæst* [bɛ:’sd] 'beast'. The only exceptions are the contracted forms *far, mor, bror* [fɑ:, mo(:)ɐ̯, bʁo(:)ɐ̯] 'father, mother, brother', and, in the younger Copenhagen standard ("Advanced Standard Copenhagen") words with assimilation of /r/ to a preceding [ɑ] or [ɒ], e.g. *mark* [mɑ:g] 'field'. (2) Almost all monosyllables with short vowel plus sonorant consonant plus consonant have stød, e.g. *kant* [kʰan’d] 'border', *helt* [hɛl’d] 'hero', *sans* [san’s] 'sense'. Only words with /r/ plus voiceless consonant are excepted, e.g. *vers* [vɛɐ̥s] 'verse', *birk* [biɐ̥g] 'birch'. (In this position /r/ was voiceless earlier and still is in a very conservative norm.) (3) Of monosyllables with short vowel plus sonorant consonant some have stød and others not, and this gives rise to various minimal pairs, e.g. *ven* [vɛn] 'friend' vs. *vend* [vɛn'] 'turn!' (imperative), *man* [man] (indefinite pronoun) vs. *mand* [man'] 'man', *spil* [sbel] 'play' (noun) vs. *spil* [sbel'] 'play!' (imperative) (final sonorants are very short in Danish, and may have been too short to get stød, except when they were geminated or in clusters; later shortenings or assimilations of long consonants and clusters gave rise to a number of minimal pairs with short vowel plus sonorant consonant). The recent shortening of vowels before [ð] has increased the number of minimal pairs, e.g. *fed* [feð] 'clove' vs. *fed* [feð'] 'fat' (adjective), in the more conservative norm [fe:'ð].

Disyllables in *-e* [ə] never have stød. But disyllables in *-er, -en, -el* [ɒ (ɔ), n̩, l̩] vary (some were old monosyllables, some polysyllables, and some are loanwords), and there is quite a number of minimal pairs in *-er*, thus *kælder* [kʰɛlɒ] 'cellar' vs. *Keller* [kʰɛl'ɒ] (a name), or *læser* [lɛ:sɒ] 'reader' vs. *læser* [lɛ:'sɒ] 'reads'.

As for polymorphemic words, the most general rule is that flexives and derivatives do not cause any stød change. The presence or absence of stød in inflected forms may therefore indicate whether the stem is mono- or polysyllabic, e.g. *tanken* [tʰɑŋgn̩] definite form of *tanke* 'thought' vs. *tanken* [tʰɑŋ'gn̩] definite form of *tank* 'tank'. However, in many cases the stød of monosyllabic stems is lost, e.g. before endings in *-e* [ə], for instance the plural *-e* in nouns and adjectives (*hus* [hu:'s] 'house', plur. *huse* [hu:sə]), and generally before *-ede* [əðə] (preterite of weak verbs), whereas in other cases there is addition of stød, e.g. in the definite form of stødless nouns in short vowel plus sonorant consonant, e.g. *ven* - *vennen* [vɛn] [vɛn'n̩]. The ending *-er* [ɒ] behaves inconsistently, which may give rise to minimal pairs like *piber* [pʰi:bɒ] plur. of *pibe* [pʰi:bə] 'pipe' or nomen agentis of the verb *pibe* [pʰi:bə] 'peep' vs. *piber* [pʰi:'bɒ] pres. of the verb *pibe*. There is inconsistency even with the same grammatical ending, e.g. *ven* [vɛn] 'friend', plur. *venner* [vɛnɒ] and *han* [han] 'male', plur. *hanner* [han'ɒ].

Monosyllabic first parts of compounds often lose their stød, e.g. *sol* [so:'l] 'sun', but *solskin* ['so:lˌsgen'] 'sunshine'. On the other hand, disyllabic verbs or verbal derivatives (as well as complex adjectives) with prefixes or as second part of compounds often have stød addition. Whereas e.g. *tale* [tʰæ:lə] 'to speak, speech' and the nominal compound *udtale* ['uðˌtʰæ:lə] 'pronunciation' do not have stød, there is stød addition in the verbs *betale* [be'tʰæ:'lə] 'pay' and *udtale* ['uðˌtʰæ:'lə] 'pronounce' and in the noun *udtalelse* ['uðˌtʰæ:'ləlsə] 'utterance' derived from the verb *udtale*. (Further examples illustrating the rules are found in the word lists, Appendix I.)

Integrated foreign words follow the stød rules for native words. Polysyllables with stress on the last syllable are treated as monosyllables, e.g. *supplikánt* with stød on *-kánt* like the monosyllable *kant* (except some French words with final vowel). Disyllables and words with penultimate stress generally do not have stød (like native disyllables in *-e*, e.g. *kane*), e.g. *káno, panoráma*. Words with stress on the antepenultimate have stød on this syllable, e.g. *fólio* (the native pattern may in this case be the type *løbene* [ˈlø:ˀbənə] definite plur. of the monosyllabic noun *løb* [lø:ˀb] (but native trisyllabic words may also lack stød, e.g. *løbende* [lø:bənə] pres. participle of the disyllabic verb *løbe* [lø:bə]). Sometimes foreign words are treated like compounds, e.g. lat. *scribunt* with stød on *-bunt*. (Latin words traditionally get stød, but otherwise stød is very rarely transferred when Danes speak foreign languages.)

Thus the rules are complicated and not always exceptionless, and the conditions may be both phonological and morphological; although it is connected with the syllable,the stød may characterize morphological types.

3. LINGUISTIC DESCRIPTION OF THE STØD

The first description of the Danish stød is given by Jens Pedersen Høysgaard (1743, 1747, 1769). He sets up a system of four so-called "åndelav" (i.e. 'breath types' or 'phonation types') based on a cross-classification of stød and vowel length (with a terminology which varies somewhat in the three different books). Høysgaard does not give examples of four very similar words like *kæle, kæler, kælder, Keller* [kʰɛ:lə, kʰɛ:ˀlɒ, kʰɛlɒ, kʰɛlˀɒ], but many pairs; his examples are perfectly clear, and he is well aware of the fact that his four "åndelav" are based on a cross-classification of stød and vowel length. He also distinguishes clearly between "åndelav", stress, metrical ictus, and the role of pitch and duration in stress. Moreover, he gives the main rules for the occurrence of stød with many examples and a number of minimal pairs, and he proposes that the different "åndelav" should be indicated in orthography by means of accents. As a first description of the stød, this is an admirable achievement. It influenced the description of Danish prosody deeply for the next hundred years, and it is still considered useful by many dialectologists. The only deviation from later descriptions of the stød is that Høysgaard considers words with stød on a syllable final vowel (e.g. [sø:ˀ] as belonging to the type [halˀ] (i.e. stød in syllables with short vowel plus sonorant consonant), and not to the type [hæ:ˀl] (i.e. stød in words with long vowel). The reason may be that he heard the type [halˀ] as "stopping of the breath", and the type [hæ:ˀl] as first stopping of the breath and then "giving it speed again", i.e. rather [hæˀæl] with a rebound of the vowel, as it is still often pronounced (and obligatorily so in the Zealandish stød in long vowels). And he may not have had this rebound finally. Moreover, in the distribution of the stød he is influenced by his Jutlandish origin. In his main work on prosody (1747) he mentions that strictly speaking one might set up a fifth "åndelav", viz. for words with apocope and lengthening of the final consonant, as in *skinne* 'shine', e.g. in Jutlandish.

Some of Høysgaard's followers made a few revisions, e.g. considering the type [sø:'] as having stød in the vowel, or adding a 6th type (thus Rask considered the contracted type *far* [fɑ:] to be a special type with overlong vowel, cp. Bjerrum 1959). Levin (1844) distinguished the stød-opposition from the length-opposition, but in a not too clear way, which was not accepted. Later Jessen (1861, cit. Bjerrum 1959) proposed this distinction again, and since then it has been customary to distinguish the two oppositions completely. At the same time the grammarians started describing the type [hæ:'l] as having "stød in the vowel" and [hal'] as having stød in the consonant, e.g. Lyngby in the fifties (cp. Bjerrum 1959, p. 226), Bruun (1883), and Jespersen (1897-99). This was, in a way, a step backwards from a functional point of view.

Uldall (1933) places the stød among the consonants in his sound chart, but later (1936) he describes it as a prosody. However, at this stage of Hjelmslev's and Uldall's linguistic theory a marginal unit which can occur only initially or finally in a syllable, but cannot occur in both positions, is a prosody, and thus /h-/ is also a prosody.

Martinet (1934 and 1936) emphasizes that the stød is a prosody in the more traditional sense of the word, arguing that it disappears in unstressed syllables and in song, and that its place in the syllable is automatically regulated and without phonological value. Martinet also states that although a long vowel with stød may be somewhat shortened, it does not represent a neutralization of long and short vowels, realized as short (as proposed by Uldall 1935), since it keeps the quality of a long vowel; this is particularly clear in the cases of /ɔ/ and /a/, where the difference in quality between short and long vowels is obvious (e.g. [æ: - a]). Martinet also mentions the only exception, viz. the so-called enclitic stød in a case like *lad os* ['la'ɔs] with [a], where the enclitic word begins with a vowel, but he considers this case as dialectal. - In any case, this type of enclitic stød is no longer common in Standard Danish (cf. Brink and Lund 1975, p. 511f), and the case is a very special one, cp. that in e.g. *lad mig* ['lam'ai] the enclitic stød occurs in the following consonant.

Aage Hansen (1943), who has given the most detailed description and discussion of the functional aspect of the stød, also describes it as a prosody. He considers it as connected with the syllable, but characterizing certain word types, in the first place monosyllables; but also, in prefix words and compounds, the last part of a complex unit.

In glossematic and generative descriptions it has been attempted to get rid of the exceptions, and thus of the stød, in the ideal (glossematic) or underlying (generative) representation.

Hjelmslev (1951) interprets the words containing short vowel plus sonorant with stød as containing a cluster consisting of sonorant plus /d/ in "ideal notation", whereas words without stød are assumed to end in a single consonant. As for disyllables in *-er, -en, -el*, the words without stød are interpreted as ending in /ɛ/ plus sonorant consonant, whereas the words with stød are interpreted as monosyllables ending in /r, n, l/ e.g. [lɛːsɒ] /lɛːsɛr/ vs. [lɛːˀsɒ] /lɛːsr/. He gives various other (rather arbitrary) rules. Rischel (1970) prefers geminated consonants to *d*-clusters. Basbøll (1971-73) improves Hjelmslev's rules on various points. In his paper 1972 he simplifies the description by permitting morphological conditions in accordance with generative phonology (this was not permitted in the glossematic expression system). Heger (1980) gives rules for monomorphemic native and foreign words. A detailed and very instructive description of stød-occurrence in native Danish words, including stød-addition and stød-loss in inflected words, derivatives and compounds, is given in Basbøll's latest paper (1985). In this paper (which has influenced the description given in the start of this section) he does not set up underlying forms with consonant clusters, etc., arguing that since these are in most cases purely ad hoc, i.e. without any other justification than the occurrence of the stød, very little is gained by this analysis, so that it is just as simple to indicate stød occurrence in the lexicon.

B. STØD IN DANISH DIALECTS

1. OCCURRENCE OF STØD AND TONAL ACCENTS

The map (figure 1) shows that although most Danish dialects have stød, the stød is lacking in the southern part of Denmark, on the island Bornholm south of Sweden (as also in the old Danish dialects in present-day southern Sweden), on the island Amager close to Copenhagen, and in a very small area in the northernmost part of Zealand. (The dialects are, however, now to a large extent being supplanted by Standard Danish or regional standards). Some of the dialects without stød have a tonal difference instead, not only the dialects in Sweden but also dialects in southern Funen and South East Jutland and some of the smaller islands in this district. Finally, there are areas in Funen, southern Jutland and some islands in Kattegat (e.g. Anholt) which have stød but also show tonal oppositions or traces of tonal oppositions. The tonal system of the dialect in Felsted in South East Jutland has been described in detail by Marie Bjerrum (1947). In this dialect old monosyllabic words have a rather low rising-falling tone movement, whereas old polysyllables have a two-peaked movement, the second peak being normally lower than the first. The tonal difference is accompanied by a dynamic difference and a certain lengthening of accent 2 words with apocope. Since Jutlandish dialects have apocope of final *-e* in former disyllables, the number of minimal pairs is much higher than in Standard Danish, e.g. corresponding to Standard Danish *hus* - plur. *huse* [huːˀs -huːsə] Jutlandish dialects with stød have [huːˀs - huːs],

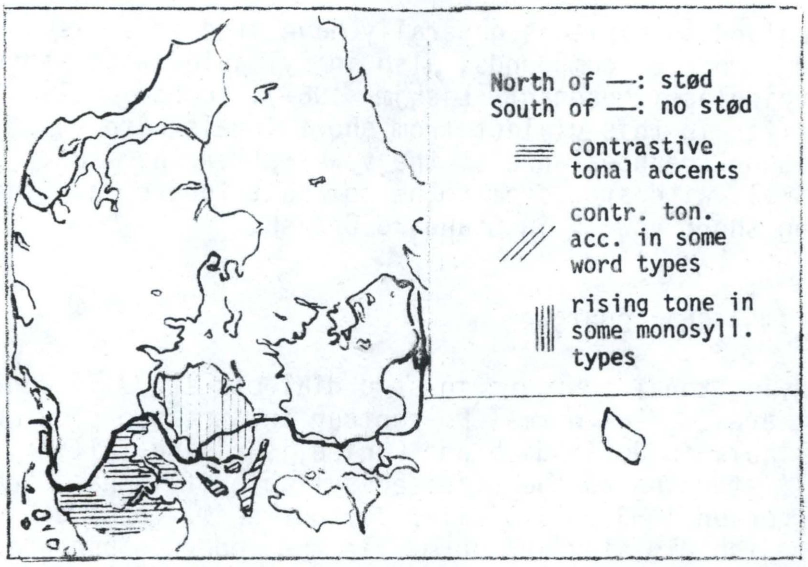


Figure 1

Stød and tonal accents in Danish dialects (after Køster et al. 1982)

and in Felsted the difference is [ˈhu:s] with the one-peaked tonal accent 1 vs. [ˈhu:s] with the two-peaked accent 2. The dialects of eastern Funen have been described by P. Andersen (1958). Here the manifestation of accent 1 and 2 is rather complicated. In some areas the stød is accompanied by a rising tone, in others rising tone and stød may occur in different words, but monosyllables with short vowel plus voiceless consonant may have falling tone, and the corresponding disyllable rising tone. The dialect on the island Ærø (Kroman 1947) has a tonal difference, but with a different distribution depending partly on vowel length.

2. DISTRIBUTIONAL RULES FOR THE STØD

The distributional rules may also differ somewhat within the stød-areas. In contradistinction to Standard Danish the Jutlandish dialects generally lack stød in words containing a short vowel plus sonorant consonant plus consonant, e.g. *kant* 'border'. Jutlandish also lacks stød in verbs with unstressed prefixes, e.g. *betale* 'pay' (but it often has stød in derivations of such verbs, e.g. *betaling* 'payment' (see, e.g., Ringgaard 1971 and K. Kristensen 1979). On the other hand, Zealandish dialects have stød in positions where the standard language does not have stød, e.g. after short vowels before voiceless consonants, consistently so in the definite form of monosyllabic nouns like *kæppen* (Zealandish [kʰæʼbin], definite form of the word *kæp* 'stick', but also in some other words in *-er*, *-en*, *-el*, and in verbs with prefix, e.g. *benytte* [beˈnyʼdə] 'utilize'.

Moreover, Zealandish dialects generally have stød in a disyllabic second member of compounds, also in syllables with short vowel plus voiceless consonant (Ejskjær 1967). Long vowels with stød differ in this dialect from short vowels with stød by having a short reappearance of the vowel after the stød. The short vowels with stød seem to be somewhat longer than the corresponding short vowels in Standard Danish.

3. ACCOMPANYING TONAL CONTOURS

The accompanying tonal contours in stød dialects are different in different areas. The normal Fo-contour in stressed plus unstressed syllable in Jutlandish and Funish is rising-falling, with the fall starting in the stressed syllable if it has stød (Fischer-Jørgensen 1983). A similar contour seems to have characterized the old standard norm. In the modern Copenhagen standard, described by Thorsen (e.g. 1983 with further references) the stressed syllable (only syllables without stød are described) is low rising and the following unstressed syllable high, with following unstressed syllables gradually falling. North Zealandish dialects have, according to Kroman (1947), a rising-falling contour in disyllabic words with stød, and a falling-rising contour in disyllabic words without stød. Andersen (1949) is sceptical, and assumes a falling-rising contour in North Zealandish in both cases. I have, however, found a rising-falling contour for several North Zealandish speakers in words without stød (Fischer-Jørgensen 1983), in contradistinction to both Kroman and Andersen.

4. WEST JUTLANDISH STØD

A large area in the western part of Jutland, which has normal Danish stød, also has a second type, the so-called West Jutlandish stød (see the map figure 2). It has been described in detail by Ringgaard (1960). Its distribution differs completely from that of the common Danish stød. It is found in polysyllabic words and in old apocopated disyllabic words before the stops /ptk/ following a voiced sound. Corresponding to Standard Danish *hat* 'hat' - plur. *hatte*, West Jutlandish has [hat - haʔt]. This stød is also found in compounds. According to Ringgaard there is a complete closure continuing into the following stop, which is unaspirated. It is not really a stød, i.e. a prosodic phenomenon, but part of a preglottalized stop consonant. It is obviously similar to the glottal stop found in many East English dialects, and also in Flamish dialects, e.g. English [bɛʔtə] or [bɛʔə] for *better*. The glottal closure may also simply replace the stop in West Jutlandish, like in English, but less often. This phenomenon is also found in North West Funish and sporadically in Jutlandish dialects with tonal differences (Ella Jensen 1961). The West Jutlandish "stød" will not be treated in the following.

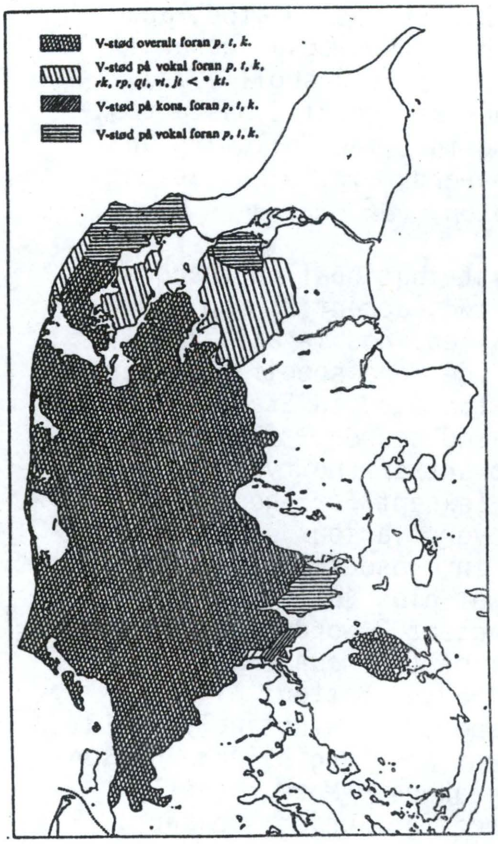


Figure 2

West Jutlandish stød in Danish dialects (after Ringgaard 1960)

before -p, -t, -k after all sounds

before -p, -t, -k under special conditions

C. THE HISTORICAL BACKGROUND

1. CORRESPONDENCES BETWEEN DANISH STØD AND SCANDINAVIAN WORD TONES

There is a close correspondence between the distribution of Danish stød vs. no stød and the Swedish and Norwegian accents 1 and 2 (as well as the South East Jutlandish accents), the stød corresponding to accent 1 and no stød to accent 2.

From a phonological point of view the systems are different. In the first place Swedish and Norwegian compounds have only one accent, spread over the whole word, whereas in Danish each part of a compound or derivative may have stød or no stød (In Felsted most compounds have only one accent, but they may have two). The Danish stød is connected with a syllable, not a whole word (though it may characterize certain word types). Secondly, whereas the Danish stød must be considered the marked term of the opposition (in the Praguian sense), it is accent 2 which is the marked term in the languages with tonal accents. This statement can be supported by various facts. In the tonal languages there is no phonological opposition in monosyllables (they do not have the Danish exceptions, e.g. [vɛn] vs. [vɛn']), and as monosyllables have accent 1, this must be the unmarked term. Further, in unstressed position, where there is no opposition in any of the languages, the tone in Swedish and Norwegian is close to accent 1, whereas Danish has no stød, and in unassimilated foreign words Swedish and Norwegian generally use accent 1, whereas Danish has no stød (see Basbøll 1972). Moreover, Elert (1970) argues that whereas accent 2 has a positive (connective) function, indicating that the following unstressed syllable belongs to the same word, e.g. *vàka*, accent 1 is neutral in this respect, e.g. *váken, vák en*. . .

In the large majority of words the distributional correspondence is, however, clear: accent 1 = stød, accent 2 = no stød. The influence of various morphological endings is also mostly parallel in the involved languages. One more specific difference is that accent 1 does not, like the stød in Standard Danish, require a long stretch of voiced sounds. Thus words with short vowel plus voiceless consonant of the type *hat*, *hatten* have accent 1, but no stød in Danish (except for the type *hatten* in Zealandish dialects). However, various older Danish linguists have observed a difference in prosodic contour between disyllabic words with short vowel plus voiceless consonants corresponding to accent 1 and accent 2 words, respectively, e.g. between *fedtet* definite form of the noun *fedt* 'fat' and *fedtet* as participle of the verb *fedte* 'fatten' either a difference in pitch (Verner 1878, Jespersen (reluctantly) 1913, Møller 1922), or a difference of force and length (Aage Hansen 1943), particularly for Jutlandish speakers. More recently Basbøll (1972) has noticed a difference for Funish speakers. I made a difference myself when I was younger, the accent 1-word having a shorter vowel, a more abrupt stress, and perhaps a higher pitch than the accent 2-word, but the difference is not consistent in my present speech, and it is hardly found in the modern Copenhagen standard speech. Anyhow, it seems probable that Danish used to share with the other Nordic languages an accentual distinction between two word types even in cases where there is no stød-basis, whereas Danish differs categorically from the other languages in this respect if we look only at Modern Standard Copenhagen.

Seen in a historical perspective Danish stød and accent 1 are (roughly speaking) found in wordforms which were monosyllabic in old Scandinavian after the syncope (i.e. after around 900), whereas no stød and accent 2 are found in wordforms which were disyllabic at that time. In old Danish the definite article was a separate word, and its presence did not affect the accentuation of the noun form, but it came to be used enclitically, and around 1200 it seems that the stem and the definite article fused into one word. However, this did not affect the accentuation of old monosyllables, which kept their accent (accent 1) also when inflected with the definite article. Later (around 1200-1500) monosyllables with final /r, l, n/ after consonant developed a svarabhakti-vowel and became disyllabic, but kept their accent 1. The difference between the accents was thus phonemicised (see, e.g., Oftedal 1952 and Gårding 1977).

2. THEORIES CONCERNING THE HISTORICAL DEVELOPMENT

According to what was said above a common dependence on word types differing in syllable number seems clear. But what is still - and will probably remain - very uncertain is when and how the development of the accents and stød took place, whether the stød developed out of a tonal accent or vice versa, or whether perhaps both developed out of a common, perhaps more dynamic difference. These problems have been the subject of intensive debate among Scandinavian linguists. Only some of the main arguments will be mentioned in the following.

a. Time of origin The fact that accents and stød are not indicated in the orthography makes it very difficult to say when they have emerged. Some short characterizations of the Danish language by foreigners from the 16th and 17th century may be interpreted as pointing to the existence of the stød. The Swede Hemming Gad has often been quoted. In 1510 he wrote that *"the Danes press the words out as if they would cough, and seem to take pains to twist the words in their throat before they come out"* (e.g. quoted by Jespersen 1913). This may be the first description of the stød. But the first explicit description is not found until Høysgaard (1743), and the Swedish accents have not been mentioned until 1737 (very briefly by A. Nicander, see e.g. Elert 1970, p. 41-42).

Most scholars have placed the origin of the stød somewhere between 1100 and 1500. But most of the arguments are rather dubious. It has often been maintained that the stød must be younger than some definite sound changes (e.g., the weakening of final stops or the lengthening of final /m/), because the stød could not be applied to the words before the sound change in question had operated (Verner 1878, Jespersen 1897, Kristensen 1898, Skautrup 1944). But this type of argument does not hold, because the stød rules may have been productive for hundreds of years (they still are) and can have applied when new sound changes made it possible (cf. also the criticism by A. Pedersen 1912). Several scholars have also argued that the stød must have originated later than the introduction of a large number of loanwords from Middle Low German (around 1350-1500), which now have stød, since if the stød had already existed at that time, the speakers would have used forms without stød which were more like the Low German prosodic form (Storm 1875, Verner 1878). But it is very improbable that Danish speakers should have tried to imitate the foreign prosodic contour. It is much more probable that they have treated the loanwords according to Danish stød rules, as we still do (the argument could also be used to prove that we did not yet have stød in the 19th century since there are loanwords from this century and even from the 20th century which have stød).

The most problematic category of words are the verbs with unstressed prefix and stød. This word type was rare in Old Scandinavian, but was introduced in great numbers from Middle

Low German. However, as Aage Hansen argues (1943), assuming that the stød originated later or simultaneously with these words does not explain why they got stød. We must assume that the type existed beforehand, and Old Scandinavian actually had a certain number of prefixed verbs (Kock 1901) which must have had unstressed prefixes. But the rule for stød application in these cases is not part of the monosyllable rule, but must be due to a special rule.

It is much safer to argue that the stød must be older than sound changes which have changed words (which actually have stød) in a way that made the stød rules inapplicable to them, e.g. the addition of the definite article and the introduction of svarabhakti vowels. However, what can be concluded from such cases is only that there must have been two distinct prosodic contours before these changes, i.e. before approximately 1200, and that the one characterizing monosyllables was maintained in these words in spite of the new changes which made them disyllabic, but we cannot know whether these contours were tonal or stød-like at that time. Oftedal (1952) assumes that they might have been stress differences accompanied by tone differences, cf. that accent 2 in Swedish and in some Norwegian dialects has a secondary stress on the second syllable. Before the changes mentioned the two accents were only junctural (indicating the number of syllables of the word); after the changes they were phonemicized, and e.g. Old Norwegian *veg-inn* (the way) and *veginn* (participle of 'to weigh') must have had their different accents already when the definite article coalesced with the stem. Gårding (1977) adds that the speakers may have found it important to keep the definite form of monosyllables apart from that of disyllables. Smith (1938) suggests that a concentration of energy due to the apocope, supported by the need to keep old monosyllables and disyllables apart and thus avoid a number of mergers, caused the emergence of the stød. Skautrup (1944) adopts this theory, and thus dates the stød to 1100-1200, when the weakening of the unstressed syllables is assumed to have taken place. It is, however, problematic how imminent the danger of mergers was. Jutlandish, where the weakening developed into a complete apocope, at least around 1300, had lengthening of a sonorous consonant in apocopated disyllables, e.g. in words like *skinne* [sgen:] and perhaps also a specific prosodic contour, the so-called circumflex, as a remnant of the disyllabicity, so that monosyllables and old disyllables were kept apart. This is still the case in West Jutlandish, and in East Jutlandish the difference did not disappear until the last century, cp. that Høysgaard mentions this lengthening, and it is also documented in other dialects, and in a few places the older generation still has lengthening; as for the words with long vowel before voiceless consonant (e.g. *hus*), Ringgaard still perceives a circumflex in West Jutlandish (1959). And in Funish and Zealandish the apocope is much later and still facultative in many dialects, and nevertheless there are more cases of stød in Zealandish than in Jutlandish.

b. Did the stød develop from a tonal accent or vice versa?

As for the relative age of tonal accents and stød most scholars assume that there was first a common Scandinavian tonal difference and that the stød originated later. There are some good arguments for this view, viz. that the tonal accents in Danish are found in peripheral and isolated areas and are disappearing, and in some dialects in Funen stød and tone may be variants (Andersen 1965). Kroman (1947) advanced the theory that the tonal accents in South East Jutland and in the southern islands should be due to a Swedish invasion in the Viking time. But this theory has not been accepted by other Danish scholars, and it does not explain the traces of tones in the small islands in Kattegat. It is thus possible that a larger part or the whole of the Danish dialect area has had tonal accents, but it is only a hypothesis.

We do not know either whether the southern Danish islands which have neither stød nor tonal accents have had one of these differences earlier or whether they never had any difference of this kind. The fact that all Scandinavian dialect areas without any distinctions are peripheral makes them look like typical relic areas. Haugen (1970) suggests influence from neighbouring foreign languages, but it seems improbable that German should have had more influence in Lolland than in southern Jutland.

Even if it should be true that the stød has replaced an earlier tonal difference, it does not necessarily follow that it has developed out of a definite, e.g. rising, tone. But this has been assumed by various scholars (e.g. by Verner (2/11 1874 (1903) and 1878). Verner suggested that a quickly rising tone involving a tension of the vocal chords, might lead to an "Überschnappen" ('snapping') and a short closure of the vocal chords. He finds this assumption supported by his own pronunciation of words with stød and by reference to the occurrence of glottal closure in Lithuanian and Latvian in connection with a rising-falling tonal contour (for a detailed discussion of Verner's theory, see Smith 1944). This theory was accepted by Jespersen (1897 and 1913), by Ekblom (1938) and by several others. But Verner's description of his own tone contour is rather different from what has been found for other speakers (see later in this paper), and nobody can know how a hypothetical Danish accent 1 has been. In Felsted it is rather low, in Funish it may be rising but also falling, in Skåne it is mainly falling, and on the whole the phonetic manifestation of the Scandinavian word tones is extremely varied, the only general feature being that if one of the accents is two-peaked it is always accent 2, and if both have one peak, the peak is later in accent 2 than in accent 1 (Gårding 1977). It is also a general experience from tone languages that the phonetic manifestation is not very stable. - J. Forchhammer (1942) has an interesting argument against Verner's theory, viz. that a rising tone is generally obtained by stretching the vocal chords, and that cannot produce the compression which he considers to be the characteristic feature of the stød. On the contrary, a falling tone with thickening of the vocal chords might rather lead to a compression.

Others think that the stød has originated from a strong concentration of stress on one syllable. Storm (1875) suggests this possibility besides assuming an earlier rising tone. Kristensen (1899) also thinks that the stød is due to a dynamic development and, as mentioned above, Smith is of the same opinion. This explanation has the advantage that a concentration of energy could also be assumed for words with prefix, so that a common explanation might be obtained.

Only few scholars have assumed the stød to be very old, e.g. A. Pedersen (1912), who dates it back to the common Scandinavian syncope.

Recently Anatoly Liberman (1976 and 1982) has advanced the hypothesis that the stød was common to Old Scandinavian (or even Common Germanic), and that the tonal accents 1 and 2 developed much later in connection with free apocope.

According to Liberman the main function of stød is to divide the syllable nucleus into two parts or morae, and stød is the marked part of the opposition, compared to no-stød. Accents, on the other hand, have a syllable-counting function; in Swedish and Norwegian accent 2 can unite the constituent parts of a word or a syntagm, and is marked compared to accent 1.

Old Scandinavian (like Old Germanic) was a mora-counting language, and the tool of mora-counting was stød. It had its main domain in words with long vowel or short vowel plus sonorant consonant, irrespective of the number of syllables. This was just the type of words which were first submitted to apocope (12th - 16th centuries). Apocopated disyllables became monosyllabic and indistinguishable from old monosyllables. Thus the stød became a signal of monosyllabicity. Accordingly words that remained polysyllabic lost their stød. Since the apocope was free in the beginning (later it could become obligatory or be given up again) and partly determined by rhythmical conditions, the same word could become monosyllabic, e.g. medially in the phrase, but keep its weak syllable finally, and these full forms also lost their stød and thus became isolated. In order to maintain the phonetic identity of the words which had been split up, the stød of the apocopated forms was transformed into a circumflex, which restored the disyllabicity, and in Swedish and Norwegian the full forms developed a second peak, an accent 2 which became the marked member of the opposition. The stød in old monosyllables was then weakened into an accent 1. In Danish no marked accent 2 developed and the old monosyllables retained their stød which, besides its mora-counting function, adopted a subsidiary function of indicating monosyllabicity.

Words in *-er, -en, -el* developed in a specific way. They have accent 1 in Swedish and Norwegian and stød in Danish. Liberman admits that they may have been monosyllabic at the time of the apocope, but he prefers the hypothesis that words ending in a closed syllable have always had stød. - He also assumes that words with voiceless geminates had stød, and that this stød developed into the so-called West Jutlandish stød, which is a juncture phenomenon.

Liberman's hypothesis is based on a very thorough knowledge of all accessible facts about Scandinavian dialects, and he finds various dialects representing what he assumes to be transitional phases of the development: the common Danish stød, the co-existence of stød and tonal accents in Funish and (according to Kroman) North Zealandish, the partly mora-counting function of accents on Ærø, some traces of redundant stød in Sörmland, and two small dialect areas in Sweden (Hedemora) and Norway (Flekkefjord), which have (or have had) accent 1 in words before certain geminates irrespective of syllable number, interpreted as a relic of the mora function.

Nevertheless, I do not find his arguments convincing. In the first place I agree with Ringgaard (1983) that the theory is contrary to the results of areal linguistics. Ringgaard states that apocope in Sweden and Norway is late (16th century) and rare, restricted to some northern dialects far from cultural centers, and he finds it improbable that a phenomenon developed in reaction to apocope in some remote Scandinavian dialects should have spread over the whole peninsula. Liberman might object that he does not talk of obligatory but of free apocope, and according to Hesselman (1948-1953, p.33ff) free apocope is found or has probably been found in many dialectal areas in Central Sweden. Even so, it is, however, improbable that the innovation should spread to large areas in southern Sweden and Norway which did not have apocope, whereas it does not arise in Danish dialects (except for a smaller area in southern Denmark) which all have full or free apocope. Moreover, whereas the very specific facts found in two small dialects before geminates (which are the corner stones of the theory) seem very dubious as relics of stød, it seems much more probable that the peripheral and isolated areas in Jutland with traces of accents are relic areas where the tones are disappearing.

The systems in the various dialects which are seen as transitional phases do not really correspond to steps in the assumed development, which therefore remains hypothetical and must be judged according to probability. And I find the suggested development phonologically and psychologically improbable. How can apocopated forms become indistinguishable from old monosyllables and then be turned back into disyllables by means of circumflex and accent 2? Would it not be much more probable that they have retained some tonal or dynamic features of the disyllables from the start? Liberman admits that the speakers must have felt them as variants of the full forms. How can the stød then have become a signal of monosyllables?

Finally, it is not always clear when the terms "stød" and "accent" are used for purely functional entities (Liberman defines them in purely functional terms) and when they are identified phonetically. Liberman is rather uninterested in manifestation, and he does not even use the phonetic argument he might have taken from Asiatic languages which - according to strong comparative and historical evidence - in some cases developed tone from syllable-final glottal closures (or other so-called phonation types).

However, one does not have to assume that accents and stød are successive phenomena in the individual languages. They may both have developed in different dialects out of an earlier distinction which had both dynamic and tonal features. This may even be the most probable hypothesis. This seems to be assumed by Oftedal (1952) and Gårding (1977). Öhman (1967) also assumes a common origin but according to a specific model, which will be mentioned in the following section.

In conclusion it must be stated that we do not have any reliable knowledge about the origin of the stød. The problem will be taken up again briefly in the final section of this paper in the hope that some more arguments may be found through a phonetic analysis of the stød in present-day Danish.

D. PREVIOUS PHONETIC DESCRIPTIONS OF THE DANISH STØD

1. OLDER DESCRIPTIONS

As mentioned in section A the stød was first described by Høysgaard (1743, 1747, 1769). Phonetically he describes his four "åndelav" (1747) as *"some peculiar thrusts and puffs of breath in the pronunciation of syllables or their vowels and other sounds ... different ways of exhaling the vowels"*. As for the stød (a term proposed by Høysgaard and meaning "thrust") he says that it sounds like *"a very little hiccup"*. After a short vowel (e.g. *sang* [sɑŋ']) *"it is as if it stops the breath"* ("stødende åndelav"), after a long vowel *"it stops the breath and then immediately gives it speed again"* (dobbelt ('double') åndelav). In 1769 he changes the term "stødende" to "standsende" ('stopping') and explains that he first called it "stødende" because *"it bumps in the pharynx"* ("det tørner i svælget"), but it is not really a thrust or push. It is rather characterized by a stop of breath produced by closing up the pharynx, which blocks the breath stream ("svælget lukker sig for ånden"). At the same time he warns against the very strong Zealandish stød. It should be milder.

This description ("svælget lukker sig for lyden") was taken over by his followers (Levin 1844, Hommel 1968). It is, of course, not very probable that there is a closure in the pharynx ("svælget"), but Høysgaard and his followers in the middle of the eighteenth century hardly made any distinction between pharynx and larynx; and later the stød is described expressly as a glottal closure, e.g. by Sweet (1877), Verner (1878) and Jespersen (1897-99, p. 297). Verner (3/7 1872 (1901)) also reported that he felt that words with stød required more energy in the throat, and he could feel a sudden contraction of his throat muscles.

2. THE FIRST INSTRUMENTAL INVESTIGATIONS

In the years 1895 and 1896 Rousselot undertook the first instrumental (kymographic) investigation of the stød with one informant. In 1899 he made another, more restricted recording with Jespersen as informant. He found (see 1897-1901, p. 873-879) that there was hardly ever a real pause (one case out of 50) but always an evident diminution of the vibrations. There also seemed to be a vertical and horizontal movement of the larynx. Nevertheless, Jespersen still describes the stød as a glottal stop in 1912 and in the 1932-edition of "Lehrbuch der Phonetik". In the second edition of his Danish phonetics (Modersmålets fonetik 1922) he gives the same description in the text, but in a footnote he modifies this description by saying that a complete closure is only found in a strong form of the stød, e.g. finally. In the interior of a sentence and particularly before voiced sounds there is only a narrowing of the glottis, involving a tension of the vocal chords, which stiffen in their movement. The narrowing occurs in the last part of a long vowel. If it occurs on a sonorant after a short vowel, only the beginning of the sonorant consonant is heard.

The very rare occurrence of a complete closure in the standard language (except for emphatic speech) was confirmed by a few later kymographic recordings: Selmer (1925), Heger (1931), Ekblom (1933) and Abrahams (1943) (six speakers in all), but there was in all cases a decrease of the vibrations. In contradistinction to Jespersen Abrahams found that in syllables with short vowel the minimum generally occurred at the limit between vowel and consonant, rarely after the beginning of the consonant. Abrahams also measured duration and found that long vowels with stød were slightly shorter than long vowels without stød.

Selmer, Heger and Ekblom also investigated the Fo-contour in words with stød. Through auditive observation of his own speech Verner (1878) had found a contour which supported his theory of the origin of the stød from a rising tone. Whereas he had falling Fo in disyllables without stød, he found that words with stød start on a low tone rising quickly about a quint at the end of the stressed vowel until the closure, the following unstressed syllable being low: Accent 1 words without stød (e.g. *drikker* 'drinks') have a low start like the words with stød, but the rise is cut off by the voiceless consonant. Thomsen (in his obituary on Verner 1896-97) suggests that this may be a special Århus-pronunciation. But it does not look like present Århus speech (see later), and as Verner's father was German and his mother from Zealand, it may have been a rather personal contour. His stød-rules are obviously influenced from Zealandish dialect, but his Fo contour is not Zealandish either.

Selmer, whose informant (professor Brøndum-Nielsen) was from Jutland, but speaking a somewhat artificial standard Danish, found a moderate rise-fall in disyllabic isolated words without stød and a pronounced rise-fall in the first syllable of words with stød (before a possible break). - The contour is thus the same, only more pronounced in words with stød. Selmer does not find this difference important. Heger thinks that the strong rise in the stød words investigated by Selmer might be due to emphasis. His own informant (who had spent most of his life in Copenhagen) had a conspicuous very deep fall in Fo in the second part of the vowel with stød. - Ekblom, whose informant was from Copenhagen, found - like Selmer - a moderate rise-fall in words without stød and a stronger rise-fall in words with stød, but in the cases of a break (which might be due to the difficulty of measuring reduced or irregular vibrations on kymograms) this was at the top of the curve, before the fall, not after the fall as for Selmer's informant. Ekblom also found a somewhat more abrupt rise in two disyllabic accent 1-words with short vowel plus voiceless consonant (and thus without stød) than in the corresponding accent 2-words. Like Verner he finds a similarity between the Fo contour of words with stød in Danish and that of words with stød in Latvian and Lithuanian. Whereas Heger recorded small sentences containing words with stød, Selmer and Ekblom recorded isolated words. This makes the judgement of the Fo contour somewhat dubious, because it must be a combination of word (or stress) contour and sentence intonation.

3. SVEND SMITH'S ANALYSIS OF THE STØD

As for the production of the stød there has never, during the whole period, been any doubt that it is produced by a constriction or closure in the larynx, and it has been implicitly assumed that the larynx was the primary source, i.e. that the stød was due to an innervation of the vocal chords.

However, this was called in question by Svend Smith, whose thesis (1944) constitutes the first detailed and thorough instrumental investigation of the phonetic aspects of the stød. It is a pioneering work, which brings a large number of new facts and a new theory built on these facts. The most important new contribution made by Smith is an electromyographic investigation of the expiratory muscles. He used surface electrodes because a preliminary experiment with needle electrodes gave too many artefacts due to movements of the muscles. The electrodes were placed on the abdomen between the navel and the trigonum scarpae (which is close to the groin), i.e. rather low down, in order to avoid interference from the heartbeat. Smith considers the activity recorded at this place as representative of the activity of the total complex of expiratory muscles. There were five subjects, all speaking Standard Danish. They pronounced a number of word pairs (one to three times each), read as an enumeration of individual words with non-final intonation, but shifting between words with and without stød. There were 11 different word pairs in all, but not all were read by all subjects, and some could not be used because of various disturbances. 83 pairs belonging to different types (mono- and disyllables, words with long and with short vowel) were analysed. In one word pair of a special type, viz.

ending in a vowel ([tʰæ:ʼ/tʰa]) (which was, exceptionally, read 17 times) no clear difference was found. But 53 of the remaining 66 pairs showed more activity in the word with stød than in the corresponding word without stød. The activity in the words with stød is also more abrupt with a quick rise and fall, whereas the activity in the words without stød is more evenly distributed over the whole word. Smith concluded that in words with stød there is a strong ballistic movement of the expiratory muscles, whereas in words without stød it is a controlled movement. A few whispered pairs showed the same difference. In the published curves (10 pairs) the difference is very clear. Since it is found in 53 out of 66 pairs, it is obviously significant, but at the same time it does not seem to be a necessary condition for the production of the stød, since it was absent in 13 pairs. It is, of course, possible that some subjects may have used muscles whose activity did not show up at the abdomen (e.g. internal intercostals). It is said that there is large inter-individual variation particularly in the amplitude of the curves, but it is not stated whether this variation implies a more or less clear difference between pairs with and without stød and how the exceptions are distributed on the individual speakers. - Unfortunately, it was not technically possible to synchronise the electromyographic recording with an acoustic recording, so that one cannot know exactly when the activity takes place.

Smith also analysed the stød from an acoustic point of view by means of a direct oscillographic recording. There were six speakers who, apart from the author, seem to have been different from those who took part in the electromyographic recordings. Smith managed to get hold of both Heger's and Ekblom's informants, and they read the same material as in the old recordings. Smith himself read a list of 46 word pairs (each pronounced once, as an enumeration of words with non-final intonation). The other speakers read only part of the list; and only one read more than ten pairs. This time the individual speakers are treated separately. Smith finds a weak tendency to a stronger rise in amplitude and frequency in the beginning of words with stød, but only in about 1/4 of the material, and rising frequency is mostly found in words starting with a sonorant consonant. Only one speaker (OF, Ekblom's subject) has a frequency rise in most of the words. - What is much more general is a fall in amplitude in the second part of the syllable in words with stød. Strangely enough individual results are not given on this essential point. In the conclusion p. 105 it is said that there is "often" a decrease in amplitude, but no exceptions are mentioned in the more detailed discussion. The decrease is treated as something given, and it is also in accordance with earlier kymographic recordings. All illustrations show this decrease. It may end in irregular vibrations but never in a complete pause. There are obvious individual variations in the occurrence of irregularities. Three of the subjects have irregular vibrations in all examples, one in almost all, one only in one example out of ten, but he is from Funen where the stød is normally weaker. Smith himself has irregularities in less than one third of the examples, which may perhaps be explained by the fact that as a speech therapist he considers a stød with irregular vibrations to be "non-normative". For most of the speakers (except Smith) the irregular vibrations are in the majority of cases preceded by a fall in Fo, more or less coinciding with the decrease in amplitude. The amplitude may increase again after the minimum, particularly in long vowels. In the case of Heger's informant Smith did not find the very deep and abrupt fall in Fo indicated in Heger's measurements. Smith assumes that this deep fall was probably due to the difficulty of measuring weak and irregular vibrations on kymograms. For Ekblom's informant Smith found a less steep rise and the irregular vibrations coming after the fall, not on the top of the curve.

Comparing the electromyographic and the acoustic recordings Smith sets up the following hypothesis concerning the production of the stød. There is a first phase, characterized by a strong, ballistic contraction of the expiratory muscles, which results in a heightened subglottal pressure. This higher pressure may cause a proprioceptive reflex innervation of the vocal chords. In the second phase the activity of the expiratory muscles falls abruptly, which causes a fall in amplitude and sometimes in frequency. A stød thus has two phases, and may have three, if there is a new increase of amplitude. Since it may be difficult to adjust the tension of the vocal chords to the quickly falling pressure (the tension may be kept too long) there may be a lack of balance resulting in irregular vibrations. There is according to this theory no primary compression of the vocal chords as assumed explicitly by Jørgen Forchhammer (1942) and by Viggo Forchhammer (1954) and implicitly by most phoneticians, and the fall in frequency is not a primary phenomenon either, but caused by the falling subglottal pressure.

Smith also finds indications of a more energetic articulation in the start of words with stød based on kymograms taken with a large and very lax membrane mounted on a Marey-capsule. There often seems to be a quicker rise of the airflow in the beginning of words with stød. The interpretation of these curves is, however, rather dubious because of the very great inertia of the membrane, which makes all delimitations very uncertain, and it is not quite obvious why a possible quicker rise of the airflow should be due to energetic articulation and not to the heightened subglottal air pressure.

In conclusion the stød is characterized as a "stress accent, a special marking movement made by a thrust-like emphasizing of sounds."

Smith's theory is very interesting, but he has only proven part of it, namely the contraction of the abdominal muscles. He has not investigated the laryngeal muscles, and one therefore cannot know whether there is also a contraction of these muscles (which is felt subjectively by many speakers), and how the temporal and causal relations between these two contractions may be.

4. LATER ACOUSTIC INVESTIGATIONS

During the following 30 years very little was published concerning the phonetic aspects of the stød, and most of the papers dealt with its acoustic properties.

In a paper on vowel length in Danish (1955) the present author published some measurements of vowels with stød. The measurements were mainly based on recordings of isolated words, viz. the two triads [pʰi:bɒ, pʰi:'bɒ, pʰibɒ] and [lɛ:sɒ, lɛ:'sɒ, lɛsɒ] read once by 10 informants, and two other triads read by one informant. In a few cases the words were placed in small sentences, viz. the first two triads plus [hy:lə, hy:'lɒ, hylə] read three times by three informants, and the first triad read eight times by one informant. The result was that the duration of vowels with stød was in between short and long vowels without stød but closer to the long vowels. In the series of isolated words all speakers except one had a difference between long vowels with and without stød, and in the series of sentences all four speakers had an average difference but with overlapping. When all speakers (in the two groups taken separately) were combined, the vowels with stød showed great overlapping with long vowels but hardly any overlapping with short vowels. The percentual duration of vowels with stød compared to long vowels without stød was 82 and 89 for isolated words and sentences, respectively, whereas for short vowels it was 50 and 60%. Thus Uldall's description of vowels with stød as phonetically short must be refuted. Martinet's observation that the quality of vowels with stød is the same as that of long vowels was mentioned above. To this may be added that the influence from surrounding consonants is also the same as for long vowels (I therefore also transcribe them with two length points, not with one as is sometimes done).

The first spectrograms of words with stød, in some cases supplemented with amplitude display, were published by M. Lauritzen (1968) in a short paper based on one informant who read 10 word pairs and some triads once. The 33 published spectrograms of words with and without stød do not show any consistent differences in formant structure, nor any indication of a difference in voice quality in the first part of the vowels with stød but, as stated by the author, a very clear drop in intensity during the stød phase (Smith's second phase) and sometimes noisiness and irregularity, and moreover a drop in Fo. - The author also mentions that the start of the vowel shows higher intensity in words with stød (and the same can be seen for Fo). - She states that the drop in intensity and Fo and the irregularities are not restricted to one segment. "Stød in the vowel" also affects the transition into the consonant, and "stød in the consonant" often affects the end of the preceding vowel.

Lauritzen also draws attention to the fact that the stød is preserved in whisper. She published spectrograms of one whispered pair which shows a clear drop in intensity.

A much more comprehensive study of the acoustic properties of the stød was published in 1973 by Pia Riber Petersen. Her material consists of four triads of the type [lɛ:sɒ, lɛ:'sɒ, lɛsɒ] and four quadruplets of the type [hy:lə, hy:'lɒ, hylə, hyl'n̩] placed in the middle of small sentences with 3-4 main stresses and read six times each by six informants. The description is made on the basis of mingograms with Fo- and intensity curves. As for the duration she did not find any consistent difference between long vowels with and without stød.

Riber Petersen also measured the consonants and found a significant difference of duration between consonants with and without stød, the former being longer (Lauritzen found the same difference, but on the whole her indications of duration are dubious because she does not distinguish between words with different number of syllables).

As for Fo, maxima and minima of the vowel contour were measured and schematized average curves based on these measurements are given for half of the material, viz. for the words with sonorant after the vowel (the quadruplets). Neither the postvocalic consonants nor the following weak syllables were measured. It would have been more informative if complete curves of the words had been given as illustrations. There are no constant differences between words with and without stød, but there are some clear tendencies. Subject 22 differs from the other subjects in having rising Fo in both types with a somewhat higher level in the words with stød. - For the five other subjects the predominating contour of the stressed vowel in words with stød is falling (more rarely falling-rising), and the predominating contour for words without stød is falling-rising for four of the subjects and rising for one of them (rising-falling contours are very rare). Generally the contour starts at a higher level and reaches a lower maximum in words with stød than in words without stød. In V:'C-words the fall is on the average 26.2 Hz greater than in V:C-words, and this difference is significant; the minimum is generally closer to the end of the vowel in words with stød.

The intensity contour is described very briefly. Like the Fo contour it has generally a higher maximum and a deeper fall in words with stød. For V:'C-words the fall is 6 dB greater than for V:C-words, and the difference is significant. Subject 22 has the same difference for long vowels, but he does not have any difference in words with short vowel.

Riber Petersen emphasizes the large variation in the acoustic manifestation of the stød. Some subjects have normally irregular vibrations (starting, on the average, 11.8 cs after the onset of a long vowel and 11.2 cs after the onset of a short vowel), and there are a few cases with complete closure; some have no irregularity, but fall in intensity and Fo, and for subject 22 there are cases without any visible difference, although the words sound allright. A few spectrograms seemed to indicate some weakening of the higher formants in the words with stød.

The author made a listening test with six examples of the word pair [lɛ:sɒ - lɛ:'sɒ] read by speakers 22 and 26 and cut out of the surroundings. The test was played twice to seven listeners, who had to identify the words. In a surprisingly high number of cases the stød was not perceived; but, strange as it may seem, this occurred more often for speaker 26 (37% of the cases), whose curves showed a clear stød, than for speaker 22 (22%).

In order to throw some more light on this question, Nina Thorsen (1974) conducted a small listening test with the words [blɛ:sɒ, blɛ:'sɒ, vi:sɒ, vi:'sɒ] read by herself, and the words [lɛ:sɒ, lɛ:'sɒ] read by Pia Riber Petersen's informant No. 22. Nina Thorsen's stød showed up in the curves as a phase with low amplitude and obvious irregularities, whereas in the curves of subject 22 the vowel showed rising pitch and intensity and no irregularities in the stød-word and a fall in intensity in the word without stød. The words were cut in steps from the end, the first cut keeping the beginning of the *s*, the last cut leaving the first part of the vowel. Five phoneticians listened to the words read by Nina Thorsen, two to the words read by No. 22. The result was that when the irregular phase was cut off from Thorsen's stød-words no stød was heard, whereas in No. 22's words the stød was identified for all cuts! - Nina Thorsen concluded that there must be different types of stød. She hears a certain strained voice quality in No. 22's stød-words, but it does not show up in spectrograms. But she adds that since the listeners had heard the word pair before the test they <u>may</u> have identified the stød-word by the higher pitch level (or <u>perhaps</u> rather by the whole pitch contour of the word).

On the whole, Smith's acoustic description has been confirmed by Riber Petersen's more comprehensive and precise analysis. But the acoustic analysis can neither prove nor disprove the central point in Smith's theory, viz. the physiological mechanism producing the stød. (Riber Petersen finds that the combination of rising pitch and falling intensity often found in No. 22's stød speaks against a relaxation of the vocal folds due to a decrease in subglottal pressure, but this informant is not typical.)

5. PHYSIOLOGICAL INVESTIGATIONS

A physiological investigation was made by Faaborg-Andersen as part of his thesis (1957). He made EMG-recordings of the vocalis muscle and the cricothyroid muscle in "a series of subjects" reading the two word pairs [mo:ɒ / mo:'ɒ] and [mølɒ / møl'ɒ] and found higher activity in the vocalis muscle in words with stød, but no difference in the cricothyroid.

A preliminary electromyographic investigation by the present author and H. Hirose (1974) had the purpose to find out whether there was a positive innervation of the laryngeal muscles in the stød. For one informant, who read a longer list of words with and without stød, recordings were made of the interarytenoid muscle (INT) and the posterior cricoarytenoid muscle (PCA), i.e. the closing and opening muscles of the larynx. They did not show any difference of activity in words with and without stød, except that there was a peak in PCA after the monosyllable [man'], probably due to a more vigorous opening of the glottis at the end of the word. For three other subjects reading the pairs [lɛ:sɒ, lɛ:'sɒ], [p^{h}i:bɒ, p^{h}i:'bɒ] and [man, man'] sixteen times each in the frame: *"han sa: ..."* recordings were made of the vocalis muscle, for one also of the lateral cricoarytenoid (LCA), i.e. the internal tensing muscles. One speaker did not show any difference, but he was nervous and the recording was bad. The two other speakers had a rather abrupt activity in the vocalis muscle in the words with stød. One of them also had a clearly audible rise in pitch, and the vocalis activity may have something to do with this rise, but this was not the case for the other, who had a sharp rise in vocalis activity starting at the beginning of the vowel and having its peak at the point of the normal start of the stød phase. There was also a slightly higher activity in LCA. Thus this investigation (like that of Faaborg-Andersen) pointed to an activity in the vocalis muscle in words with stød.

S. Öhman (1967) sets up a specific model for the description of the production of the Scandinavian accents including the stød. He considers them to be produced by a negative pulse superimposed on the basic phrase contour and the (positive) phonatory stress pulse which starts at the beginning of the stressed syllable. The timing of this negative pulse in relation to the stress pulse produces the different word tones. If the negative pulse comes at the start of the word, the tone will be rising; if it comes in the vowel, it will be falling-rising, etc. There is always a difference between accent 1 and accent 2 in this respect, but the places may vary in different dialects. The stød (which is described as a glottal stop) is produced by a very strong negative pulse at the end of the vowel, and the Scandinavian tonal accents are considered to be a kind of soft glottal stops.

This model is also applied to a theory of the origin of the word accents. Öhman assumes that they are developed in sentence final position in Common Scandinavian. By the common Scandinavian syncope the new monosyllables come close to the final fall in the basic phrase contour (which is assumed to start immediately after the end of the last stressed word). The tonal rise of the stressed syllable is therefore truncated and dominated by a fall. This fall comes to be considered characteristic of monosyllables, and when later a number of monosyllables become disyllabic by addition of the definite article and by insertion of svarabhakti-vowels, so that the distance to the final contour is increased again, the specific pitch contour of the monosyllables is maintained by the insertion of a negative pulse in the beginning of the second syllable of the former monosyllables, or, if the high pitch of the second syllable of the disyllables was considered the characteristic feature, a negative pulse could be inserted at the start of the stressed syllable of these words.

This is, of course, highly speculative. The author tries to support the idea of the negative pulses by interpreting them as an inhibition of the activity of the cricothyroid muscle (CT) which is generally held to be the main muscle responsible for pitch movements. In a pilot experiment (Öhman et al. 1967) EMG recordings were made of this muscle and the vocalis muscle for one informant. In these recordings he finds an inhibition of the CT at the points where he had placed the negative pulses and in many cases a brief increase of activity in the vocalis muscle 20 ms before the CT inhibition. In a glottal stop (an example of hard attack) he finds increase of vocalis activity.

However, a decrease in CT activity correlated with the negative pulses is not surprising, since the pulses were placed at the points of low pitch, and the increase of vocalis activity is not seen in the published curves.

Gårding (1970) made recordings of CT and vocalis for two Swedish informants speaking different dialects. She has also recorded a glottal stop in an emphatic "yes" and "no" in one of the dialects [jaʔa - nɛʔɛ]. In the glottal stops she finds a (small) peak in the vocalis muscle, but in the word tones vocalis and CT go together having higher activity for rising pitch. If the Scandinavian tonal accents were a sort of glottal stops or stød, one should expect activity in the vocalis muscle but not in the CT (see also later in this paper). Thus, Öhman's theory is not supported.

Gårding prefers to simulate word tones by positive pulses manifested in activity of the CT and vocalis muscles, which also seems more natural.

II. MATERIAL, SUBJECTS AND PROCEDURES

A. INTRODUCTORY REMARKS

The present investigation started as a teamwork at the Institute of Phonetics in Copenhagen in 1974. Its main purpose was an electromyographic analysis of the activity of the larynx muscles in the production of obstruents, stød, and (to a certain extent) stress, in continuation of preliminary investigations by H. Hirose and me conducted at the Haskins Laboratories (see Fischer-Jørgensen and Hirose 1974a and b). The main participants in the teamwork were Jørgen Rischel, Birgit Hutters, Peter Holtse, H. Hirose, and the present author. Almost all recordings took place in 1974 with some supplementary recordings in 1977, when Hirose visited Copenhagen again, and in 1979, with the help of S. Niimi. The work was delayed partly because of computer problems, partly because the members of the team were busy with other tasks, particularly the international phonetic congress in 1979. In the beginning of 1982 it was agreed that the further processing of the obstruent recordings should be made by Birgit Hutters in connection with her fiberoptic studies (see her report in ARIPUC 18, 1984), and that I should take care of the material on the stød. This work was further delayed by illness but has now been finished. An analysis of the simultaneous acoustic recordings and of quite a number of supplementary recordings undertaken 1985-86 was included.

B. THE MATERIAL

The main corpus consisted of a list, used in 1974 for the recording of the vocalis and the cricothyroid muscles, containing eight word pairs, viz. [pʰi:bɒ/pʰi:'bɒ, hu:ən/hu:'ən, lɛ:sɒ/lɛ:'sɒ, kʰɛ:lə/kʰɛ:'lɒ, kʰɛlɒ/kʰɛl'ɒ, vɛnɒ/vɛn'n̩, vɛn/ven'], and [du/du:'] plus the words [vɛ:'n, vɛ:'nɒn, lɛsɒ, pʰibɒ] (see Appendix I, list 1; for the phonetic transcription, see Note 1). Thus care was taken to include both monosyllables and disyllables, stød in long vowels and in the consonant after a short vowel, and both high and low vowels as well as different postvocalic consonants. The word pairs are not all perfect minimal pairs: in [du/du:'] a short vowel is compared to a long vowel with stød, and the vowel in [hu:ən] may be pronounced relatively short (there is no opposition of length before [ə]), but it is generally pronounced long with assimilation of [ə]. The words [lɛsɒ] and [pʰibɒ] were included for the purpose of a comparison between the duration of long vowel, long vowel with stød and short vowel. These examples (and those of the following lists) may also illustrate the different types of commutable word pairs with and without stød.

The words were read by seven subjects in the frame *det er ... de siger* [de: ... di siɒ] 'it is ... they say'. This is a commonly used frame, and it was essential to choose a short frame in order not to prolong the electromyographic session unnecessarily. But since the test word was the only stressed word in the sentence its Fo movement might be influenced by the sentence intonation, which was sometimes final and sometimes nonfinal. This complicated the comparison between the Fo contours of words with and without stød, which turned out to be more interesting than first assumed.

In BF's reading of this list 1977 and 1979 the words [vɛn] and [vɛn'] were replaced by [sɛn] and [sɛn'], and the extra unpaired words were left out. In 1977 the words were also read in the frame *de siger alle* ... 'they all say ...', and in 1979 *de siger også* ... 'they also say ...' with emphasis on *alle* and *også*, the purpose being to have the test words read on a low tone. These recordings also contained examples of hard attack for the purpose of a comparison with the stød, and scattered examples of hard attack were also found in other recordings.

In 1977 and 1979 BF also read two pairs with and without stød in a syllable with secondary stress (see Appendix I, list 2).

In the 1974 session a further list intended for the analysis of stress and stød was recorded. It consisted of a number of nonsense words of the type *bibibibi* differing in respect of vowel length, stød and stress. Only JR read the full list of 24 different words. For the present purpose only five pairs were averaged (see list 3, Appendix I). They differ in stød vs. non-stød on the stressed syllable (as first, second and third syllable), and two of the pairs also differ in stød vs. non-stød on a syllable with secondary stress. Three of the pairs were also read by other informants, but as they had difficulty in pronouncing them correctly, each word was preceded by a normal Danish word with the same rhythm and stød-occurrence, but this only worked for one informant, and the real words were so different in their phonetic set-up that a comparison was problematic.

A very small list (list 4, Appendix I) consisting of the words [vɛn, vɛn', vɛ:'n] was read by three subjects during a recording of the interarytenoid (INT) and the posterior cricothyroid (PCA) muscles.

Part of the results from the Haskins-investigation 1972 (see Fischer-Jørgensen and Hirose 1974b) were also included. The words, which were said in the frame *de sagde* ... [di sæ: ...] 'they said ...', are listed in Appendix I, lists 5a and 5b.

In 1977 a restricted EMG-investigation with one subject (FJ) and recording of the lateral cricoarytenoid (LCA) and the middle constrictor was made at the Haskins Laboratories in cooperation with S. Niimi (see Appendix I, list 6).

In 1981 a recording of pharyngeal and esophageal pressure with one subject (also FJ) was undertaken in Oxford, using the frame *de vil sige ... igen* [di ve si: ... i'gɛn] 'they will say ... again' (see Appendix I, list 7).

In 1985 a relatively long list of word pairs with and without stød was read by four subjects with the special purpose of an analysis of the airflow. This list contained the same words as the main list plus a number of other word pairs (see Appendix I, list 8). It was first read by FJ with inclusion of a number of words from Smith's investigation (list 8a), but as these words were difficult to delimit, they were replaced by other word pairs for the three other speakers (list 8b). This is the main list for measurements of duration because the airflow curve made the delimitations particularly precise. It is also important for Fo measurements, partly because the words were said in a longer frame (*Jeg kan godt sige ... til Palle* [ja ka 'gɔd si: ... tʰe 'pʰalə] 'I am willing to say ... to Palle', partly because tracing of Fo averages by hand is in some ways better than computer averaging (see below).

In 1986 a list of four word pairs was read by four subjects and used for an analysis of larynx position and for acoustic analysis (see Appendix I, list 9). They were placed in the frame *jeg kan let sige ... fem gange* [ja ka 'lɛd si:... 'fɛm' 'gaŋə] 'I can easily say ... five times'.

Moreover, in 1986 three word pairs placed in natural sentences were read by three speakers (see Appendix I, lists 10,11 and 12).

A fiberoptic investigation of the vocal cords made in cooperation with Birgit Hutters (1986,seven subjects) was based on a list of isolated words with the vowels [iː] and [iː'], see Appendix I, list 13).

Finally, a restricted number of words, read by two speakers, were subjected to inverse filtering, viz. two examples of the words [væːlən, væː'lən] read in isolation by FJ, and four word pairs read in sentences by BRP (see Appendix I, list 14).

In Appendix I the words are listed systematically in pairs. In the actual lists used for the recordings they were randomized in different ways.

C. THE SUBJECTS

There were 15 subjects in all. Seven main subjects took part in the original EMG-investigation 1974, viz.: BF, BH, BM, HU, JJ, JR, and NR. Some EMG recordings and other recordings were also made of the subject FJ. Further subjects are: BRP, LG, MF, ND, OB, PD, and PM. Moreover, TB and PMi from the Haskins investigation 1974 are sometimes included. LG and MF only read a list of three words. BH, FJ, HU and MF are female, the others male.

BF, OB and PM speak Standard Danish on a Jutlandish background, FJ and JR speak a slightly conservative Standard Danish, the others speak "Advanced Standard Copenhagen" (ASC). (For further information on the subjects, see Appendix I.)

D. RECORDINGS, PROCESSING AND MEASUREMENTS

1. ELECTROMYOGRAPHIC RECORDINGS

The main EMG-recording was undertaken at the Institute of Phonetics in Copenhagen in 1974. The insertion of the electrodes was performed by H. Hirose. A supplementary recording of subject BF was made in 1977. A third recording of BF (plus a recording of a restricted number of words read by FJ) was made in 1979. In the latter case the electrodes were inserted by S. Niimi. Bipolar hooked wire electrodes were used in all cases. For the recording of the vocalis muscle (VOC) and the cricothyroid muscle (CT) the insertion was made percutaneously through the skin of the neck, whereas for the interarytenoid (INT) and the posterior cricothyroid (PCA) the insertion was made transorally (see Hirose and Gay 1972 and Hirose et al. 1971). The correct placement was controlled by a series of tests, for VOC and CT by swallowing, high and low tones, gliding tones, glottal closure (ʔa ʔa ʔa) and strain. For PCA and INT by breathing, swallowing, ʔʔʔ, and voiceless aspirated consonants ([ipʰi]) (see Hirose 1971, cf. also Hirano and Ohala 1967). The tests were recorded, so that they could be inspected afterwards. It was not always possible to get at the right muscle. For NR and for BF 1979 the lateral cricothyroid (LCA) was hit instead of CT. It also happened that the electrode moved away after the start of the recording. This was the case for CT in BH's recording. Probably the sternohyoid was recorded instead. (It might have been practical to include tests for identifying not only the muscles aimed at but also those which might be hit by mistake.) It turned out that it may be advisable to avoid swallowing (if possible) until the end of the recording, because swallowing may involve a movement of the electrodes. - The identification tests were repeated at the end of the session, but in two cases (BF 1974 and JR) this was not possible because the FM-recorder broke down.

The EMG-signals together with the audio-signal, picked up by a microphone close to the mouth, were transferred to an 8-channel FM tape-recorder. The recording was controlled continuously on an oscilloscope screen and at intervals by means of mingographic recording.

After the session an octal code was recorded on one of the channels of the tape. The code, together with raw and integrated EMG-signals, a duplex oscillogram, an Fo-curve, and an intensity curve based on the audio-signal were recorded on an 8-channel mingograph at the speed of 100mm/sec. The mingographic curves were used to prepare the computer treatment of the signals. The simultaneous recording of raw and integrated EMG-signals made it relatively easy to identify artefacts as spikes with low frequency components at unexpected places, and the recording of duplex oscillogram, Fo and intensity permitted a rather precise segmentation. Up to 7 segmentation lines could be transferred to the computer and any of them used as line-up point. The sampling window was also marked on the mingograms (see Figure 3). The mingographic recording and the segmentation and marking of artefacts was undertaken by A. Löfqvist and the present writer. The information was later transferred to code sheets and used for sampling instructions.

A good number of the recordings contained artefacts (it had not been possible to glue the two wires together), and some showed microphony. A number of trials showed that both microphony and most of the artefacts could be removed by highpass filtering without damaging the signal. Therefore a number of filtering experiments were carried out by Jørgen Rischel and Birgit Hutters (see Rischel and Hutters 1980) with samples from both EMG channels for all subjects, in order to find out which cut-off frequency would be adequate. This turned out to be different for different subjects and muscles. Rischel and Hutters found that the EMG-signal from larynx muscles mostly covers a frequency range from 100 Hz upwards, the spectral energy being most prominent below 1000 Hz, and particularly from 200-600 Hz. There may, however, often be energy even at 2000 Hz, and in some cases it was possible to choose a cut-off frequency between 1000 and 2000 Hz without changing the signal except for minor details. The artefacts generally had their main energy

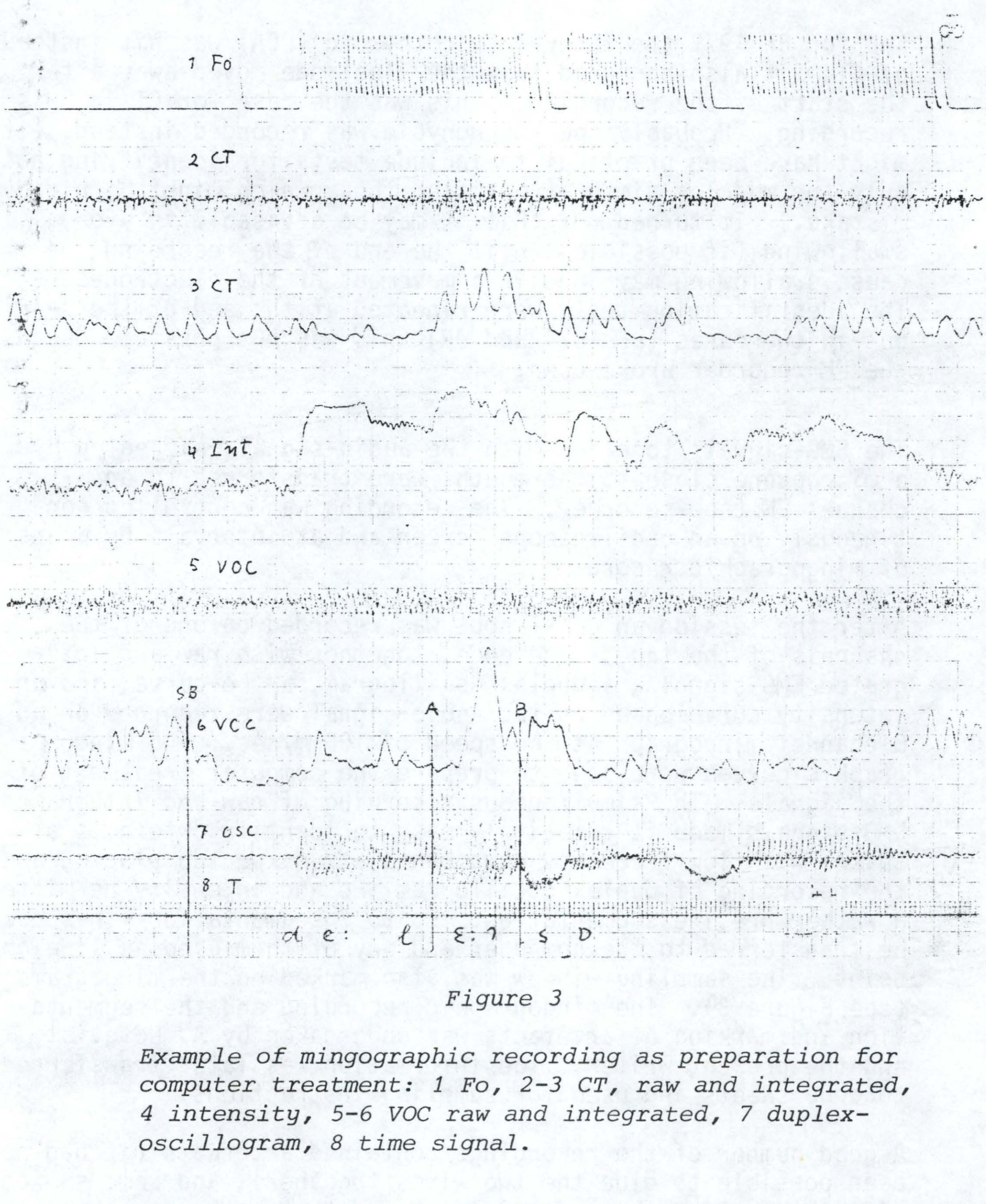


Figure 3

Example of mingographic recording as preparation for computer treatment: 1 Fo, 2-3 CT, raw and integrated, 4 intensity, 5-6 VOC raw and integrated, 7 duplex-oscillogram, 8 time signal.

at low frequencies up to 100 or 150 Hz, and in these cases they could easily be removed by filtering, but there were also artefacts which contained higher frequency components, in some cases above 1000 Hz, and in these cases it depended on the frequency components of the EMG signal whether they could be removed or not. Therefore, specific cut-off frequencies were chosen for each subject and muscle.

In the final sampling (1984-85) the following cut-off frequencies (in Hz) were used:

		VOC	CT	LCA
BF	1974	470	220	
BF	1977	390	390	
BF	1979	220		230

	VOC	CT	LCA
BM	330	51	
HU	1800	51	
JJ	420	280	
JR	230	340	
NR	165		51

The slope of the filters was 18 dB per octave except for BF 1977, BF 1979 (VOC), and HU 1974, where it was 36 dB/oct.

2. SUBGLOTTAL PRESSURE

In the 1974 investigation subglottal pressure was recorded for one subject, BF, together with the EMG-curves by means of a catheter inserted between the thyroid and the cricoid cartilages and connected to a pressure transducer (Simonsen & Weel, Model HB 66). After one reading of the list the catheter dropped out and was replaced by a new one, and the recording started over again. In the middle of the 6th repetition the catheter dropped out again and was not replaced, so that there are only 6-7 examples of each word. The first recording was weaker and has not been included in the averages. At the sampling the curve was LP-filtered at 68 Hz.

A calibration curve in cm H_2O was recorded together with the signals, but the computer-produced average curve can only be measured in mm. A scale has, however, been constructed by averaging the mingographic curves of a number of words by hand and comparing their difference with the computer-produced average curves.

Esophageal pressure was recorded for one subject (FJ) in the phonetic laboratory in Oxford in 1981 for a number of words with and without stød (see Appendix I, list 7) in co-operation with Ameen Al-Bamerni. The recording was performed by means of a multiple-transducer catheter with a diameter of 2.5 mm containing two small pressure transducers (Gaeltic 3 CT) intended to record pharyngeal and esophageal pressure at the same time. However, the distance was intended for men with a long throat, and when the transducer for esophageal pressure was supposed to be in the right place in my case, the transducer for pharyngeal pressure was in the nose. This placement was used for an obstruent series and gave very regular and reliable esophageal pressures. However, for the stød series the catheter was pushed further down so that the transducer for pharyngeal pressure was in place, with the consequence that the curve for esophageal pressure showed more, and more variable, amplitude in the gross movements and less amplitude in the ripple representing vocal vibrations, and the zero line dropped out.

There was, however, a clear difference in esophageal pressure between words with different stress placement, which were recorded in the same session, and there were rather consistent differences between words with and without stød, so that it was possible to start from the syllable *si:* of the frame as arbitrary zero point and compare the contours, measured in mm.

3. PHARYNGEAL PRESSURE

Pharyngeal pressure in words with and without stød was recorded for BF in the 1974 session by means of a tube inserted through the nose (pressure transducer Simonsen & Weel, Model HB 66). It was calibrated in cm H_2O. A scale for the computer-produced average curves was obtained in the same way as for subglottal pressure.

Pharyngeal pressure was also recorded for FJ in Oxford 1981 (see above). The recording was good, but there was no calibration. The same was the case for a recording of list 1 read twice by JR in Copenhagen in 1974.

4. AIRFLOW

Oral airflow was recorded for BF together with the other curves in 1974 by means of a Frøkjær-Jensen aerometer. It was calibrated in l/min., and a scale for the computer-produced averages was constructed as for subglottal and pharyngeal pressure.

In 1985 airflow was recorded by means of a flowmeter (pneumotachograph, built in the Phonetics Institute in Copenhagen) for four subjects reading list 8. It was calibrated in l/min.

5. LARYNX POSITION

The position of the larynx was studied for four subjects reading list 9 according to the method used by Reinholt Petersen (see Petersen 1985, p. 100). I quote from his description: *"The recording equipment consisted of a television camera (Sony AVC 3250 CES) and a video-recorder (Sony U-Matic type 2630). The frame frequency of the equipment was the normal 50 frames per second. The speech signal was recorded on the sound track of the video-tape via a Sennheiser MD 21 microphone placed about 15 cm from the subject's mouth. In order to synchronize speech and video-signals a timer signal was recorded on the video-tape using a timing device (FOR-ACO, type VTG 33). On playing back the tape, the timer signal was displayed on the monitor screen in minutes, seconds and centiseconds and it could, moreover, be registered together with the speech signal on an ink writer as pulses for seconds and centiseconds. In this manner it was possible to relate each TV-frame to the speech signal.*

During the recording the subject was seated in a dentist's chair with a fixed head-rest. The camera was placed at the level of the subject's thyroid prominence and at right angles to his mid-sagittal plane at a distance which allowed the area *between the subject's chin and sternum to be covered by the field vision. The subject was wearing a light but firmly fitting headgear to which a measurement scale was attached in such a manner that it formed the background of the front of the neck and the laryngeal prominence on the TV picture. The scale was divided into units which corresponded to millimeter units at the subject's mid-sagittal plane."*

The contour of the larynx was drawn on transparent paper placed on the video-screen for eight word pairs read by each of the four subjects.

6. FIBEROPTIC INVESTIGATION OF THE VOCAL FOLDS

For seven subjects reading list 13 the movements of the vocal folds were recorded by means of a video camera, using the same instrumentation and set-up as described above for the recording of larynx position, but with the optic of the TV-camera replaced by a fiberscope (Olympos VF, type 4a), the light guide of the fiberscope being inserted through the subject's nose and placed in his pharynx. The video-recorder was equipped with a step-function, so that it was possible to step forward frame by frame. Selected frames were photographed from the screen by means of a polaroid camera. Since the distance between frames was 2 cs, they could be identified with points on the mingographic recording (comprising duplex oscillogram, Fo and intensity curves with a temporal inaccuracy of ± 1 cs).

7. ACOUSTIC ANALYSIS

a. Duration A number of the recordings made for other purposes (EMG, airflow, etc.) were also used for measurements of duration. The words without stød did not give many problems, except for a small uncertainty concerning the boundary between initial [v] and [h] and the following vowel. But the words with stød give problems because the stød often shows up as weak and irregular vibrations, and these are not always restricted to one segment. In the 1974 recording the boundary between [ɛ] and [l] in [kʰɛ:'lɒ] is sometimes placed rather arbitrarily where the stød phase ends, and in [kʰɛl'ɒ] where it begins. In the 1985 recording the airflow curve was of great help, showing a clear small dip at the start of the [l] in all cases. And these curves showed that the irregularities in [kʰɛ:'lɒ] may continue into the [l] and cover the boundary between [ɛ:'] and [l] in the duplex oscillogram. Likewise they may continue into the following weak syllable in [kʰɛl'ɒ]. The boundary between [i:'] and [b] in [pʰi:'bɒ] may also be problematic because the [i:] with stød is very weak at the end. But here again, the airflow shows a clear boundary. It cannot, however, always solve the problem of finding the boundary between vowel and [n], e.g. in [be:'nəð] or in [vɛn'] and [vɛn'n̩].

However, in spite of these uncertainties there is a very good agreement between the measurements of the same words and subjects in list 1 and the more precisely measured list 8. The postvocalic consonants have only been measured in list 8 ([l] also in list 1). The delimitation of vowel before [s] does not give any problems when the start of the *s*-noise is chosen as boundary, i.e. the small pause which is often found before [s] is included in the vowel duration.

b. Intensity The 1974 recording (lists 1 and 3) was also utilized for intensity measurements. The direction of the difference is clear, but it is not possible to make any quantitative measurements because, by mistake, the intensimeter (which is part of the "Transpitchmeter") was set on "linear display", and this scale is not linear in dB. However, intensity curves of lists 9-12 could be measured in dB.

c. Fundamental frequency Both the audiosignal from the 1974 recording and from the 1985 and 1986 recordings (lists 8-12) were used for fundamental frequency analysis by means of the "transpitchmeter". There is no problem in looking at individual Fo-curves or in measuring a fall in Hz. The problem arises when one wishes to produce average Fo-curves. This problem will be treated in section 8.

d. Spectrography A number of wide- and narrow-band spectrograms and sections of words with and without stød were produced by means of the Kay Elemetric Sonagraph 7800 (printer 7900).

e. Inverse filtering Both recording and analysis were carried out at the Department of Speech Communication and Music Acoustics at the Royal Institute of Technology, Stockholm. The recordings were made in an unechoic chamber using a condensor microphone, and the speech samples were stored on a digital tape recorder. The recorded signal contained frequencies down to 20 Hz. The inverse filter analysis was done by Inger Karlsson using an interactive digital filter programme. A normal oscillogram, an inverse filtered oscillogram, and the integral of the inverse filtered curve were produced for each word.

8. STATISTICAL TREATMENT

a. The production of average curves Both the physiological and the acoustic signals from the 1974-79 recordings were further processed by computer and transformed into average curves.

Sampling and averaging were performed using a PDP-8 computer. The programme was partly based on the Haskins procedure, but in an enlarged and modified version. It was first worked out by P. Holtse in co-operation with J. Stellinger (see Holtse and Stellinger 1976). Later it was modified and simplified by P. Dømler and P. Holtse. Data are sampled through an eight-channel multiplexed analog-to-digital converter controlled by a real time clock. Data and results are manipulated and displayed via a Tektronix 4014 graphic terminal. The sampling takes place with a 1.250 sec. window at a sampling frequency of 200 Hz. The maximum number of examples that can be sampled is 17, but if there are more, they can be stored in two files and combined during the averaging procedure.

A preliminary sampling of most of the subjects was undertaken in 1977, and a write-out was inspected by a team consisting of H. Hirose, Jørgen Rischel, Birgit Hutters and the present writer. Some artefacts in the EMG-curves had been removed by moving or shortening the sampling window (this could be done if the artefact was found outside the relevant word). Some curves had to be rejected, but the programme made it possible to retain most of the material, i.e. not rejecting all curves of a whole word because of an artefact in one of them. Each of the curves (EMG, Fo, intensity, etc.) can be left out individually, and a special programme permits to cut out small sections in one of the curves only. Later it turned out that a number of curves had been disturbed during the sampling. Thus in 1984-1985 a new sampling was undertaken for all curves relevant to the stød-analysis. The integration time used for the EMG-signals was 25 ms and for the intensity curves 13 ms. The 1977 and 1979 recordings of BF and the recordings of JR, which had not been sampled earlier, were also sampled at this occasion. P. Dømler and Sv. E. Lystlund took care of the technical aspect of the sampling.

The final corrections and the averaging were performed by Jens Bechsgaard-Christensen and Niels Jørn Dyhr according to my instructions. Two examples of average curves are shown in Fig. 4. The line-up point was in all cases the start of the stressed vowel. The time scale is in cs. The scale of the amplitude of the curves is linear (except for intensity), but all scale values are arbitrary except for Herz in the case of Fo. A percentual standard deviation curve is given below each average curve. It should be kept in mind that a good deal of the apparent deviation is due to timing differences. Cases with hesitation or large tempo differences were left out, but there are, of course, a good deal of tempo differences left, and the farther you come from the line-up point, the more the individual tokens will deviate on the time line. Time differences are thus transposed into deviations of amplitude, which may be somewhat misleading.

This is particularly true of the Fo curve, which, in stød words, contains rather abrupt falls and rises which may not come exactly at the same time.

Averaging Fo curves of stød words by computer is, on the whole, a somewhat dubious procedure, particularly because the stød sometimes turns up as an abrupt fall in pitch, sometimes as irregularities, and sometimes simply as a gap in the curve

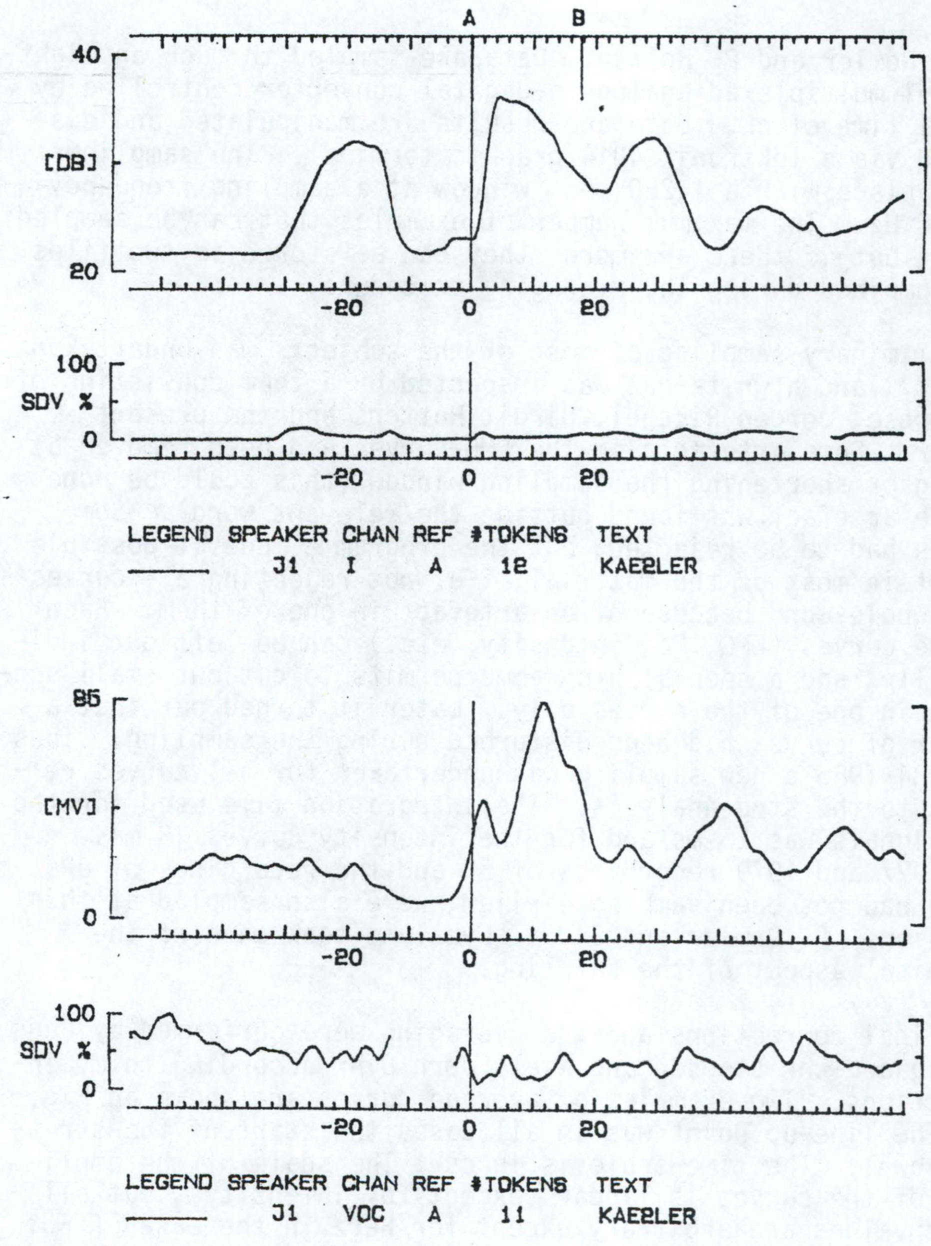


Figure 4

Print-out from computer; average curves of intensity and VOC with standard deviation. A (0): start of vowel, line-up point. B: end of vowel. Duration in cs (MV and OB are not real). Subject BF 1977; text: [deː kʰɛː'lɒ di siɒ̯].

because the signal may be rather weak. When these possibilities are all realized for different tokens of the same word, the average is not very informative. In the cases where only a few tokens had irregular vibrations and others a dip in frequency, the former were left out (this was the case for BM, JJ, and in most words for HU), but when there were many cases they were included. An example with much irregularity is shown in Fig. 5. Since the irregular vibrations are often of rather low intensity it also depends on the sensitivity setting of the pitchmeter whether they will show up in the curves, and the setting was not quite the same for all subjects, so that some have more gaps. This, then, does not mean that there was a closure during the stød, but only that there were irregularities and that they were of low amplitude. Averaging the fundamental frequency of curves with such irregular vibrations is a problematic matter anyhow.

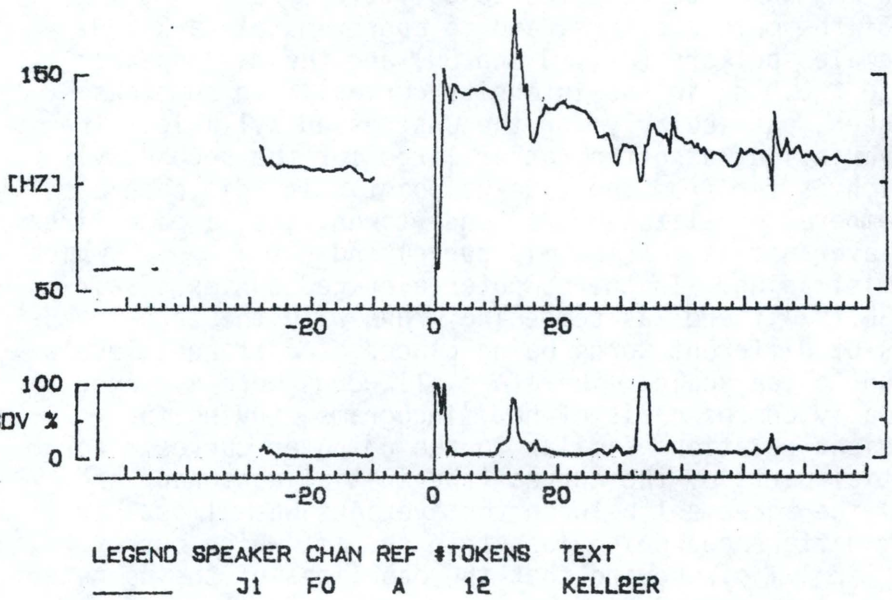


Figure 5

Example of dubious average curve of Fo. Subject: BF 1977, text: [de: kʰɛl'ɒ di siɒ̯]*; line-up point = start of* [ɛ].

Octave jumps also give problems. A particular programme permits the correction of evident jumps, but sometimes the sampling has caught the octave jump on its way up or down, so that it only shows up as a small jump. Some irregularities of this kind have been cut out. In some cases averaging had to be given up. For this reason only a restricted number of Fo-curves averaged by computer are reproduced in Appendix IV.

Airflow, intensity, and Fo-curves of the 1985-86 recordings (lists 8-12) were not averaged by means of the computer, but superposed tracings of the 8 tokens were made by hand, and an average line drawn on this basis. In this case octave jumps do not give problems, and irregular vibrations were left out, but this means that the average curve of the latter half of the syllable in words with stød may be based on a smaller number of individual tokens than the start of the syllable or the following syllable. If it is based on a small number of individual curves, this is indicated by using points instead of broken lines (see Appendix IV). BH's curves (1974) were also averaged manually, and the same is true of the words [p^{h}i:bɒ] and [p^{h}i:'bɒ] read by subjects JJ, HU and BM, because [p^{h}i:bɒ] had been forgotten in the sampling procedure.

The exactitude of these average curves may differ according to the variability of the readings. Very often the individual curves were very close together, and the exactitude was less than $\pm$ 0.5 mm, which corresponds to a little more than $\pm$ 1 Hz for most of the male speakers, and to approximately $\pm$ 2.5 Hz for the female speakers (HU, FJ and BH) and the male speaker BRP (and to $\pm$ 0.5 dB in the intensity curves). In some cases it was higher, particularly for the unstressed syllable. The temporal variation was often rather large for the second syllable, which is far from the line-up point. In this case a certain temporal equalization was undertaken, i.e. a case like was averaged as (the mid curve) and not as , which would be misleading. In the computer-averaged curves of airflow for BF 1974 there was something wrong with the zero-line, the curves of different words being placed at different levels in relation to the scale. Therefore all words were averaged again manually on the basis of new mingograms, trying to achieve height relations similar to the computer curves. For the essential parts of the curves (the initial consonant and the vowel) the agreement between the averages was almost perfect, most differences being less than one mm, which corresponds to 1-2 l/min., showing that the baselines of the computer curves themselves were OK, only the placement relative to the scale was wrong. The computer averages were therefore used, the baselines being adjusted to the same level. At the same time the comparison showed the rather good accuracy of the manually produced average curves. (Examples of manually averaged curves are given in Fig. 6.)

To the inaccuracies of the average curves should of course be added the uncertainty of the measurements, which was around 0.5 mm.

b. Significance tests Significance tests for the durational differences were made by means of Student's t-test or (in some cases) the Mann-Whitney U-test. For manually traced curves it was generally possible to superpose the two words with and without stød and state the overlappings at the relevant points. Very often there were no overlappings, or just a single overlapping between the 8-10 examples of the two words, and it was easy to state by the Mann-Whitney test that the significance was below the 0.1 level. In some cases there was almost complete overlapping, and thus no significance. In the relatively few examples of doubt concerning the number of overlappings the lower significance level was chosen (see Fig. 6).

For the average curves produced by computer it was more problematic. In the Haskins programme it is possible to get a print-out of all values with standard deviation, and then cal-

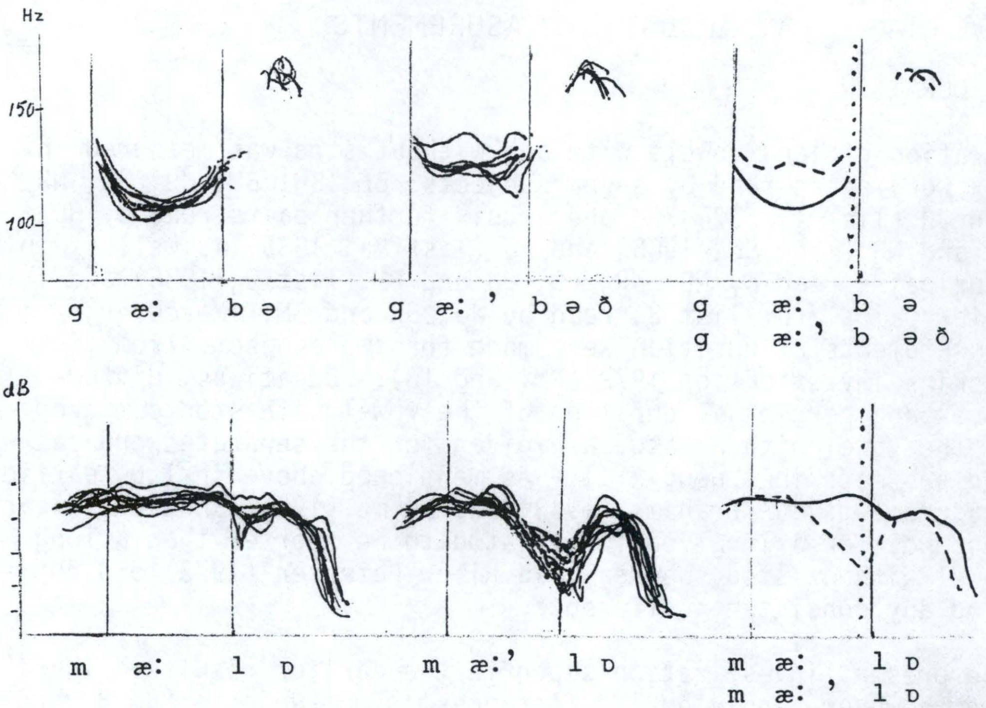


Figure 6

Examples of manually superposed and averaged curves. a: Fo curves (NR, list 8, 1985); b: intensity curves (NR, list 9, 1986). *5 dB*

culate the significance at selected points. This was not possible with the present programme. Moreover, the standard deviation curve printed below the average curve has a very narrow scale, one mm corresponding to approximately 8%, so that it cannot be calculated exactly. In some cases, i.e. rather often for the intensity curves, the standard deviation is very small, so that the inexactitude does not matter so much; in other cases, i.e. very often in the EMG-curves, the standard deviation is large. It also often happens that the percentual standard deviation is very similar for the two words to be compared, but the averages very different, so that the absolute standard deviations are too different to permit the application of a t-test. In these cases a non-parametric test should be used, but this would require measurements of the individual curves. Therefore, for lists 1-3 (1974-79) significance tests were applied to all word pairs of one subject taken together. It was, however, often possible to state that there was no overlapping between the maxima of the individual tokens of corresponding words with and without stød.

III. RESULTS

A. ACOUSTIC MEASUREMENTS

1. DURATION

Duration of long vowels with and without stød was measured in six word pairs read by seven subjects: BF, BH, BM, HU, JJ, NR and JR (list 1, 1974-79) and in six further pairs read by HU, JR and NR (list 8b, 1985) and FJ (list 8a, 1985) as well as in four pairs read by ND, NR, PD, OB and PM (list 9, 1986) and in a few pairs from list 3, read by JJ, JR and BM. Moreover, measurements of duration were made for two subjects from the Haskins investigation 1972 (PMi and TB). Durations, differences and percentual duration of the vowel with stød compared to the vowel without stød are given for the separate word pairs and subjects in Appendix II. As mentioned above in I,D, earlier measurements by Abrahams (1943) and by me (1955) showed a clear tendency for a long vowel with stød to be shorter than a long vowel without stød, whereas Pia Riber Petersen (1973) did not find any consistent difference.

The present investigation supports the earlier results. There are, however, individual differences. Two subjects (BH 3 word pairs) and BM (6 word pairs) do not show any difference, whereas 12 subjects (BF, FJ, HU, JJ, JR, ND, NR, OB, PD, PM, TB and PMi) have a clear difference, the vowel with stød being shorter. In Table I a concentrated survey of the results is given, all lists and pairs combined for each subject. (Averages of individual word pairs are given in Appendix II, 2a-c), and durations are also indicated in the graphs for intensity (Appendix III), Fo (Appendix IV) and airflow (Appendix VI). The pairs [pʰi:'bɒ/pʰi:bɒ] and [lɛ:'sɒ/lɛ:sɒ] were read by eight subjects and [kʰɛ:'lɒ/kʰɛ:lə] by six subjects. These main examples were read in two different sessions and frames by HU, JR, NR and FJ and five times in different sessions and frames by BF. These readings in different sessions and frames are counted as separate pairs in the survey.

Table I

Differences (in cs) between long vowels with and without stød (V: - V:') and percentual duration of [V:'] compared to [V:]. N = number of word pairs (averages).

	BH	BM	BF	FJ	HU	JJ	JR	ND	NR	PD	PM	PMi	TB	OB
N	3	6	15	8	12	6	16	4	16	4	4	2	2	4
diff. (cs)	-0.1	0.2	2.9	3.6	3.3	3.9	1.7	5.1	3.1	3.1	2.7	2.6	4.3	2.1
%	102	99	85	83	84	81	90	80	85	82	87	86	78	88

The percentage is very similar for the different subjects, except that JR has a higher percentage (and a smaller difference) than the other subjects. For BH and BM 5 of the 9 pairs have a shorter vowel in words with stød and 4 a longer vowel, and none of the differences are significant; but for the other 12 subjects the difference is consistent in the sense that 92 out of 93 pairs of averages show a shortening of the vowel with stød, the difference being significant at the 1 or (more often) 0.1% level in 74 out of the 93 pairs. In 5 pairs it is only significant at the 5% level, in 1 it is non-significant, and in 3 (JR) the significance cannot be calculated because there were only three readings, but there is some overlapping.

Although the tendency to shortening is clear, vowels with stød remain longer than short vowels. In list 8 the two words [pʰibɒ] and [lɛsɒ] were also recorded. The relation between short and long vowel compared to the relation between long vowel with and without stød is shown in Table II.

Table II

Duration of long vowel with stød and of short vowel, both of them in percentage of long vowel without stød (N = 8)

	FJ	HU	JR	NR	av.
pʰibɒ/pʰi:bɒ	50	34	56	61	50.3
pʰi:'bɒ/pʰi:bɒ	75	85	88	79	81.8
lɛsɒ/lɛ:sɒ	61	56	61	67	61.3
lɛ:'sɒ/lɛ:sɒ	88	93	82	93	89.0

The averages of long vowels with stød and of short vowels are clearly different, and there is only overlapping in one individual case.

Almost all examples without statistically significant difference concern the pair [lɛ:'sɒ/lɛ:sɒ], and on the whole there seems to be a certain tendency to shorten high vowels with stød more than low vowels and a more pronounced tendency to shorten vowels before sonorants more than before obstruents (particularly *s*). The pairs [kʰɛ:'lɒ/kʰɛ:lə], [pʰi:'bɒ/pʰi:bɒ] and [lɛ:'sɒ/lɛ:sɒ] can be compared in 13 different cases (5 different subjects in different sessions or frames) and in 11 cases (for the percentual shortening 10 cases) [kʰɛ:'lɒ] is shortened most, and [lɛ:'sɒ] least. But a number of the other examples (from lists 8 and 9) do not fit into this pattern; it is thus only a tendency.

It is a problem why Riber Petersen did not find the same difference between long vowels with and without stød. None of her six subjects had a consistent shortening, and on the whole it is only found in 50% of the cases. The difference can hardly be due to age or dialectal background. All Riber Petersen's subjects were Copenhageners (of two different generations), and most of the subjects in my 1955 investigation were also from Copenhagen or North Zealand (and only a few of them were somewhat older than the subjects of the older generation in Riber Petersen's investigation). Of the subjects in the present investigation from Copenhagen or North Zealand seven had a consistent difference, and two none.

It is more probable that the difference has something to do with the sentence types used. Riber Petersen's corpus consisted of small, real sentences. The 1955 material comprised mostly isolated words but also some small sentences, and in the latter case the difference between words with and without stød was very small and hardly significant. In the present investigation the test words were placed in frame sentences. In 1974 there was only one stress group, but in 1985 and 1986 three. This did not make any difference. Perhaps words in frame sentences are pronounced more distinctly than in real sentences, so that small differences come out more clearly. This assumption may be supported by the observation that the subjects with small or no differences (JR, BH, BM) read the sentences in a relatively fast tempo, and the subject with the largest difference read the sentences slowly.

In order to test this assumption a new recording was made of three subjects (HU, NR and OB) reading three of the same word pairs in small sentences (for HU and NR Riber Petersen's sentences were used, see Appendix I, lists 10 and 11, and Appendix I, 2f). The result supported the assumption. In the sentences (with 3-4 stresses) there is less difference than in the test words in frames (with 4 stresses). There are still 7 positive cases out of 9 (i.e. shorter vowel in words with stød), but only 4 differences are significant at the 1 or 0.1% level, one case at the 5% level, and two non-significant. None of the three subjects have a significant difference in all three pairs. The difference between vowels with and without stød is thus still there as a tendency, but it is not consistent. All vowels are shortened in the sentences compared to the corresponding words in frames (with the exception of NR's [kʰɛ:'lɒ]),the average shortening being 4.6 cs, but vowels without stød are shortened about 1 cs more than vowels with stød. A new recording of sentences read by Pia Riber Petersen's subject BRP was also undertaken. He had a significantly shorter vowel in [mæ:'lɒ] and [må:'lɒ] than in [mæ:lɒ] and [må:lɒ], respectively, but the opposite (without significance) in [lɛ:'sɒ] vs. [lɛ:sɒ].

The consonant following a long vowel was measured for list 8 (4 subjects, 31 word pairs) and the consonant [l] was measured for 5 subjects reading list 1 (10 pairs) and for one subject reading list 3 (4 pairs). Of these 45 pairs 24 had a longer consonant in words with stød, 17 a shorter consonant, and 4 had no difference. There is thus no consistent difference.

As for words with short vowel plus sonorant consonant both Lauritzen and Riber Petersen found the vowel to be shorter and the consonant to be longer in words with stød. The difference in consonant length was significant in all Riber Petersen's four word pairs (all subjects combined), but the difference in vowel length in only two of the four word pairs. These findings are fully confirmed by the present investigation. The lengthening of consonants in words with short vowel and stød in the consonant is consistent for all subjects, and in only one out of 20 pairs the difference is non-significant. But the shortening of the vowel is only a tendency, and it is only found in disyllables, where 23 out of 28 pairs have shortening (17 with significance at the 1 or 0.1% level), whereas the monosyllabic pairs have shortening in only 50% of the pairs (7 out of 14 pairs). Durations and differences for the separate pairs are given in Appendix II, 3a,b and 4a,b. A survey of the absolute and relative lengthening of the consonant in words with stød is given in table III, both lists (1 and 8) combined. In list 8 all consonants were measured, in list 1 only [l]. A survey of vowel duration is given in table IV.

Table III

Absolute and relative lengthening of consonants in words with short vowel and stød (N indicates number of word pairs (averages)) (V$\underline{C}$' - V$\underline{C}$)

	BF	BM	FJ	HU	JJ	JR	NR
N	1	1	5	4	1	4	4
cs	+1.3	+1.6	+3.0	+2.6	+2.2	+1.9	+1.9
%	121	129	150	134	132	136	133

Table IV

Shortening of vowels in words with short vowel plus stød in consonant (N = Number of word pairs (averages)) ($\underline{V}$C' - $\underline{V}$C)

		BH	BM	BF	FJ	HU	JJ	JR	NR
disyll.	N	2	2	5	4	4	2	4	4
	cs	+0.7	-1.9	-2.7	-0.5	-2.1	-0.2	-1.5	-2.3
monosyll.	N	1	1	5	2	2	1	2	2
	cs	+3.0	-0.1	-0.5	-0.1	-1.1	+0.8	+1.0	+0.7

Duration of initial consonants in words with and without stød was measured for four speakers (FJ, HU, JR and NR) on the basis of four selected word pairs from list 8 with different types of consonants ([pʰ, b-, s-, l-]). FJ had a longer consonant in words with stød in all four pairs (and she showed the same tendency in list 7), but the difference was not significant, and the other three speakers had no consistent difference.

2. IRREGULARITY AND CLOSURE

The most conspicuous acoustic characteristic of words with stød is the presence of irregular vibrations in the latter part of a long vowel or in a sonorant consonant following a short vowel. i.e. in what Smith calls the "second phase" of the stød, generally considered as the real stød phase. Smith considers this as a "non-normative" stød because, as a speech therapist, he does not find this way of pronouncing the stød recommendable. But as a matter of fact this is quite a normal pronunciation of the stød in distinct speech. In the present investigation irregularities were found in 70.8% of all cases. The analysis was based on about 1700 words with stød. The irregularity concerns both frequency and intensity and is seen very clearly in the duplex oscillogram and also in intensity and Fo curves. However, it is not always visible in the Fo curves which, depending on the sensitivity level of the pitch analyser, may show a gap instead. All recordings from 1985-86 (comprising almost half of the examples) contained a duplex oscillogram plus either an intensity curve or an airflow curve, besides the Fo curve. All cases with gap in the Fo curve showed irregularity in the other curves. There were only two or three cases where it may have been due simply to a weak signal. As for the older computer-analysed recordings (lists 1-2), the analysis was based on the sampled signals, which did not comprise any duplex oscillogram. Here a gap in the Fo curve was taken as a sign of irregularity.

Some examples of different degree of irregularity are shown in Fig. 7 (see also Riber Petersen 1973, p. 201-204). The degree of irregularity is very variable. There is a certain tendency to more irregularity in consonants and in high vowels than in low vowels ([vɛn'] and [vɛn'n̩] show irregularity in almost all cases and, for instance, BM has much more irregularity in the [bibibibi]-series than in the other words, although they were read in the same session). There are also individual differences (OB and BM having fewer cases of irregularity than the other speakers, and JR and BRP often having somewhat weaker irregularity than most of the other speakers), but the largest differences are found between different readings by the same speaker. This is only partly dependent on the character of the list (HU and OB have less irregularity in the words in sentences than in the words in frames, but this is not the case for NR; and BRP, who did not have irregularities in Riber Petersen's investigation, has irregularity (though sometimes rather weak) in 76% of the cases in the present investigation, although both texts consisted in normal (and partly in the same) sentences. It seems mainly to be a question of the distinctness level chosen by the speaker in the session in question. Table V gives the percentage of words with irregular vibrations for the individual speakers and sessions. In a few cases with weak irregularity the decision depended on a subjective estimate, but generally there was no doubt. (Lists 10, 11, 12 contained words in sentences).

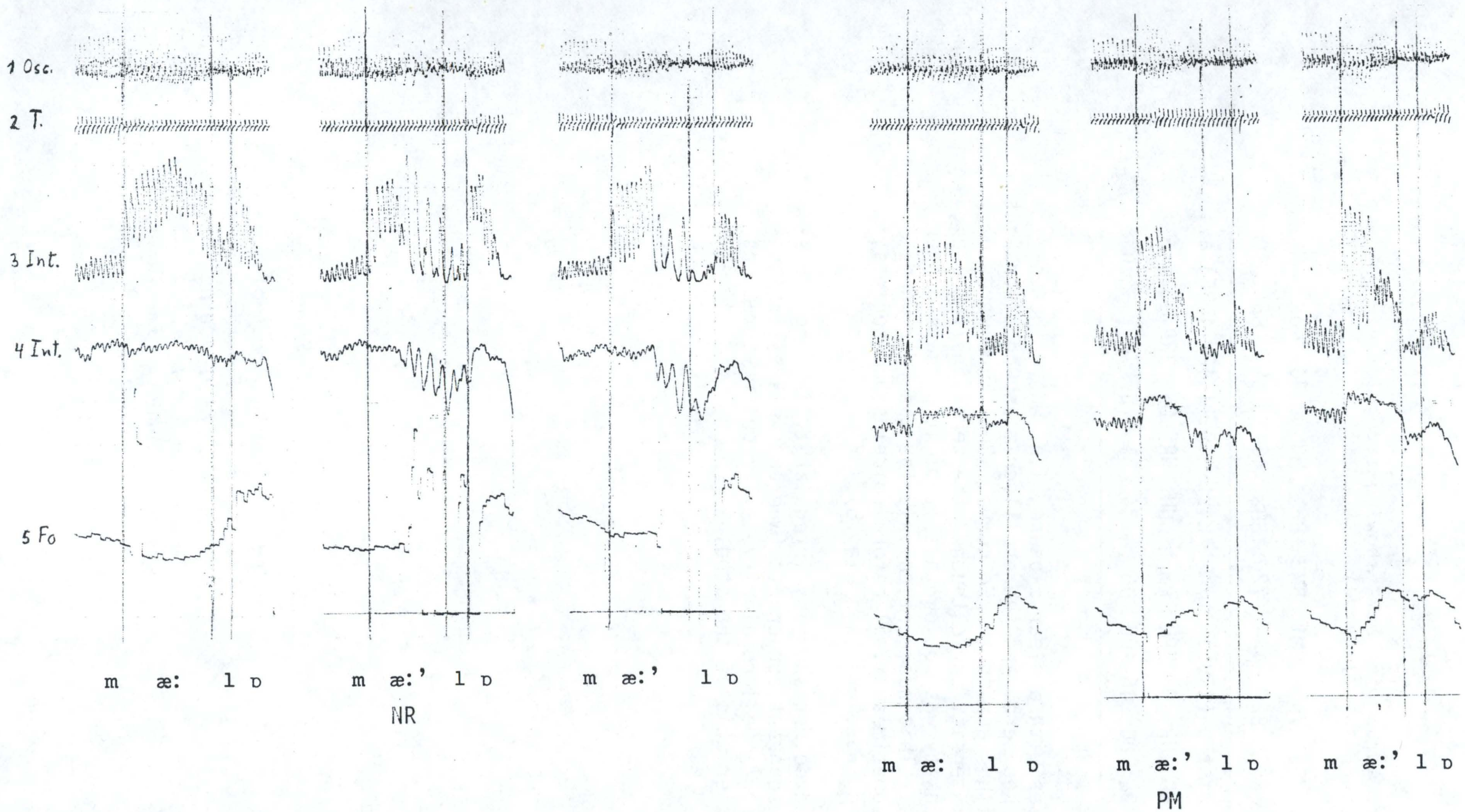


Figure 7

One example of [mæ:lɒ] and two of [mæ:'lɒ] read by NR and PM and showing varying degree of irregularity in [mæ:'lɒ]. 1: duplex oscillogram, 2: time, 3: Intensity, HP 500 Hz, integr. time 5 ms, 4: Log. intensity, integr. time 10 ms, 5: Fo.

Table V

Percentage of words with stød showing irregular vibrations. Lists 1-2 (1974-79).

BF 74	77a	77b	79a	79b	BM1	BM2	BH	HU	JJ	JR	NR
53	73	90	80	82	44	72	88	46	52	86	90

List 8 (1985)				List 9 (1986)					Lists 10,11,12 (1986) av.				
FJ	HU	JR	NR	ND	NR	OB	PD	PM	HU	NR	OB	BRP	
75	94	63	41	98	100	46	100	96	34	81	8	76	70.8

There were no cases with a clear closure, i.e. where the intensity line reached zero and the oscillogram showed a straight line combined with a gap in the Fo curve. But there were some cases where the intensity curve touched the zero-line for a cs, or where the intensity was so low that it might perhaps be perceived as a pause. This was particularly the case for words with [u:ʔ] (and sometimes [i:ʔ]) before voiceless consonants, e.g. [mu:'sən] and [sbi:ʔsɒ] (see Fig. 8).

Words without stød do not show any irregularity in long stressed vowels or in sonorant consonants (whereas weak syllables with schwa may show some irregularity). Irregular vibrations are thus a characteristic of the stød.

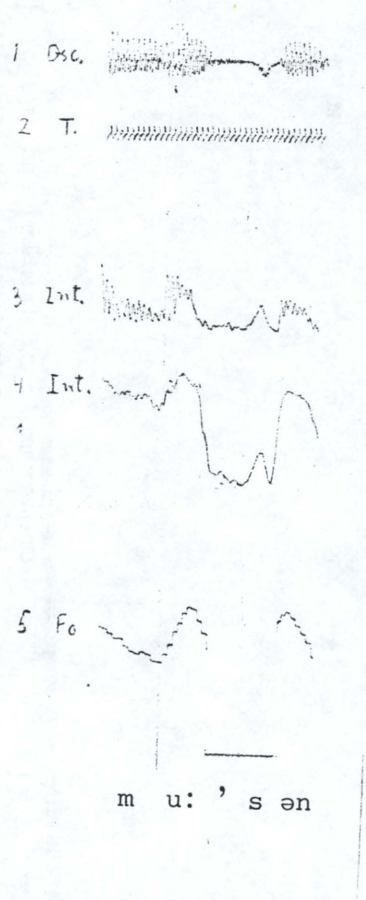


Figure 8

PM [mu:'sən]; almost closure. 1: duplex oscillogram; 2: time; 3: intensity HP 500 Hz, integr. time 5 ms; 4: log. intensity, integr. time 10 ms; 5: Fo.

3. INTENSITY

The intensity contour of syllables with and without stød was analysed on the basis of 74 pairs of averages from list 1 read by 6 different subjects, 8 pairs of averages from list 3 read by two different subjects, and 32 pairs from lists 9, 10, 11 and 12 (1986) read by 7 different subjects, two of whom also read list 1 (see Appendix III, p. 225). (Intensity was not measured for list 8, because it might be affected by the mask used for the recording of airflow.) The pairs from lists 1 and 3 (1974), which were computer-averaged, could not be analysed quantitatively (see above, p. 90). But for the pairs from 1986 two points of interest in the beginning and end of the syllable were measured in dB.

The result was that the intensity contours of syllables with and without stød differ in a very consistent way (see Appendix III, Figs. 1-2, pp. 226-231.

There is, in the first place, a tendency for words with stød to reach a higher level of intensity in the beginning of the vowel, i.e. in what Smith (1943) calls the first phase of the stød (Smith also observed a tendency to a steeper rise in the start). This is true of 59 out of 82 pairs from lists 1 and 3 (with 15 opposite cases and 8 of equal height). Similarly, in the 1986-recordings, 23 out of 32 pairs show a higher level in words with stød (with 7 opposite cases and 2 of equal height). However, the difference is small, for the 1986-pairs 1.7 dB on the average, and it is only rarely significant (11 cases out of 32). There are also individual differences, OB showing a consistent difference, NR, JR and BRP no difference.

In the second place, in words with stød the contour reaches a lower point at the end of the vowel (or after a short vowel in the sonorant consonant), i.e. the second phase (the stød phase) than in words without stød, and this difference is consistent. It is valid for all the analysed 78 pairs from lists 1 and 3 and for 31 out of 32 pairs in the 1986-recordings, the only pair without any difference belonging to list 11 (sentences).

Significance could be calculated for each individual subject reading list 1 or 3, all pairs and the two unpaired words taken together. It was 0.1% for BH, BM, JJ, NR, BF 1977 and 1979 (a and b), 1% for HU, and 5% for BF 1974 and for JR. For the 1986-recordings significance could be calculated for each word pair. The words with stød reached a lower level in all 32 pairs, and the difference was significant at the 0.1% level for 31 of the 32 pairs, and at the 5% level for one pair (from the sentences), the average difference in dB being 10.1 dB in list 9 (test words in frame) and 6.7 dB in lists 10, 11 and 12 (sentences), differences which are well above the measurement uncertainty.

There is thus a deeper drop in intensity from the start of the vowel to the lowest point in words with stød. This is the case in 77 out of 78 pairs in lists 1 and 3, and in 31 out of 32 pairs in the 1986-recordings (the only exception belonging to the sentence examples).

The occurrence of a deeper drop in intensity in words with stød in pairs from lists 1-3 (1974-79) is indicated in table VI for the different subjects, whereas the intensity decrease (in dB) in words with and without stød and the difference between them for the individual subjects in the 1986-recordings are given in table VII.

Table VI

Number of averages with deeper (+) or smaller (-) drop in intensity in words with stød than in words without stød. (List 1)

	BF	BH	BM	HU	JJ	JR	NR	sum
+	33	6	10	7	7	5	7	75
-	0	1	0	0	0	0	0	1

Table VII

Intensity decrease (in dB) in long vowels with and without stød. A: 4 pairs, each comprising 10 tokens; B: 3 pairs, each comprising 8 tokens.

A. Words in frame (list 9)

	ND	NR	OB	PD	PM	av.
V:ʾ	14.0	13.8	13.6	14.6	14.8	14.2
V:	3.9	3.1	0.4	1.6	2.8	2.4
diff.	10.1	10.7	13.2	13.0	12.0	11.8

B. Words in sentences (lists 10, 11, 12)

	HU	NR	OB	BRP	av.
V:ʾ	11.5	11.0	8.2	10.3	10.3
V:	4.0	3.8	4.3	1.0	3.3
diff.	7.5	7.2	3.9	9.3	7.0

The difference is very clear in all cases but somewhat smaller in sentences than in frames.

The decrease starts early in the vowel, the average distance from the start of the vowel being 4.8 cs in the 1986-recordings with the individual means rather close (4.2 - 5.8 cs). All examples in these recordings contained long vowels. In list 1 it is possible to compare the start in long vowels with stød with the start in short vowels followed by a consonant with stød. It is interesting to find that the fall starts at the same point in both cases, which is a further indication that the stød is a syllabic phenomenon and does not belong to a definite segment. This can be seen for the individual subjects in table VIII (here also unpaired words with long vowel are included.

Table VIII

Distance from vowel start to start of intensity decrease (in cs) in words with stød. List 1. N = Number of averages.

	BF	BH	BM	HU	JJ	NR	av.
A. V:'							
N	27	7	7	7	7	7	
cs	5.8	6.4	7.0	10.1	4.5	6.3	6.7
B. VC'							
N	11	3	3	3	3	3	
cs	5.2	6.5	5.7	8.7	5.2	6.5	6.3

The distance to the end of the decrease is also almost the same in the two cases. It is in almost all cases at the very end of the long vowel (in only three averages a small rise is found after the lowest point) and in the sonorant consonant after a short vowel, but somewhat dependent on the duration of the vowel (see also Figs. 1-2 in Appendix III). In long vowels without stød the lowest point is also normally at the end, but the small decrease may start at different points, often at the beginning, but also later, so that it does not make sense to calculate an average.

Thus the intensity decrease starts in the vowel in the case of "stød in the consonant" and, moreover, the decrease of intensity continues into a following sonorant consonant after "stød in the vowel". A sonorant consonant like [l] normally has lower intensity than the preceding vowel, but it is much lower after a long vowel with stød than after a long vowel without stød, the difference for 10 averages of the words [kʰɛ:lə] and [kʰɛ:'lɒ] in the 1986-recordings being 7.3 dB, all statistically significant.

4. FUNDAMENTAL FREQUENCY

a. First part of the stressed syllable

The frequency contour of the first part of the syllable in words with and without stød was analysed on the basis of 75 word pairs from list 1, read by 6 different subjects (1974-79), 8 from list 3 read by 2 different subjects (1974), 62 from list 8, read by 4 subjects (1985), and 32 from lists 9, 10, 11 and 12 (1986), read by seven different subjects, i.e. 178 word pairs in all, each word comprising 8-10 tokens (see Appendix IV, p. 232). The Fo contour was in almost all cases different for words with and without stød.

The most stable difference consists in a higher level of Fo in the start of words with stød (the first phase) compared to words without stød. The differences in Hz for each subject are given in Table IX for lists 1 and 3, and in Table X for lists 8-12 (i.e. 1985-86). BH's curves were not calibrated, and in this case a "+" indicates a positive difference. The difference was measured as the largest difference within the first 10 cs of the word (see also the graphs in Appendix IV).

Table IX

Difference (in Hz) between the levels of Fo within the first 10 cs of the vowel in words with and without stød (maximum difference). Lists 1-3 (N = number of pairs (averages)).
A: Disyllables with long vowel; B: Disyllables with short vowel;
C: __bibibi__-words; D: monosyllables.

	BF	1974	1977a	1977b	1979a	1979b	BM	BH	HU	JJ	JR	NR
A	N	4	4	4	4	4	4	4	4	4		4
V:'-V:		27.0	28.5	13.0	17.0	8.3	17.0	+	30.0	22.0		12.6
B	N	2	1	1	1	1	2	2	2	2		2
VC'-VC		19.5	31.0	13.0	11.0	7.0	13.5	+	20.0	15.0		4.5
C	N						3				5	
V:'-V:							21.3				22.0	
D	N	2	2	2	2	2	2	2	2	2		2
mon.		19.0	15.0	7.5	11.0	8.0	10.5	+	17.5	14.5		3.5

It is apparent from the tables that words with "stød in the consonant" have a higher Fo level in the vowel than their stødless counterparts, just as words with "stød in the vowel", thus again indicating that the stød is a syllabic phenomenon.

The difference is smaller in monosyllables than in disyllables, the main reason being that the monosyllables without stød have a relatively high Fo level approaching the words with stød. It is tempting to guess that this could be due to the fact that they are old accent 1 words. However, in two of the three pairs read by a larger number of speakers (viz. [ɗu / ɗu:'] and [tʰa/ tʰæ:'] there is also a difference in vowel duration, and the short vowel might favour a higher Fo. In comparable disyllables [kʰɛlɒ] has a slightly higher Fo in the vowel than [kʰɛ:lə] and [pʰibɒ] a clearly higher Fo than [pʰi:bɒ] for most speakers,

Table X

Difference (in Hz) between the levels of Fo within the first 10 cs of the vowel in words with and without stød (maximum difference). N = number of pairs (averages) (Lists 8, 9, 10, 11, 12). A: Disyllables with long vowel; B: Disyllables with short vowel; C: Monosyllables; D: Disyllables with long vowel in sentences.

	List 8				List 9					List 12
	FJ	HU	JR	NR	ND	PD	OB	PM	NR	BRP
A. dis. N	7	10	10	10	4	4	4	4	4	
V:’-V:	20.6	11.2	24.9	24.1	18.3	12.5	26.0	26.5	26.2	
B. dis. N	5	2	2	2						
VC’-VC	9.0	11.0	26.5	18.5						
C. N	5	3	3	3						
mon.	-2.8	7.3	13.0	13.0						
sent. N		3		3			3			3
V:’-V:		5.7		3.3			11.7			21.0

whereas there is no difference between [lɛsɒ] and [lɛ:sɒ]. The only monosyllabic pair without any difference in vowel duration is [vɛn / vɛn’]. [vɛn] is in between [vɛnɒ] and [vɛ:n’] in Fo level but clearly lower than [vɛn’] in most cases. Only one of the speakers (FJ), who read five pairs of monosyllables, has no difference between the words without and with stød in this case, on the average the words without stød are even higher. But in four of the five pairs the word without stød has a short vowel and the word with stød a long vowel (she has a slightly higher Fo in [k^{h}ɛlɒ] than in [k^{h}ɛ:lə] and has not read the other two disyllabic pairs with short and long vowel). Thus there is not much evidence to support the assumption of a higher accent 1. BF has much less difference between Fo in words with and without stød in recordings 1977b and 1979b than in the other recordings, the reason being that in these two recordings the test words were in final position after a word with emphasis. The difference, though smaller, is, however, retained even in this position.

In all, 171 out of 178 pairs (96%) show a positive difference. As for the significance of the differences it could not be calculated for lists 1 and 3 for the individual pairs, but it is evidently significant for all subjects, since it is positive in 74 out of 76 pairs. In the 1985-86 recordings significance could be calculated by comparing the overlappings. Disyllables in frames show a significant difference at the 1% or 0.1% level (generally 0.1%) in 42 out of 48 pairs of averages (1 at the 5% level, 5 not significant). In sentences 9 out of 12 pairs are significant at the 1% or 0.1% level, and 3 non-significant.

For monosyllables only 4 out of 14 pairs are significant at the 1% or 0.1% level, 2 at the 5% level, and 8 non-significant (of these 4 are due to subject FJ).

This difference is thus much more consistent than the corresponding difference in intensity, where the difference was positive in only 72% of the cases, and in the 32 pairs where significance could be calculated only one third showed significance.

b. Second part of the syllable In the second part of a long vowel (or in the sonorant consonant after a short vowel) (the second phase) most authors have found a tendency to decrease of Fo in words with stød, though neither Smith nor Riber Petersen found this decrease to be a consistent phenomenon.

In the present investigation such a decrease was found in approximately half of the examples (53.8%). As was the case with the presence of irregularity this analysis could not be based on average curves, since average curves based on cases of which some show irregularity and some not, are not very informative. It was therefore based on individual inspection of the 1700 words with stød mentioned in the section on irregularity. - It turns out that lack of decrease in Fo is not a well defined parameter since it may mean two quite different things: (1) the whole second half of the vowel may be characterized by irregular vibrations, so that a description of the direction of Fo does not make any sense. (2) The Fo curve may be smooth, showing an even or rising direction. (1) is by far the most common case. Very often the same speaker may show either irregular vibrations, falling Fo mixed with irregular vibrations, or simply a fall or a dip in Fo in examples of the same word in the same session, depending on how distinctly or forcefully he has pronounced the word at that moment. Irregularity is characteristic of a strong stød, Fo dip of a weak stød as pronounced by the same speaker. An example is given in Figure 9.

The second case, an even or rising Fo, is extremely rare for almost all subjects, with a few exceptions. In table XI the cases are divided into four types: A: only irregularity; B: a (larger or smaller) decrease in Fo mixed with irregularity; C: only decrease of Fo; D: neither-nor, i.e. even or rising Fo. The numbers are percentages (the sum of A+B+C+D is in some cases slightly above 100, because the decimals have been left out and the preceding integer raised if the decimal was above 0.5). - The actual number of cases on which the percentages are based are, on the average, 70, reaching from 21 to 143, for each column.

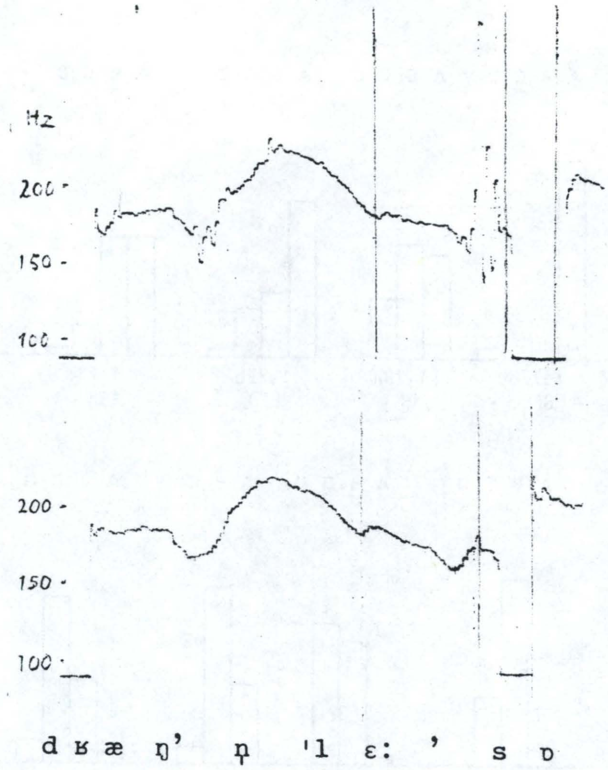


Figure 9

Two examples of Fo from the same reading by HU, one with irregularity, one with Fo drop; text: [dʁæŋ'n̩ lɛː'sɒ].

Table XI

Percentage of words with stød showing A: only irregularity in the second half of the syllable; B: irregularity and decrease of Fo; C: only decrease of Fo: D: neither-nor.

Lists 1-2 (1974-79)

	BF 74	77a	77b	79a	79b	BM1	BM2	BH	HU	JJ	JR	NR
A.	3	22	74	38	58	7	41	44	3	6	69	80
B.	50	51	15	42	24	37	31	44	43	46	17	10
C.	44	22	8	22	18	52	28	11	52	47	10	3
D.	2	5	4	1	3	4	0	3	2	1	3	7

	List 8 (1985)				List 9 (1986)					Lists 10,11,13 (1986)				
	FJ	HU	JR	NR	ND	NR	OB	PD	PM	HU	NR	OB	BRP	av.
A.	6	29	49	7	66	92	15	79	73	4	10	8	76	38.4
B.	69	65	14	34	32	8	32	21	23	30	71	0	0	32.4
C.	25	6	19	48	0	0	54	0	4	61	19	31	0	23.4
D.	0	1	18	11	2	0	0	0	0	8	0	62	23	6.4

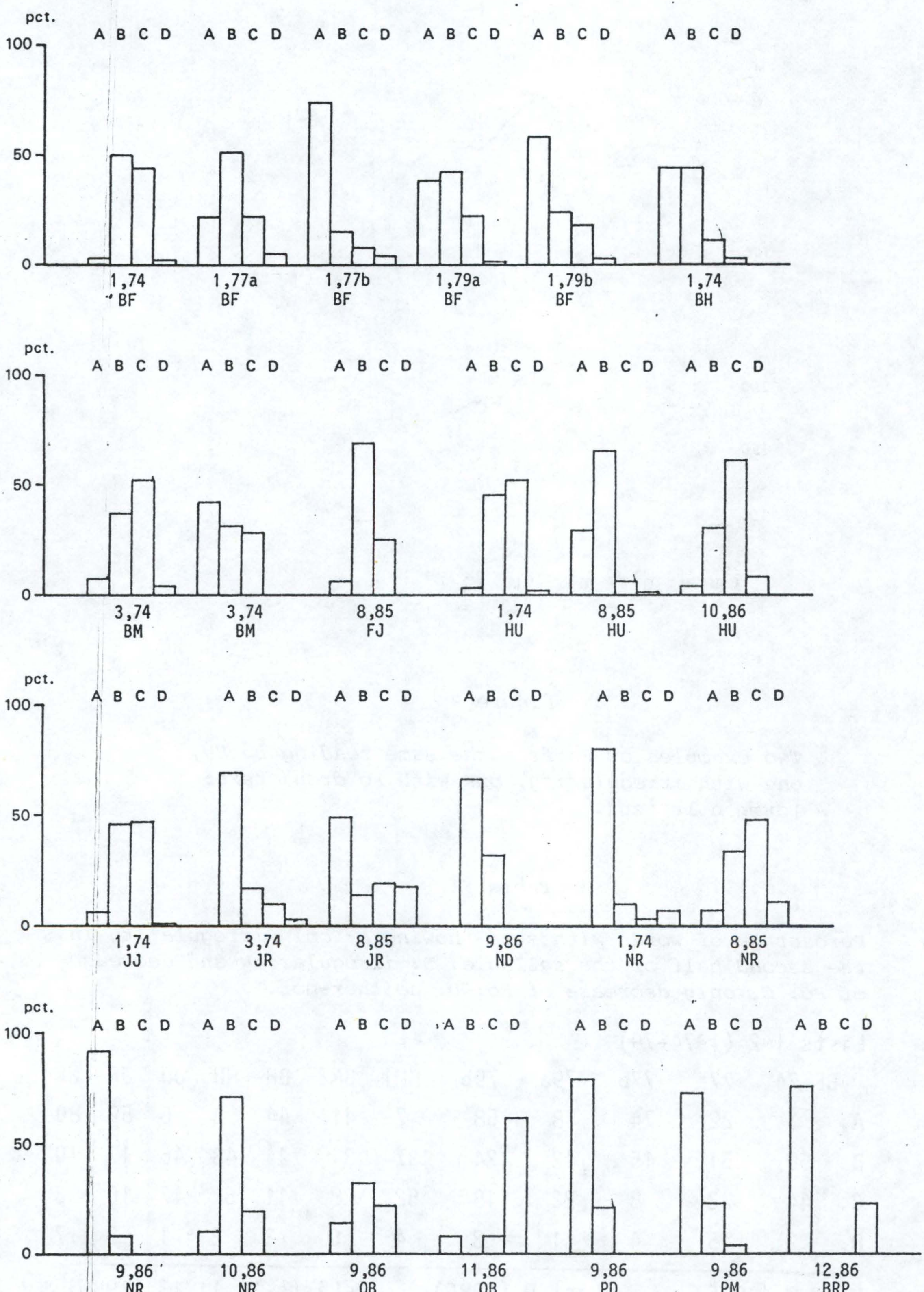


Figure 10

Relative number of examples of words with stød having A: only irregularity, B: irregularity and Fo fall, C: only Fo fall, D: neither-nor, for individual speakers and lists. The numbers below the columns indicate list and year.

The same facts are represented graphically in figure 10. Here different sessions with the same subject are grouped together to demonstrate the large intra-individual variation more clearly. BF has less Fo-decrease and more irregularity in 77b and 79b than in the other recordings because in these two cases the test word was placed at the end of a frame after a word with emphasis, i.e. on a low Fo-level. BM has more irregularity and less fall in list 2, where all words contained the vowel [iː'],than in list 1. - NR has less irregularity and more cases with Fo-drop in lists 8 and 10 than in list 1. In list 10 the words are placed in real sentences. In list 8 the test word is one of three stressed syllables, whereas in list 1 it is the only stressed word. HU also has less cases with irregularity and more Fo-drop in the sentence list No. 10, but in contradistinction to NR she has more irregularity in list 8 than in list 1, which is surprising.

The distance from the start of the vowel to the Fo-fall is rather variable and sometimes somewhat dubious. HU has, for instance, generally a slow fall from the very start as in vowels without stød, but the later point of abrupt fall is generally clear. FJ has a strong fall from the start after voiceless consonants, which may continue almost directly into the fall for the stød. But in most cases it is possible to see where the fall for the stød starts. In table XII the approximate averages for the different speakers are given, based on lists without too much irregularity.

Table XII

Average distance (in cs) from start of the vowel to start of Fo drop.

BF	BH	BM	FJ	HU	JJ	JR	OB	NR
9.2	10.0	10.8	7.5	10.3	10.5	11.0	9.5	7.7

Sometimes there is a small rise again at the end of the long vowel (generally accompanied by a small rise in intensity). - This happens particularly often in the monosyllable [d̥uː'] where the vowel with stød is final, and in [lɛː'sɒ] (see Fig. 9, HU [lɛː'sɒ]). In other words, this occurs only occasionally, and never in [pʰiː'bɒ], probably because the vowel in this word is rather short. In the monosyllable [vɛn'] with stød in the final [n] there is generally great irregularity, but the vibrations may reappear after a while. In the word [huː'ən] (often pronounced [huː'un]) there is generally a clear drop followed by a rise, but as no delimitation is possible, this rise may belong to the second syllable.

In words with long vowel and stød plus [l] the drop in Fo (or irregularity) very often continues into the [l] (see, e.g., Fig. 7 above, p.101), whereas in words without stød it is the final rise of the vowel which continues into the [l]. The Fo contour of the sonorant is thus very different in the two cases, see e.g. Fig. 7 above and Fig. 11 (NR). Here most of the drop or irregularity is in fact in the [l]. It may even happen that it does not start until the [l] (see Fig. 15 below (JR)). On the other hand, the Fo contour of [kʰɛ:'lɒ] and [kʰɛl'ɒ] may be almost exactly alike (see, e.g., the average curves of BM 1974 in Appendix IV, p. 235).

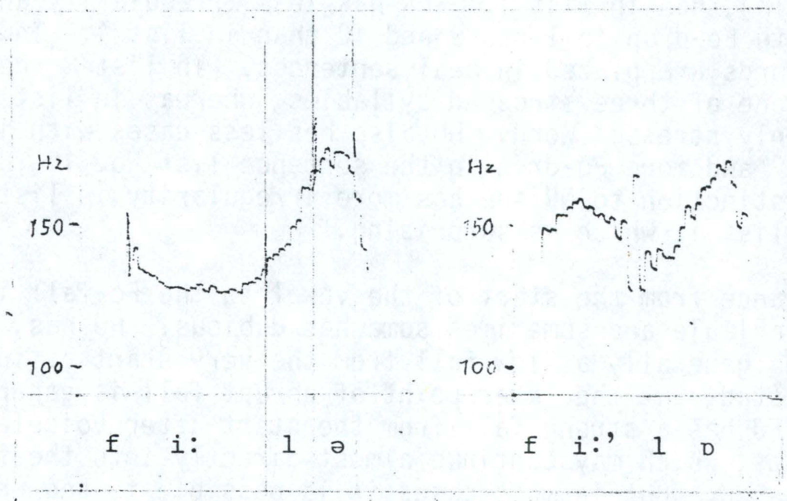


Figure 11

NR. Fo of [fi:lə] *and* [fi:'lɒ] *showing the different contour of both* [i:] *and* [l].

Words with stød which have neither Fo drop nor irregularity are rare. It appears from table XI that for most of the speakers (viz. BF, BM, BH, HU, JJ, FJ, ND, PD, PM) this happens in only 0-5% of the cases, which corresponds to 0-4 individual words, 23 examples in all, of which 13 concern the word [pʰi:'bɒ], probably because the vowel may be so short that there is no time for Fo drop or irregularity to develop (the four examples from BM have, for instance, a duration of around 10 cs).

But for four speakers: BRP, JR, NR and OB there are more examples. For BRP it is very clear. He never has any Fo drop, but rising pitch throughout the vowel with stød. (This was also the case in Riber Petersen's recording of this subject.) JR (list 8, 1985) has 18% (or 21 examples) without either Fo drop or irregularity (see, e.g., Fig. 12 [lɛ:'sɒ]. The [s] is partly voiced. The delimitation is quite clear in the oscillogram, which is left out here). Moreover, the irregularity is rather weak, and in many of the examples with "only irregularity" it is possible to state that there is no Fo drop, and in four examples of [hu:'ən] listed as fall it may be a fall in the second syllable. The irregularity in this word is on the top of a rising-falling curve, quite different from the falling-rising curve of the other speakers (see Fig. 13 and the aver-

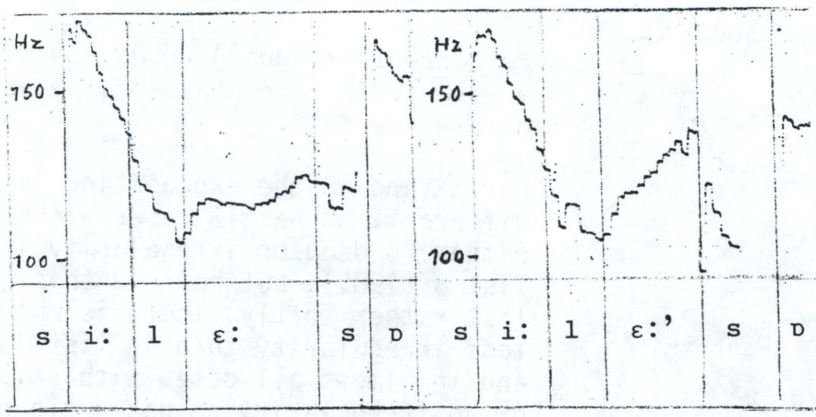


Figure 12

JR. Fo of [lɛ:sɒ] *and* [lɛ:'sɒ] *showing rising Fo of the word with stød.*

age curves, Appendix IV). However, in other cases he has a fall, particularly in the words [du:', bu:'sɒ, gæ:'bəð, tʰæ:'bəð] and in half of the examples of [lɛ:'sɒ], thus finally and before a voiceless consonant, and there is often a rise before the fall, starting when the intensity goes down, e.g. in [du:'] (see Fig. 14). Before [l] and [n] there are only a few cases with fall, but in [fi:'lɒ, kʰɛ:'lɒ, be:'nəð] (but not in [sæ:'lən]) there may be a fall in the following sonorant consonant in contradistinction to the corresponding words without stød, which have a rise in the consonant (see Fig. 15). Thus, this speaker does not have a consistent pattern.

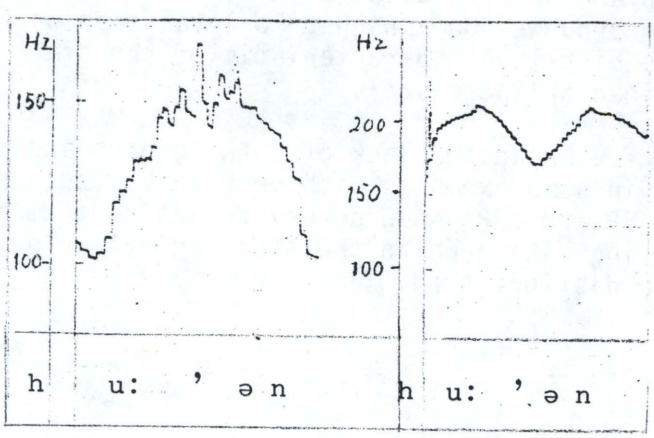


Figure 13

Fo contour of [hu:'ən] *by JR and by FJ (the latter contour is the typical one).*

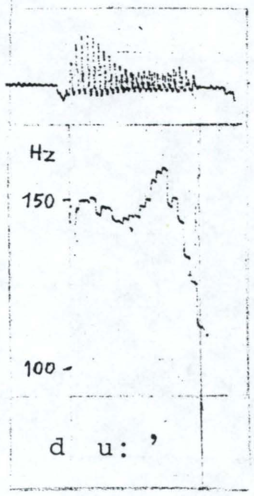


Figure 14

Fo contour of [du:’] *by JR, showing a rise during the phase of the stød before the fall.*

For NR and OB the explanation is different. NR has 13 cases without either Fo drop or irregularity in list 8 (1985), but he read this list rather softly. There is much less irregularity than in list 1, and in almost all cases with small or no irregularity he has a clear drop in Fo. The cases without this drop are simply pronounced with a very weak stød, which also appears from the intensity and airflow curves.

The same is the case for OB. He has, on the whole, a relatively weak stød, but in list 9, which was read distinctly, there is always a clear rising-falling Fo in words with stød, whereas in list 11 (the sentences), which was read quickly and somewhat slovenly, there are relatively many cases with neither fall nor irregularity (list 11 was a short list, so that 62% corresponds to 16 examples out of 26). In 8 examples of [mæ:’lɒ] there is a drop in the following [l]; and 3 examples of [pʰi:’bɒ] without Fo drop or irregularity are pronounced on a considerably higher Fo level than [pʰi:bɒ]. But 5 examples of [mu:’sən] look very much like [mu:sən]. There is no clear difference in the Fo contour of the stressed syllable, but the unstressed syllable is somewhat lower than in [mu:sən], and the decrease in the intensity contour starts earlier. For the other three subjects (BPR, JR and NR) all cases with neither Fo drop nor irregularity are pronounced on a higher Fo level than words without stød (i.e. the high level characteristic of the start of the vowel is retained or increased).

Thus, whereas for NR and OB lack of both Fo drop and irregularity is only found in some examples with very weak stød, the other two speakers, JR and BRP, show a real deviation from the general pattern by having rising Fo in the stressed syllable in many cases of quite distinct stød.

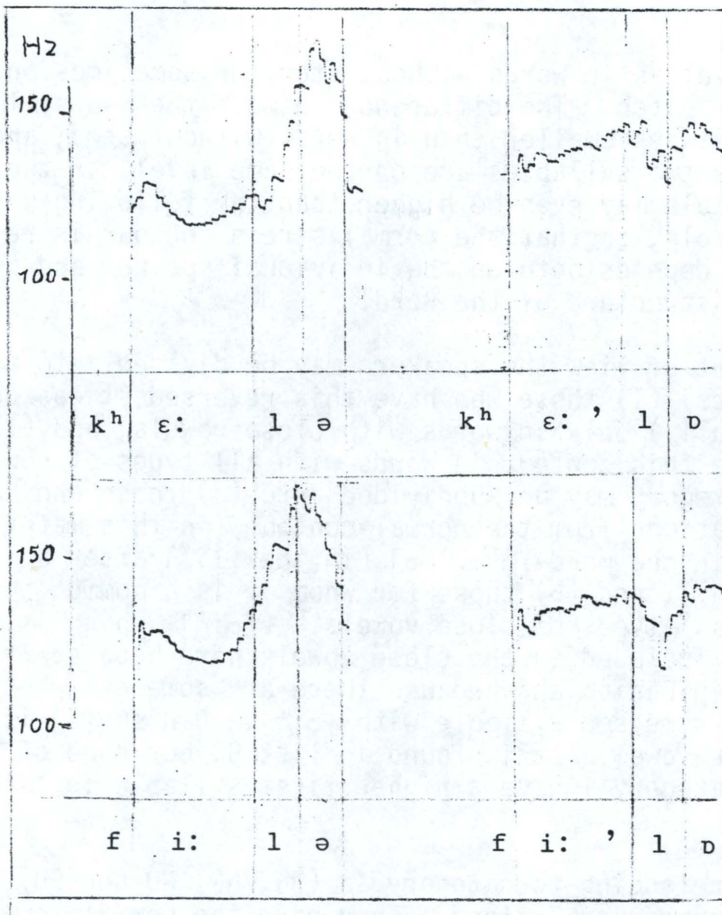


Figure 15

Fo contour of JR [kʰɛ:lə, kʰɛ:'lɒ] and [fi:lə, fi:'lɒ], showing a rise in the vowel and a fall in the consonant in words with stød.

c. The word contour (= stress contour) In words without stød all subjects have the contour described in a number of papers by Nina Thorsen (e.g. 1978 and 1983) as the typical Copenhagen stress contour (this contour is generally taken over by people who have moved to Copenhagen from other parts of the country): i.e. a low stressed syllable, from which the pitch glides or jumps up to the first posttonic syllable with following unstressed syllables pronounced on a gradually falling pitch. The stressed syllable often has a falling-rising pitch contour, particularly if it has a low vowel (typical examples can be seen in the average curves of NR, Appendix IV).

In words with stød the first part of the stressed vowel is higher than in words without stød (see above, p. 106), whereas the following unstressed syllable is generally said on the same pitch level as in words without stød, or sometimes on a slightly lower pitch. The difference between the two syllables is therefore always smaller than in words without stød, and in some cases the two syllables are on the same level, or the stressed syllable may even be higher than the following unstressed syllable, so that the normal stress contour is reversed. This depends both on the individual speaker and on the segmental structure of the word.

From this point of view the speakers may be divided into two main categories: (I) those who have this reversed stress contour (practically) only in words with close vowels, and (II) those who have this contour in words with all types of vowels. The former category may be subdivided into (a) those who have very few deviations from the normal contour (in this material particularly in the word [pʰi:'bɒ] (in the [i:'] after an aspirated [pʰ])), and (b) those for whom it is a common phenomenon with all types of close vowels. ([o:'], which is found in list 9, is included in the close vowels here because it is rather close in Danish and because there are some examples with a higher stressed syllable with [o:']. Danish [e] is also a rather close vowel. It is found in list 8, but none of the speakers of category I have a higher first syllable in this case.)

The speakers belonging to category Ia (HU, NR, ND and PD) are all from Copenhagen or Zealand. They have the normal low-high contour in 82% of the words with close vowel and in all words with more open vowels. The speakers belonging to category Ib (BH, BM, FJ) are dialectally a more heterogeneous group: BH is from Copenhagen, BM lived in Jutland until he was seven and from then on in Copenhagen, and FJ is from Funen and speaks a standard language which in various respects is rather conservative; she has, however, adopted the Copenhagen pitch contour. For these three subjects only 27% of the words with close vowels have the normal low-high contour, and in a few exceptional cases also words with [ɛ:'] or [ɛl'] have an even or falling contour (one example for FJ, two for BH and BM), but in an extra reading of list 9, pronounced with particular force in order to see what happens to the airflow, FJ has four more examples with open vowels.

Category II comprises JR, who is from Funen but speaks a rather conservative Standard Danish, and PM, OB and BF, who all have a perceptible Jutlandish rhythm. However, they all have high unstressed syllables after stressed syllables without stød. But in words with stød JR has this type in only 51% of the cases, PM in 41%, OB in 24%, and BF in only 18%. They have a clearly high-low pattern in 32, 44, 61 and 74 percent of the cases, respectively. In Appendix IV, Table I and II the number of cases is indicated for different speakers and words. (The analysis is based on individual tokens, not on averages). The average curves in Appendix IV also show the differences between speakers. Fig. 16 shows two sentences read by OB. In A there

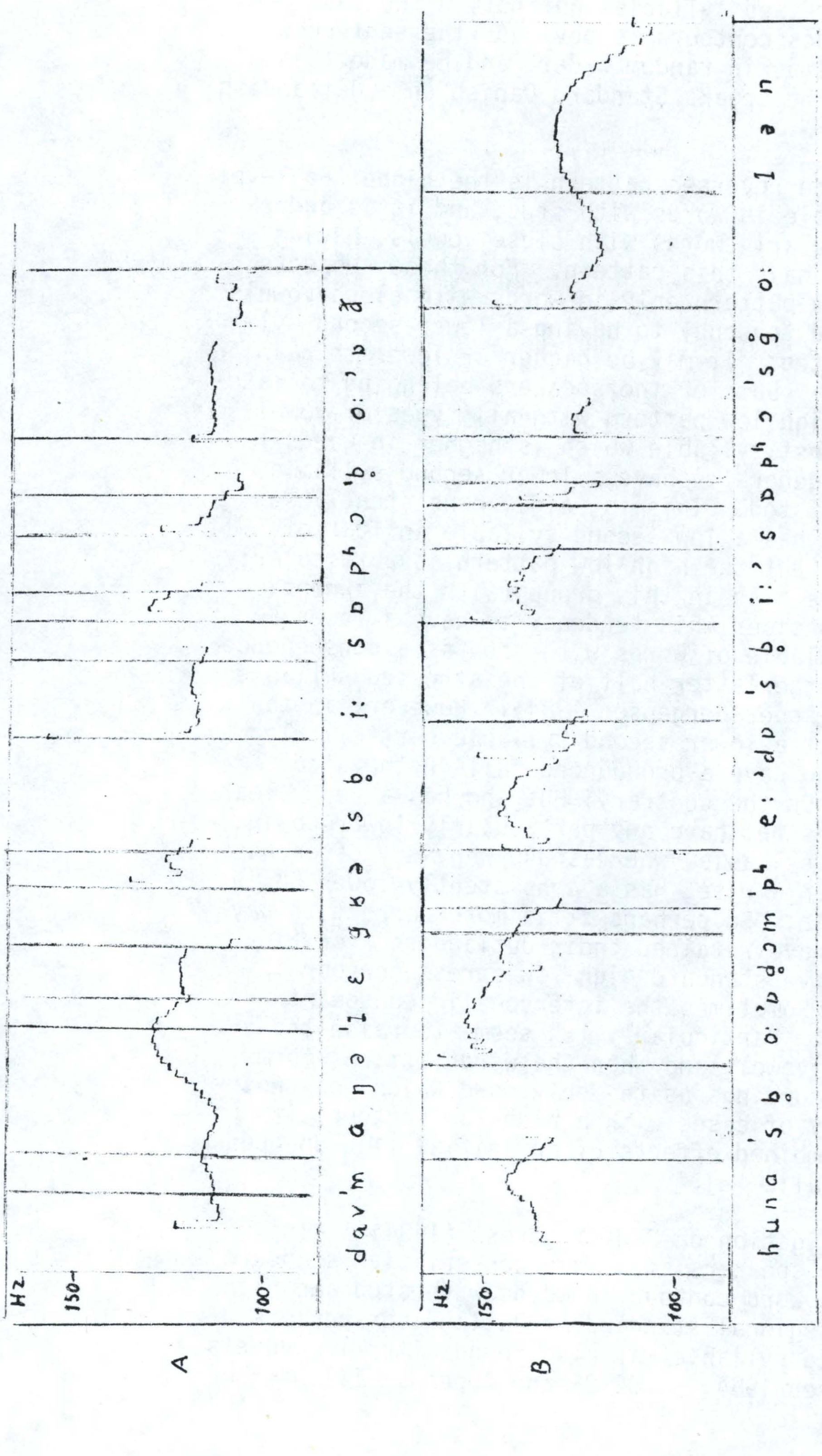


Figure 16

Two sentences read by OB, showing different contours for words with and without stød.
A: the first three stressed words (without stød) showing a low-high contour.
B: the first three stressed words (with stød) showing a high-low contour.

is only stød in the last stressed syllable, in B there is stød in the first three stressed syllables but not in the last one. The difference in stress contours is obvious (the sentences were repeated eight times in random order, and he made this difference each time; he speaks Standard Danish on a Jutlandish background).

The main reason for the reversed pattern is the higher Fo level of the stressed syllable in words with stød, and it is understandable that particularly words with close vowels, having an intrinsic high Fo, have this pattern. For those subjects who have this high-low pattern only in words with close vowels there is no pronounced tendency to having a lower second syllable in words with stød. It may be higher or lower than in words without stød. - But for the speakers belonging to category II, having the high-low pattern with all types of vowels, it is not only the first syllable which is higher in words with stød, they also generally have a lower second syllable than in words without stød. This is, e.g., consistently so for JR and OB, and BF has a low second syllable in four of his five recordings. But the high-low pattern is particularly clear for close vowels also in this group (with the exception of JR). One might consider this tendency to have a lower Fo in the unstressed syllable of words with stød as a consequence of the falling Fo in the latter half of the stressed syllable (as I have done in Fischer-Jørgensen 1984). However, in that case one should expect a lower second syllable particularly for those speakers who have a pronounced fall in the stød. And this is not so. On the contrary: HU, who has a very clear fall in the stød, does not have any particularly lower Fo in following unstressed syllable, whereas JR, who very often has no fall and even often a rise, has a consistently lower Fo in the following syllable. So perhaps it is more correct to say that these speakers have retained their Jutlandish - or (in JR's case) conservative standard high-low stress contour in words with stød. - Sometimes the intervocalic consonant seems to play a role. Particularly [s] seems to raise the following unstressed vowel, and when the word [lɛ:'sɒ] forms exception in BF's recordings as the only word which does not have a large majority of cases with a high-low contour, it may be due to the combined effects of an initial [l], an open vowel, and a postvocalic [s].

In my earlier investigation on Danish stress (1984) I also found a tendency for speakers of a more conservative standard to have the high-low word contour in words with stød and high vowels; and in the regional standard of Jutlandish speakers this lower unstressed syllable was also found after low vowels (cf. Fischer-Jørgensen 1984, p. 84-86 and Appendix III of the 1984-paper, 3, 6, 7).

Corresponding differences are found in unstressed words after monosyllabic words with and without stød (e.g. after [du] and [du:'], see Fig. 16a). It is thus a question of stress contours, not specifically word contours.

In list 1 (1974-79), where the test word was the only stressed word, it may be influenced by sentence intonation, e.g. the use of non-final intonation might favour a rise in the second unstressed syllable of the test word. HU has generally used this intonation, but she has just the same rise in the unstressed syllable of words with stød in other recordings without non-final sentence intonation. In BF's 1974-recording there is, however, an influence from sentence intonation, then he shifts to non-final intonation with retained high pitch at the end. This has influenced the words with stød and open vowel, so that they get more rising contours in the last four recordings. Four of the five cases of [vɛ:'nɒn], four of the eight cases of [lɛ:'sɒ], and four of the six cases of [kʰɛ:'lɒ] with high unstressed syllable are found in the last four readings. But the final intonation of the preceding readings have not changed the normal rising contour of words with stød, except for two cases of [hu:ən] with level contour.

In the Haskins recording 1972 the test word was in final position, the frame being [di sæ: ...]. Here Fj has non-final intonation, but nevertheless [hu:'ən], [pʰi:'bɒ] and [kʰɛl'ɒ] have a lower second syllable or (in some cases) equal height, whereas [lɛ:'sɒ] and [kʰɛ:'lɒ] have a higher second syllable. Of the two other speakers PMi, who is from Copenhagen, has a pronounced non-final intonation with a strong rise in the last syllable of all words, whereas TB, who is from southern Jutland but speaks Standard Danish, has a small fall at the end of the sentence and makes a clear distinction between words with and without stød, the final syllable being on a higher level in words without stød but in almost all cases lower in words with stød, irrespective of vowel height.

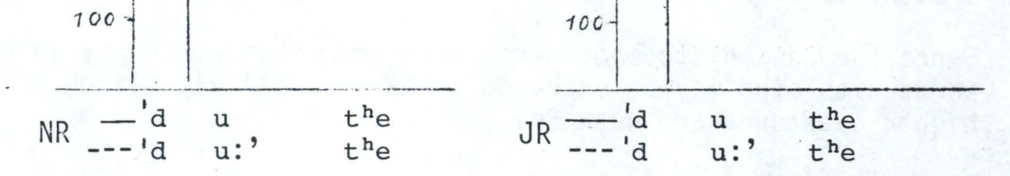


Figure 16a

Fo curves of the words [du] *and* [du:'] *followed by* [tʰe] *in the sentence* [ja ka'gɔd si: '[du (du:')] tʰe 'pʰalə], *read by NR and JR.*

5. SPECTROGRAPHIC ANALYSIS

The spectrographic analysis is rather restricted. It comprises 56 word pairs in all (only words from the same reading were compared). For 12 pairs only wide band spectrograms were produced (BRP 1, HU 3, JJ 2, ND 2, NR 2, PD 1, PM 1). For the other 44 pairs both wide band spectrograms (300 Hz), narrow band spectrograms (45 Hz) and power spectra (45 Hz) were produced. The sections (power spectra) were placed in the first and the last third of the vowel, generally 3-5 cs from the boundary, and in the case of the second measuring point as close as possible to the dip in fundamental frequency and intensity in vowels with stød. 25 of the word pairs contained the open vowels [æ: / æ:'] and [ɛ: / ɛ:']. They were read by BF (4), BM (2), BH (2), BRP (6), FJ (6), JR (2) and OB (3). The other 19 pairs contained the close vowels [i:] and [i:']. They were read by BF (3), BH (1), BM (4), JR (8), FJ (1) and OB (2).

In the first place the spectrographic analysis demonstrates the same characteristic features of vowels with stød as those described in the preceding chapters, i.e. shorter duration, decrease in intensity and fundamental frequency and in many cases irregular vibrations, features which (except for duration) could be measured more precisely by means of other types of display. Fig. 17 shows wide band spectrograms of the pair [mæ:lɒ / mæ:'lɒ] read by three different speakers with decreasing distinctness of the stød.

The power display may, however, also show measurable differences in relative intensity of different parts of the spectrum. Such differences have been mentioned as characteristic of particular phonation types, and might therefore be relevant for the stød. Greater energy in the upper part of the spectrum is mentioned by Laver (1980, p. 149) as characteristic of tense voice, and relatively strong higher overtones and weak Fo are mentioned as characteristic of tense voice by Sundberg and Gauffin (1978) and of creaky voice by Löfqvist et al. (1983). Ladefoged (who has recorded some words in the language !Xoõ, spoken by Bushmen in Southern Africa) and Kirk et al. 1984 (who have recorded a number of words from the Jalapa de Diaz dialect of Mazatec) have found that the best measure is the difference between the amplitude of Fo and F1, Fo being relatively weaker than F1 in creaky voice, relatively stronger in breathy voice and in between in modal voice.

Since the Danish stød has often been described as creaky voice, words with stød may be expected to have relatively strong higher overtones and weak Fo.

Lauritsen (1968) published 33 wide band spectrograms of Danish words with and without stød read by one informant. In a few cases vowels with stød show higher intensity, particularly in F4 and F5. Riber Petersen (1973) published only one pair of spectrograms, but she recorded quite a number, which I have had occasion to see. There were 16 comparable pairs, of which 6 showed somewhat more intensity in higher formants at the start of the vowel in words with stød.

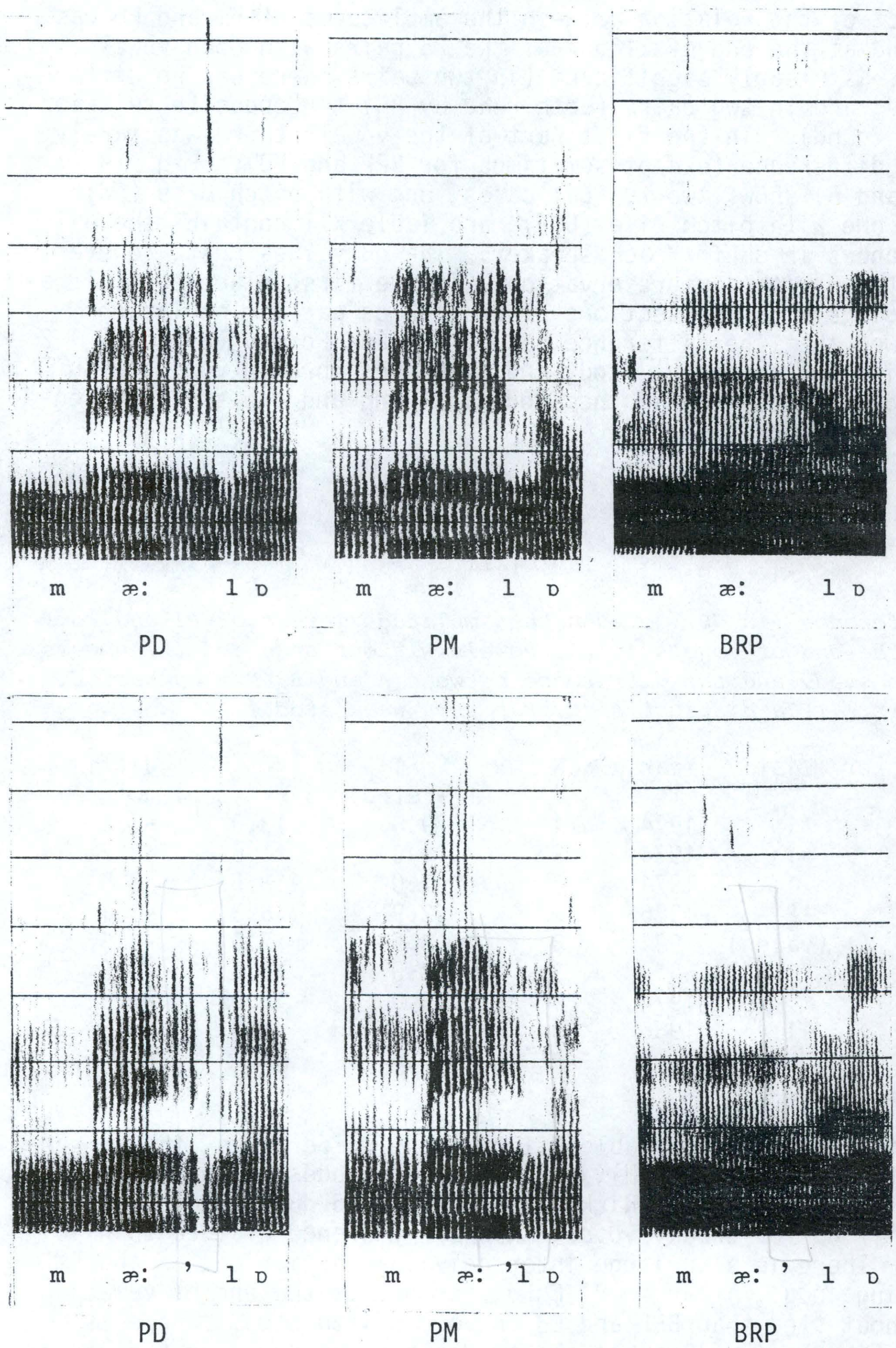


Figure 17

Spectrograms of [mæ:lɒ] and [mæ:'lɒ] with strong, weaker and very weak stød.

In the present corpus higher intensity in F4 and F5 was visible for some speakers (BF, BH, HU, JJ and JR) but rarely found for other speakers (BM, BRP, FJ, ND, NR, OB).

A clear difference between words with and without stød in respect of the relation between the amplitudes of F1 and Fo was found at the end of 21 out of the 25 pairs with open vowels. This is clearly significant (in two pairs there was no difference, and in two pairs (both read by BH) the opposite relation was found). In the first part of the vowels there was rarely any difference (except sometimes for BRP and FJ). Fig. 18 (A and B) shows two typical cases, one with pitch drop (FJ) and one with pitch rise (BRP), and Table XII contains the differences in dB for each speaker. The dB values must, however, be taken with some reservation. In the first place control recordings with the sections placed 1-2 cs earlier or later showed that the difference between F1 and Fo may vary some 1-2 dB in vowels without stød, and sometimes more in vowels with stød, particularly if the stød is strong and the spectrum consequently irregular.

Table XII

Difference (in dB) between the amplitude levels of F1 and Fo at the end of vowels in (A) vowels without stød and (B) vowels with stød, and the difference between A and B; N = number of pairs. (FJa distinct stød, FJb very weak stød.)

Speaker	List	Year	N	F1 - Fo A (- stød)	F1 - Fo B (+ stød)	diff.
BF	1	1974	4	9.8	13.0	-3.2
BH	1	1974	2	15.3	11.6	+3.7
BM	1	1974	2	7.0	13.5	-6.5
BRP	12	1986	6	2.9	6.3	-3.4
FJa	(valen)	1981	3	8.5	17.0	-8.5
FJb		"	3	8.0	10.2	-2.2
JR	1	1974	2	9.0	13.0	-4.0
OB	11	1986	3	2.2	6.0	-3.8

It is apparent from Table XII that the differences, though consistent (except for BH), are relatively modest compared to the differences found by Kirk et al., viz. 6.6 dB for modal voice and 17 dB for creaky voice, thus a difference of more than 10 dB. There is also large interindividual variation, BF and BM having, e.g., a larger F1-Fo difference at the end of vowels without stød than BRP and OB in vowels with stød. There is also overlapping between the two categories for each individual speaker, in spite of the small number of pairs. Only BM (with two pairs) does not show any overlapping. FJ shows a clear difference according to the distinctness of the stød, very weak stød showing a smaller F1-Fo difference than distinct stød.

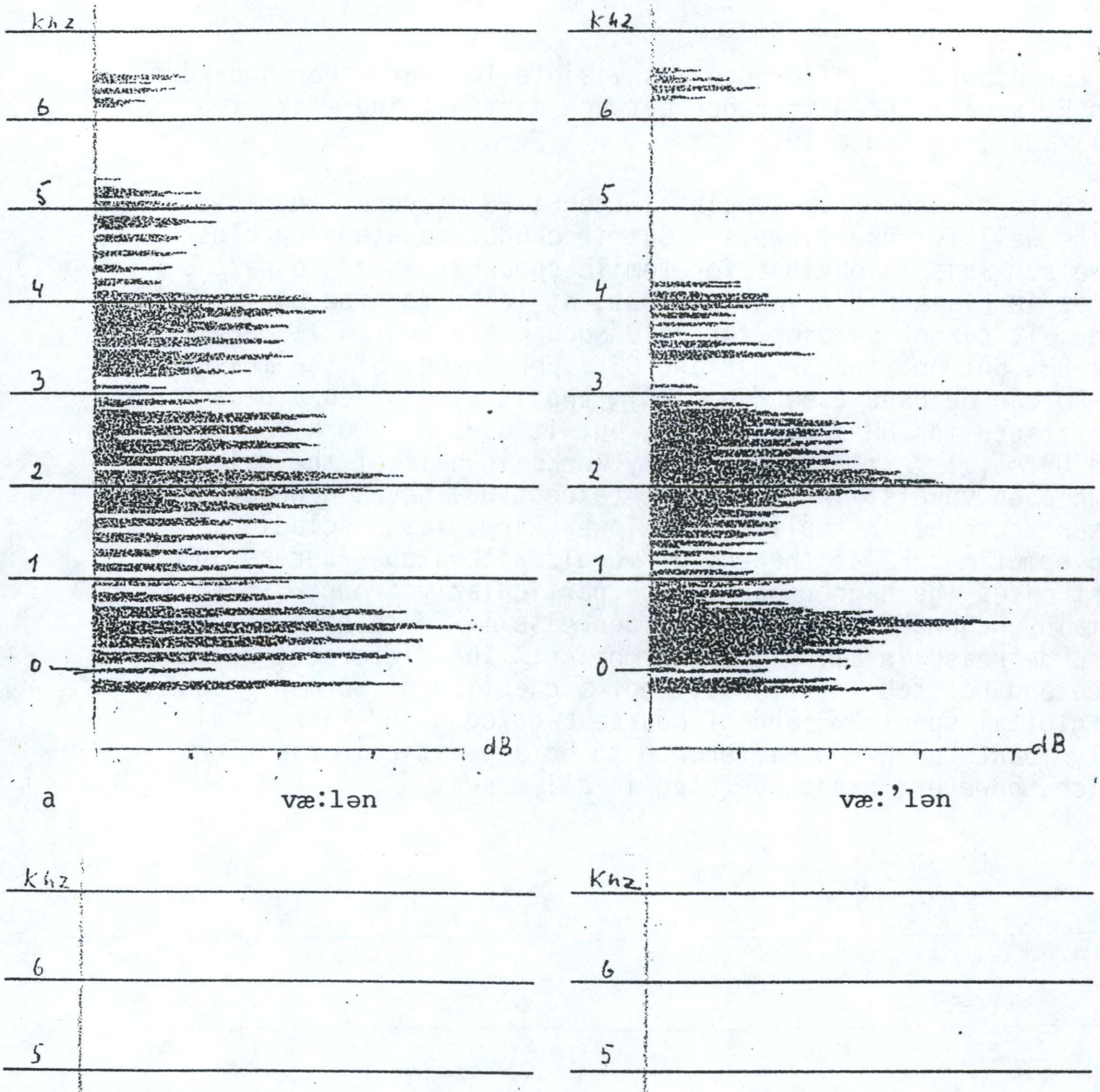
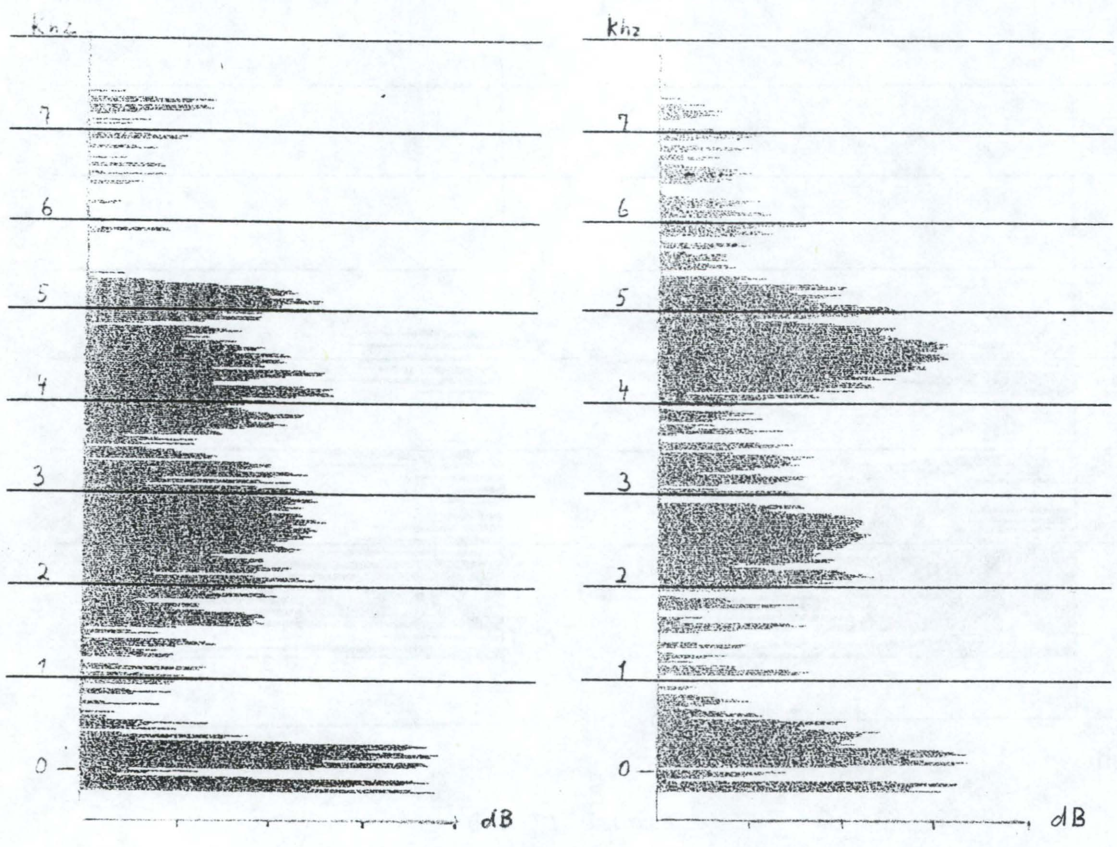


Figure 18 a-b

Power spectra (45 Hz) taken at the end of the vowels. ⊢——⊣ *10 dB.*
(a) [væ:lən] *and* [væ:'lən] *(speaker FJ, distinct stød)*
(b) [må:lɒ] *and* [må:'lɒ] *(speaker BRP, normal stød).*

No corresponding difference was visible for the other speakers (in FJ's case the difference between distinct and weak stød was made intentionally).

In spite of these overlappings, the F1-Fo measure functions quite well for open vowels. But it cannot be used for close vowels. This is obvious for female speakers, whose Fo participates in F1 in close vowels. But, at least for the Danish stød, it cannot be used for male speakers either. It works for BM, but not for BF, JR and OB. For JR and BM the measure F2-Fo can be used (see Fig. 18C), and it also gives a clear difference for BH's [ɛ: / ɛ:'], but it does not work for BF's and OB's [i: / i:'], and it only works in half of the pairs with open vowels. All speakers (except OB) have, however, a clear decrease in amplitude in lower harmonics, including F1 and sometimes F2 at the end of vowels with stød, whereas in most cases the higher harmonics (particularly around 3-5 KHz) remain unchanged. OB has more decrease in Fo than in F1 but also decrease in all higher harmonics. The difference between stød and no stød is obviously not a question of formants but of glottal spectrum, and of course Ladefoged and Kirk et al. only meant the F1-Fo difference to be a practical criterion, which, however, cannot be used in all cases.



bi:lə bi:'lən

Figure 18 c
Power spectra (45 Hz) of [bi:lə] *and* [bi:'lən] *taken at the end of the vowels (speaker JR).* ⊢—⊣ *10 dB.*

6. INVERSE FILTERING

An inverse filtering analysis of a number of words with and without stød was undertaken by Inger Karlsson, Stockholm (see above, p. 90). By inverse filtering the formants are removed (as far as possible), so that the curve should show the waveform at the glottis. The integral of the filtered oscillogram is supposed to reflect the airflow at the glottis (for the technique and its use, see, e.g., Fant (1983) and Javkin et al. (1983).

In 1985 FJ read six examples of the words [væ:lən] and [væ:'lən] half of them with distinct stød, the other half with very weak stød. Three words from this list were selected for inverse filtering; one example of [væ:lən] and two of [væ:'lən], one with distinct stød and one with very weak stød (see Fig. 19a-c). Moreover, some words were selected from a reading of list 12 (sentences) by BRP, viz. [væ:lən / væ:'lən, mæ:lɒ / mæ:'lɒ, må:lɒ / må:'lɒ] and [lɛ:sɒ / lɛ:'sɒ], all from his fourth reading. As mentioned above p. 79, BRP, who was one of Pia Riber Petersen's subjects, had rising Fo, no irregularity and sometimes no decrease in intensity in stød words in the recording she undertook in 1973, but nevertheless he had a clearly perceptible stød. It would therefore be interesting to see whether a difference between vowels with this type of stød and vowels without stød would appear from inverse filtering. Unfortunately BRP spoke much more distinctly in the Stockholm recording (1986, list 12). In the four pairs which were filtered first he had both intensity decrease and irregularity, although the irregularity was very weak in [må:'lɒ]. Therefore some further words with stød were filtered. The word [må:'lɒ] from his first reading was the one that came closest to the pronunciation used in his 1973-recording. It has no irregularity and only a small decrease of intensity at the end of the vowel. Fig. 20a-c shows this word compared to [må:lɒ] and to [må:'lɒ] from the fourth reading with a somewhat stronger stød. The pairs [væ:lən / væ:'lən], [mæ:lɒ / mæ:'lɒ] and [lɛ:sɒ / lɛ:'sɒ] from the fourth reading are presented in Appendix V.

For reasons of space Figs. 19 and 20 are arranged differently which may be confusing; but in all cases the numbers 1, 2 and 3 are used to indicate (1) words without stød, (2) words with normal stød, and (3) words with weak stød, and the letters A, B and C indicate (A) normal oscillogram, (B) inverse filtered oscillogram, and (C) integral of the inverse filtering. The sampling frequency was 16 KHz for FJ and 10 KHz for BRP.

In all words with distinct stød both spectrograms and normal oscillograms as well as inverse filtered curves show the expected decrease of intensity in the stød phase and sometimes irregular vibrations, as well as a shorter duration of vowels with stød, and - for FJ - decrease of Fo. - But the filtered curves show further differences. The most conspicuous feature of the oscillogram with inverse filtering is the decrease in amplitude of the negative spikes in the latter half of the vowel with stød. This is seen clearly in all examples, although

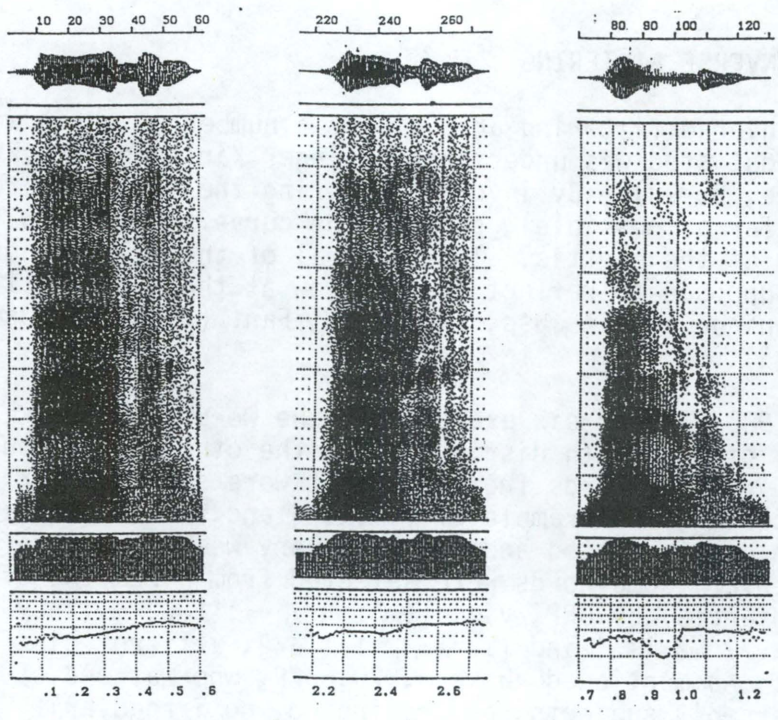


Figure 19 a

Spectrograms of 1 [væ:lən], *2* [væ:'lən] *with distinct stød and 3*[væ:'lən] *with weak stød, read by FJ. From above: oscillogram, spectrogram, intensity, Fo.*

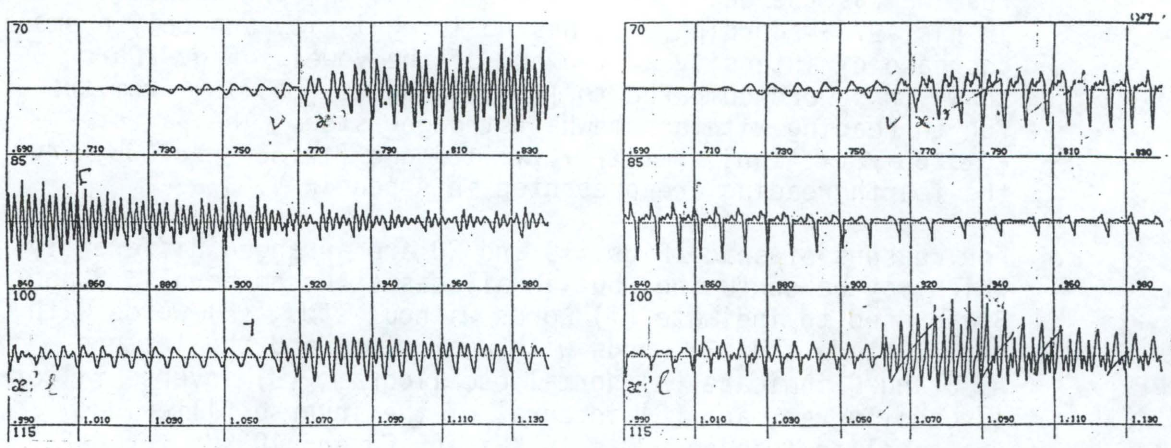
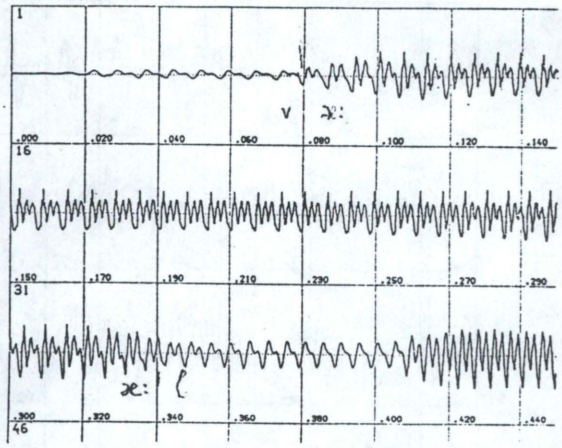
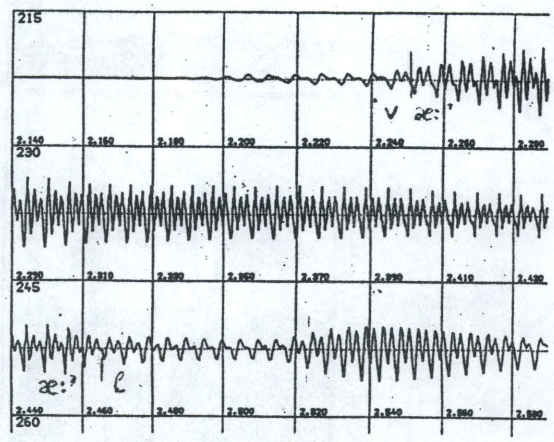


Figure 19 b

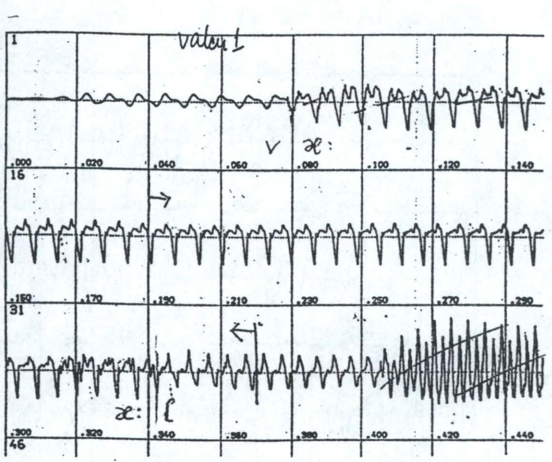
2A: Normal oscillogram, 2B: inverse filtering of 2 [væ:'lən] *with distinct stød, read by FJ.*



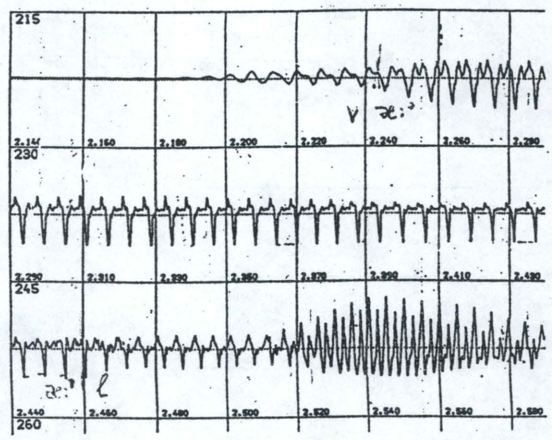
1A væ:lən



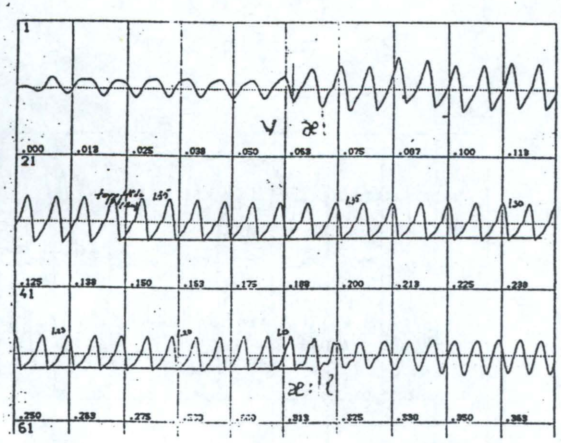
3A væ:'lən



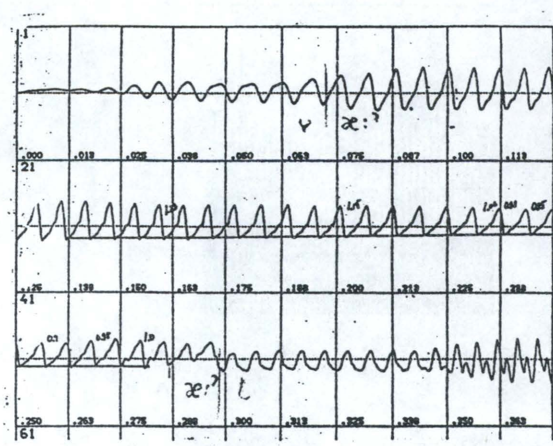
1B væ:lən



3B væ:'lən



1C væ:lən



3C væ:'lən

Figure 19 c

A: Normal oscillogram, B: inverse filtering, C: integral of inverse filtering of 1 [væ:lən] *and 3* [væ:'lən] *with weak stød, read by FJ.*

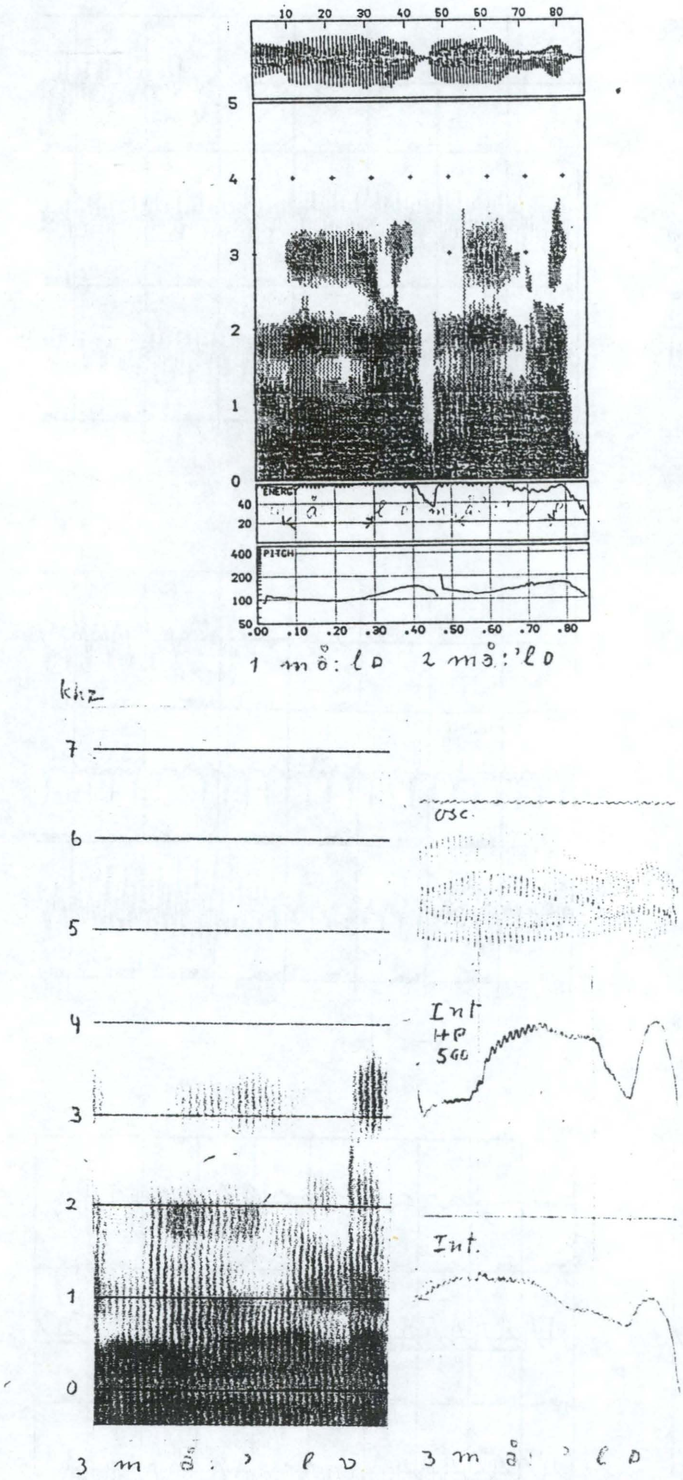


Figure 20 a

Spectrograms of 1 [må:lɒ], *2* [må:'lɒ] *with normal stød, and 3* [må:'lɒ] *with weak stød, and mingogram of* [må:'lɒ]*3, read by BRP.*

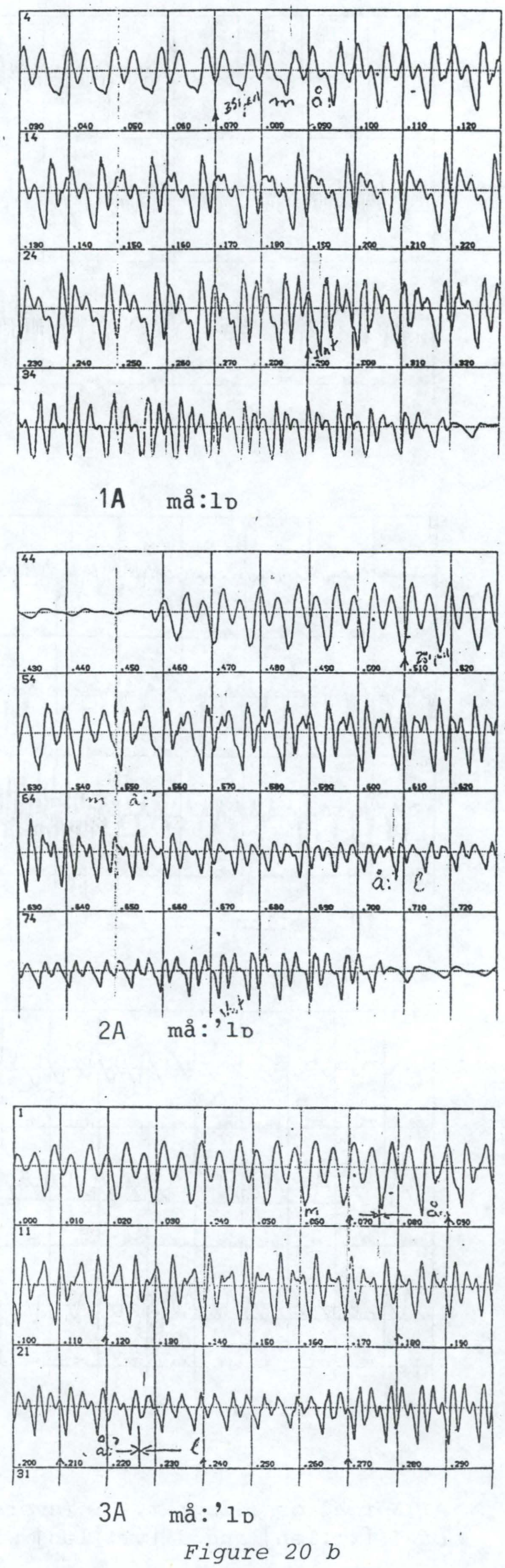


Figure 20 b

Normal oscillogram of 1A [må:lɒ], *2A* [må:'lɒ] *and 3A* [må:'lɒ].

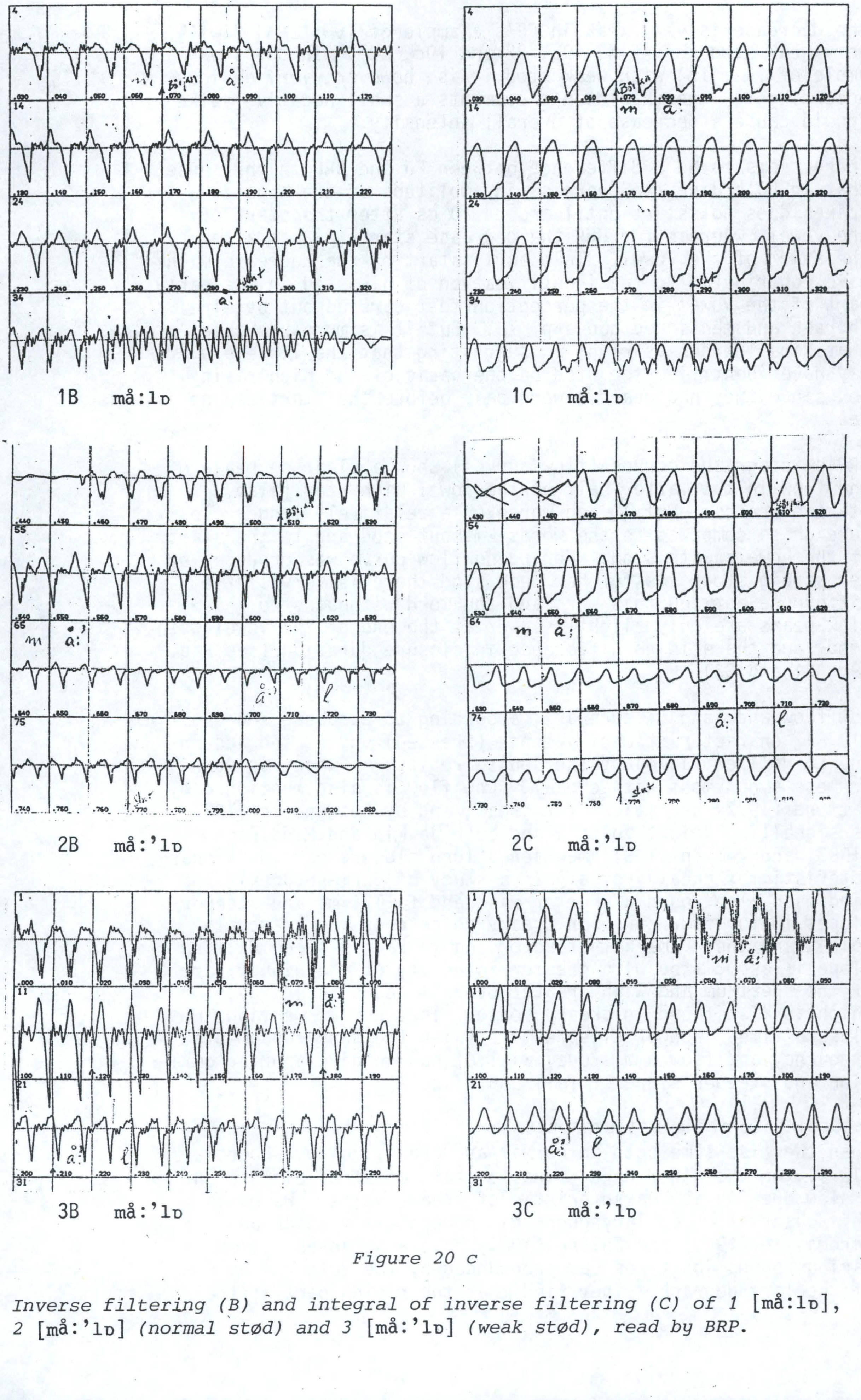


Figure 20 c

Inverse filtering (B) and integral of inverse filtering (C) of 1 [må:lɒ], *2* [må:'lɒ] *(normal stød) and 3* [må:'lɒ] *(weak stød), read by BRP.*

the decrease is very weak in FJ's example of [væ:'lən] 3 with very weak stød (cf. Fig. 19b, B2 and 19c, B3). In BRP's example of [må:'lɒ] with weak stød it is, however, very obvious. According to Inger Karlsson's comments a small negative spike should cause a decrease of overall intensity.

There seems to be a difference between FJ and BRP in the sense that in FJ's case the decrease in amplitude of the negative spikes does not start until around 10 cs after the start of the vowel, whereas for BRP the decrease starts 2-3 cs after the start of the vowel. This early start of the decrease might have contributed to the identification of his stød in the early part of the vowel in the perception test carried out by Nina Thorsen and mentioned above p. 79. But it is more probable that Nina Thorsen is right in suggesting that the listeners may have identified the stød on the basis of the high rising Fo, since they had heard a word pair before the start of the test.

BRP's integrated curves (flow curves) show a clear decrease of the flow in the latter half of the vowel with stød (also starting rather early), and moreover a relatively longer closure phase compared to the words without stød and to the start of the vowels with stød. For FJ no flow curve was produced of her strong stød. As for her weak stød there is very little difference between this word and the word without stød (the flow peaks are only slightly lower at the end of the vowel with stød, and there is no difference in closure duration (see Fig. 19c, C1 and C3).

Low flow and long closure are, according to Sundberg and Gauffin (1978), characteristic of a tense (pressed) voice, and according to Hollien (1974) of the "pulse register" (which is more or less synonymous with creak). Low flow is also mentioned by Catford (1977) as typical for creak, and by Rothenberg (1972) as signalling "tight voice"; and both Javkin and Maddieson (1983) and Zemlin (1981) mention a long closure period as characteristic of creaky voice. In a study of Burmese Javkin and Maddieson also found a shorter rise and fall time and steeper slopes in the flow curve in creaky voice compared to modal voice, and they remark that according to Fant a steep falling slope is associated with greater intensity of the higher part of the spectrum and with greater overall acoustic energy, which is also found in creaky voice. They do not mention the closure time. Longer closure time (with the same fundamental frequency and flow amplitude) will of course give shorter duration and steeper slope of fall and rise.

According to their measurements the fall time is shorter than the rise time both in normal and creaky voice. Fourcin (1974), on the other hand, finds a sharp onset of closure and a slow opening as characteristic of creaky voice. He bases this observation on laryngographic recordings. Roach and Hardcastle (1979) and Esling (1984) have also investigated various phonation types (as pronounced by the authors) by means of the laryngograph. They find that the rising part of the laryngogram (interpreted as approximately indicating the closing movement of the vocal folds) is relatively short in creaky voice and that it gets longer with decreasing stricture of the glottis in different phonation types.

As mentioned by Javkin and Maddieson, a comparison between normal and creaky voice presupposes similar fundamental frequency and amplitude of the glottal flow. - In [væ:ˀlən] read with weak stød by FJ amplitude and fundamental frequency are almost the same as in [væ:lən], and the peaks slightly lower at the end, which should give less steep slopes, but only the rising slope (which in these curves represents the opening movement) is somewhat less steep. In the examples read by BRP a comparison between words with and without stød is difficult because vowels with stød have longer closure, higher pitch and a smaller amplitude. Combined this seems to give shorter and lower but less steep slopes in words with stød. In 6 out of 8 examples there is a tendency for the closing movement to have a steeper slope than the opening movement, a tendency which is less pronounced at the start of the vowel and in vowels without stød. But since the pulses are of much lower amplitude in the stød vowels, this does not give increased intensity.

B. PHYSIOLOGICAL ANALYSIS

1. LARYNX POSITION AND MOVEMENT

Position and movement of the larynx in vowels with stød compared to vowels without stød was investigated by means of a videofilm (see p. 88 above) for five speakers (ND, PD, NR, OB, PM) reading list 9 containing four different word pairs in the frame *"Jeg kan let sige ... fem gange"* 'I can easily say ... five times', each word occurring ten times. Two of the ten repetitions were subjected to a more thorough analysis, consisting in a frame by frame tracing from the videoscreen on transparent paper. Words with and without stød from the same reading, or at least two consecutive readings, were compared in detail.

It was not possible to detect any consistent pattern apart from the fact that the larynx tends to move more in vowels with stød than in vowels without stød, this being the case in about half of the 40 pairs with only 1-2 countercases. But in many pairs the movement was of the same extent in words with and without stød, or there was practically no movement. There were both individual differences and differences between vowel types. PD had more movement in the vowel with stød in six out of eight pairs, OB and PM only in two out of eight pairs, and there was a difference between [u:] and [u:ˀ] in eight out of ten pairs, whereas for [i: / i:ˀ] a difference was only found in two out of ten pairs. On the whole, [i:] and [i:ˀ] showed very little movement.

In about one third of the pairs the starting position was practically the same for vowels with and without stød, but in most pairs there was a certain difference. The larynx had a lower and more fronted position in [u:'] than in [u:] for PD and ND; otherwise there were no clear tendencies, and as for the movements, they differed in a non-consistent way; thus PD showed a forward and downward movement of the larynx in [u:'], whereas for ND the direction of the movement was backward and upward.

On the basis of this preliminary analysis it was concluded that it would not be worth while to undertake a quantitative investigation on a larger scale.

The generally observed tendency for [u] to have a lower position of the larynx than [i] and [a] was confirmed for all five speakers.

2. FIBEROPTIC ANALYSIS OF THE VOCAL FOLDS

A fiberoptic analysis of the vocal folds by means of a videotape-recording (50 frames per sec., see p. 89 above) was undertaken for seven speakers (BF, BM, BH, FJ, HU, JR and ND) reading list 13 which contained four word pairs (one of them occurring twice), all with the vowel [i], which is best suited for fiberoptic research. BF also read some examples of the sentence [si 'ʔi:lə] with hard attack.

The recording of FJ was not quite successful since only part of her vocal folds were visible, but this recording could be supplemented with an analysis of a fiberscope film made in the Research Institute of Logopedics and Phoniatrics in Tokyo in 1976. This film contained four words with stød: [pʰi:'l, bi:'l, fi:'l, vi:'l] repeated four times, and a number of words in [-i:lə]. In this recording the vocal folds were visible in their full length.

The video-recordings were played back several times, and a number of the readings were inspected frame by frame. 109 frames were selected as typical for the speakers (8-24 for each speaker) and photographed from the screen. The film from Tokyo was inspected frame by frame by means of a motion film viewer, and 12 frames were traced manually on transparent paper. It was not possible to make usable copies.

Most of the selected frames show the vocal folds a few cs after the start and before the end of the vowel, the exact point being chosen on the basis of a comparison with mingographic recordings comprising a duplex oscillogram and intensity and Fo-curves, so that the picture illustrating the last part of the vowels with stød corresponded, as far as possible, to the moment of minimum Fo and intensity. Moreover, four series of successive frames of words with stød (read by BF, BH, HU and JR) were photographed, the individual frames being correlated with the mingograms.

A number of photographs are reproduced in Figs. 21-32. Since the speed of the film was 50 frames per second and the shutter was closed half of the time, the pictures represent an average

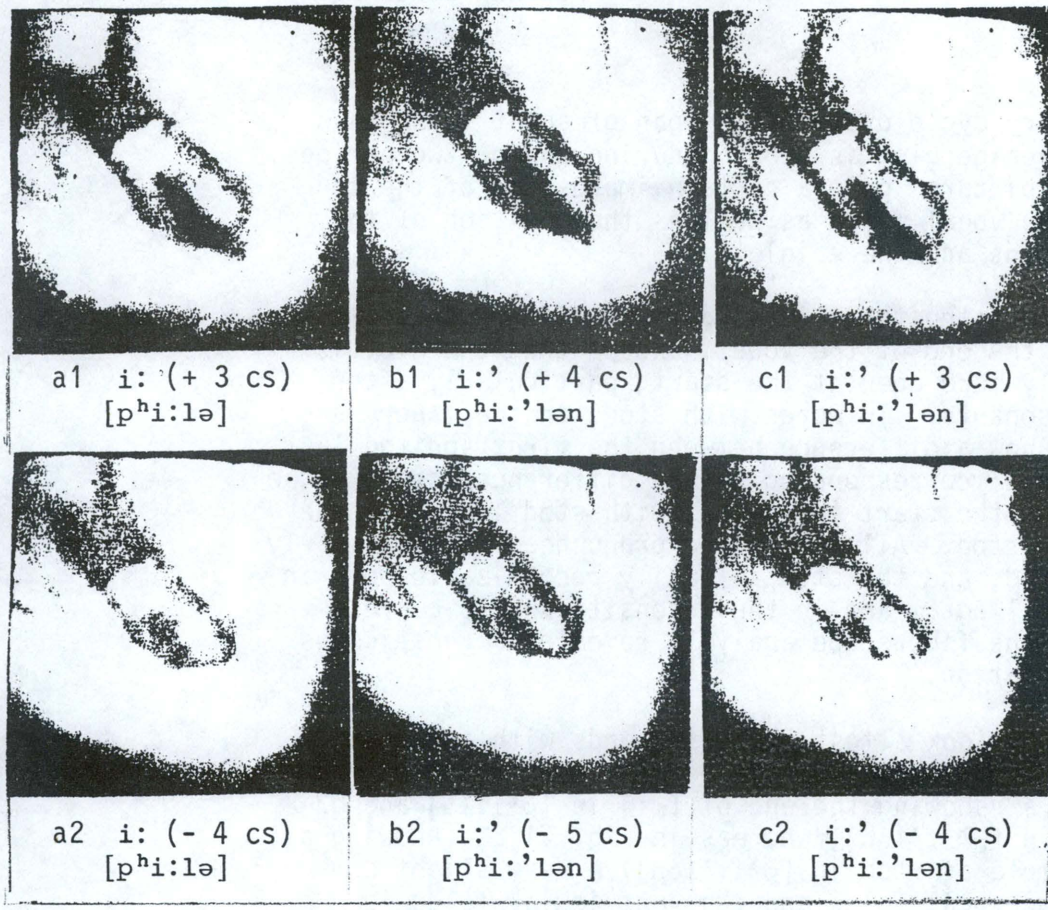


Figure 21

Frames from a fiberoptic film of the vocal folds. (1) first part of vowel, (2) second part of vowel. + = distance from vowel onset, - = distance from vowel end. Speaker FJ.

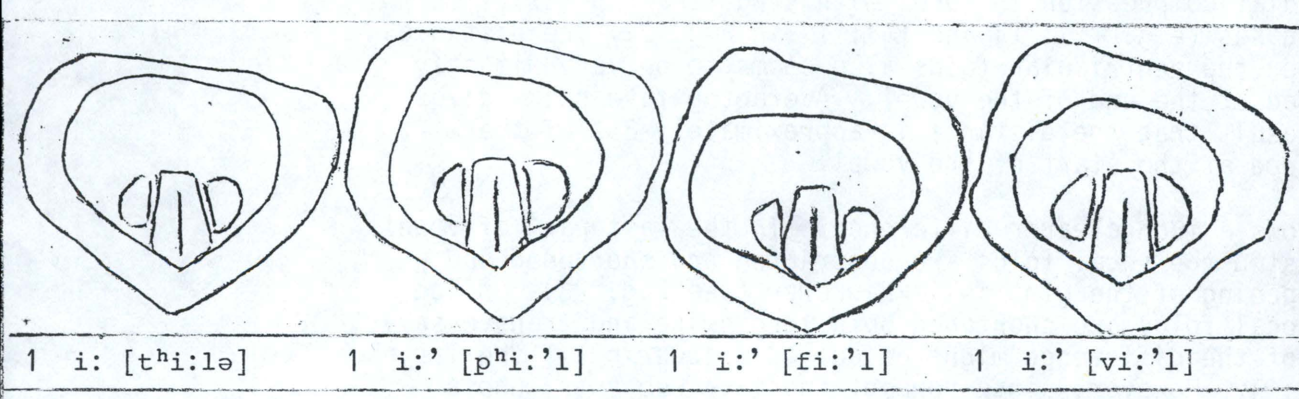


Figure 22

Frames from a fiberoptic film of the vocal folds (Tokyo), traced manually from a viewer. 1 first part of vowel, 2 second part of vowel. Speaker FJ.

of the vibratory cycle over a time span of about 1 cs, thus showing the average glottis opening during one or two periods. Moreover, the pictures give a certain impression of the contraction of the vocal folds as well as the position of the ventricular folds and the epiglottis.

In words without stød there is hardly any difference between the start and the end of the vowel, except that the glottis may be slightly more open at the start, particularly after voiceless consonants. In words with stød, on the other hand, all subjects show a difference between the first and the last part of the vowel corresponding to the differences seen in the mingograms. At the start the vowels with stød look like the vowels without stød. All words were pronounced with a clearly perceptible stød, and the stød is easily recognizable both in the duplex oscillogram and in the intensity and Fo-curves. Nevertheless, the fiberscope analysis revealed a conspicuous individual variation.

FJ's vocal folds look almost alike in words with and without stød. It is, e.g., hardly possible to see any difference between Fig. 21 a2 showing the end of [i:] in [pʰi:lə] and b2 showing stød in [pʰi:'lən], whereas in Fig. 21 c2 (showing a different example of stød in [pʰi:'lən]) a very slight contraction of the vocal folds and the ventricular folds is visible. As for the recordings made in Tokyo, the vocal folds are close together in all vowels with only a narrow slit in the middle, but there is a consistent, though very small difference, the vocal folds showing a slight contraction looking as medial compression in words with stød (see Fig. 22). In some cases (e.g. [fi:'l] and [vi:'l] in Fig. 22) the distance between the ventricular folds also seems to be very slightly reduced at the end of the vowel. Averaging five pairs gives the result that the distance is approximately 85% of the distance at the start of the vowel.

HU shows a much clearer difference. In the last part of vowels with stød the vocal folds are contracted and shortened and the opening of the glottis is narrower (see Fig. 23). Since the vocal folds are shortened both lengthwise and transversally, some of the difference might be due to a lowering of the larynx in [i:']. However, since none of the five subjects, whose larynx position was investigated (see p. 131 above) showed lowering of the larynx in [i:'], this is not very probable. Moreover, in vowels with stød the ventricular folds come closer together, the distance between them being reduced to about 70% (average of three pairs).

Fig. 24 shows a series of photos from the word [bi:'lən] read by HU. The numbers indicate distance from the start of the vowel in cs. No.s 7 and 11 are taken well before the start of the stød phase. At No. 15 the intensity has dropped somewhat, but there is not yet any drop in Fo. Both intensity and Fo decrease rapidly from No. 15 to 21. At 21 both have reached their minimum value, and the vocal folds have reached their maximum contraction. There is very little change in Fo and

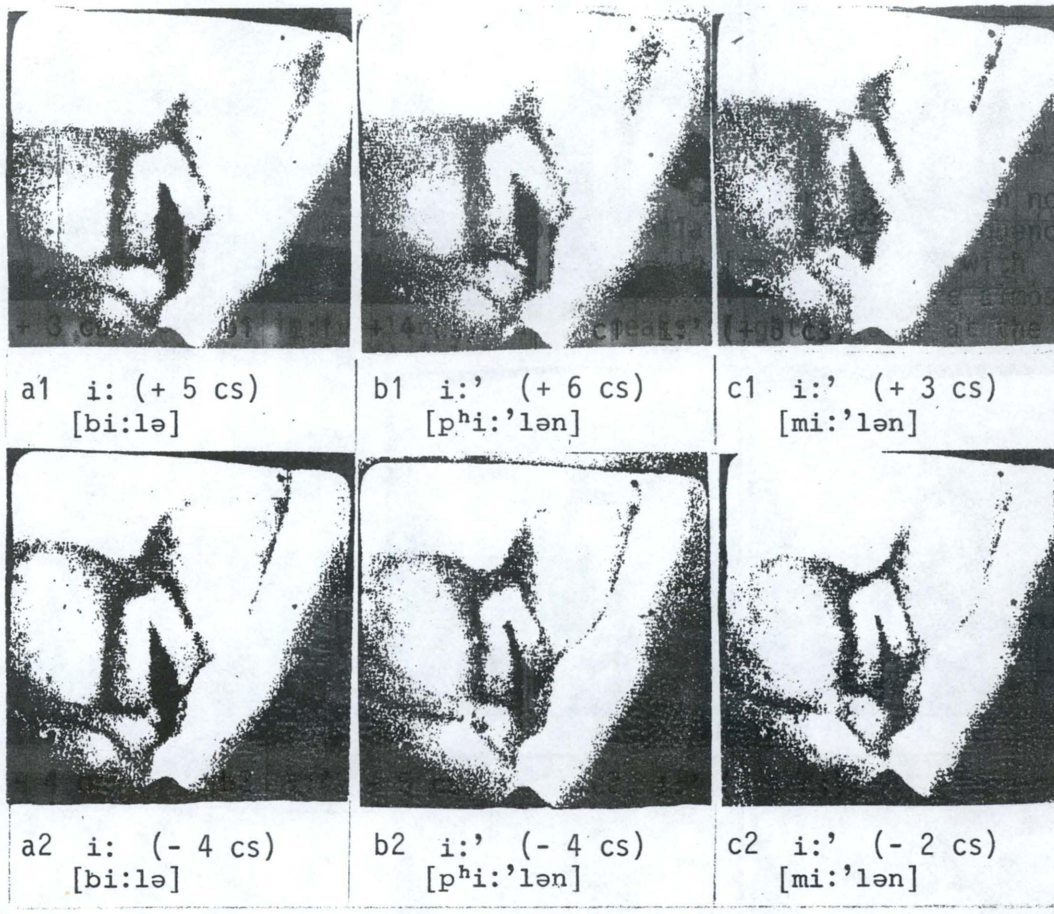


Figure 23

Frames from a fiberoptic film of the vocal folds. 1. first part of vowel, 2. second part of vowel. + = distance from vowel onset, - = distance from vowel end. Speaker HU.

intensity from 21 to 25, and the vocal folds keep their contraction. Immediately after No. 25, Fo and intensity start rising. At 29 (in [l]), they have reached the maximum again, and there is a clear relaxation of the vocal folds.

ND (Fig. 25) also has an adduction of the ventricular folds at the end of vowels with stød, their distance being reduced to approximately 70% (average of three pairs). (This is not seen very clearly in the copies in Fig. 25; the measurements were made in the original photos.) At the end of vowels with stød his right vocal fold is almost covered by the ventricular fold, so that it is difficult to see the glottis, but pictures taken just at the start of the stød (Fig. 25c-1a) and at the end where the glottis appears again (Fig. 25c-2a) show a very narrow glottis. Vowels with stød also have a slight depression of the epiglottis.

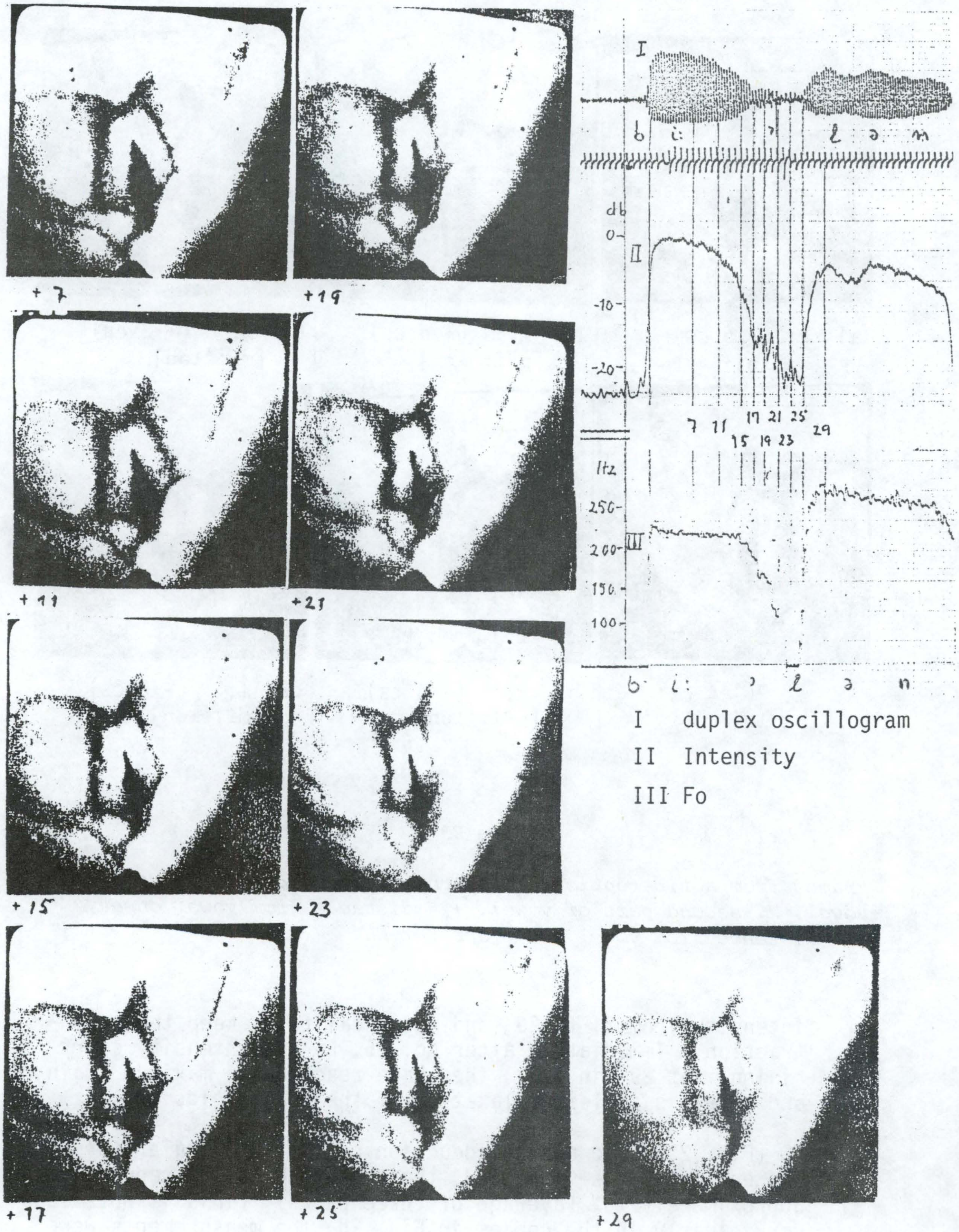


Figure 24

Frames from a fiberoptic film of the vocal folds. Successive frames showing the vowel [i:'] in [bi:'lən], compared to a mingographic recording. The numbers indicate distance in cs from vowel onset (the last picture is from the following [l]). Speaker HU.

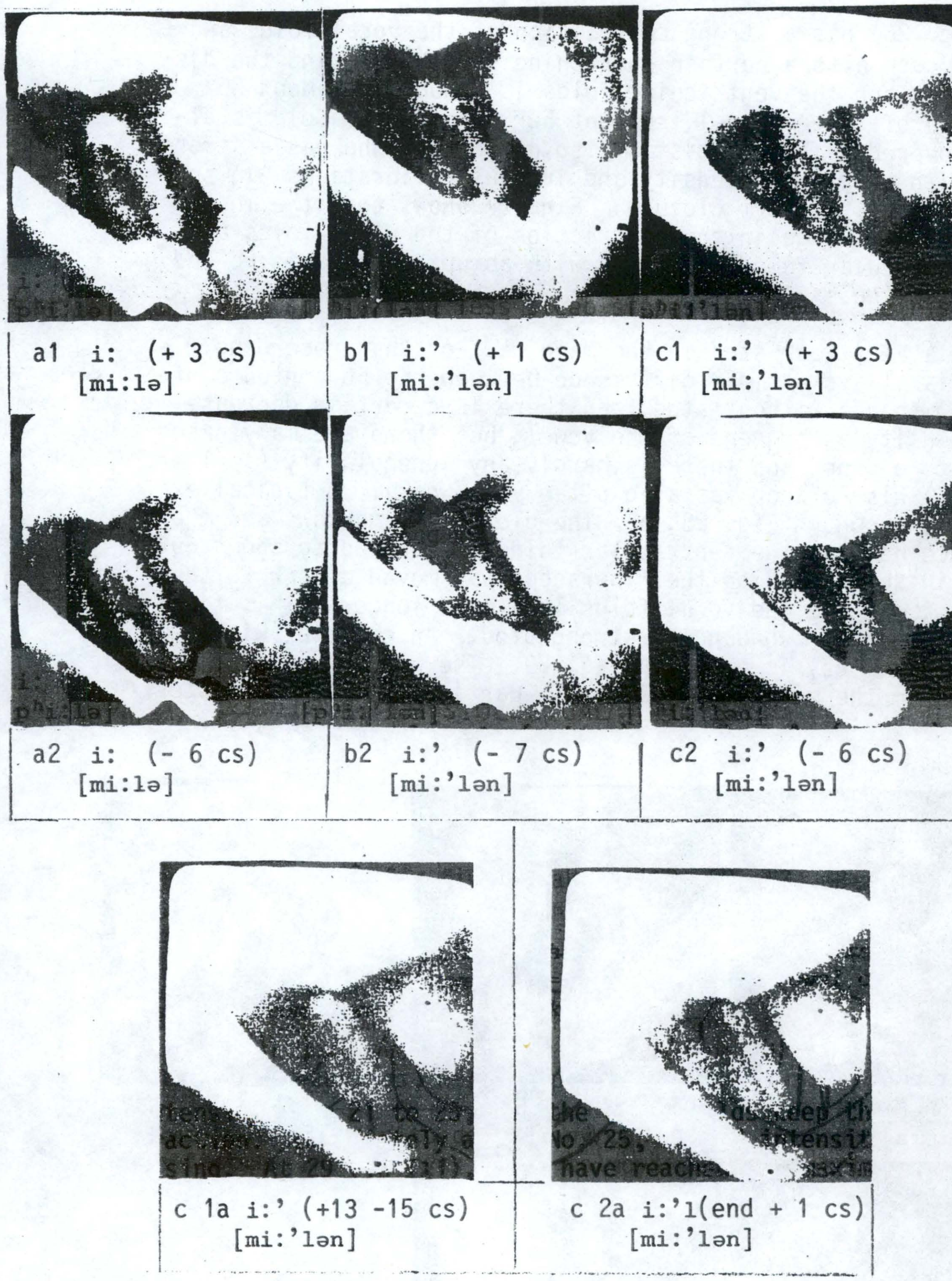


Figure 25

Frames from a fiberoptic film of the vocal folds. 1. first part of vowel, 2. second part of vowel. c 1a start of the stød in [mi:’lən], *c 2a start of* [l]. *+ = distance from vowel onset, - = distance from vowel end. Speaker ND.*

BH (Fig. 26) has a strong contraction of the vocal folds and in one case also a certain shortening lengthwise, and the distance between the ventricular folds is reduced to about 55% (average of three cases), so that her right vocal fold is almost covered. The glottis is also narrowed. She has a strong stød with very low intensity and irregular vibrations, in some cases perhaps a short closure. Fig. 27 shows that the most conspicuous change in the contraction of the vocal folds and the ventricular folds coincides with abrupt changes in Fo and intensity (No.s 31-35 of Fig. 27).

BF has a very weak stød in the main part of this recording. There is always a clear difference between the Fo contours of words with and without stød, and there is a certain decrease of intensity at the end of the vowel, but there are many cases without Fo drop, and there is hardly any irregularity (in list 1 (1974) his Fo drop was also often very weak). A typical example is shown in Fig. 28, b2. The glottis is narrow, and the distance between the ventricular folds is reduced to about 60%. Later in the recording the fiberscope was moved closer to the glottis, so that the vocal folds look much longer. This time he was asked to pronounce a strong stød. An example (with a closure of 5 cs) is given in Fig. 29. The glottis gets narrower from the middle of the vowel, particularly in the poste-

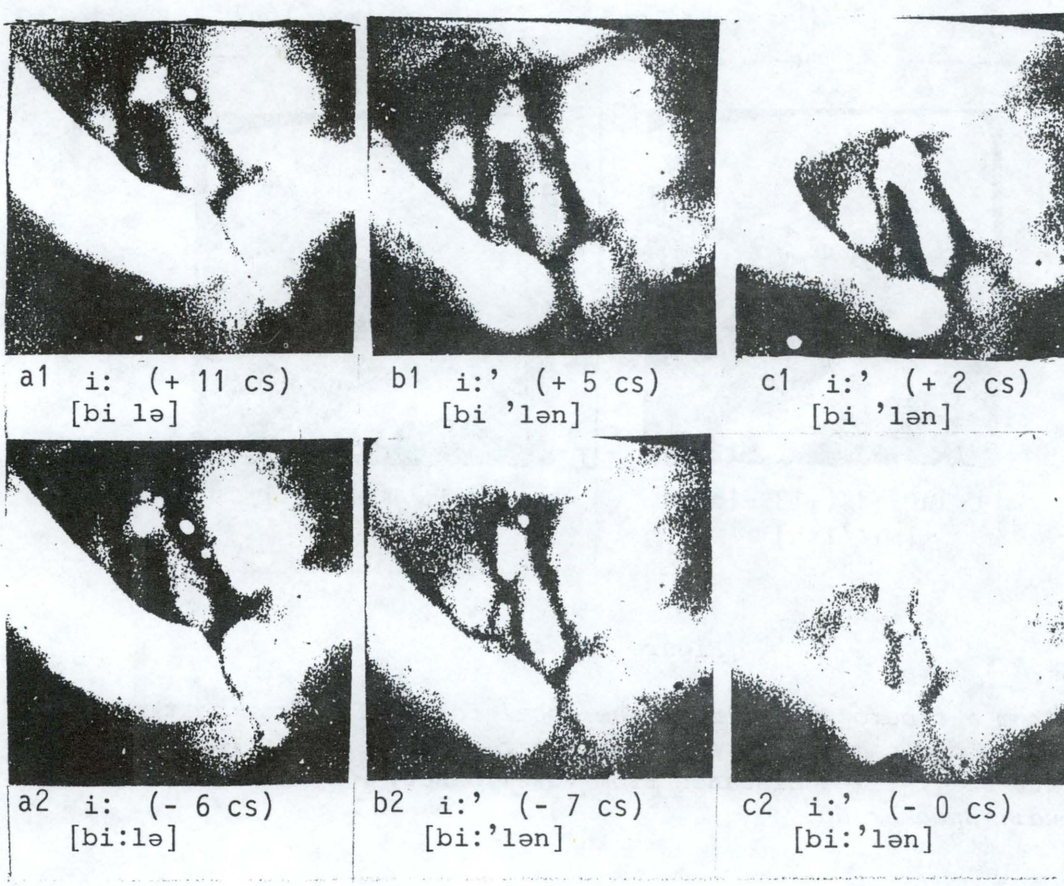
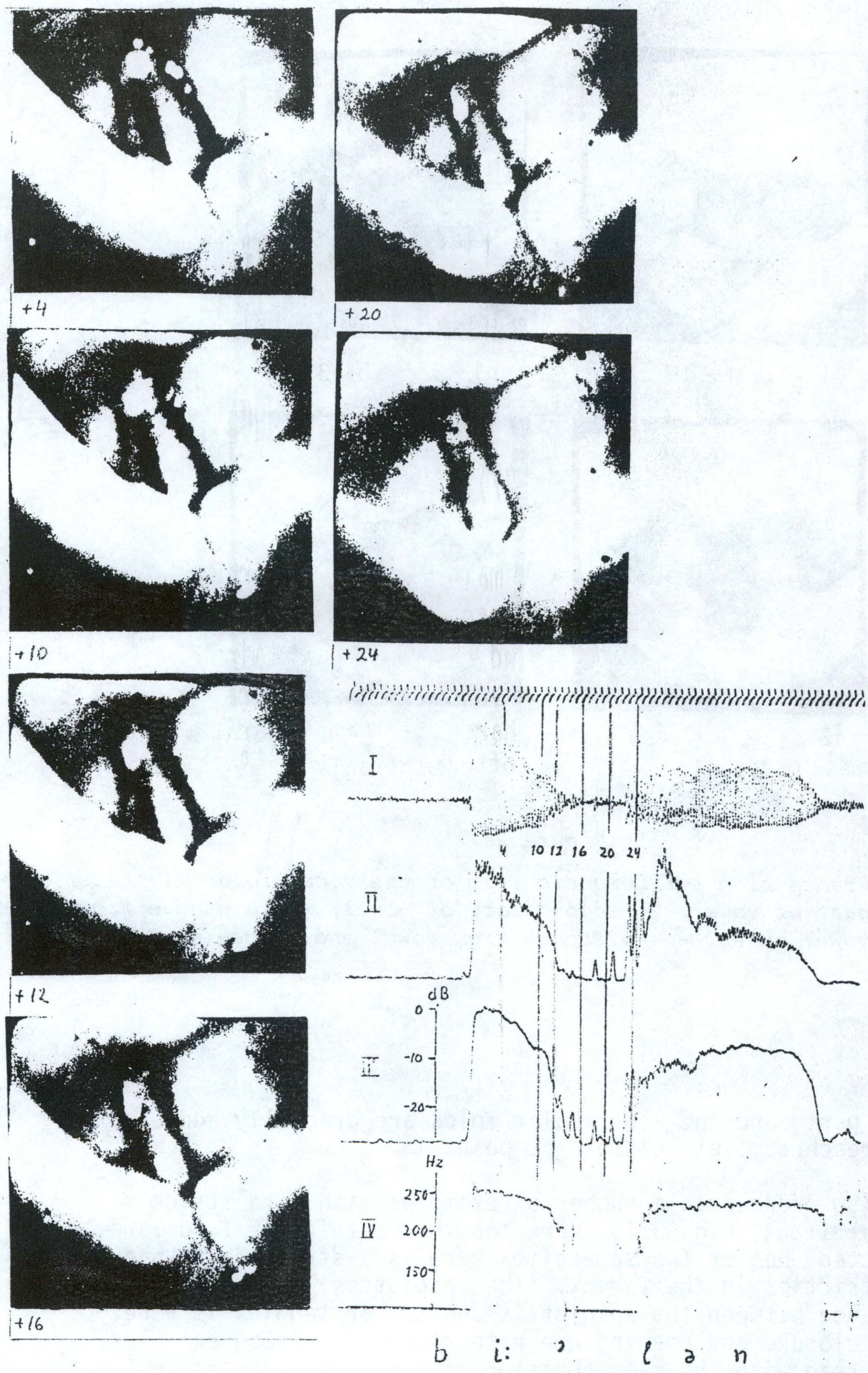


Figure 26

Frames from a fiberoptic film of the vocal folds. 1. first part of vowel, 2. second part of vowel. + = distance from vowel onset, - = distance from vowel end. Speaker BH.



I Duplex oscillogram; II Intensity HP 500
III Intensity; IV Fo.

Figure 27

Frames from a fiberoptic film of the vocal folds. Successive frames showing the [i:'] in [bi:'lən], compared to a mingographic recording. The numbers indicate distance in cs from vowel onset. Speaker BH.

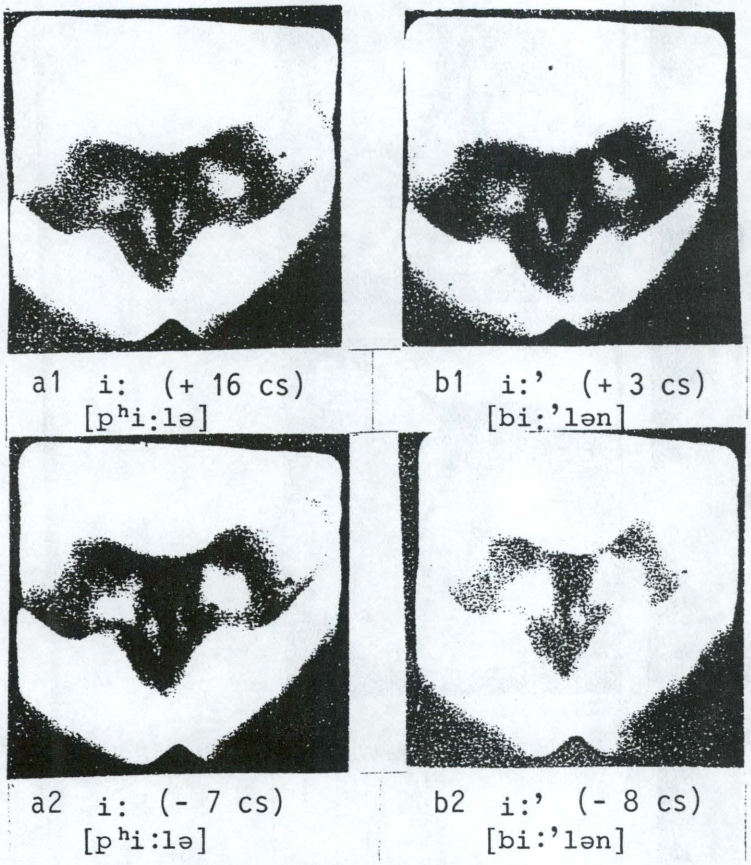


Figure 28

Frames from a fiberoptic film of the vocal folds. 1. first part of vowel, 2. second part of vowel. + = distance from vowel onset. - = distance from vowel end. Speaker BF.

rior part, and the ventricular folds are gradually adducted and reach complete closure at point 16.

BF also pronounced a number of examples with hard attack ([si ˈʔi:lə], Fig. 30). Here too the ventricular folds are adducted, but at the same time there is a strong front-back constriction in the larynx. The epiglottis goes down and the distance between the epiglottis and the arytenoids is reduced. Both closure and opening are rather abrupt. These examples were read with the same position of the fiberscope as in Fig. 27.

JR (Fig. 31) uses a more normal stød from an acoustic and perceptual point of view, although often without Fo-drop (see above p. 112-113), but the fiberscope pictures show a very strong adduction of the ventricular folds, on the average (5 examples) to 25%, and in one case even to 15% of the distance at the start. Because of this movement very little of the vocal folds is visible. The successive frames in Fig. 32 show

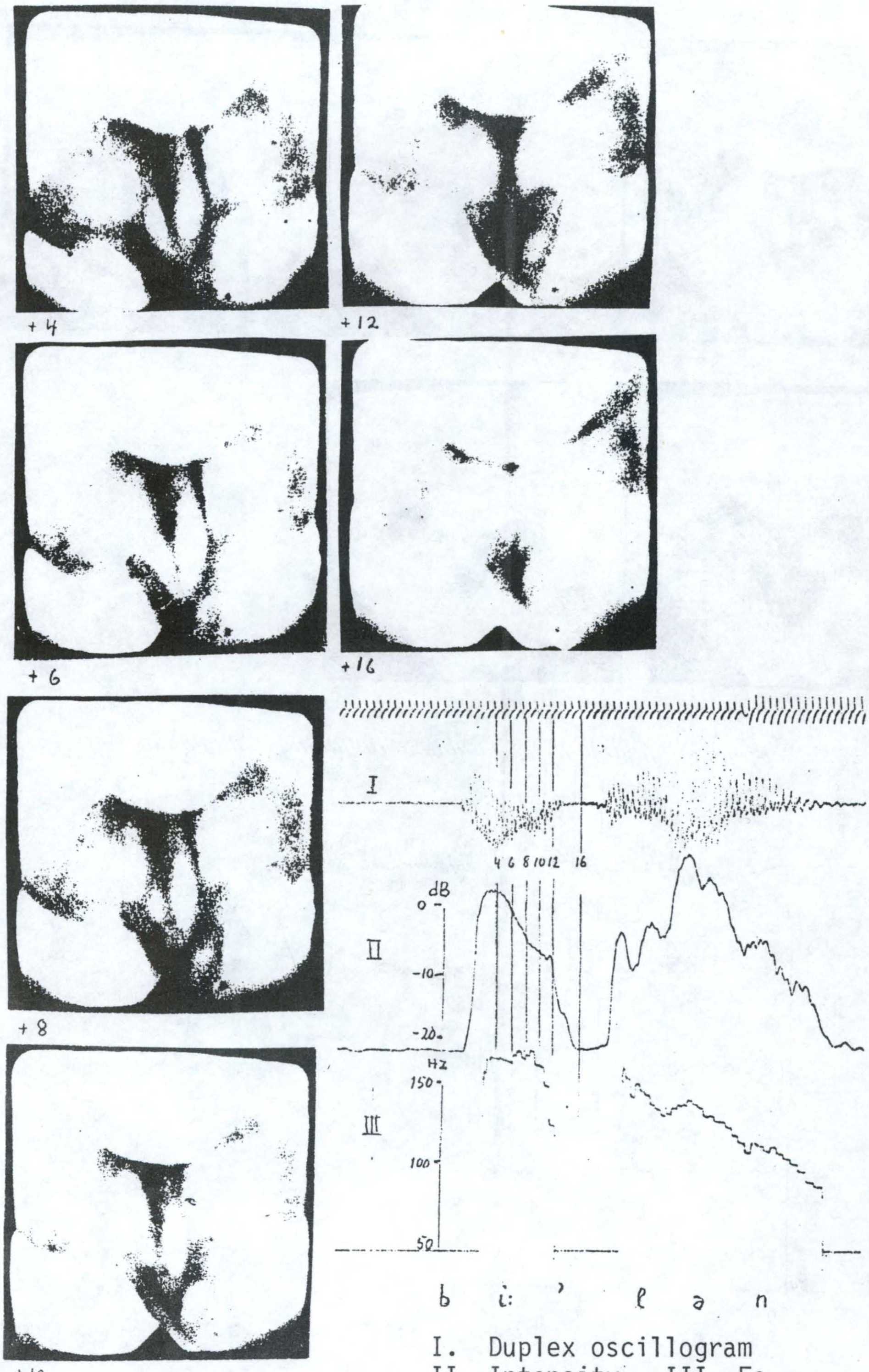
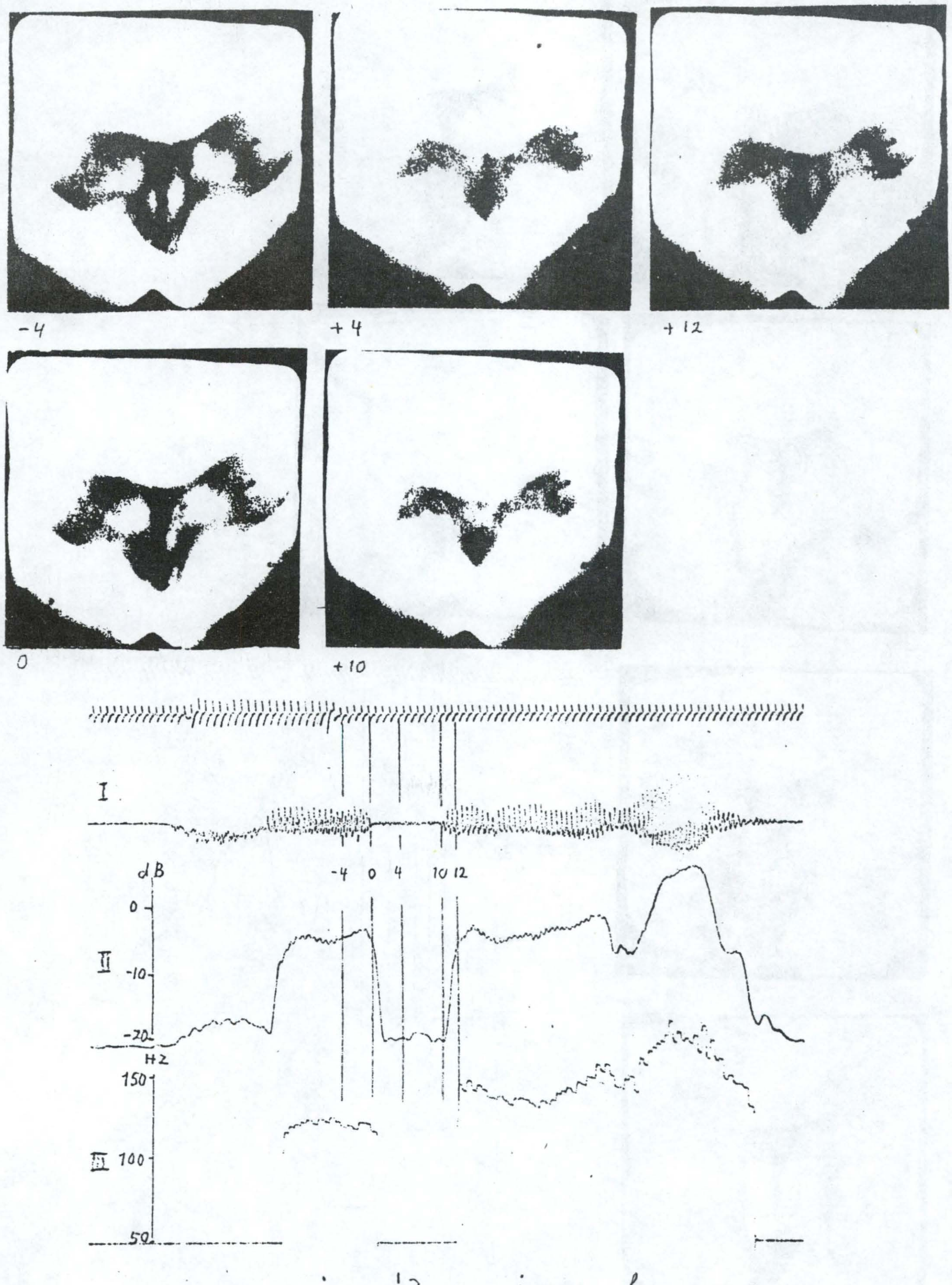


Figure 29

Frames from a fiberoptic film of the vocal folds. Successive frames showing the [i:'] in [bi:'lən] (very strong stød), compared to a mingographic recording. The numbers indicate distance in cs from the start of the vowel. Speaker BF.



I. Duplex oscillogram, II. Intensity, III. Fo.

Figure 30

Frames from a fiberoptic film of the vocal folds. Successive frames showing hard attack in the sentence [si ˈʔi:lə]. *Numbers indicate distance in cs from the end of the first* [i]. *Speaker BF.*

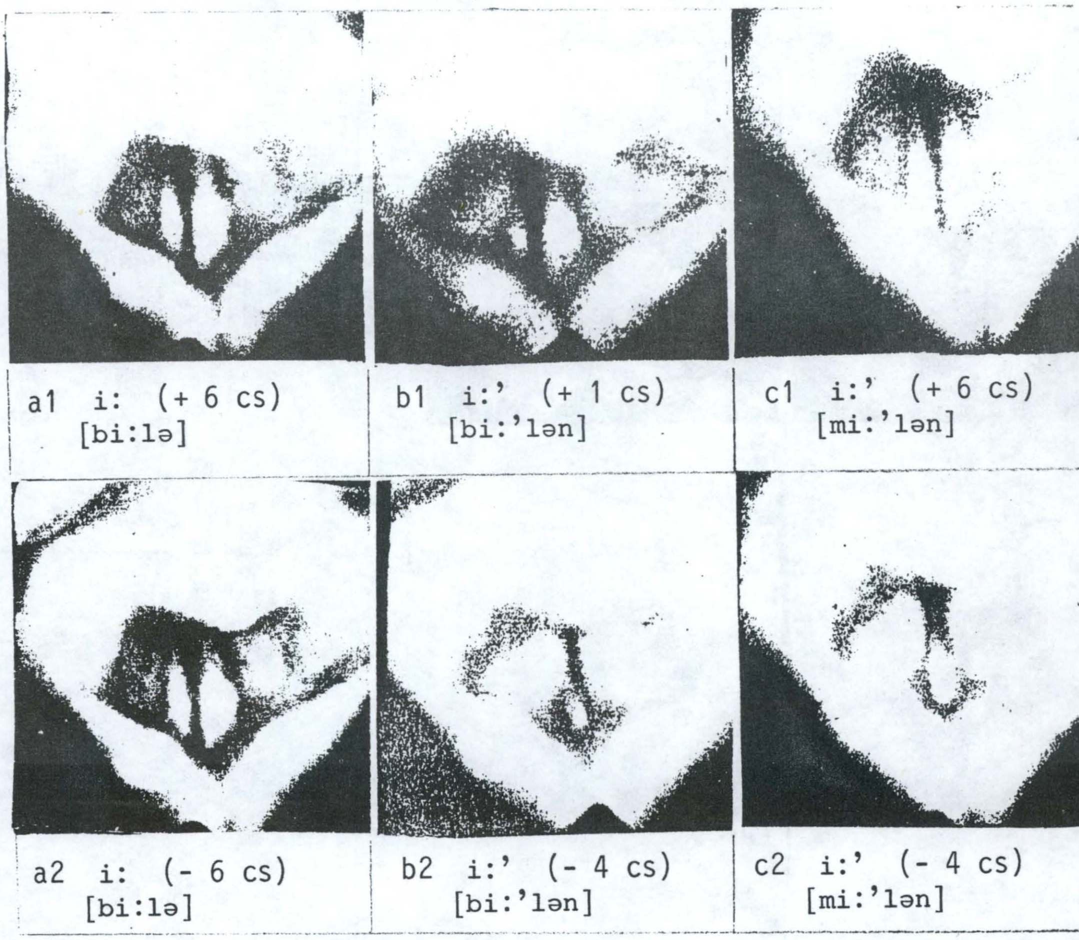
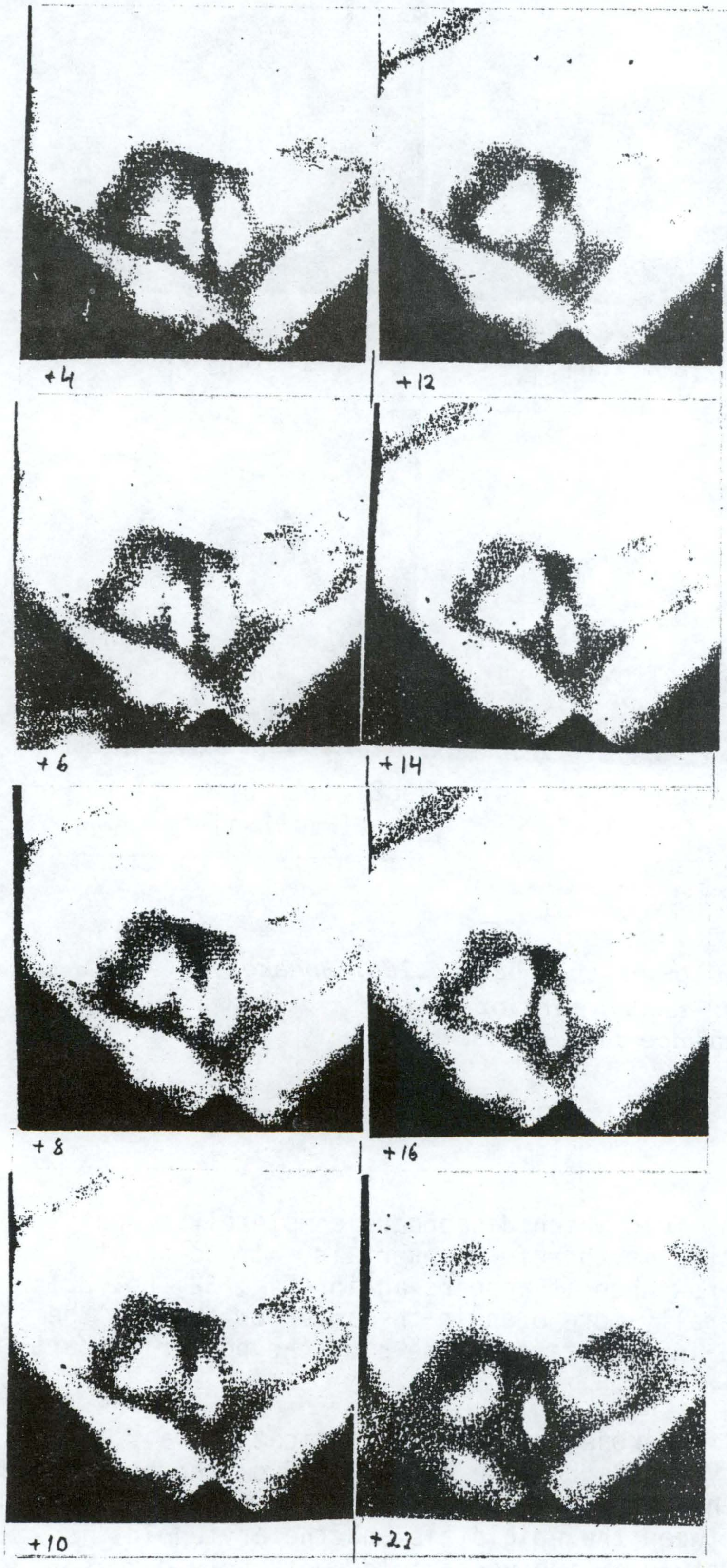


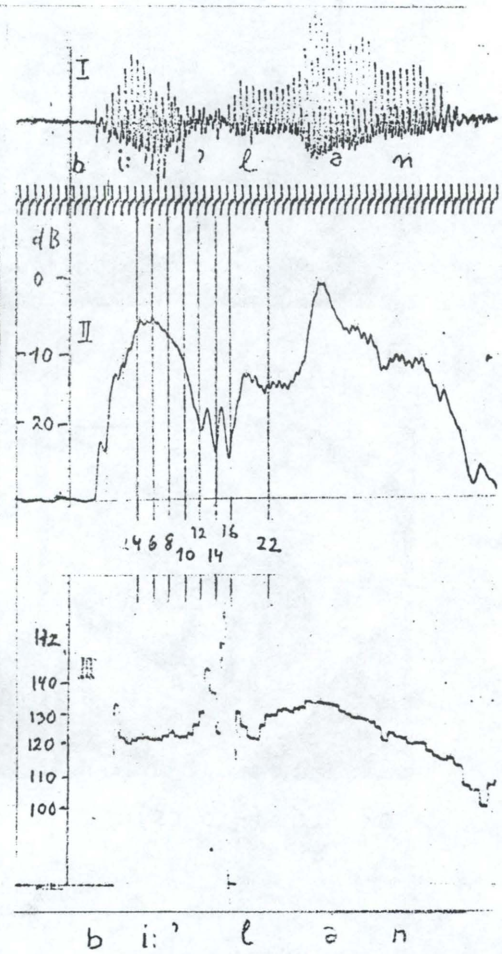
Figure 31

Frames from a fiberoptic film of the vocal folds. Speaker JR. 1. first part of vowel; 2. second part of vowel. + : distance from vowel onset, - : distance from vowel end.

that it is the right fold which disappears completely. What happens to the glottis is therefore uncertain. It does not seem to be very narrow when it appears again (Fig. 32, No. 22); his glottis is generally more open in the anterior than in the posterior part, and in the start of the stød the posterior part is closed first.

BM has (according to Hirose, personal communication) a slightly twisted supralaryngeal structure extending from the base of the epiglottis to the ventricular fold. When he starts phonating the distance between the epiglottis and the arytenoids is reduced, and the picture of the vocal folds gets very dark so that it is difficult and sometimes impossible to distinguish the glottis. It is therefore not possible to say what happens to the vocal folds, and copies of the photos only show a dark area, but the ventricular folds seem to be considerably more adducted at the end of words with stød than in the beginning, the distance being reduced to almost 25% in the two examples which have been photographed.





I. duplex oscillogram

II. Intensity.

III. Fo.

Figure 32

Frames from a fiberoptic film of the vocal folds. Speaker JR. Successive frames showing the vowel [i:ʼ] *in* [bi:ʼlən], *compared to a mingographic recording. The numbers indicate distance in cs from the start of the vowel, the last picture showing the following consonant* [l].

There is thus much interindividual variation, and it seems possible to produce the stød in different ways. The extremes are FJ and JR, although both are from Funen, and both speak a somewhat conservative Standard Danish. FJ has hardly any adduction of her ventricular folds in vowels with stød, whereas JR has a very strong adduction; and the difference is very consistent, the range for the 5 examples measured being 81-94% of the distance at the start of the vowel for FJ, and 15-38% for JR. There is also an acoustic difference: In the 1985 recording FJ had pitch decrease in 94% of the cases, JR in only 33%. But whether there is any causal relation between these two findings is very dubious. Both speakers have approximately the same percentage of irregular vibrations.

Closure of the ventricular folds was found by Ringgaard (1960 and 1962) in the so-called West-Jutlandish stød, and by Fujimura and Sawashima (1971) in the very similar phenomenon in English postvocalic stop consonants (e.g. *fat teeth*).

In section IV B (p. 179) the question of constrictions in the larynx will be taken up again in connection with a discussion of the stød as a phonation type.

3. AIRFLOW

Oral airflow was recorded for one subject (BF 1974, reading list 1) and a combination of oral and nasal airflow for 4 subjects reading list 8. The material comprised 70 different word pairs with 8 (for BF 10) repetitions, i.e. 566 word pairs in all (but BF's two pairs with postvocalic [n] could only be used for analysis of the first part of the vowel, because the mask did not cover the nose). Average curves are found in Appendix VI.

a. First phase As was the case for intensity and Fo, it is practical to consider the first and the second phase of the stød separately. Since both intensity and Fo tend to reach a higher level in words with stød than in words without stød in the first part of the vowel, the same might be expected for airflow. A glance at the 54 average curves in the appendix shows that this is only rarely the case. More often in words with stød the airflow rises more quickly and higher for the initial consonant and falls more quickly down to the vowel.

Smith (1944) found a steeper rise in the start of the open phase of an initial voiceless consonant and in the vowel after a voiced consonant in words with stød and a larger area under the first part of the curve, but the delimitation was quite arbitrary. - He used traditional kymographic recordings with a very lax membrane and a valve in the tube. With this lax membrane a peak of a [d]-explosion may be delayed up to 5 cs after the start of the vowel. It might be of interest to repeat his analysis with more modern instruments and using a larger corpus.

Preliminary inspection showed that an analysis of the area was problematic since a consistent delimitation after consonants would be impossible and since the effects of a higher rise and quicker fall might cancel each other. Instead steepness and peak were analyzed. Steepness was measured as the horizontal distance in ms between the start of the rise and a point corresponding to vertical height close to the peak. - Both measures were undertaken on the individual curves, not on the average curves, and only as relations between corresponding words with and without stød within the same reading of the list, because the airflow might be expected to change in the course of the recording. Partly due to the quicker reaction of the instruments used (see p. 88) it was often difficult to see any difference in steepness in the case of *bdg* and the rise of the vowel after [l] and [v], and there were thus many judgements of "same". For the strongly aspirated *ptk* it was simpler. For *fsh* the start was sometimes problematic.

Smith found no difference for monosyllables. The material is therefore divided into disyllables and monosyllables. Tables XIII and XIV give a survey of the results, and Tables I and II in Appendix VI contain the results for (A) *ptk*, (B) *fshbdg*, and (C) vowel after *l* and *v* separately for disyllables.

Table XIII

Disyllables.

A. Number of pairs in which the word with stød has a steeper (+) or slower (-) or the same (0) rise in airflow at the start of the word compared to the corresponding word without stød in the same reading.

B. Number of pairs in which the word with stød has a higher (+) or lower (-) or the same (0) airflow peak at the start of the word compared to the corresponding word without stød in the same reading.
*Significance: * <5%, ** <1%, *** <0.1%.*

	A. steepness				B. height			
	+	0	-	sf.	+	0	-	sf.
BF	43	8	10	***	42	9	10	***
FJ	30	31	23		46	8	30	
HU	41	34	21	*(*)	67	9	20	***
JR	45	26	25	*	58	9	29	**
NR	52	28	16	***	66	9	21	***
sum	211	127	95	***	279	44	110	***
%	48.7	29.3	21.9		64.4	10.2	25.3	

Table XIV

Monosyllables.
A. Steepness of rise, and B. peak airflow in words with and without stød. See legend to Table XIII.

	A. steepness			B. height		
	+	0	-	+	0	-
BF	11	8	3	8	4	10
FJ	7	18	15	14	5	21
HU	9	3	12	12	2	10
JR	9	8	7	12	1	11
NR	8	8	8	11	2	11
sum	44	45	45	57	14	63
%	32.8	33.6	33.6	42.5	10.5	47.0

There is a clear tendency to a steeper rise and a still more evident tendency to higher peaks in disyllables with stød, but there are some individual differences, the tendencies being particularly strong, and significant at the 0.1% level, for BF and NR, and very weak and not significant for FJ. But for all speakers there are negative cases, also in individual word pairs, except for [sæ:lə / sæ:'lən] and [vɛnɒ / vɛn'ŋ̩] for HU.

The test used for calculation of significance was the sign test (Siegel 1956, p. 68-75) which is applicable to the relation between members of pairs. But its application to steepness may be somewhat problematic because it presupposes that the number of "same" cases can be disregarded. If these cases are distributed on + and -, the significance is sometimes smaller. This is indicated by parentheses around the stars.

The tables in the appendix show that the tendencies are most pronounced for *ptk*.

Whereas there is a clear tendency to a steeper rise and a higher peak in disyllables with stød, there is no difference in the monosyllabic words, and thus Smith's observations are confirmed. However, it is highly problematic whether this is really due to the difference between disyllabicity and monosyllabicity. In section A.4 above (see p. 106-107) a similar difference was found for the Fo peak in the start of the vowel, but it was argued that the difference might also be due to differences in vowel length. This argument is also valid for the airflow, and the argument has even more weight in this case. - Only one of the monosyllabic word pairs has the same vowel length in the words with and without stød, viz. [vɛn / vɛn'], and this pair shows the same difference as the disyllabic pairs. The height difference is exactly the same (63% of the cases have a higher peak after the [v] in [vɛn']), and as for the steepness the percentage is even higher than in the disyllabic words (viz. 61% vs. 49%). In all the other monosyllabic pairs investigated the word without stød has a short vowel, and the word with stød a long vowel ([du / du:', tʰa / tʰæ:'] and (for one speaker) [pʰib / pʰi:'b] and [føl / fø:'l]). For these words there is no significant difference, and the tendency is rather reversed. The pairs investigated by Smith also had a difference in length (the examples were in fact taken over from him in order to verify his observations with better instruments, but they should have been supplemented with pairs without this length difference). The assumption that words with short vowels may have a stronger and steeper airflow than words with long vowels is supported by a comparison of the examples [pʰi:bɒ / pʰi:'bɒ / pʰibɒ] and [lɛ:sɒ / lɛ:'sɒ / lɛsɒ]. Whereas the words with long vowel and stød have a significantly steeper rise and higher peak than the words with long vowel without stød, there is no significant difference between the words with long vowel and stød and the words with short vowel, and for [pʰi:'bɒ / pʰibɒ] the tendency is even reversed as far as the height is concerned. - A comparison between [kʰɛ:lə] and [kʰɛlɒ] (see Appendix VI) also shows a higher peak in [kʰɛlɒ] for four of the five speakers.

b. Second phase Smith did not analyse the airflow in the second phase of the stød, which other phoneticians consider as containing the stød proper (with low intensity and irregularities and/or Fo-decrease). Here a low airflow should be expected. An analysis of the present material confirms this expectation. The analysis consisted partly in a comparison of individual words in the same reading, partly in measurements of the difference in l/m for words with long vowel on the basis of average curves. A survey of the results is given in Table XV, A and B, and measurements of l/m values and differences for different word pairs and speakers are given in Appendix VI, Table III.

A "+" was chosen if only a short stretch at the end of a long vowel or in the consonant after a short vowel had lower airflow in the word with stød. The difference in l/m was measured at the lowest point of the vowel with stød. In [pʰi:bɒ] without stød the airflow increases clearly just before the [b]; thus if the end point of the vowel had been chosen, the difference would have been larger.

There was no difference between disyllables and monosyllables, so that both are included in Table XV A. As for the measurement of l/m only long vowels in disyllables were included because it was problematic to choose a relevant point for measurement with any consistency in consonants and in monosyllables; in the latter case there was generally a length difference between words with and without stød.

Table XV

A. Number of pairs in which the word with stød has a lower (-), higher (+) or the same (0) airflow in the second part of the syllable compared to the corresponding word without stød in the same reading.

B. Difference in l/m between words with long vowel with and without stød.

C. Distance from vowel onset to the point where the airflow gets lower in words with stød than in words without stød.

	A.				B.	C.
	-	0	+	sf.	diff. (l/m)	distance (cs)
BF	59	1	1	***	8.5	6.2
FJ	99	9	16	***	2.3	6.2
HU	120	0	0	***	3.9	4.3
JR	120	0	0	***	6.9	4.3
NR	112	6	2	***	1.5	5.0
sum	510	16	19	av.	4.6	5.2

The difference in airflow in the second phase of the stød is obviously highly significant; and in contradistinction to the differences in the first phase, which were only (partly) significant for groups of words and not for separate word pairs (with extremely few exceptions), the difference in the second phase is generally highly significant for separate word pairs as well, since generally all 8 (or 10) repetitions show the same difference. This is true of 53 out of 65 word pairs. According to the sign test the significance is 1% in these cases. There are further 6 cases with 5% significance and 9 non-significant cases. - Average curves were made of 54 pairs, and for these words the overlappings were analyzed. This gave almost the same result, except that no overlapping of 8-10 examples, which was very common, gives 0.1% significance according to the Mann-Whitney test.

4. SUBGLOTTAL AND ESOPHAGEAL PRESSURE

Subglottal pressure was recorded for BF reading list 1 in 1974 simultaneously with the other recordings. It was recorded by the direct method inserting a needle into the trachea (see p. 87 above). There were 8 different word pairs with 5-6 repetitions of each word (in one case only 4). The curves look very reliable. The zero-line is almost stable, and there is very little variation within the same word. According to a rough estimate from the standard deviation curve of the computer

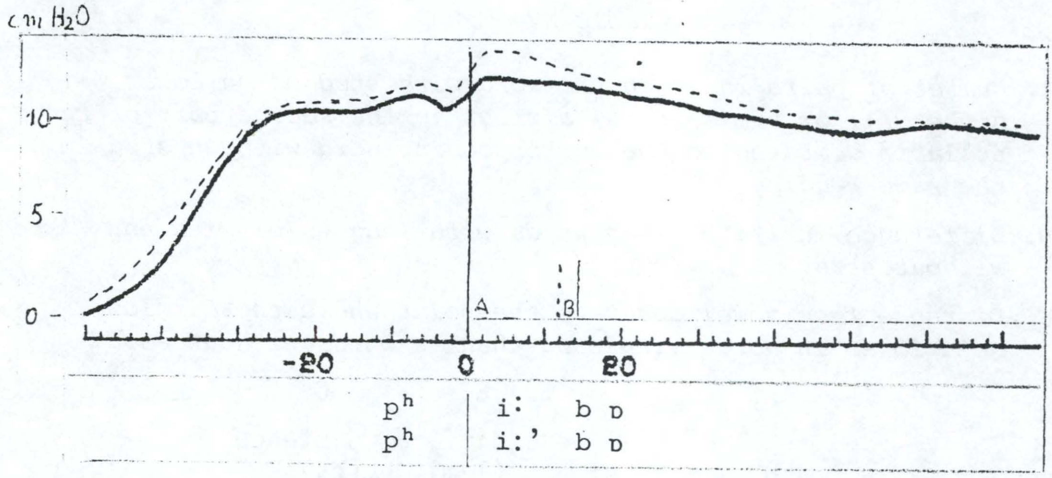


Figure 33

Subglottal pressure, average of 5 examples, speaker BF.

averages, the s.d. is less than 5% for words without stød, and around 10% for words with stød. Expected differences due to stress and aspiration are also visible. The material is given in the form of curves averaged by computer in Appendix VII. A typical example is shown in Fig. 33.

All 8 pairs show a higher maximum and a steeper rise in the first part of the vowel (in [vɛn'] and [vɛn'n̩] in the [v]) in words with stød compared to words without stød. The differences are small (generally less than 1 cm H_2O), but they are consistent. Due to the small number of repetitions significance for individual word pairs can only be proven for four of the eight pairs ([kʰɛl'ɒ / kʰɛlɒ], [hu:'ən / hu:ən] 1%, and [pʰi:'bɒ / pʰi:bɒ], [vɛn'n̩ / vɛnɒ] 5%); but eight pairs with the same difference gives 1% significance for the total material according to the sign test. Moreover, corresponding words in the same reading with and without stød were compared, and of 38 pairs 35 had a higher maximum in the word with stød, and 31 a higher start of the vowel. This is evidently highly significant.

The distance from the start of the vowel to the pressure maximum in words with stød is on the average 5.0 cs, individual averages varying between 2.6 and 6.4 cs except for [hu:'ən] where the rise is much slower (11 cs). After the maximum the pressure decreases again. Within the first 10 cs, i.e. until the start of the acoustical stød, the decrease is, on the average, 0.5 cm H_2O (but [lɛ:'sɒ] does not show any fall at all), and during the phase of the stød the pressure is still slightly higher in words with stød except for [vɛn']. (The strong decrease found in the words [kʰɛl'ɒ], [vɛn'] and [du:'] (see Appendix VII) is much later and has nothing to do with the stød, being due to cases where the speaker made a pause after the test word.) In words without stød the distance to the peak is very variable, and very often there is no decrease during the first 10 cs.

Quantitative measurements in cm H_2O were undertaken both on the computer-averaged and on the manually averaged curves as well as on the individual words in the mingographic recording. Averages for different word pairs from the latter measurement are given in Appendix VII, Table I, and the grand means of the three different types of measurement are shown in Table XVI.

Table XVI

Averages (in cm H_2O) at vowel start and maximum, and rise of subglottal pressure in words with and without stød (speaker BF, eight word pairs with 5-6 repetitions), (A) based on measurements of individual words, (B) based on manually produced average curves, and (C) based on computer-produced average curves).

	A (indiv. meas.)			B (man. av. c.)			C (computer av. c.)		
	vowel start	max.	rise	vowel start	max.	rise	vowel start	max.	rise
+stød	11.9	12.6	0.7	11.8	12.4	0.6	11.5	12.6	1.1
-stød	11.4	11.8	0.4	11.3	11.7	0.4	10.8	11.5	0.7
diff.	0.5	0.8	0.3	0.5	0.7	0.2	0.7	1.1	0.4

The reason for these extra control measurements was that the differences are small, but at the same time of great interest for the theories concerning the production of the stød. The accordance between A and B, i.e. averages of individual measurements and measurement on manually produced average curves is very high. As for C (computer averages) the maximum in stød words is exactly the same as in A, but the maximum of words without stød is 0.3 cm H_2O lower, which I cannot explain. At any rate it is not much, and the maximum is higher in words with stød in all eight pairs according to all three methods of measurement. As for the start of the vowel it is 0.4 and 0.6 cm H_2O lower in the computer averages, which gives a higher rise (1.1 compared to 0.7 cm H_2O in stød words). This is mainly due to the words [du:'], [kʰɛ:lə] and [kʰɛlɒ] and can partly be explained by the fact that there is sometimes a certain lag in the computer averages probably due to the sampling, so that the line-up point is slightly more to the left, and some of the rise at the end of the dip during the aspiration will thus be included. I am therefore inclined to think that the two other types of measurement give a more correct result. Anyhow, maximum and rise are only around 1 cm H_2O higher in words with stød. The question whether these small differences are sufficient to explain the acoustic differences will be taken up in the final section. But a slightly higher subglottal pressure during the stød phase combined with a considerably lower airflow (see above p. 149) points to increased glottal resistance.

Esophageal pressure was measured for speaker FJ reading list 7. The list contained the pairs [di:sǝð / di:'sǝn, si:lǝ / si:'l, mi:lǝ / mi:'l] and [vɛn / vɛn']. There were 12 repetitions of each word. This recording is less reliable. The zero line is often missing, and when it is present it is very variable in height. Moreover, the subject sometimes did not breathe in between the sentences (this was apparent from a simultaneous airflow recording), and in these cases the esophageal pressure was often considerably higher in the second sentence, as should be expected if esophageal pressure reflects thoracic pressure and not the combined thoracic and recoil pressure (see Kunze 1964). No correction for lung volume was undertaken, and the pressure was not calibrated. Therefore superposed tracings were made with the start of the vowel [i:] in the frame [di vi si:] as vertical starting point. There was a rather large variation, so that the tracing of the average was difficult. However, the peaks are exact, and there is a clear difference in all four pairs, the word with stød having a higher maximum. Average curves are shown in Appendix VII.

In 1974 Jørgen Rischel (JR) made a recording of his esophageal (and pharyngeal) pressure, while reading list 1 and list 3. List 1 was repeated twice, list 3 four times. The recording of esophageal pressure is, however, problematic. The curve is strongly smoothed (no vibrations are seen), and the excursions are very small. Moreover, the zero-line is moving up and down all the time both between and within the sentences. In list 1 sentences with stød often seem to be on a generally higher level, and sometimes there seems to be a peak in the beginning of vowels with stød, but it is too uncertain. In list 3 (the *bibibibi*-list), there also often seems to be somewhat more rise and fall in syllables with stød, starting in the consonant, but it is all very problematic.

5. PHARYNGEAL PRESSURE

Pharyngeal pressure was measured for BF reading list 1 in 1974 together with the recording of other properties (see Appendix VIII), for FJ reading list 1 (1981) and for JR reading lists 1 and 3, i.e. together with esophageal pressure (see above). BF's recording was calibrated in cm H_2O, the other two recordings were not calibrated.

In BF's recording there is a tendency for the maximum pharyngeal pressure in the initial consonant (i.e. just before the release of [pʰ] and [kʰ] and at the transition to the vowel for [v] and [l]) to be higher in words with stød. The difference is found in all eight word pairs and is thus significant for the material as a whole, but the difference is small (0.3 cm H_2O on the average), the variation is much larger than for the subglottal pressure, and the difference within individual pairs is not statistically significant except for [hu:ǝn / hu:'ǝn] (5% level). The zero line varies (about 1 cm H_2O) which gives some uncertainty. Moreover, the pressure is smaller than expected. Shortly before the release of aspirated [pʰ] and [kʰ] one should expect to find identity between subglottal and pharyngeal pressure (see, e.g., Löfqvist et al. 1982), but for the three relevant word pairs the pharyngeal pressure is 3.2 - 3.3 cm H_2O lower. About 1.5 cm H_2O would be gained by using the zero-line of the computer averages, but these zero-lines are arbitrary (except for Fo). The zero-line in the curves in the Appendix has been placed by comparison with manually averaged curves from the mingograms, which were calibrated, and the error in this procedure is at most 0.2 cm H_2O. The deviation is therefore difficult to explain. BF read the sentences in a rather loud voice so that the subglottal pressure of about 10 cm H_2O is not higher than should be expected (see, e.g., Daniloff et al. 1980, p. 202). But the scale and thus the differences are OK. Measurement and averaging of selected mingograms gave the same differences with a deviation of only 0.1 cm H_2O.

During the stød phase the pressure (measured at the minimum) is lower than the corresponding point in words without stød in all word pairs except [kʰɛ:lə / kʰɛ:'lɒ]. This difference is, however, also small (0.6 cm H_2O on the average). All word pairs taken as a whole give significance at 5%, but there is no significance within separate word pairs except for [hu:ən / hu:'ən]. Averages for individual word pairs as well as computer produced averages are given in Appendix VIII. The tendency to slightly higher subglottal pressure in the stød phase compared to slightly lower pharyngeal pressure points to stronger glottis constriction in the stød, but the differences are small.

Pharyngeal pressure was also recorded for FJ reading list 7, which contained four word pairs (see section (d) above). All four word pairs showed a higher pressure in the initial consonant in words with stød, and the difference is significant except for [di:səð / di:'sən]. On the other hand, [di:'sən] has a steeper rise during the [d] closure in 11 out of 12 cases, when words from the same reading are compared (see Appendix VIII).

JR read list 1 twice. In this list no difference between words with and without stød can be seen, although the base line is quite stable in this recording in contradistinction to the esophageal pressure. In list 3, which was read four times, the initial consonant ([b]) has a higher pressure at the end of the closure in most words with stød, but the difference is not significant. There is, however, a clear difference in the movement of the pressure during the closure. After the first steep rise the pressure remains stable in words without stød in 8 out of 12 examples, whereas in words with stød there is a rise in 10 out of 12 examples. This difference is significant according to Fischer's probability test.

In JR's and FJ's curves the DC amplitude was rather small and the vibrations very large in voiced sounds, which made measurements of pressure during the stød phase difficult. But measurement of selected examples did not reveal any difference. What could be seen very clearly, however, was a pronounced decrease in the amplitude of the vibrations during the stød phase.

The stød thus also shows up in the pharyngeal pressure, but the differences are small and not always significant.

6. ARTICULATORY FORCE

Since both airflow, pharyngeal pressure, intensity and pitch tended to be higher at the start of the vowels with stød, it seemed worth while to look for signs of more articulatory force as well. Very informal observations seemed to indicate more protrusion of the lips in rounded vowels with stød. But this has not been investigated thoroughly.

Muscle activity in orbicularis oris superior (OOS) in initial labial consonants in words with and without stød could be com-

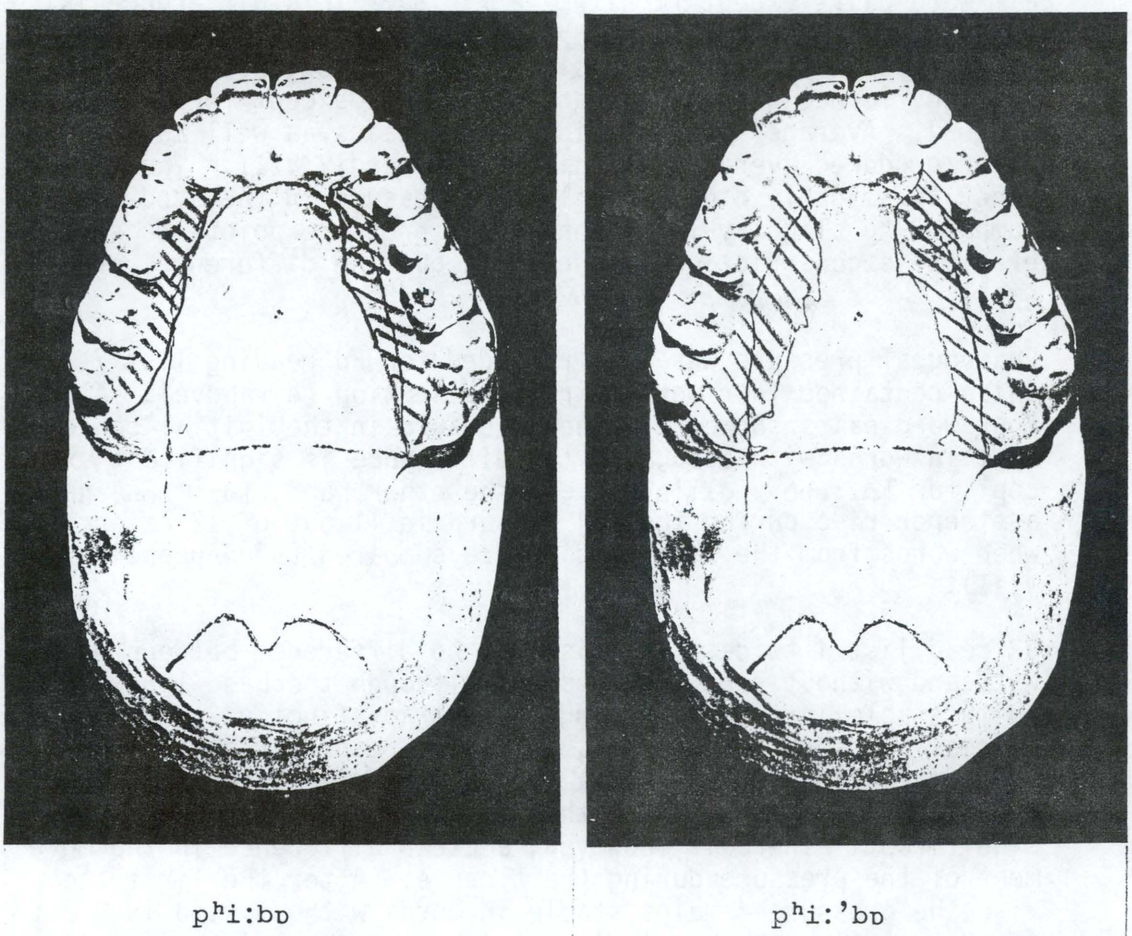


Figure 34

Palatograms of the words [p^{h}i:bɒ] *and* [p^{h}i:'bɒ] *pronounced by FJ.*

pared in two word pairs: [pʰi bɒ / pʰi:'bɒ] and [man / man'] (average of 16 examples) in the Haskins recording 1972 (see Fischer-Jørgensen and Hirose 1974b), but the activity was not consistently stronger in the word with stød. PM had the same activity in initial [p] in both words, whereas TB had more activity in the word with stød. In [man / man'] PM had more activity in the [m] in the word with stød, whereas for TB the opposite was true. In the Haskins recording 1976 of FJ it was also possible to compare OOS in a word pair with and without stød ([pʰɛ:nə / pʰɛ:'n]). This comparison did not show any difference either.

A number of palatograms dating from 1949 were also inspected more closely. There were five speakers: FJ, KS, NE, OR and OT. In one of the series with FJ as a speaker an artificial palate was used (FJb), in the other cases the method was direct palatography. The tongue was painted with a mixture of yellow ochre, medical coal and gum arabic, and immediately after the pronunciation of the word a small mirror was inserted, and the outline of the contact area was drawn on a photo of a plaster cast of the palate. An example is shown in Fig. 34 (the curved lines indicate 50% height of the palate counted from the highest point to the surface of the molars). The subjects pronounced partly isolated vowels with and without stød, partly words of the type [pʰi:bɒ / pʰi:'bɒ], where only the stressed vowel would show contact with the palate. The distance between the right and left boundaries of the contact at the narrowest passage was measured for each vowel. Since words and isolated vowels behaved alike, and the total number was small, they have been combined in Table XVII, which shows the difference between the

Table XVII

*Average difference in mm between vowels without and with stød in respect of the distance between right and left contact area on palatograms, measured at the narrowest point of the passage. N = number of individual examples; significance: * < 5%, ** < 1%, *** < 0.1%.*

	i: - i:'		e: - e:'		ɛ: - ɛ:'		y: - y:'		u: - u:'	
	N	diff.	N	diff.	N	diff.	N	diff.	N	diff.
FJa	8/11	3.4**								
FJb	9/9	2.9	9/9	7.5***	9/7	-1.3	2/2	4.5		
NEa	3/3	3.0	3/3	7.0	3/5	2.9	3/2	1.7	5/12	5.0
NEb	5/5	7.3*								
KS	6/10	1.6	3/3	-2.7			3/3	0.6		
OR	4/5	1.8	4/4	-1.0	4/4	0.4			4/5	1.4
OT	10/6	1.6								

measurements for vowels with and without stød. These measurements in mm are not real, in the first place because the photos of the casts were about 10% shorter in both dimensions than the originals, and in the second place because the contact areas are larger than seen on the drawings due to the steepness of the sides of the palate. But they give a reliable picture of the direction of the difference between words with and without stød and an approximate impression of the size of the difference. Because of the restricted number of examples it is only rarely possible to demonstrate significant differences in the individual averages, but seen as a whole the difference is significant, vowels with stød having a smaller distance and thus a larger contact in 17 out of 20 averages. There is thus a clear tendency to pronounce vowels with stød with more articulatory energy.

7. ELECTROMYOGRAPHIC INVESTIGATION

a. Interarytenoid (INT) and posterior cricoarytenoid (PCA) It is well known that INT is an important muscle (or muscle group) for closing the glottis by bringing the arytenoids together and that PCA has the function of opening the glottis by pulling the muscular processes in an arc towards the back, thus separating the vocal processes which move outwards (see, e.g., Hirose 1975).

Since it is a general opinion (see below p.182) that the arytenoids are close together in creaky voice, INT might perhaps be expected to be active at the start of the stød and PCA active for opening the glottis again (although, according to the fiberoptic pictures only JR and BF seemed to have more constriction in the posterior part of the glottis in words with stød).

In the Haskins investigation 1972 HA read two words with stød: [pʰeˈdæ:ʼl] and [beˈtʰæ:ʼlə]. The latter word could be compared with [tʰanə] without stød. But there was no difference in the activity in INT for the two words. FJ read six word pairs and moreover two words with and without stød and with the same initial consonant. There were 16 repetitions of each word. In four of the pairs the word with stød had, on the average, a slightly higher peak in INT, in the three others a slightly lower peak. There was thus no difference, nor was there any difference in the duration of the activity. In her case PCA was also recorded. It did not show any consistent difference for the stød. But it showed a somewhat higher activity in the preceding voiceless consonant in words with stød in four pairs starting with [pʰ, kʰ] and [h], the average difference being 27 mv. This is in good agreement with the general finding that voiceless initial consonants have stronger airflow in words with stød (see p. 149) though this difference was not significant for FJ.

In the 1974 investigation the material is very restricted. Three subjects (MF, LG and PM), whose INT and PCA were recorded in connection with an investigation of obstruents (see Hutters 1984), also read the three words [vɛn], [vɛnʼ] and [vɛ:ʼn] twelve times in the frame [de ... di siɒ̯]. Moreover, the text contained a certain number of words with stød which did not have any counterparts without stød. PM's INT was not very reliable, whereas the other recordings were good. The twelve mingograms of each word were superposed and scrutinized for LG and MF.

LG read the sentences rather quickly, and his stød was not very strong. There was decrease of intensity, but hardly any irregularity. Two simultaneous recordings of his INT had been made with a slightly different placement of the wire. In one the peak before the start of the vowel was slightly higher in [vɛn’] than in [vɛn], in the other recording the relation was reversed, and in both there was complete overlapping. In all cases the INT decreased slowly down to the valley for the (voiceless) [d̥-] of the frame. No differences between the three words could be found.

MF read the sentences very slowly and with a very strong stød with a long irregular phase of around 9 cs, starting about 15 cs after the start of the vowel. In [vɛn’] there sometimes seems to be a real closure. Her tempo was rather irregular, which made averaging somewhat problematic, and therefore her recording was not utilized by Hutters, but on the other hand the slow reading often makes the interpretation of individual words easier, and both INT and PCA have peaks and valleys at the expected places for voiceless consonants and vowels. Her INT had a slightly higher peak before [vɛn’] than before [vɛn] and [vɛ:’n], but there was complete overlapping. There was, however, a small difference in the vowel, [vɛn’] and [vɛ:’n] showing a small valley, whereas there was hardly any dip in [vɛn] (see Fig. 35 showing average curves of INT for the three words). For LG a possible valley in the vowel could not be distinguished from the valley for [d̥], whereas for MF, who spoke more slowly, this dip came later.

The different sentences used for the investigation of obstruents also contained some examples of stød, but it was not possible to see any particular activity in INT for the stød. In most cases there was a pause or a voiceless consonant following the vowel with stød, so that a possible valley would not be visible, but the word [bʁø:’ðəd] had a small valley before the stød in almost all cases in MF's recording, whereas a corresponding valley is rare in, e.g., the words [bi:ðə] or [pʰi:nə].

Thus, if there is any difference it rather consists in a certain relaxation of INT for the stød. Hirose (see Hirose et al. 1974) also interprets the examples of Danish stød as having no particular activity in INT.

As for PCA, LG does not show any activity for the stød, but he has a peak for the following [d] of the frame. MF very often makes a pause after the test word. In these cases she has two peaks in PCA, one for the pause and one for the [d̥]. In [vɛn’] the peak is in the [n] and could theoretically indicate PCA activity for the opening of the glottis, but in [vɛ:’n] it comes after the stød, and there is also a peak in [vɛn], so it must be interpreted as activity for the opening of the glottis for the pause in all cases. She sometimes has a small peak in PCA

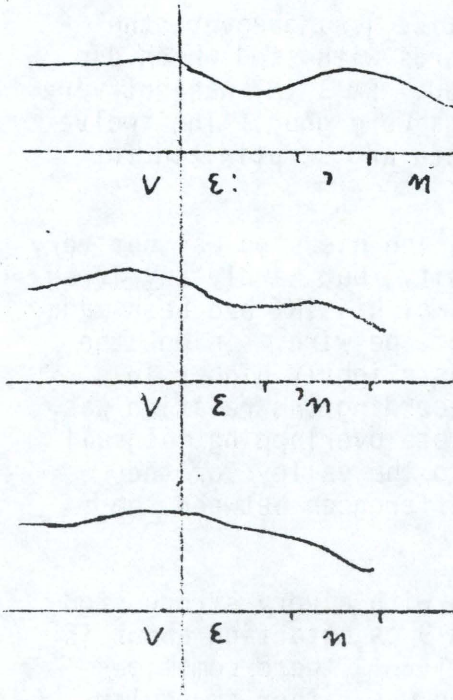


Figure 35

EMG (INT) average of 12 examples. Speaker MF.

for the [v] in [vɛn’] and [vɛ:’n] but not in [vɛn]. This may have to do with the degree of voicing in these tokens ([v] sometimes being voiceless).

Faaborg-Andersen (1957) included some examples of words with and without stød in his electromyographic investigation of the intrinsic laryngeal muscles. There were only two examples with INT, one had higher activity in the word with stød and one the same level of activity.

It may be of interest to compare the activity of INT and PCA in the stød with the activity in related phenomena, above all hard attack. Hirose and Gay (1973) investigated the activity of various laryngeal muscles in vocal attack in the syllables [ʔa], [ba] and [ha] said in isolation by English speakers. INT was recorded for three speakers. One had no difference in INT between [ʔa] and [ba]. One had a very small extra peak in INT around 20 cs before the onset of voicing, and one had a clear peak about 25 cs before the onset of voicing in [ʔa]. PCA was recorded for two speakers only. One speaker had a small peak at voice onset in [ʔa], not in [ba], and the other also had some activity, but less clearly.

In the 1974 investigation a series of [ʔ ʔ ʔ] and [ʔa ʔa ʔa] was used as identification test for INT and PCA at the start and at the end of the recording. The distance between the bursts was approximately 17 cs for PM, 20 cs for LG and 40 cs for MF. After the first mentioned series [ʔ ʔ ʔ] there was in all cases a short burst of sound, [ə]; PM and MF also pronounced [ʔa ʔa ʔa] with varying length of the [a]. - INT and PCA showed the expected alternating activity (see, e.g., Hirose and Gay 1972, and Hirose 1975; Hirano and Ohala 1967 also found alternating activity in PCA and LCA in a series of [ʔ ʔ ʔ]). - The INT activity starts in or just after the preceding sound and has its peak 5-10 cs before the onset of voicing, but it cannot be decided whether the peak would have been lower for [ə] or [a] without hard attack.

As for PCA it starts at the peak of INT in the case of LG, and also in the case of MF if [ʔ] is only followed by a short burst of sound. Moreover, it occurs at a corresponding point in time for PM, i.e. before the [ʔə] or [ʔa], and it <u>might</u> therefore be seen as an activity for the opening of the glottis after [ʔ]. However, in the case of MF's [ʔa ʔa ʔa] which sometimes have a vowel duration of 10-14 cs, it very often starts after voice onset, about 10-13 cs before the end of the vowel, and thus its function is to open the glottis for the pause (which often contains a rather strong airflow). Thus PCA activity is not needed for the opening of the glottis from closed to voicing position.

In the text there are various examples of hard attack, and in two cases it comes after a vowel followed by two voiced segments, the vocalic contexts being [eːˈʔeː] (24 examples) and [ɔˈʔeː] (12 examples). Here the vocal folds are already in voicing position, and an extra activity might not be needed for the second vowel. However, MF, who always has a strong hard attack with around 7 cs of glottal constriction, always has a valley in INT with a new peak just before voicing onset in [ˈeː]. But a valley with new onset of activity is also often found for LG, who has hard attack only in a limited number of cases, and this valley and new peak have no connection with the presence or absence of hard attack; the peak is evidently a new onset of activity for the following (stressed) syllable. Thus nothing speaks for a particular activity of INT for stød or hard attack (except for one of Hirose's speakers).

Faaborg-Andersen (1957) found a very small increase of activity (10 mv) in INT in two examples of [ʔɔb] compared to [bɔb]. He concludes that there is no significant difference.

As for PCA, LG and PM have no activity in these cases, but MF has a peak in PCA during the glottis constriction, i.e. simultaneously with the INT peak, in contradistinction to the normal activity in these two muscles. The occurrences of a peak in PCA are in agreement with two cases in Hirose and Gay 1973, but in only one of the two cases does it coincide with a peak in INT. These peaks in PCA seem in fact to have something to do with the opening of the glottis after hard attack (probably in the case of a strong constriction, stronger than in a stød). Fig. 36 shows average curves of INT and PCA for MF's [ɔˈʔeː].

b. Vocalis (VOC), crico-thyroideus (CT)
and the lateral cricoarytenoideus (LCA)

(i) General function of CT, VOC and LCA.

The three muscles VOC, CT and LCA are treated together because they have partly common functions, which gives some problems for the interpretation. It is well known and generally accepted that CT's main function is to lengthen the vocal folds, making them thinner and more tense and thus raising the pitch. VOC is also normally active in raising the pitch in the chest voice. This has been documented in numerous papers, e.g. Faaborg-Andersen 1957 (7 subjects), Shipp and McGlone 1971 (14 subjects), and Dejonckere 1980 (15 subjects). It is therefore also often active in pitch accent (cf., e.g., Sawashima et al. 1973,

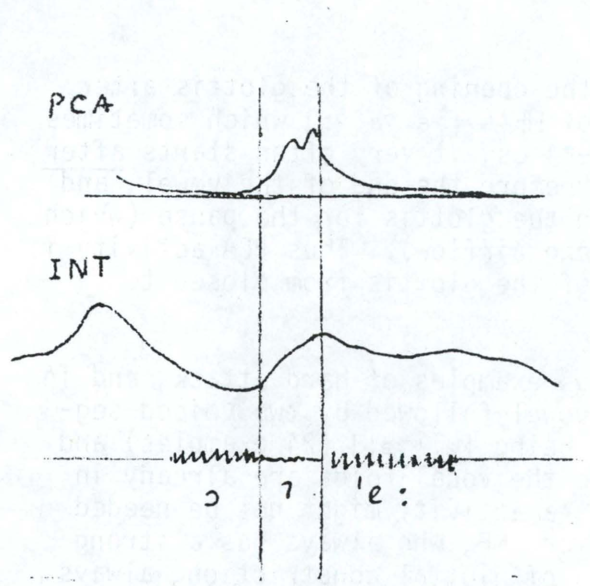


Figure 36

EMG (PCA and INT) of hard attack; average of 12 examples. Speaker MF.

Yoshioka and Hirose 1981, and Gårding 1970) and sentence intonation (Harris et al. 1969). Its pitch raising function is, however, less consistent than that of CT. Atkinson's subject (1978) showed a rather low correlation between VOC and Fo, and Shipp (1982) found much intra-subjective variation in this respect. This was also the case in the present investigation (see below). It is also somewhat uncertain what the mechanism is: whether the increased tension in VOC raises the pitch, or whether its task is to keep the vocal folds close together against their tendency to be slightly separated by the CT-tension (Hirano 1981), or whether VOC acts as an antagonist to CT in the sense that simultaneous activity for lengthening (CT) and shortening (VOC) of the vocal folds results in increased tension (Gårding 1971, Daniloff et al. 1980, Zemlin 1981), or whether, finally, a contraction of the body of the vocal folds makes the cover looser and better suited for vibrations when it is being drawn tight by the activity of CT. The last mentioned explanation has been proposed by Hirano in 1972 (see Hirano 1977 and 1981); he finds, however, that in the case of strong contraction the whole vocal fold may be stiffened (1977). The distinction between cover and body and the emphasis on the relatively free vibration of the cover was proposed already in 1957 by S. Smith (the "membrane-cushion theory") on the basis of a rubber model of the vocal folds, whereas Hirano has based his description on an anatomical analysis.

It can sometimes be seen in published curves that VOC starts around 5 cs later than CT and also has its peak correspondingly later (e.g. Gårding 1970), and it is a very general phenomenon in the present material. (In Yoshioka and Hirose 1981 the peak is earlier in VOC than in CT, but this is because VOC is active for the hard attack in the test word, which begins with a vowel.) The later rise of VOC cannot be due to a slower contraction time, on the contrary: VOC is quicker than CT (cf. Sawashima 1974, Atkinson 1978 and Mårtensson 1982). The later activity in VOC speaks for Hirano's theory, and the fact that VOC does not always participate in Fo-rise speaks against the assumption that both CT and VOC must be contracted to produce tension.

VOC has, however, a number of other functions. It is always active in voiced sounds, and generally starts its activity around 25 cs before the start of an utterance after a pause, whereas CT remains inactive during the same period and does not show activity until there is a pitch rise. This is mentioned by Gårding (1970) and is seen very often in the present material. (The initial period of VOC activity may be preceded by a short period of CT activity and VOC inactivity.) On the other hand, VOC is relaxed for voiceless sounds (and more so for aspirated than for unaspirated consonants) so that there is a clear dip in the curve (see, for Danish, Hutters 1984), whereas CT's behaviour is less clear and more dependent on the pitch contour. Finally, VOC has been found to be active in cases of strong glottal constrictions, e.g. in hard attack (Faaborg-Andersen (1957), Hirose and Gay (1973), Gårding (1970)) and Korean laryngealized (fortis) consonants (Hirose et al. 1973). CT did not seem to have any function in the Korean stops, whereas its role in hard attack is less clear. Hirose and Gay (1973) found stronger activity in [ʔa] than in [ba] in CT, whereas Faaborg-Andersen found this stronger activity only in VOC. Lindquist (1972) says that glottal stops show peaks in VOC but inhibition of CT, and Gårding (1970) has found this confirmed for one subject producing a glottal constriction in emphatic Swedish [jaʔa], but for another subject (Gårding et al. 1970) this is not clear. On the whole, the activity of CT must always be seen in connection with the pitch contour; and glottal attacks after a pause (Hirose and Gay 1973, Faaborg-Andersen 1957) are not easy to interpret because all adductor and tensing muscles and in many cases the raising muscle CT as well, must be active in this position.

As for LCA, it acts, of course, in a different way from VOC, because its attachments are different (its contraction brings the vocal processes together and raises the medial compression of the vocal folds (see, e.g., Laver 1980), but in speech it very often has the same functions as VOC: it has been found to be active in glottal stops (Hirano and Ohala 1967), glottal attack (Hirose and Gay 1973), Korean fortis stops (Hirose et al. 1973); it also takes part in voicing and pitch raising, and the curves of VOC and LCA are often practically indistinguishable, but it seems to be particularly active in glottal constriction (Hirose and Gay 1973) and its activity in pitch raising seems to be somewhat less regular (see, e.g., MacNeilage 1972).

In order to judge the function of the muscles the time lag between muscle contraction and acoustic effect must be taken into consideration. This aspect has not been studied very extensively, but some observations have been made. Buchthal and Faaborg-Andersen (1964) studied the time interval between the onset of electrical activity and the onset of phonation, using isolated vowels and syllables. For CT they found an interval of 10-20 cs. But onset of phonation may require longer time than changes during phonation. Simada and Hirose (1971) found that the activity of CT begins to increase 12-18 cs before the onset of the speech signal and that it reaches its peak 7-8 cs before the corresponding peak in the pitch contour. Fujimura (1977) mentions 10 cs as a typical lag time in speech gestures. Atkinson (1978) used the method of shifting the EMG-curve forward in time until the correlation with the Fo curve was at its maximum. In this way he found extremely short time lags (15 ms for VOC and LCA, and 40 ms for CT). He finds excellent agreement between these findings and the results of experiments with cats and dogs, cited by Sawashima (1974), but these latter experiments concerned twitch time of single motor units, which should be expected to be shorter. Niels Jørn Dyhr (personal communication) found 5-7 cs as the most common distance between the peaks of CT and Fo. In the present material I found 5-10 cs in the majority of the cases both for the start and the peaks, but the distance may be both shorter and longer, and there is much variation, the distance between the start of activity in CT and Fo being more uncertain than the distance between peaks. When the vocalis muscle participates in pitch, it may sometimes have its peak after the Fo peak, or stay at a high level after Fo has decreased.

(ii) Function of VOC, LCA and CT in the stød

The EMG activity of laryngeal muscles in the Danish stød was first investigated by Faaborg-Andersen (1957) and later by Fischer-Jørgensen and Hirose (1974) (see the summaries in section Id, p. 79-80 above). In both investigations the activity of VOC was found to be stronger in words with stød than in words without stød, but the material was restricted.

In the present investigation recordings of VOC and CT were made in 1974 for seven subjects reading list 1 in the frame: [de: ... di siɒ̯]. The subjects were BF, BH, BM, HU, JJ, NR and JR. NR read the list (which contained 8 word pairs) 6 times, JR 3 times, the others 10-12 times. BM and JR also read list 3 ([bibibi] nonsense words). A new recording of BF was made in 1977 and again in 1979. In both cases list 1 was read, both in the normal frame and in the frame [di siɒ ˈalə ...] or [di siɒ ˈɔsə ...] (1977 and 1979, respectively), and list 1 was further supplemented with the short list 2 with stød on secondary stress (see Appendix I, p. 1).

According to the activity of VOC in stød the seven subjects form two groups. Five speakers (BF, BM, HU, JJ and NR) have a clear peak in VOC in words with stød, whereas two (JR and BH) do not show any difference between words with and without stød. The two groups will be treated separately.

Group 1

In the first group it is pretty certain that the recorded muscle is really VOC. Besides for the stød, it shows activity for swallowing and for [ʔa ʔa ʔa], and there are valleys for voiceless consonants (see Hutters 1984), except for NR, where the valleys appear irregularly and are very weak. Moreover, BF, BM and NR have clear activity for rising pitch in the tests, but for BM and NR there is only very moderate activity for pitch rise in the sentences. The recording of CT was successful for BM, HU, JJ and BF (1974 and 1977; in 1979 LCA was chosen for BF instead of CT). For BH CT was allright in the test, but then the wire must have moved, and during the word list it looked rather like sternohyoid. For NR LCA was hit instead of CT. Thus VOC and CT can only be compared for BF, BM, HU and JJ.

The higher activity in VOC for stød is quite consistent for the five subjects of group 1, the average activity being higher in the word with stød in all 75 pairs. Moreover, 67 word pairs from list 1 were analyzed individually for significance. In BF's recording 1974 the activity of VOC increased in the middle of the recording, but within the same reading the word with stød always had higher activity than the corresponding word without stød. All other recordings (i.e. 59 pairs) could be analyzed by means of the Mann-Whitney test. One pair (NR [du / du:']) showed 1% significance, all other pairs 0.1%, and only 9 pairs showed a slight overlapping, whereas there was no overlapping at all in the other pairs. The difference in VOC activity is thus very stable.

The extra activity in VOC in words with stød begins in most cases 2-4 cs after the start of the vowel (for BF 1974 often a few cs before vowel start). It has its peak 10-13 cs after vowel start (see Table XVIII), i.e. shortly after the point where the stød phase (with decrease in frequency or irregular vibrations) starts (see Table XII, p. 111 above). The activity decreases quickly again and crosses the curve for the corresponding word without stød approximately at the end of the vowel for long vowels with stød and at the end of the consonant in the cases of short vowel with stød in the following consonant (sometimes about 2 cs later) (see Appendix IX, p.261-265). The activity is thus generally of rather brief duration (10-20 cs in the average curves and often somewhat shorter in individual examples), and the peak may be very sharp.

Table XVIII

Distance (in cs) from vowel start to the peak in VOC in words with stød (grand means of 7-8 averages).

BF 74	BF 77a	BF 77b	BF 79a	BF 79b	BM	HU	JJ	NR	av.
10.9	11.3	11.6	9.7	10.8	11.8	12.6	11.3	13.0	11.4

There is thus a clear connection between VOC and stød. CT has, however, also a peak in the beginning of the vowel in words with stød. In BF's curves it occurs about 8 cs earlier, just after the start of the vowel, whereas for BM, HU and JJ it is later, only 2-4 cs before the peak in VOC. This difference between the speakers can be explained by their Fo-curves. BF has a jump up to the stressed syllable in stød words (with fall in the following unstressed syllable), whereas the other speakers have approximately the same pitch as in the preceding vowel of the frame in words with [ɛ] (only slightly higher after voiceless consonants) and a jump up only in words with [i] or [u] (the following unstressed syllable normally being higher than the stressed syllable). Therefore their CT-peak is later. This explanation is corroborated by the fact that BM (and partly HU) have an earlier CT-peak in words with [i] and [u] than in words with [ɛ] (this, by the way, shows that CT-activity may be involved in the intrinsic pitch difference, a question which is being investigated by Niels Jørn Dyhr).

The presence of a peak both in VOC and in CT in the stressed vowels of words with stød raises the problem whether the peak in VOC might be partly (or completely) due to the pitch movement, and (on the other hand) whether the peak in CT (or at least its amplitude) may have anything to do with the stød.

In order to throw some light on this question some selected examples (two for each speaker and recording) will be analyzed in more detail (they are averages of 10-16 examples (6 for NR)).

Fig. 37 shows VOC, CT and Fo for the words [hu:ən / hu:'ən] and [kʰɛlɒ / kʰɛl'ɒ] in BF's 1974-recording. It is evident that his VOC is very active in pitch rise in words without stød. The peak is clearly later in VOC than in CT, and the activity continues for a longer time (this is not an unusual phenomenon, see p. 160 above). In words with stød the peak in VOC also comes later than the CT-peak. It can therefore not be excluded that the VOC-peak in stød-words might be mainly due to the pitch contour. This was the reason why BF was recorded again in 1977 and 1979. A correct analysis of his recordings was also particularly important because he is the only speaker for whom subglottal pressure and airflow have been recorded simultaneously with the electromyographic recordings.

In 1977 and 1979 BF was asked to say the words both in the generally used frame [de: ... di siɒ̯] and in the frame [di siɒ̯ 'alə ...] (1979: 'ɔsə), where the test word was found finally after an emphatic word, and where it might thus be expected to have low pitch. Fig. 38 contains the same words as Fig. 37. In Fig. 38a the frame is [de: ... di siɒ̯]. Here again VOC is active for pitch and has a later and longer peak than CT in the words without stød. But whereas the CT-peaks are of approximately the same height in words with and without stød (in accordance with the Fo-curves), the peaks in VOC are considerably higher and sharper in words with stød than in words without stød. A good deal of this activity must be for the stød. In Fig. 38b, where the stød word is said finally after an emphatic word, the pitch is definitely low, but BF still makes the same difference in pitch contour between words with and without stød, although with smaller amplitudes. However, just as in Fig. 38a, the peak in VOC in stød words is considerably higher and sharper than should be expected on the basis of its activity in words without stød. If it were a peak for higher pitch, it would also be expected to continue

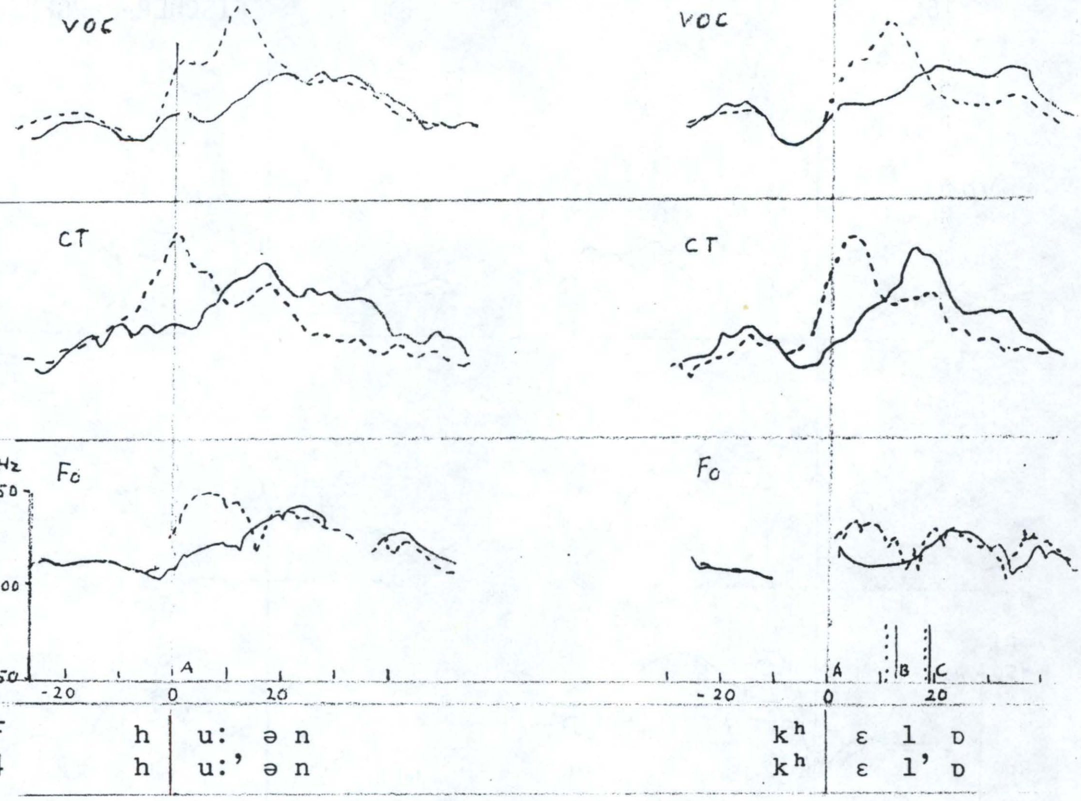


Figure 37

EMG of VOC and CT, and Fo for words with and without stød. Speaker BF 1974. A: start of vowel (line-up point), B: end of vowel. C: end of postvocalic consonant.— no stød,-- stød. ⟝—⟞ 10 cs.

for a longer time. In [kʰɛl'ɒ] (both in Fig. 38 a and b) there is a small peak in VOC at the line-up point, which is also found in the words without stød. This is evidently activity for voicing after the valley for the initial aspirated [kʰ]. The same is seen, though less clearly, in [hu:'ən] in Fig. 38 a.

Fig. 39 a and b show the words [lɛ:sɒ / lɛ:'sɒ] and [đu / đu:'] read by BF in 1979 in the same two frames. Here CT is replaced by LCA, which looks almost exactly like VOC. The second peak in [lɛ:sɒ / lɛ:'sɒ] must be activity for voicing after [s] (cf. that there is no peak at the line-up point after [l]). Both VOC and LCA show activity for pitch rise in Fig. 39 a, but the peaks in words with stød are much higher than should be expected for pitch. In Fig. 39 b the pitch is low in the test words (but they are still different), and particularly in the word [đu:'] the peaks in VOC and LCA cannot be explained by the pitch contour (and a peak after the voiceless [d̥] should occur earlier).

In 1977 and 1979 BF also read the word pairs [ˈhɔi̯ˌhu:sə / ˈhɔi̯ˌhu:'səð] and [ˈɑu̯ˌtʰæ:lə / ˈɑu̯ˌtʰæ:'lɒ] with stød in a syllable with secondary stress (he has low pitch in secondary stress in contradistinction to the normal contour in the Copenhagen Standard). Fig. 40 a, b and c contain three examples. In Fig. 40 a the pitch contour of the second syllable is almost the same

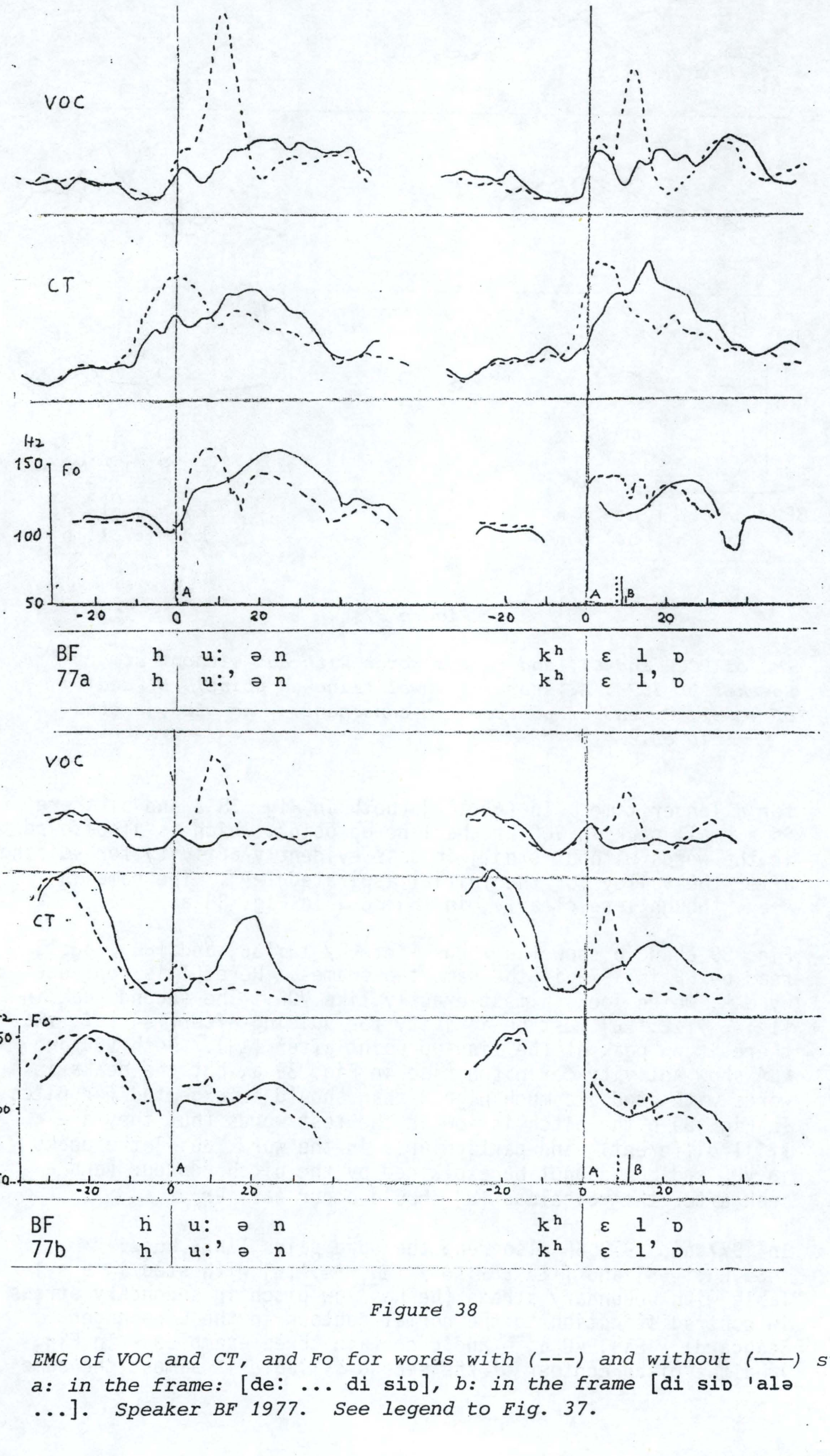


Figure 38

EMG of VOC and CT, and Fo for words with (---) and without (——) stød. a: in the frame: [de: ... di siɒ], *b: in the frame* [di siɒ 'alə ...]. *Speaker BF 1977. See legend to Fig. 37.*

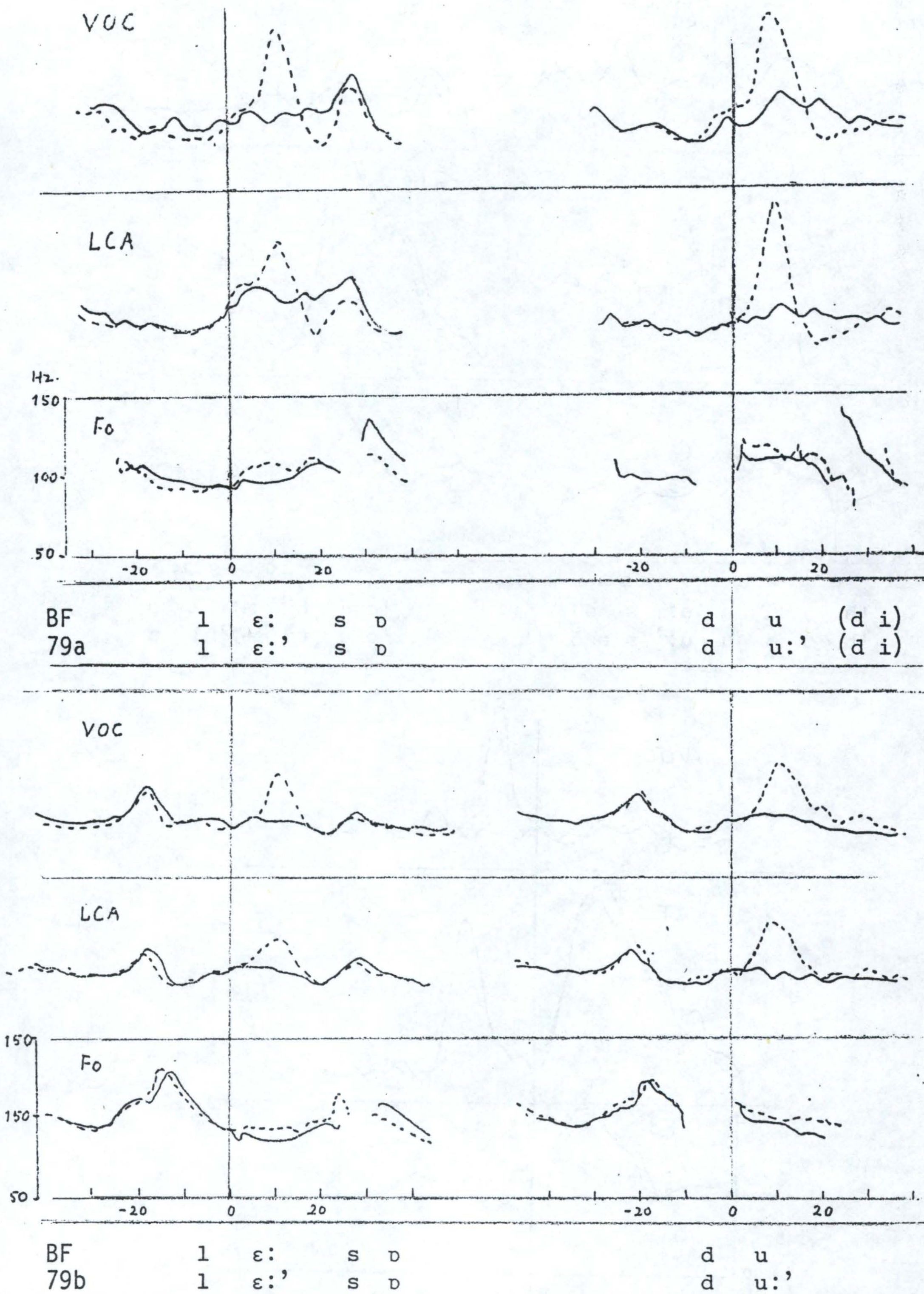


Figure 39

EMG of VOC and LCA, and Fo of words with (---) and without (——) stød. (a) in the frame [de: ... di sip̥], *(b) in the frame* [di sip̥ 'ɔsə ...]. *Speaker BF 1979. See legend to Fig. 37.*

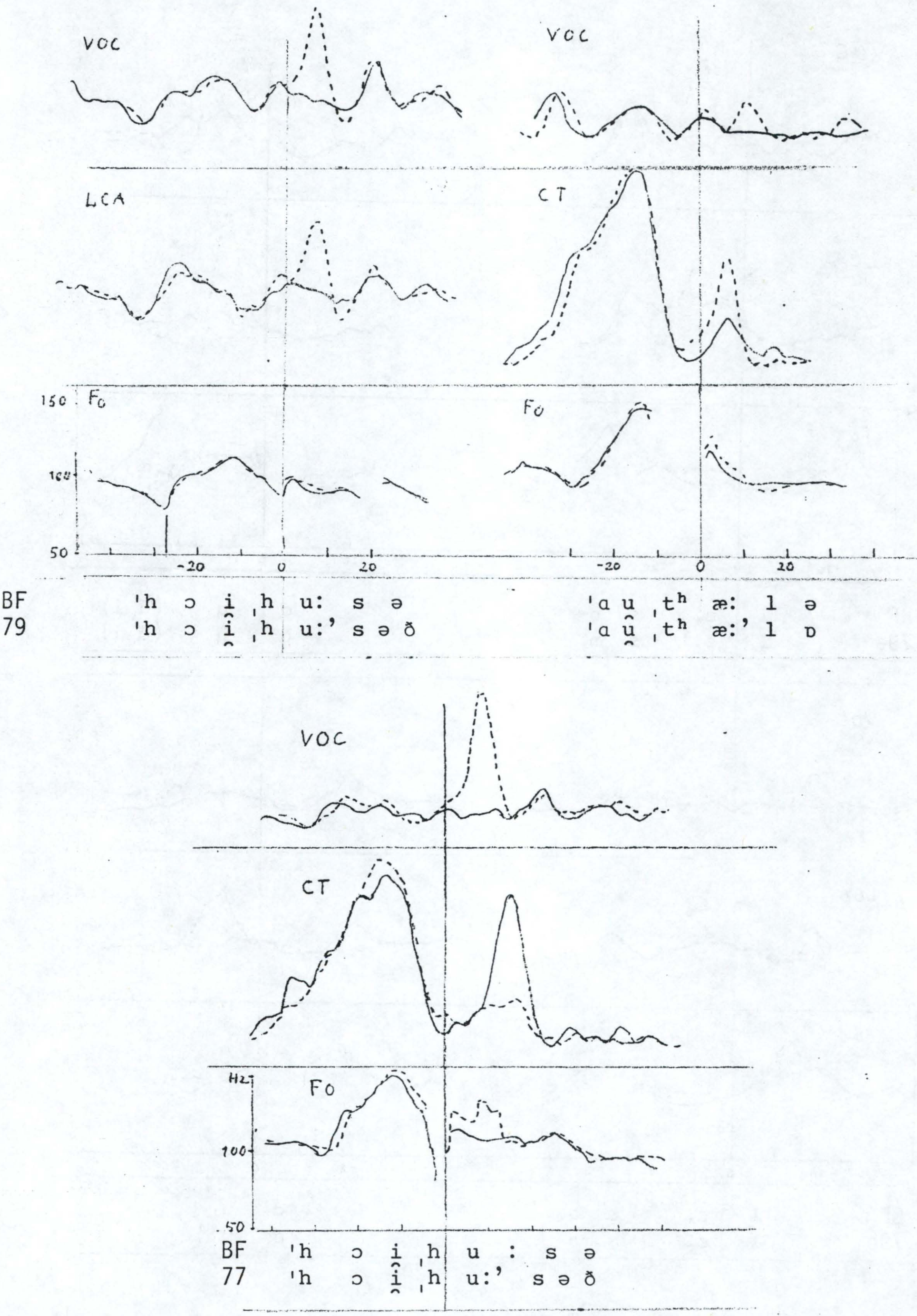


Figure 40

EMG of VOC and LCA, and Fo of words with (---) and without (——) stød in secondary stressed syllables. Speaker BF. See legend to Fig. 37.

in the words with and without stød, so that the peaks in VOC and LCA must be for the stød. In Fig. 40 b the peak in VOC in [æ:'] is rather low, but it should not be expected to be very high for an [æ] (see below).

The conclusion is that the peaks found in VOC for stød-words in BF's recordings may be somewhat influenced by the pitch contour, but that the activity must be mainly for the stød. This can be concluded from (1) the consistent temporal difference between the peaks in VOC and CT (8 cs), which is smaller and less clear when only pitch is involved, (2) the height of the peak compared to the height for pitch rise alone, (3) the sharp peak with quickly decreasing activity compared to the activity for pitch, which remains high for a longer time.

As for CT, its behaviour can be almost completely understood as activity for the pitch contour. In [hu:'ən] and [kʰɛl'ɒ] 1974 (Fig. 37) and in [hu:'ən] 1977 (Fig. 38 a) it has a dip corresponding to the peak in VOC, which might be interpreted as an inhibition (as assumed by Lindquist 1972) or as a preparation for the frequency dip during the stød, but in [kʰɛl'ɒ] 1977 (Fig. 38 a) it is too late for that. - On the other hand, in [kʰɛl'ɒ] 1977 (Fig. 38 b) CT has a surprisingly high peak for the rather low first syllable of the test word. This is also the case for most other words in this series, i.e. [kʰɛ:'lɒ, lɛ:'sɒ, pʰi:'bɒ, sɛn'], whereas [hu:'ən] has a relatively high peak in only 5 out of 16 examples, and therefore a low average peak (Fig. 38 b), and [du:'] has no peak. In all these cases the test word comes after an emphatic word with a strong and quick rise and fall of CT and Fo, and it may therefore be necessary to make a new start (BF also often makes a short pause before the test word). Words without stød have a different pitch contour with rising pitch on the second syllable, which may require a different CT-activity. The CT-peak in [ˈɑu̯ˌtʰæ:'lɒ] (Fig. 40 b) is more problematic. In this case the pitch contour of the second part of the compound is very similar in the words with and without stød. Nevertheless the word with stød has a much higher CT-peak. Still more enigmatic is the CT-peak in [ˈhɔi̯ˌhu:sə] in Fig. 40 c which, contrary to the preceding example, is found in the word <u>without</u> stød (it is quite regular in all 12 tokens).

The other speakers give less problems. Fig. 41 shows the word pairs [hu:ən / hu:'ən] and [vɛn / vɛn'] read by JJ with recording of VOC, CT and Fo. He has very clear activity in CT for pitch rise, but hardly any activity in VOC for pitch. (This was also the case in the introductory identification test, which contained strongly rising and falling tones.) Nevertheless he has high peaks in VOC in words with stød. They can hardly have anything to do with pitch.

Fig. 42 shows the pairs [kʰɛ:lə / kʰɛ:'lɒ] and [vɛn / vɛn'] read by HU. Just like JJ, she has activity in CT for pitch rise, but hardly any activity in VOC. The high peaks in VOC in words with stød must therefore reflect activity for the stød.

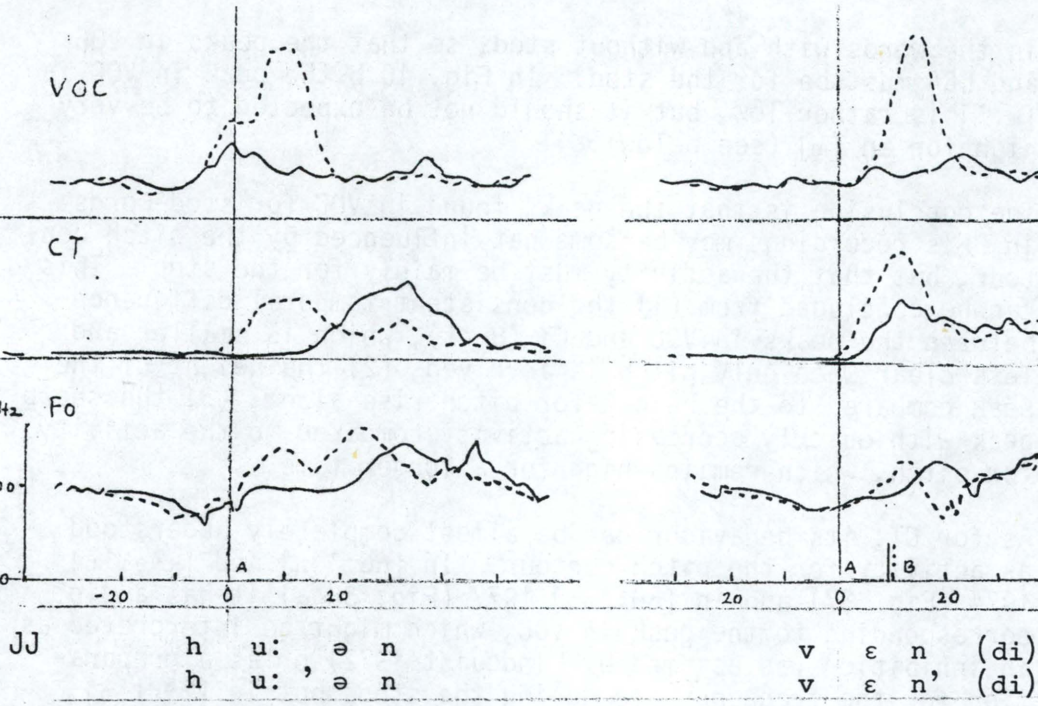


Figure 41

EMG of VOC and CT, and Fo of words with (---) and without (——) stød. Speaker JJ 1974. See legend to Fig. 37.

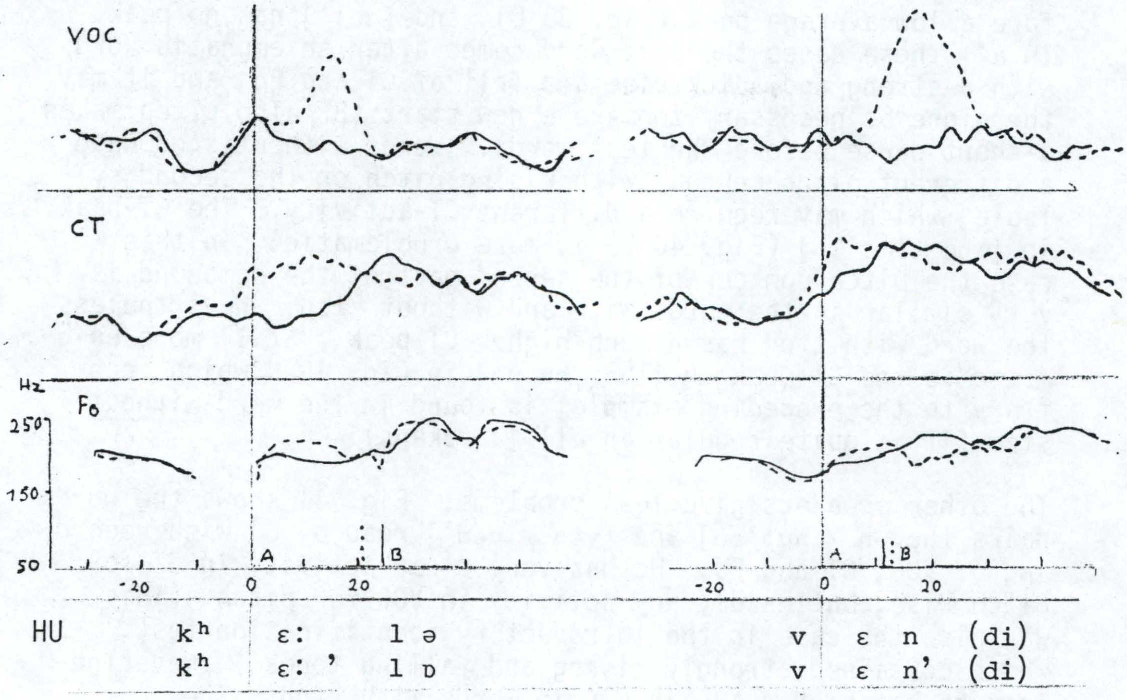


Figure 42

EMG of VOC and CT, and Fo of words with (---) and without (——) stød. Speaker HU 1974. See legend to Fig. 37.

Fig. 43 contains the word pairs [kʰɛ:lə / kʰɛ:'lɒ] and [du / du:'] read by BM. In the identification test he has activity in VOC for pitch (except for falsetto), but it is very weak in the text. The peaks in words with stød are so much stronger than the small rise for pitch in words without stød that they clearly reflect activity for the stød.

Fig. 44 shows the word pairs [kʰɛlɒ / kʰɛl'ɒ] and [du / du:'] read by NR, with recording of VOC and LCA. The curves of these two muscles are very much alike. Both have activity for pitch rise, but the peaks in VOC and LCA in [kʰɛl'ɒ] cannot have anything to do with pitch, since in that case it would be much later (cp. the contour for the word without stød), and in [du / du:'] the pitch contours are almost identical and cannot in any way explain the peaks in VOC and LCA.

It is apparent from these examples that activity in VOC is closely connected with the stød. A final problem is whether it might be activity in order to obtain the right conditions for voicing after the glottal constriction. This was the interpretation which was suggested for INT activity prior to hard attack, and it has also been proposed for VOC by Fujimura (1977 a and b) for fortis consonants in Korean and for the [ʔ] in Swedish [jaʔa]. As far as the Swedish example is concerned, I think that the peak comes too early in the Skåne example to permit this interpretation. And as far as the activity in words with stød is concerned, this assumption can be refuted. In the first place there is very often voicing all through the stød, only with a dip in frequency, and in the second place clear peaks in VOC are also found in the cases where the stød occurs before a voiceless consonant (as in [lɛ:'sɒ]) or finally before a pause, e.g. [sɛn'] and [du:'] in BF 1977 b and 1979 b (see Fig. 38 b and Appendix IX).

For all speakers the VOC activity tends to be stronger in words with high vowels and in monosyllables than in disyllables with [ɛ]. I cannot explain this tendency.

BF sometimes has a small dip in CT corresponding to the peak in VOC. But the other three speakers (BM, HU and JJ) do not have such a dip. Thus, in their speech at least, CT is only active for the higher start of the pitch in words with stød but does not seem to have anything to do with the stød phase or the dip in frequency concomitant with it. In the Swedish accent 2, on the other hand, which has a dip in pitch at the end of the first syllable in Standard Swedish, there is a corresponding dip both in VOC and in CT (Gårding 1970).

BM, HU and JJ have rising pitch in the unstressed syllable both after syllables with and without stød. Very often the activity in CT decreases in spite of a new peak in the following weak syllable, but that is also the case in words without stød, see, e.g., BM [kʰɛ:lə / kʰɛ:'lɒ] (Fig. 43) and JJ [vɛn / vɛn'] (Fig. 41). Only HU maintains a high activity in CT. Otherwise it seems to be particularly active for the first rise.

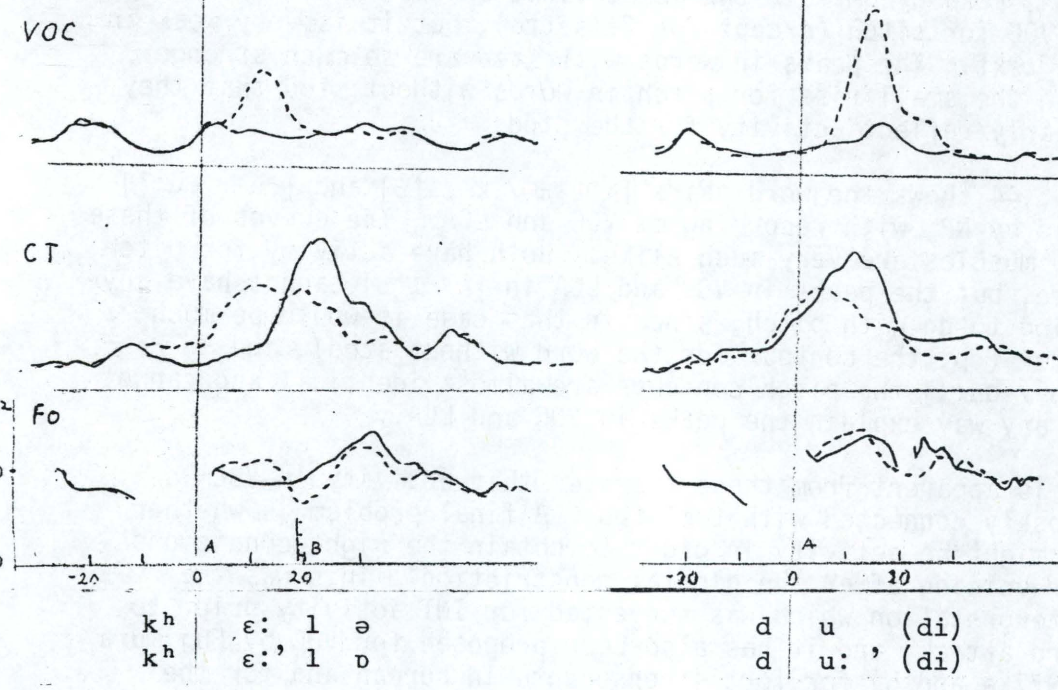


Figure 43

EMG of VOC and CT, and Fo of words with (---) and without (——) stød. Speaker BM 1974. See legend to Fig. 37.

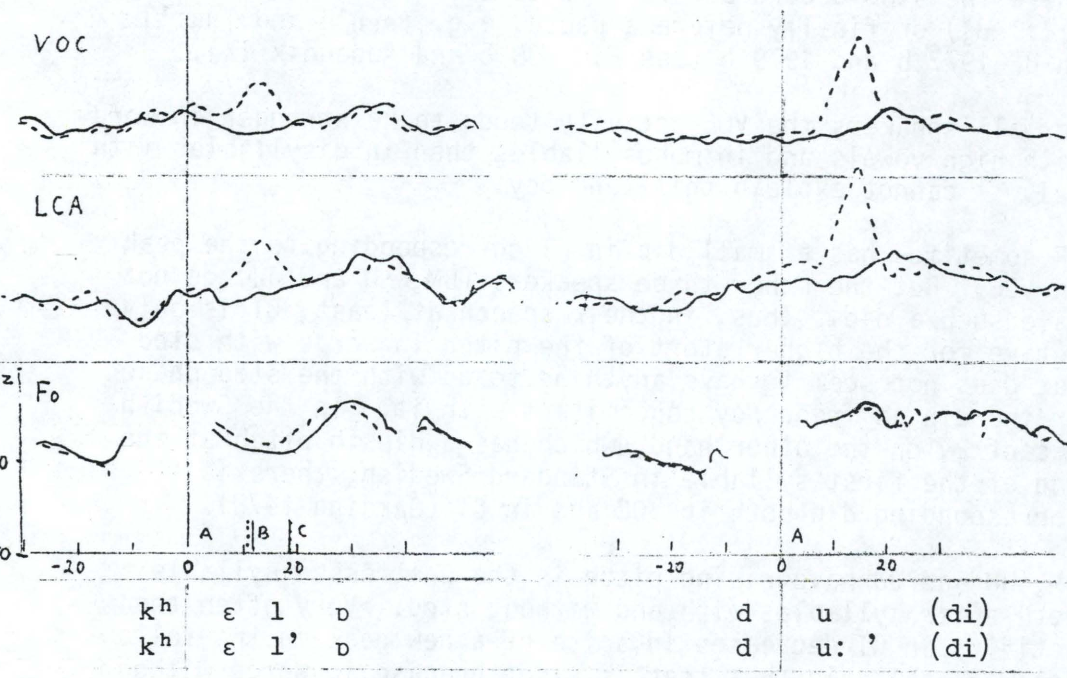


Figure 44

EMG of VOC and LCA, and Fo of words with (---) and without (——) stød. Speaker NR 1974. See legend to Fig. 37.

For HU there is possibly a slight contamination with LCA since her CT is active in swallowing. It is true that Faaborg-Andersen (1957) found activity in CT for swallowing in a number of cases, but he used needle electrodes which may move, particularly during swallowing, and according to Hirose's clinical experience (based on thousands of cases) CT is always suppressed in swallowing (personal communication, see also Hirose 1971).

VOC and LCA were also found to be active for hard attack for BF, and in this case the activity is often still stronger than for the stød. In 1977 and in 1979 he was asked to include the word [alə] as a test word and to pronounce it partly with soft attack and partly with hard attack. He did not always succeed in pronouncing it with soft attack, but a comparison between the cases with soft or moderately hard attack and the cases with an evident hard attack shows a clear difference (see Fig. 45). The 1979 recording showed the same activity in LCA. CT does not show any inhibition. On the contrary, it has a small peak (cf. that Lindquist 1972a found CT inhibition in glottal stop, and Gårding (1971) found decrease in CT-activity in [ʔ] as a boundary signal in Swedish). Activity in VOC was also found in occasional hard attacks in the recordings of other speakers and in a large number of cases in a recording of a German subject. The peak coincides with the start of the hard attack, and it is therefore highly probable that it is activity for glottal constriction, not for voicing after the glottal constriction.

Group 2

In JR's and BH's VOC recordings it was not possible to see any difference between words with and without stød. JR read list 1 only twice in the first session and once in the second session, because the tape-recorder broke down in the first session, and the recording had to be interrupted in the second session. This list has therefore not been averaged. But list 2 ([bibibi] words) was read 10 times and has been averaged. Fig. 46 shows "VOC", CT and Fo for two word pairs [ˈbi:biˌbi:ˈbi/ˈbi:ˈbiˌbi:ˈbi] and [bibiˈbi:bi/bibiˈbi:ˈbi]. "VOC" and CT look practically alike, and the relatively small extra activity for the syllables with stød can be explained completely by the Fo contour. For comparison BM's VOC of the same pairs is given below.

BH's recording was not computer-averaged, but four pairs were averaged manually. It is not possible to compare her VOC with her "CT", because it was evidently not CT, but perhaps the sternohyoid or a contamination. Fig. 47 shows her VOC for the pairs [vɛn / vɛnˈ] and [kʰɛ:lə / kʰɛ:ˈlɒ]. In [vɛnˈ] there is slightly more activity than in [vɛn], but there is extensive overlapping; the same was the case for [pʰi:ˈbɒ / pʰi:bɒ], whereas [lɛ:sɒ / lɛ:ˈsɒ] and [kʰɛ:lə / kʰɛ:ˈlɒ] are quite alike.

There are two possible explanations of the missing activity in VOC: (1) The muscle aimed at was not reached, and (2) these speakers do not use their vocalis muscle but some other muscles for the stød. They both had an acoustically and perceptually clear stød.

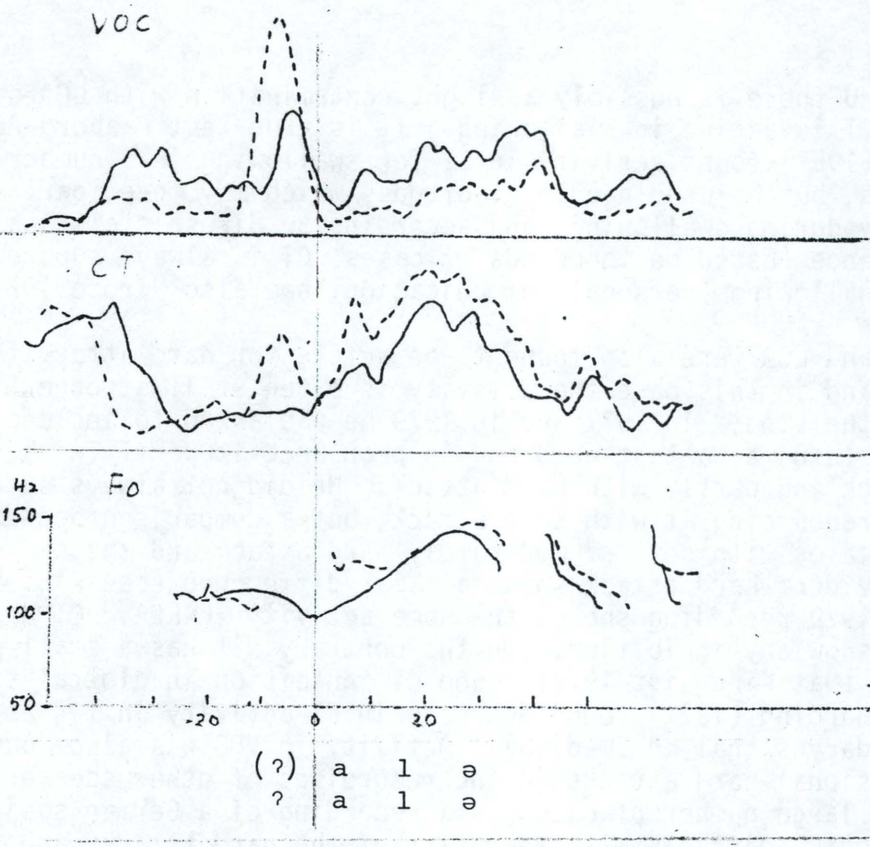


Figure 45

EMG of VOC and CT, and Fo in words with soft (or moderate) glottal attack (——), and with hard attack (---). Speaker BF 1977. See legend to Fig. 37.

(1) BH's VOC seems in many respects in accordance with expectations. In the identification test it reacted to swallowing, to voicing and very clearly to [ʔa ʔa ʔa], but not to pitch, and it has clear valleys for voiceless consonants. Birgit Hutters (1984) accepted it as a good VOC. According to its reactions it might be INT, but it is hardly possible to hit INT when aiming at VOC. A better guess is perhaps that the wire has slid somewhat outwards, as it did in the case of CT, and that it was rather the lateral part of the thyro-arytenoid muscle, also called thyromuscularis, not the inner part, the vocalis proper, which was recorded. These two parts seem to be anatomically somewhat different (Bowden 1974, p. 297), and may not have quite the same function. But not all scholars think that it is possible to make this distinction (e.g. Zemlin 1981), and those who make the distinction do not ascribe the same function to thyromuscularis. Some (e.g. Daniloff et al. 1980) assume that its function is to shorten and relax the vocal folds, others (e.g. Broad 1973, Sonesson 1968, and Laver 1980) assume that it may help closing the glottis by drawing the vocal processes together (like LCA). In the latter case it should be supposed to be active in the stød.

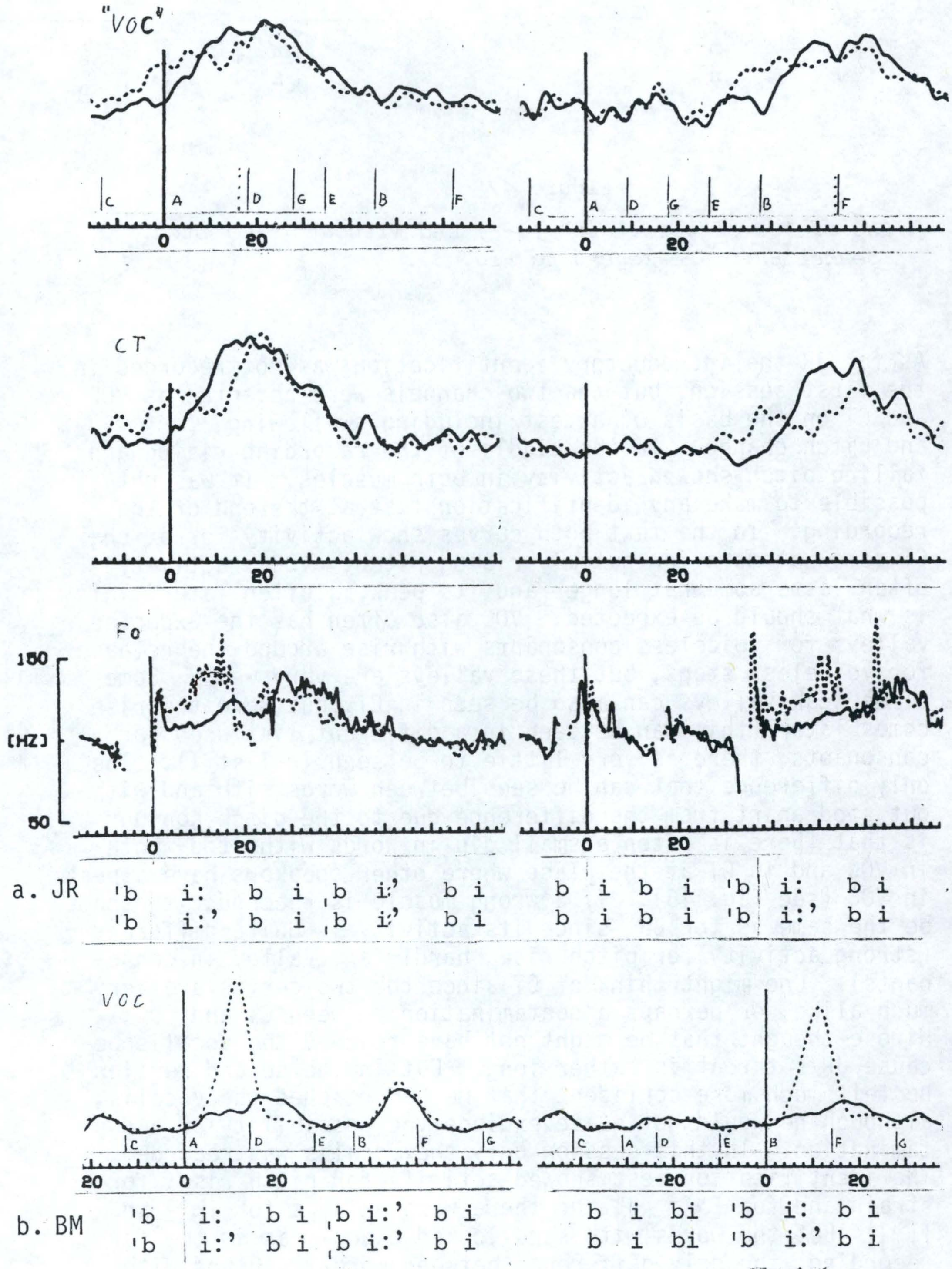


Figure 46

a. EMG of "VOC" and CT, and Fo of words with (---) and without (——) stød in the first and the third syllable. Speaker JR 1974.
b. VOC of the same words read by BM. See legend to Fig. 37.

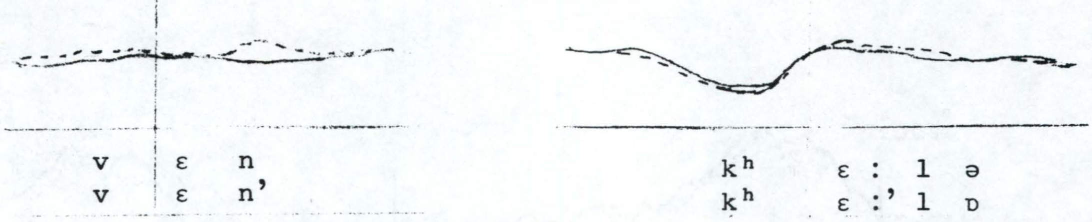


Figure 47

EMG of VOC of words with (---) and without (——) stød. Speaker BH. See legend to Fig. 37.

As for JR the introductory identification was not recorded in the first session, but the two channels were accepted as VOC and CT on the basis of a test including swallowing, [ʔ ʔ ʔ] and pitch change. In the middle of the recording rising and falling pitch showed activity in both muscles. It was not possible to make any identification test at the end of the recording. In the text both curves show activity for pitch, CT somewhat more for quickly rising pitch. VOC's activity often lasts somewhat longer and its peak is often later. This is what should be expected. VOC also often has the expected valleys for voiceless consonants with rise around the release for voiceless stops, but these valleys are very weak. Sometimes weak valleys can also be seen in CT, but here the rise comes later (this can be seen in a different list used for consonants; there is very little to be seen in list 1). The only difference that can be seen between words with and without stød apart from the difference due to the pitch contour is that there is often a small dip in words with stød, both in VOC and in CT at the place where other speakers have a peak in VOC (see Fig. 46). If a wrong muscle is reached, it cannot be the same as for BH, since its activity is quite different (strong activity for pitch rise, hardly any valley in consonants). One might think of CT since the two curves are very much alike, or perhaps a contamination between CT and VOC. Hirose thought that he might not have reached the vocalis because JR's throat is rather long. But in the second session he felt much more confident that he had reached the vocalis, although he would not quite exclude the possibility of a contamination. In this session only the vocalis was recorded. The identification test showed activity for pitch rise, for strain and for [ʔ ʔ ʔ], and there were valleys for $[p^h]$ and $[t^h]$. But the words with stød looked exactly as in the first recording, the only difference between words with and without stød consisting in an earlier rise in the first case because the syllable was higher (as was also the case in the first recording) (see Fig. 46).

(2) Particularly in JR's case much speaks in favour of the second explanation, viz. that this subject does not use his vocalis muscle in the stød. It should be remembered that although his stød sounds exactly like that of other speakers,

it differed acoustically by often having a rising Fo with small irregularities and no Fo dip. Moreover, the fiberoptic pictures of his vocal folds showed a very strong constriction between the ventricular folds, so that his vocal folds could practically not be seen. BH also had a stronger contraction of her ventricular folds than most of the other subjects, but not as strong as in the case of JR. However, BF and BM, who have activity in VOC, also have adduction of the ventricular folds. A constriction of the larynx above the vocal folds in glottal stops was found by Lindquist, e.g. in [ʔ ʔ] used in the case of hesitation in Swedish (1969, 1972 a and b). He is of the opinion that a contraction of the sphincter muscles including the aryepiglottic sphincters is important in laryngealization and that a glottal closure can be made without assistant activity in VOC. An increase of activity in the aryepiglottic sphincters results in a shortening and thickening of the vocal folds, and it also serves as a pitch lowering mechanism. Simultaneous activity in VOC serves to keep the pitch high. He also explains the low pitch in the Danish stød by this contraction. It is possible that JR and BH use this mechanism, but just JR did not have regular pitch drop in the stød. Catford (1977) criticizes Lindquist for generalizing one possible way of making a glottal stop. Unfortunately JR's and BH's sphincter muscles were not recorded, nor has any recording been made of their LCA.

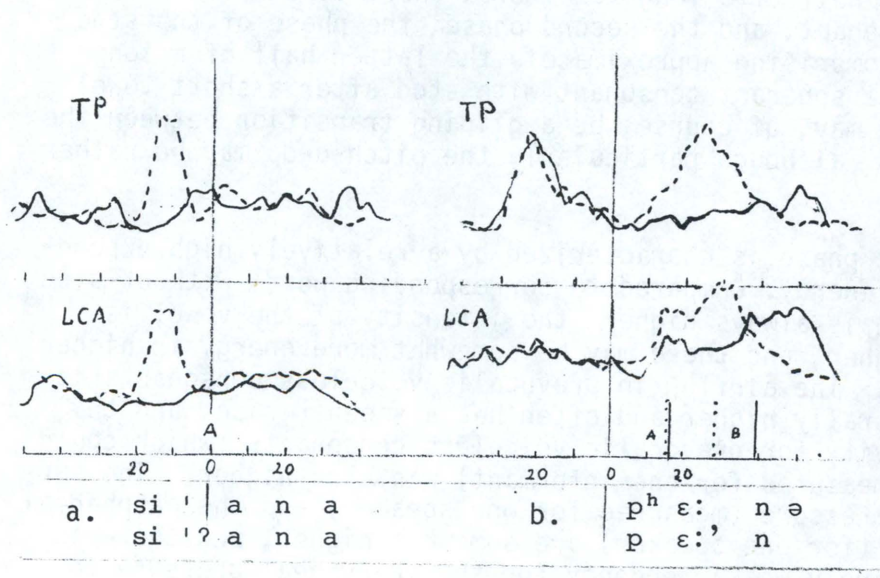


Figure 48

a. *EMG of LCA and TP in hard (---) and soft (——) attack. Speaker FJ. Line-up point start of vowel.*

b. *EMG of LCA and TP in words with (---) and without (——) stød. Speaker FJ. Line-up point start of implosion in [p]. A. start of [ɛ(:)], B. end of [ɛ(:)]. See legend to Fig. 37.* ⟼ *10 cs.*

In 1977 a recording of FJ's LCA and thyropharyngeus (TP) was undertaken at the Haskins Laboratories in cooperation with Seiji Niimi. FJ read list 6 (with 20 repetitions) containing examples of stød and of hard attack (see Appendix I). There was a very clear peak in both muscles for hard attack (see Fig. 48a). There was also activity in both muscles for strong stød like [pʰɛ:'n]and [pʰɛn'] said rather vigorously (see Fig. 48b). In [li:'] there was a clear peak in LCA but not in TP. But in disyllables like [kʰɛ:lə / kʰɛ:'lɒ] the difference was very small in LCA, and there was hardly any difference in TP. It must, however, be remembered that in FJ's fiberscope recordings there was hardly any adduction of the ventricular folds. TP showed strong activity for the pharyngealized Danish [ʁ], and for the ending *-er*, pronounced as a pharyngealized [ɒ] by this speaker. The peak at the start in Fig. 48b is probably due to a certain pharyngealization of the [æ:] in [sæ:] as a sort of boundary signal before the test word. There is no peak in [si:], nor in [tʰæ:lə].

IV. SUMMARY AND DISCUSSION

A. SUMMARY

In the preceding sections the stød has been described from different angles. In accordance with Svend Smith (1944) a distinction was made between the first phase, i.e. approximately the first half of a long vowel or a short vowel before a sonorant consonant, and the second phase, the phase of the stød proper, comprising approximately the latter half of a long vowel or a sonorant consonant with stød after a short vowel, but there may, of course, be a gliding transition between the two parts, although particularly the pitch-drop may be rather abrupt.

The first phase is characterized by a relatively high expenditure of energy: Compared to corresponding words without stød the pitch is always higher, the intensity of the vowel is often higher, and there may be somewhat more energy in higher formants. The airflow in prevocalic voiceless consonants is also generally higher and often has a steeper rise, and the PCA-activity for prevocalic voiceless consonants (which could only be measured for one informant) was also higher. The subglottal pressure (measured for one speaker) and the esophageal pressure (for one speaker) are somewhat higher, and there is a (relatively weak) tendency for the pharyngeal pressure to be higher in the initial consonant. Whether the larger contact area in palatograms of vowels with stød belong to this first phase cannot be decided. The difference in airflow was not found in monosyllables, and the pitch difference was also smaller in monosyllables, but in most monosyllables a short vowel without stød was compared to a long vowel with stød, and the smaller difference might be due to a tendency for words with short vowels to have relatively higher pitch and airflow.

The second phase, the stød proper, is characterized by a strong fall in intensity (which, however, starts already during the first phase, except for HU), and very often by a decrease in fundamental frequency followed by or combined with irregular vibrations (but BRP and often JR have rising Fo). Moreover, there is a tendency to a decrease in the level of the lower harmonics; inverse filtering shows a decrease in the negative spikes, and the integrated curve (the flow curve) shows a decrease in glottal flow and a longer closure time. There is also lower oral airflow and a tendency to lower pharyngeal pressure; and there is decrease in subglottal pressure, but it is still slightly higher than in the words without stød. Fiberscopic pictures of the larynx show constriction of the vocal folds and adduction of the ventricular folds, but with large interindividual variation. Relatively high subglottal pressure combined with low airflow also points to glottal constriction. Finally, five out of seven (and if the Haskins investigation is included, seven out of nine) speakers show a consistent strong activity of the vocalis muscle starting during the first phase of the vowel, but with its peak shortly after the start of pitch decrease or irregular vibrations, thus preparing for the second phase. LCA showed a similar peak in the cases where it was measured (three subjects plus one from the Haskins investigation).

Finally, long vowels with stød were found to be significantly shorter than long vowels without stød (but only in distinct speech), whereas sonorant consonants with stød were significantly longer than sonorant consonants without stød.

B. DISCUSSION

1. THE STØD AS A PHONATION TYPE

In some of the preceding sections the stød was compared to creaky voice. It may be useful now at the end to take these scattered observations up again and raise the problem of the stød as a phonation type. This is not a simple question, since phonation types are described differently by different scholars, and the terminology is by no means unambiguous; and moreover, the stød is not always implemented in the same way.

Catford (1977) defines phonation as any laryngeal activity of speech that has neither initiatory nor articulatory function. According to this definition the difference between chest voice and falsetto should be included, but they are generally treated as two registers within normal voicing, probably because this difference does not seem to have any linguistic function. Hollien (1974), however, sets up three registers, distinguished by their fundamental frequency domain: loft (= falsetto), modal (= normal voice) and pulse register. The latter is identified with creak (or vocal fry), which by other scholars is placed in the system of phonation types as a step in a dimension of glottal stricture.

Ladefoged (1971 and 1973) describes the different phonation types in one dimension according to glottal stricture with increasing stricture from voiceless sounds over breathy voice, murmur, lax (slack) voice, normal voice, tense (stiff) voice, creaky voice, creak, and ending with glottal stop. This is a gliding scale, and he does not always distinguish between creak and creaky voice or between murmur and breathy voice.

Catford (1964 and 1977) also uses the dimension of stricture, comprising breath, whisper, voice and creak. Creaky voice and murmur are not considered as steps in this scale, but as combinations (creaky voice as a combination of creak and voice, and murmur as a combination of whisper and voice). Tense voice is considered to belong to a different dimension called location and comprising full glottal, anterior and ventricular location. He considers tense voice to be produced with closed cartilagenous glottis, so that only the membranous part vibrates (hence the name "anterior"). These dimensions may be combined in different ways. Both whisper and voice may be anterior, and creak often, but not necessarily, is anterior. The cartilagenous part of the glottis is narrow, but there need not be any active compression.

Lindquist (1969, 1972a) also uses the stricture dimension, called "adduction", and comprising voice, lax voice, breathy voice and voiceless, thus starting from Ladefoged's mid point: voice. The other end of Ladefoged's stricture scale (voice, creak and glottal stop) is considered to be a different dimension called laryngealization. Creaky voice is lax creak, and whisper is a laryngealized form of breathy voice or voiceless.

Finally Halle and Stevens (1971) sets up a rather different system comprising four binary features: ± constricted, ± spread, ± stiff and ± slack (i.e. two dimensions with three steps in a binary formulation). According to this system breathy vowels are + spread, - constricted, - stiff and + slack, whereas creaky voice is - spread, + constricted, - stiff and + slack. But creaky vowels are distinguished from glottalized vowels, which are also - spread and + constricted, but + stiff and - slack.

In a paper on articulatory parameters (1979) Ladefoged distinguishes between glottal aperture and glottal tension. Of course, articulatory parameters, i.e. parameters that need to be controlled in a model of speech production, are not the same as linguistic features. Nevertheless, it is conspicuous that he now states that glottal aperture is relevant for voiced-voiceless, whereas glottal tension determines phonation types. He thus seems to have modified his system.

Laver (1980) gives extensive summaries of the preceding literature (except for Halle-Stevens). He describes the following main types: modal voice, falsetto, whisper, creak, harshness and breathiness. Like Catford he sets up combined types, e.g. creaky voice, harsh voice, etc., and like Catford he treats tenseness separately, but in contradistinction to Catford he includes supralaryngeal tension in this type.

In spite of all these different systems there is, fortunately, a good deal of agreement on at least some of the characteristica of the individual phonation types, e.g. breathy voice and creak.

The Danish stød is mentioned by various authors. Catford (1964) says (cautiously) that creaky voice may be one form of the Danish stød. Abercrombie (1967, p. 101) also mentions the Danish stød as creaky voice, and both of them have had good opportunity to listen to Danish. Ladefoged (1983) does not use this label, but says that *"the Danish glottal catch .. may also be considered an additonal phonation type"*. Thus he is not certain that it can be identified with any of the current types. Finally, Halle and Stevens (1971) describe the Danish stød as glottalized. As mentioned above, this feature differs from creaky voice in their system by having stiff vocal folds. But since in this system stiffness is correlated with high pitch, and since vowels with stød often start on a high pitch followed by a fall, they suggest that the first part of a vowel with stød is + constricted + stiff and then changes into - constricted - stiff. This is obviously in contradiction to the facts, since it is always the second part of the vowel that shows constriction in the glottis, not the first part (see particularly the section above on the fiberscope investigation, but the same is apparent from oscillograms, airflow curves, etc.). But it is, of course, correct that the first and the second part of a vowel with stød cannot be described as belonging to the same phonation type.

The phonation types which may be relevant for a description of the stød are tense phonation, creaky voice, creak and, perhaps, harsh voice.

It is evident that the second phase of the stød, the stød proper, belongs in the constricted end of Ladefoged's stricture dimension. Perhaps one might describe an exaggerated stød as a glottal stop, a strong stød as a creak, and a milder stød as creaky voice. The perceptual effect of a creak is described by Catford as the sound of a stick being run along a railing, i.e. the pitch is so low that the single pulses are perceived. The distance between them may be irregular. The wide band spectrogram of a creak in Laver 1980, p. 115 looks very much like a strong stød (see, e.g., the spectrogram of PD, p.121 above). Creaky voice is also generally considered to have low pitch (Zemlin 1981, Ladefoged 1973, Catford 1964), but Ladefoged states that this tendency, which he ascribes to a shortening of the vocal folds, may be counteracted by activity in other muscles, e.g. CT, and it is not unusual to find creaky voice combined with higher tone levels in tone languages (see also Matisoff 1973). Moreover, creak and creaky voice are characterized by a low level of Fo (Löfqvist et al. 1983), particularly compared to F1 (Ladefoged 1983, Kirk et al. 1984) and the glottal wave is characterized by a long closure time (Zemlin 1981, Kitzing et al. 1982, Javkin and Maddieson 1983) and low glottal flow (Catford 1977, Hollien 1974). It is also characterized by period to period variation in fundamental frequency (Monsen and Engelbretson 1977) also called jitter (Kirk et al. 1984, Javkin and Maddieson 1983). There is often constriction in the larynx, the vocal folds are close together (Ladefoged 1973, Catford 1977, Zemlin 1981), and there seems to be medial compression (Laver 1980). There may also be adduction of the ventricular folds (Hollien 1974).

All these features were also found in the preceding analysis of the Danish stød. There is some disagreement concerning the tension of the vocal folds in creaky voice. Some find that they are close together but with relatively loose borders (Zemlin 1981, Catford 1977), others consider them as stiff, thus apparently Ladefoged (1973). The degree of stiffness in the borders of the vocal folds in the stød cannot be decided on the basis of the fiberoptic pictures.

There are, however, also some divergencies between the description of creak and creaky voice and the properties found for the stød. In the first place all authors agree that in creak and creaky voice the cartilagenous glottis is very narrow, whereas there is an opening in the front, and most assume that the cartilagenous part of the folds do not take part in the vibrations (Ladefoged 1974, Catford 1977), whereas Abercrombie (1967) assumes that they vibrate at a slower rate than the membraneous part. (Ladefoged has given a similar description earlier in his analysis of laryngealization in some West African languages (1964), i.e. separate vibration of the two parts.) In the fiberoptic pictures of the vocal folds only BF and JR showed earlier narrowing of the posterior part, for HU it was rather the opposite, for the others it was difficult to decide, but nothing pointed to a particular narrowing of the cartilagenous part. It is at any rate not a dominating or conspicuous feature of the stød. In this case one should also expect a particular activity in INT, and it should be remembered that INT, which as a pure adductor muscle is active in voicing, is not active in the stød. Only those adductor muscles which are at the same time tensor muscles (VOC and LCA) are active in this case. This, by the way, speaks against placing all phonation types in a single dimension. - To my knowledge, nobody has made electromyographic recordings of the activity of the muscles in creak and creaky voice; but strong vocalis activity has been found for glottal stop, e.g. in hard attack (Gårding 1970, Hirose and Gay 1973) and in Korean forced stops (Hirose et al. 1973), which have closure in the posterior part of the glottis and a small opening in the front (Kagaya 1974).

In the second place, the most consistent acoustic feature of the stød, i.e. the decrease of overall intensity, is never mentioned for creak or creaky voice. On the contrary, Javkin and Maddieson find steeper slopes in the glottal wave in creaky voice and mention that the consequence of steeper slope in the closing phase of creaky voice is higher intensity and intensity of higher overtones, adding that this is characteristic of creaky voice. A steep closure phase in creaky voice was, as mentioned (p. 130), also found by Roach and Hardcastle (1979) and by Esling (1984), and there were indications of this in BRP's flow curves. However, this effect must be counteracted by the low flow amplitude. - Finally Catford (1977) says that there is very low subglottal pressure in creak. But BF's subglottal pressure and FJ's esophageal pressure did not show this. The pressure was decreasing but still higher than in normal vowels.

Thus many features are identical for creak or creaky voice and stød, but it is not quite the same. Stød is not _just_ creaky voice.

The concept of harshness may also be relevant for the stød. According to Laver (1980), who refers to a number of investigations, the predominant characteristic of harshness is aperiodicity of the fundamental frequency, and there is strong laryngeal and pharyngeal tension. In strong harshness the ventricular folds are also involved. MacCurtain (1979) mentions constriction in the laryngopharynx and emphasizes that the pharynx should not be neglected in the description of voice qualities. Harsh voice seems to be used paralinguistically as a sign of anger. But the properties described also apply to the stød. Some cases of strong stød may perhaps be described as harsh creaky voice. But the irregularity in the stød is not just a question of fundamental frequency; there is also irregularity in intensity.

The first part of vowels with stød has some features in common with what is often called tense, tight or pressed voice, i.e. a relatively high subglottal pressure (Laver 1980), relatively strong higher overtones and overall intensity (Laver 1980, Sundberg and Gauffin 1979) and more articulatory energy (Laver 1980). But other features mentioned as characteristic of tense voice are practically the same as those mentioned for creaky voice, e.g. low Fo compared to F1 (Sundberg and Gauffin), low flow pulses (Rothenberg 1972), closed cartilagenous glottis (Catford 1977), constriction of the glottis, medial compression (Laver 1980), and these features are not characteristic of the start of the vowel with stød. For BRP low flow and shorter negative spikes in the inverse filtered curve start rather early in the vowel, but not quite at the start; for FJ the shortening of the negative spikes starts later. And only BRP and FJ had relatively low Fo compared to F1 in the beginning of the vowel, whereas the others did not show any difference in this respect between vowels with and without stød. At the start of the vowel the fiberscope pictures also looked quite alike for vowels with and without stød.

Thus a syllable with stød may be said to start with a relatively strong expenditure of energy, but it is not what is called tense or tight phonation in the literature.

2. CAUSAL RELATIONS BETWEEN THE PROPERTIES OF THE STØD

An important factor when one is looking for causal relations is the temporal relation between the properties investigated.

In this connection the recordings of BF in 1974 are particularly useful since a large number of different types of recordings were made at the same time: electromyography of VOC and CT, subglottal pressure, pharyngeal pressure and airflow as well as the audio signal, which permitted measurement of duration, fundamental frequency and intensity. The discussion will therefore be based mainly on BF 1974. In Fig. 49 a-d the different curves are placed in a vertical column with the same line-up point.

As mentioned in the introductory chapter, Svend Smith proposed the theory that the dominating factor in the production of the stød was a quick contraction and relaxation of the expiratory muscles, causing an abrupt rise and fall in subglottal pressure. The vocal folds are supposed to react to the pressure rise by a constriction of the glottis (there is thus no primary contraction in the larynx). The following abrupt fall in subglottal pressure causes a fall in intensity and sometimes in frequency, and if the tension in the vocal folds is not adjusted sufficiently to the quickly falling subglottal pressure, irregular vibrations may result.

In the first place we must therefore ask: which of the stated differences between words with and without stød can be caused by the change in the subglottal pressure contour? It was found (see p. 151 above) that BF's subglottal pressure was about 1 cm H_2O higher in words with stød, the difference starting at vowel onset (in [lɛ:'sɒ] and [hu:'ən]) or 5-10 cs earlier. In aspirated consonants there is a small difference in pressure during the aspiration, which might perhaps explain the slightly higher airflow (but a wider glottis opening cannot be excluded). The higher subglottal pressure may also be responsible for the tendency to higher intensity at the start of the vowel. The difference between vowels with and without stød was on the average 1.7 dB. According to Flanagan (1958) 3 cm H_2O may cause a rise of 5 dB (= 1.7 dB per cm H_2O), and MacNeilage (1972) mentions 0.5 - 3 dB per cm H_2O (largest effect at low levels).

However, the fall in intensity in the stød cannot be due to the fall in subglottal pressure, since the intensity often starts falling earlier than the subglottal pressure. For BF the intensity decrease starts on the average 5.8 cs after the start of the vowel (in the 1974 recording 4.3 cs), whereas the fall in subglottal pressure in, e.g., [lɛ:'sɒ] and [hu:'ən] is much later (around 15 cs after vowel start). In [pʰi:'bɒ] and [kʰɛ:'lɒ] it is earlier (3-5 cs after vowel start), but it is slow, and a decrease of, on the average, 1.5 cm H_2O in [pʰi:'bɒ] and around 1.0 cm H_2O in [kʰɛ:'lɒ] cannot explain a decrease in intensity which for all speakers is from 10-13 dB. It was not measured for BF, but his intensity curves show a drastic fall.

The recording of esophageal pressure for FJ was not calibrated, but the temporal relations can be observed: in two of the four words (each comprising 10-14 repetitions) the decrease in esophageal pressure and intensity is approximately simultaneous, in the other two the intensity decrease starts 3-4 cs earlier (and it starts earlier in 29 out of 44 individual cases in the four words). At the end of the vowels with stød the esophageal pressure is of the same height (two word pairs) or definitely higher (two pairs) than in the corresponding vowel without stød (see Appendix VII, Fig. 2).

The pitch decrease starts later than the intensity decrease, for BF on the average 9.2 cs after the vowel onset, but still too early to be caused by the decrease of subglottal pressure in e.g. [hu:'ən] and [lɛ:'sɒ], and it is often much too extensive to be explained by the slow and small decrease in subglottal pressure. In [kʰɛ:'lɒ], for instance, the drop in Fo for BF is on the average 15 Hz, and the drop in subglottal pressure during the same time is less than 1 cm H_2O.

As for the high pitch at the start of vowels with stød found in the present investigation and by Riber Petersen (1973) but not by Smith, it cannot possibly be explained by the higher subglottal pressure. For BF 1974 this difference was on the average 27 Hz for long vowels and 19 Hz for short vowels, measured at the maximum, and even Lieberman, who goes farther than anybody else in assuming frequency rise to be due to subglottal pressure, mentions 3-18 Hz per cm H_2O (the highest effect for low intensity, and BF used a rather loud voice (Lieberman et al. 1967)). The general assumption is 2-5 Hz / cm H_2O (e.g. Ohala and Ladefoged 1970, Ohala 1978, Shipp 1982, MacNeilage 1972, Marchal and Carton 1980 and Baer 1979).

The next question to be asked is whether the subglottal pressure change can be the cause of the vocalis contraction. The extra rise in subglottal pressure starts sometimes 3-4 cs before and sometimes 3-5 cs after the start of the extra rise in vocalis activity. The peak is in most cases earlier than the VOC peak (5-9 cs in [pʰi:'bɒ, kʰɛ:'lɒ, kʰɛl'ɒ, vɛn'] and [vɛn'n̩]). This means that it is at least excluded that it can be the glottis constriction which gives rise to the extra subglottal pressure (the fiberoptic pictures also showed that the strong constriction comes in the latter half of the syllable, about the time when the pitch starts falling). The timing difference in most cases permits the hypothesis that the vocalis activity might be a reaction to the rise in subglottal pressure. According to recent research the larynx contains various reflex organs which may react to raised pressure and to a consequent stretching of the tissue. Only a restricted number of spindles have been found (but Baker (1971) found some). There are, however, a number of spiral endings, both in the mucosa, in the muscles and in the joints (see Wyke 1967, 1974 and 1983), and there are afferent fibres in the recurrent nerve feeding the intrinsic muscles (with the exception of CT) (Bowden 1974), which can bring the information to a higher center. The problem is how fast this system works. In the discussions in the

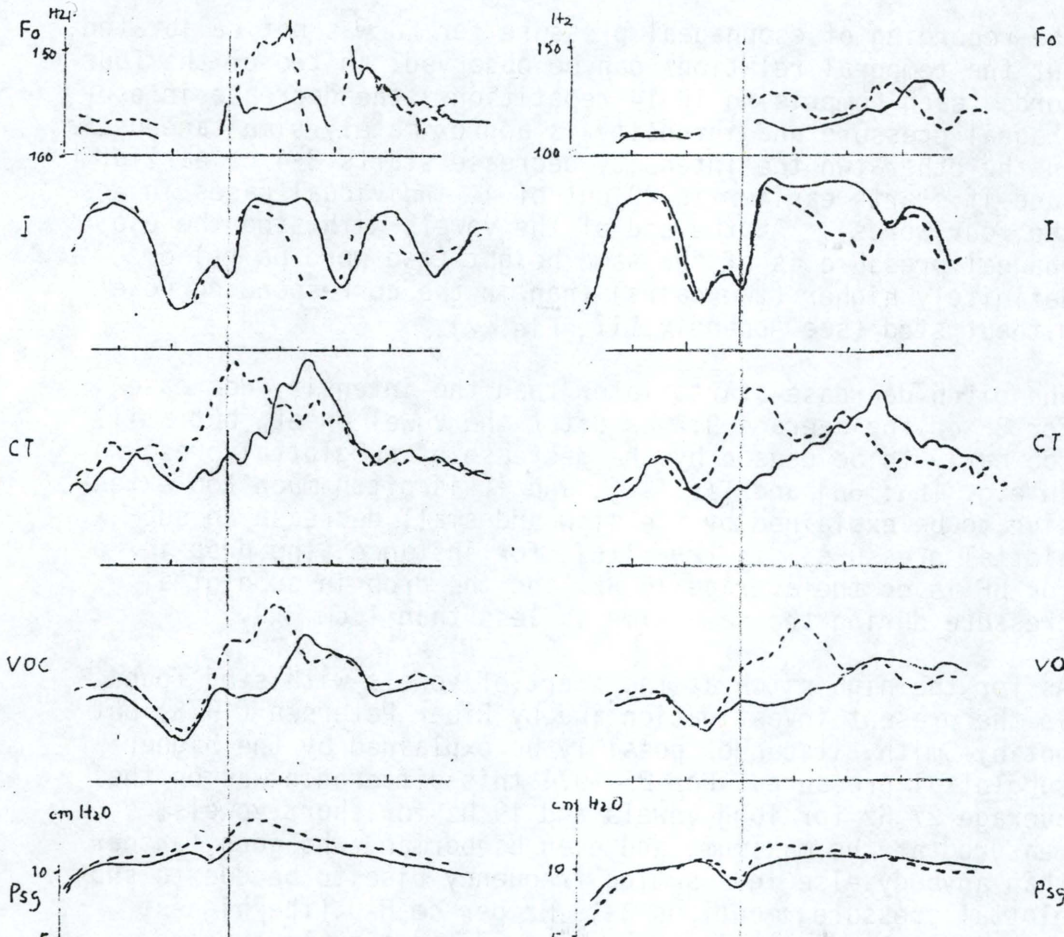


Figure 49 a.

Fo, Intensity (I), CT, VOC, Subglottal pressure (Psg), Pharyngeal pressure (Psup.) and airflow (AF). Speaker BF 1974. —— : no stød, --- : stød. A: vowel start (line-up point), B: vowel end. ¦ no stød, ⁝ stød. ⊢—⊣ 10 cs.

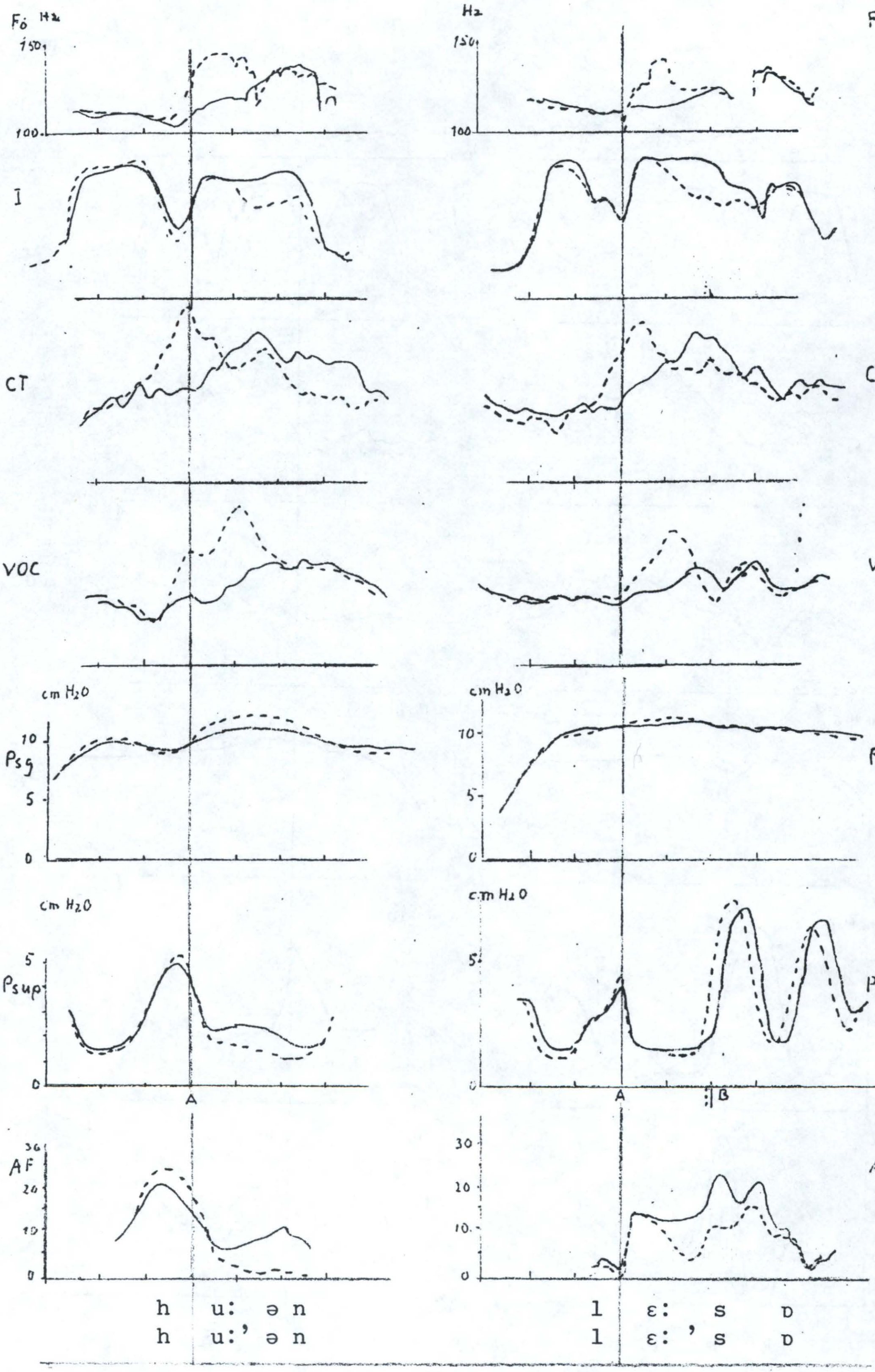


Figure 49 b.

—— : no stød, --- : stød. Speaker BF 1974. See legend to Fig. 49 a.

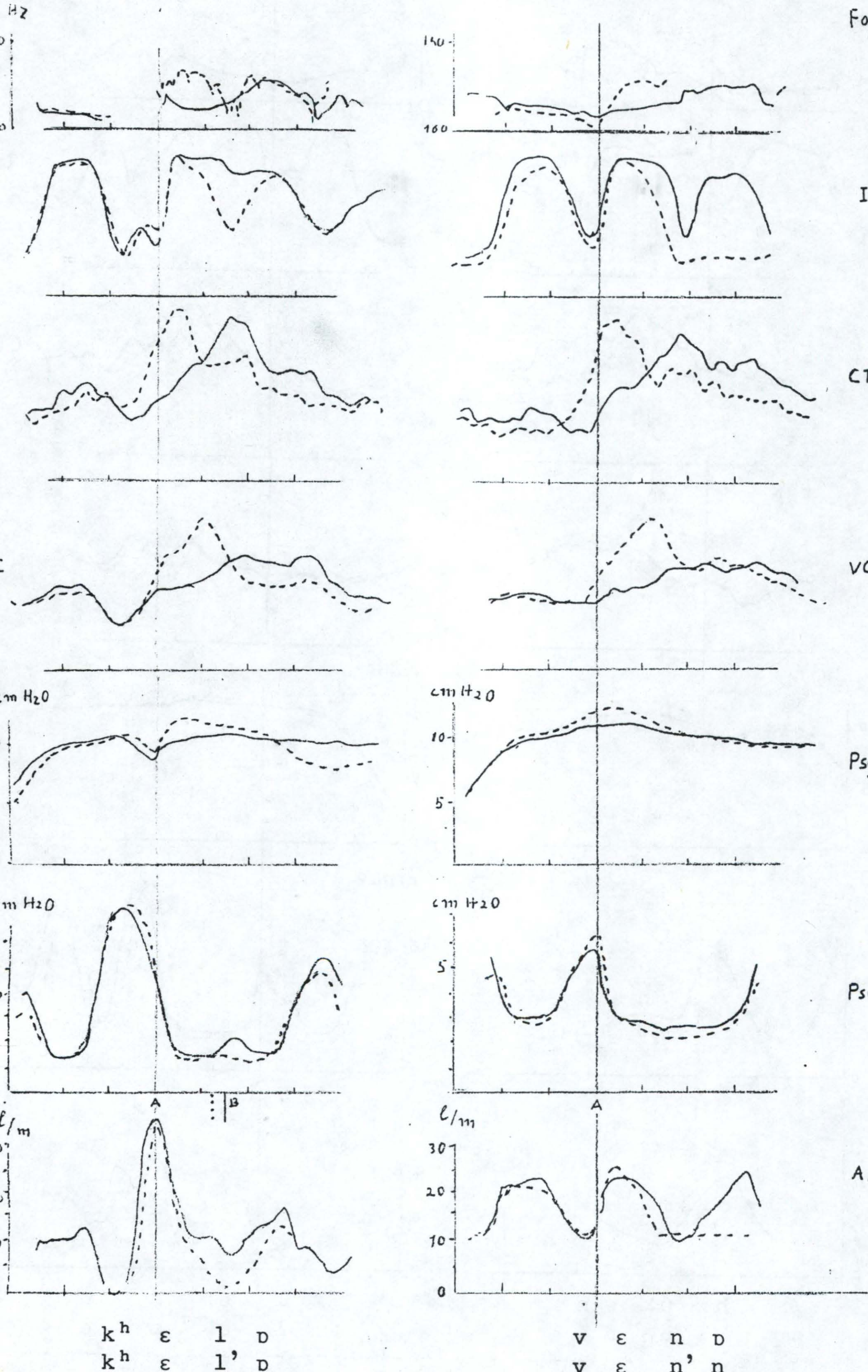


Figure 49 c.

—: *no stød*, ---: *stød. Speaker BF 1974. See legend to Fig. 49 a.*

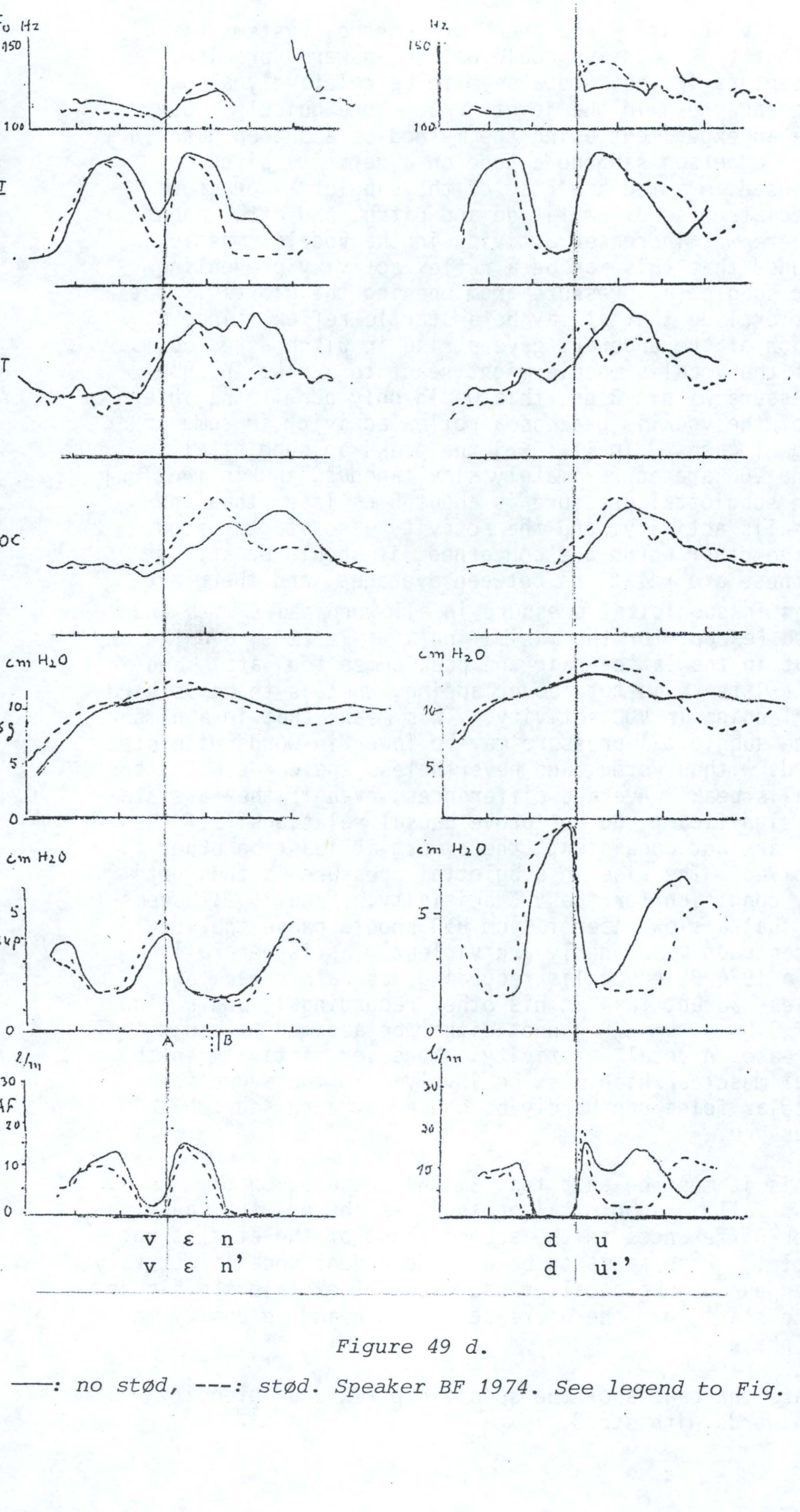


Figure 49 d.

——: no stød, ---: stød. Speaker BF 1974. See legend to Fig. 49 a.

conference on ventilatory and phonatory control systems (1974) Wyke said that this question could not be answered precisely, but the receptors in the mucosa seem to be relatively slow, whereas the receptors in the joints react more quickly. Baer (1979) made an experiment using the method of a sudden push in the chest of a person singing a tone on a definite pitch. The push caused an immediate rise of the subglottal pressure and an immediate rise of amplitude and pitch, and after about 30-40 ms there was increased activity in the vocalis muscle. Baer concluded that this may be a reflex activity preventing the rise in subglottal pressure from opening the glottis. But he does not exclude that it may be a startle reflex, since a painful touch of the underarm gave a rise in pitch after 50 ms. But even if the vocalis muscle might react to a rise in subglottal pressure within 3 cs, this would only permit the interpretation of the vocalis peak as a reflex activity in some of the individual cases. In [lɛ:'sɒ] the peaks in subglottal pressure and VOC are approximately simultaneous, and in [hu:'ən] the peak in subglottal pressure is about 5 cs later than the peak in vocalis activity, and the activity also starts later. As far as the other words are concerned, it should be kept in mind that these are relations between averages, and there are overlappings in subglottal pressure in all word pairs with and without stød (except for the maxima in [kʰɛlɒ/kʰɛl'ɒ] and [hu:ən/hu:'ən], but in the latter pair the peak comes too late), and in [lɛ:sɒ/lɛ:'sɒ] there is total overlapping, whereas there is hardly any overlapping in VOC activity. This means that in a number of cases the subglottal pressure may be lower in words with stød than in words without stød, and nevertheless the words with stød have a vocalis peak. Average differences, even if they are statistically significant, do not prove causal relations. If the differences are not consistent, there must at least be other causes involved. The rise in subglottal pressure is thus not a necessary condition for the VOC acitivity. Finally, it seems improbable that a slow rise of 1 cm H_2O should cause the vocalis muscle to contract so suddenly and violently as is generally the case (in 1974 BF's vocalis recording was rather weak and the peaks less abrupt than in his other recordings), and a slow decrease of 0.5 - 1 cm H_2O cannot either be assumed to cause a sudden decrease in vocalis activity. Moreover, activity in the supraglottal muscles, which must be involved in the adduction of the ventricular folds, can hardly be caused by a raised subglottal pressure.

On this basis it must be said that Smith's assumption of a sudden rise and fall in subglottal pressure as the primary cause of the other differences in the second phase of the stød is not very probable. There seems to be an independent vocalis activity, and the changes in subglottal pressure cannot explain the higher pitch in the start, nor the decrease of pitch and intensity in the second phase.

What then are the causes of the specific pitch and intensity contours in words with stød?

The high pitch in the beginning of words with stød can be sufficiently explained by the early CT activity, which starts around vowel onset and has its peak 5-10 cs before the Fo peak. But the frequent pitch drop in the second phase of the stød cannot be explained by CT relaxation. CT starts falling again in the beginning of the vowel, sometimes even before the pitch peak is reached, but this is normal, also in words without stød. High activity in CT seems to be necessary for stretching the vocal folds, but once the position is reached less activity is necessary to maintain it. BF has a small dip in CT in stød words, but this is not found for other speakers. There is a gradual decrease but no dip and rise again corresponding to the dip in pitch. One might think of a possible activity in sternohyoid. This muscle was not recorded. But it did not show any activity for the pitch valley in Standard Swedish accent II (see Gårding 1970). It is, however, possible that a strong contraction of VOC and LCA resulting in a strong compression of the vocal folds often combined with adduction of the ventricular folds, may hamper the vibrations and thus cause a decrease in pitch and also irregular vibrations. Both VOC and LCA have their peaks just when the pitch decrease and the irregularities start.

The point where Fo starts decreasing is not always quite unambiguous, but its distance from vowel onset was measured in a number of clear cases (see above p. 111) and found to be on the average 9.7 cs for BF, BM, HU, JJ and NR. - The VOC peak is generally quite clear. For the same speakers it was on the average 11.6 cs after vowel onset with very little variation. This means that Fo decrease (and irregularity) starts very shortly before VOC activity has reached its peak.

The decrease in intensity is more difficult to explain. It starts earlier (in BF's 1974 recording on the average 4.3 cs after the start of the vowel) and gets lower than in vowels without stød after, on the average, 5 cs (the airflow also starts decreasing early, in BF's 1974 recording, on the average 6.2 cs after vowel start). In BRP's inverse filtering curves there is a rather close correlation between decreasing negative spikes, decreasing amplitude of the flow pulses, and decreasing overall intensity. In [må:'lɒ]3 with weak stød there is not much decrease in overall intensity corresponding to the decrease in the glottal pulses, but otherwise it is quite clear (in 7 out of 8 examples). If we assume that BRP, like BF and FJ, does not have much decrease in subglottal pressure, there must be a certain constriction of the larynx at a rather early point. The decrease of oral airflow for the other speakers also points to a larynx constriction. But intensity and airflow start decreasing before the peaks in vocalis and LCA are reached and before the strong constriction of the larynx is seen in the fiberoptic pictures.

The steep rise in the VOC curve (after the small rise for voicing) takes place, on the average, 5.1 cs after vowel onset in the 1974 recordings, and LCA activity starts at the same time; in the same recordings the decrease of intensity starts

6.4 cs after vowel onset, i.e. only a little more than 1 cs later. Thus a possible larynx constriction at this point can hardly be ascribed to the activity of VOC. In BF's strong stød the adduction of the ventricular folds starts early in the vowel, but this adduction takes place later for the other speakers. However, HU, who has a later VOC peak than the other speakers (13.6 cs), also has a later start of the intensity decrease (9.1 cs), 4.1 cs after her VOC activity began to increase. But for the other speakers the early intensity decrease has not been sufficiently explained. - However, it often decreases more rapidly later, simultaneously with the Fo decrease.

In conclusion of this discussion about causal relations I agree with Svend Smith in considering the first phase of the stød as characterized by a relatively high energy in expiration, phonation and articulation, but I do not think that the rise in subglottal pressure is the primary factor. It is rather a general energetic accentuation, which also comprises the intrinsic laryngeal muscles. As for the second phase, Smith considers it to be a phase of relaxation, and he describes the cases where the glottis remains constricted as a non-normative stød due to lack of adjustment to the falling subglottal pressure. But strong constriction in the second phase is quite normal in Danish, as shown in this study. It is only from the point of the speech therapist that, e.g., creaky or breathy voice must be considered as due to malfunction. They are linguistically relevant phonation types in a large number of languages and certainly intended by the speaker.

Finally one may ask why long vowels with stød are shorter than long vowels without stød, and why only in distinct speech? This may probably be explained by the fact that although vowels with stød are long in the sense that their duration is closer to long vowels than to short vowels and that they have the quality of long vowels and are subjected to the same modifications by following consonants as long vowels (and not as short vowels), they are not susceptible to lengthening in slow speech in the same way as normal long vowels because they are characterized by a more or less continuous change in phonatory quality, and the creaky part cannot be lengthened indefinitely. If one tries to say, e.g., [pʰi:'bɒ] or [kʰɛ:'lɒ] very slowly, the vowel will generally end in a glottal stop.

When, on the other hand, sonorant consonants with stød are longer than consonants without stød, it is probably a question of perceptibility. A sonorant consonant is generally only 5-6 cs, and if it were covered completely by the low intensity second phase of the stød, it would hardly be identifiable. Therefore it must be somewhat longer.

3. PHONETIC EXPLANATIONS OF THE ORIGIN OF THE STØD

Is it possible, on the basis of a phonetic description of the stød, to throw some light on the theories of its origin? - Not very much, but a few tentative observations may perhaps be of some relevance. There are two main theories concerning the origin of the stød (see p. 67ff above). Verner thought that it had developed out of a quickly rising tone involving a strong tension ending in a "snapping" of the vocal folds and a short closure. Others (Kock and A. Pedersen) assume that it is the result of a concentration of energy on the stressed syllable due to syncope, and Skautrup and Smith connect the origin of the stød with the later apocope.

Verner described the tonal movement in his own pronunciation of words with stød as a low tone, which at the end of a long vowel rises quickly ending in a glottal closure, with the following unstressed syllable on a low tone. But this does not correspond to any contour found in the present investigation. All speakers had a high start or a quick rise in the first few centiseconds, often followed by a quick fall. In modern Jutlandish dialects the contour also seems to be rising-falling during the first syllable. But it is true that there is a high tone, and that may be old (although in southern Jutland, where there is a tonal opposition, accent 1 is slowly rising-falling and not very high, see M. Bjerrum 1948). But in present-day Danish, as in other languages, the main muscle responsible for pitch rise is the cricothyroid, and a strong activity of this muscle does not involve a constriction of the glottis but rather a slight opening and more breathy voice. The muscles used for the constriction of the glottis in the stød are the vocalis and lateral cricothyroid and perhaps some of the sphincter muscles. It is, of course, conceivable that the vocalis has acted as an antagonist to the CT to keep the vocal folds together, and that this reaction has been exaggerated, but that is pure speculation.

However, the problem is complicated, and the pitch hypothesis is not so easily refuted. It is a striking fact that languages with phonation type oppositions are very often tone languages or related to tone languages. These connections are found in some African and in many Southeast Asian languages, particularly the Sino-Tibetan language group, but also in Austro-Thai and Austro-Asiatic (see, e.g., Matisoff 1973, Egerod 1971, Henderson 1977 and Ivanov 1983). Very often low or falling pitch is combined with breathiness and high or rising pitch with glottal stop or creakiness (Matisoff 1973). In some cases a glottal stop has disappeared in the preceding vowel leaving a rising tone (e.g. in Vietnamese according to Matisoff 1973); and Ivanov (1983) and Hombert et al. (1979) mention quite a number of languages in Asia, Africa and North America where glottal stop and rising or high tone are connected. In Kachavi (a Tibeto-Burmese language) rising tone and final glottal stop are in complementary distribution (Ivanov 1983) and a Middle Chinese rising tone comes from a final glottal stop (Hombert et al. 1979 with references to some of the relevant literature, e.g. Haudricourt). On the other hand, a final [h] seems to lower the tone of the preceding vowel. Hombert has recorded the time course of Fo for four Arabic speakers. He found that an [h] produced a drop in Fo (varying from 25-50 Hz) on the preceding vowel, while [ʔ] produced a rise (from 9-48 Hz). There are, however, exceptions, where a glottal stop seems to have lowered the tone of a preceding vowel. Hombert et al. mention Mohawk and a number of Middle Chinese dialects, but they suggest that it may not have been a glottal stop but creaky voice. However, Javkin and Maddieson, who measured the Fo contours of the tones of a Burmese speaker, distinguish expressly tone 3 with creaky voice from tone 4 ending in a glottal stop, both being falling tones.

In Thai various types of glottalization are found in combination with both high and low (level or contour) tones in different dialects, but in Thai (as well as in Chinese) there are distinct historical layers of tonal development: an older layer of tonogenesis due to final (probably partly glottal) consonants and a later layer due to initial consonants, so that the situation in modern dialects cannot be immediately used as a basis for conclusions about the causal relation between glottalization and tone level or tone contour. (Rischel, personal communication.)

It is not straightforward to apply these experiences to the Danish stød and its origin. In the first place: in all the examples mentioned it is a glottal stop which has raised the pitch of a preceding vowel; it is not a rising pitch which has produced a glottal stop. In the second place the connection between glottal stop and preceding high tone does not seem to be an absolute universal. In the third place the connection between creaky voice and tone seems to be still more uncertain. Matisoff says that creaky voice is connected with high tone (1973), Henderson (1977) mentions that this is often the case, and the Danish stød may be combined with both falling and rising Fo depending on the speaker (see above p.112). Finally we do not know whether the stød started as a type of creaky voice or as a glottal stop. The fact that all phoneticians in the 19th century mention it as a glottal stop might indicate that it may have been stronger than it is now in the standard language.

On the other hand, it is a fact that the stød is found in word forms which had become monosyllabic through the old Scandinavian syncope (around 8-900), and this may have conditioned the strong concentration of energy which is still characteristic of the stød, and - perhaps at a later time - has caused the glottal constriction.

A parallel development is found in the Finno-Ugrian language Livonian, which is spoken in areas very close to Latvian. Professor Kalevi Wiik has drawn my attention to some descriptions of Livonian (Posti 1942 and Kettunen 1947). Posti describes the "Stossintonation" in the following way: *"Bei der*

Stossintonation steigt der Ton zuerst stark an, dann tritt der Stoss auf, und nach diesem fällt der Ton schnell, der fallende Teil ist länger als der steigende." Kettunen quotes Endzelin's description of the "Stosston" in Latvian: *"Beim Stosston, der zum Beispiel auch im Livischen und im Dänischen vorkommt, zerfällt die Länge in zwei Teile, indem nach dem stärker schallenden Anfang inmitten der Silbe ein momentaner Glottisverschluss eintritt (der aber oft durch Stimmschwächung ersetzt wird), worauf der zweite Teil hervorgestossen wird."* Kettunen describes the "Stossintonation" in Livonian as very variable. A complete closure is not rare, but sometimes it is only a falling tone, which is characterized by a shorter syllabic quantity than the so-called lengthened ("gedehnt") tone, which is rising. Latvian also has a rising tone, and both languages also have a purely falling tone, which, however, is rare in Livonian.

These descriptions remind very much of the Danish stød, except that the rebound after the laryngealization seems to be more common than it is now in Standard Danish.

As to the origin of the stød in Livonian and in the Baltic languages there are different opinions. Ivanov (1983) mentions Latvian and Lithuanian as examples of a stød which developed from a rising tone. As for Livonian it is generally assumed that the stød was taken over from Latvian. However, Kettunen (1947) argues that since it can be explained by historical sound changes within Livonian,it is more probable that the Latvian stød is due to Livonian substratum (Livonian was spoken in a much larger area earlier). According to both Posti (1942) and to Kettunen it is a fact that very often Livonian stød appears in cases where there has been syncope or apocope of a weak syllable after a short stressed syllable. Further it is found before a disappearing [h], in which case there is also apocope, or before a final [h] followed by a consonant initiating the following syllable; in the latter case Kettunen assumes that a schwa had developed between the [h] and the following consonant and then disappeared, so that all cases might be seen as due to syncope or apocope. Through this development the first syllable was reinforced and (perhaps at a somewhat later date) developed a stød. (Both in Latvian and Livonian there is also a stød in some syllables with secondary stress, which must be explained in a different way.)

Posti thinks that the reinforcement involved a strong pitch rise, and that this is what gave rise to the stød (he thus accepts Verner's explanation). Wiik has a somewhat different explanation (personal communication). He assumes that the stød is a remnant of the old syllable boundary between the contracted syllables and refers to the stød which may appear in hiatus (like Danish *sofa* - *sofaen* ['so:fa - 'so:fæ:'ən]). A similar phenomenon is found in Finnish.

This is, of course, all very hypothetical, but it seems that the development in Livonian supports the hypothesis of a reinforced accent due to syncope as being the origin of the Danish stød as well. The reinforcement may have involved a pitch rise and consequently a tonal difference between reinforced syllables and other syllables, so that developments in various directions were possible.

4. VARIABILITY AND INVARIANCE

The phonetic description of the Danish stød given in this paper, revealed a high degree of variability both in the production and in the acoustic nature of the stød. Not all seem to use their vocalis muscle in the stød, and those who do use it use it in different ways for other purposes. Some subjects have strong activity for pitch rise, some very little, some have deep valleys in voiceless consonants, some hardly any valleys, and all combinations seem to occur. It can, of course, not be excluded that some of these observed differences may be due to slightly different placements of the electrodes (there are differences in vocalis activity for pitch and consonant dips in different recordings by BF), but there is no doubt that there is genuine individual variation. Moreover, some have strong adduction of the ventricular folds, some hardly any adduction. Some have a strong pitch decrease, some have rising pitch, and in both cases there is decrease of intensity and there may be irregular vibrations. Nevertheless there is no problem in the perceptual identification. A similar interindividual variation has been found in other phonetic studies, e.g. in the function of the strap muscles and the hyoid bone.

I agree completely with Lindblom (1982) when he states that what is aimed at is not invariance, but perceptual equivalence. Sufficient, but not necessarily identical acoustic cues are supplemented by top-down predictability.

5. PROSPECTS FOR FUTURE RESEARCH

In spite of the relatively large material and different methods of analysis used in this study, there are still many gaps in the description, and much remains to be done. It would certainly have been preferable to record a larger number of muscles and to measure subglottal pressure on more subjects. It is also a serious drawback that the respiratory function has not been investigated (a short experiment with surface electrodes was negative). But with this type of physiological investigation what is scientifically desirable is not always humanly possible. Most subjects having tried laryngeal electromyography once do not want to repeat the experience. And a planned recording of the internal intercostals was given up because Hirose declared that there was a 20% risk of piercing the pulmonary pleura.

Finally, it must be emphasized that the perceptual aspect has not even been touched upon in this investigation. A thorough study of the relative importance of the acoustical differences as cues for the perceptual identification is a great desideratum. I hope that the present description of the acoustic features of the stød may be useful as a basis for such studies.

V. NOTE

1. The phonetic transcription used in this paper is in principle IPA.

The stød is, however, transcribed ['] in accordance with a common Danish tradition, in order to emphasize that it is not a glottal stop [ʔ].

IPA is ill suited for the transcription of Danish lower rounded back vowels. For the long vowel in e.g. *måle* (IPA [ɔ:+˔]) the Danish letter *å* has therefore been used ([å:]). The short vowel in, e.g., *komme* (IPA [ɔ(+)˔]) is transcribed [ɔ], and the r-coloured vowel in e.g. *hår* (IPA [ɒ˔]) is transcribed [ɒ]. Many Danish phoneticians (wanting to avoid non-IPA symbols) use [ɔ:] for the long vowel in *måle* and [ʌ] for the short vowel in *komme*, but this symbol is somewhat misleading, since the unrounded pronunciation is very rare nowadays, and the fronting is being reduced.

The unstressed endings *-en, -el, -et* are transcribed [ən, əl, əð] as a generalization of slow pronunciation. The actual pronunciations in the text are variable. After a consonant [ə] is very often elided, and the final consonant becomes syllabic. After [n] the ending [ən] is practically always [n̩], and therefore this transcription is used in *vennen* ['vɛn'n̩]. After a vowel [ə] may also be assimilated to this vowel, and the stressed vowel may be shortened, thus [hu:ən, huən, hu:un, huun, hu:n̩, hun̩]. Here [hu:ən] has been generalized.

Danish */bdg/* are voiceless in syllable-initial stressed position and finally, but may be (partly or fully) voiced initially in unstressed syllables. The symbol for voicelessness (˳) has been omitted here, except in a few cases where it was relevant for the argument.

Danish */ptk/* in syllable-initial position are aspirated, and *t* (sometimes also *k*) is affricated, particularly before high vowels. The affrication is not indicated in the transcription here, */ptk/* being transcribed [p^h, t^h, k^h] in syllable-initial position.

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APPENDIX I

Material and subjects

A. The material

<u>List 1</u> 1974-79 (the main list) (frame: det er ... de siger)

piber	[pʰiːbɒ]	pl. of *pibe* 'pipe', or nomen agentis derived from the verb *pibe* 'to squeak'.
piber	[pʰiː'bɒ]	pres. of the verb *pibe*
huen	[hu(ː)ən]	definite form of *hue* 'cap'
huen	[huː'ən]	definite form of *hu* 'mind' (obsolete)
læser	[lɛːsɒ]	nomen agentis of the verb *læse* 'to read'
læser	[lɛː'sɒ]	pres. of the verb *læse*
kæle	[kʰɛːlə]	infinitive, 'to fondle'
kæler	[kʰɛː'lɒ]	pres. of the verb *kæle*
kælder	[kʰɛlɒ]	'basement'
Keller	[kʰɛl'ɒ]	a family name
venner	[vɛnɒ]	pl. of *ven* 'friend'
vennen	[vɛn'n̩]	definite form of *ven*
ven	[vɛn]	'friend'
vend	[vɛn']	imperative of *vende* 'to turn'
du	[du]	'you'
dug	[duː']	'table-cloth'
væn	[vɛː'n]	'beautiful' (poetic)
Vænern	[vɛː'nɒn]	name of a lake in Sweden
læsser	[lɛsɒ]	pres. of the verb *læsse* 'to load'
pipper	[pʰibɒ]	pres. of the verb *pippe* 'to chirp'

<u>List 2</u> 1977-79 (frame: det er ... de siger)

aftalen	['au̯ˌtʰæːlən]	'the agreement' def. form of *aftale*
aftaler	['au̯ˌtʰæː'lɒ]	'makes an agreement'
højhuse	['hɔi̯ˌhuːsə]	'skyscrapers', pl. of *højhus*
højhuset	['hɔi̯ˌhuː'səð]	'the skyscraper', def. form of *højhus*

<u>List 3</u> 1974 (frame: det er ... de siger)

5/25	['biːbiˌbibi / 'biː'biˌbibi]
15/17	['biːbiˌbiːbi / 'biː'biˌbiːbi]

16/18 [ˈbi:biˌbi:ʼbi / ˈbi:ʼbiˌbi:ʼbi]
6/10 [biˈbi:ˌbibi / biˈbi:ʼˌbibi]
7/11 [bibiˈbi:bi / bibiˈbi:ʼbi]

List 4 *ven* *vend* *væn* (frame: det er ... de siger)

[vɛn] [vɛnʼ] [vɛ:ʼn]

(see list 1)

List 5a 1972 (frame: de sagde ... .)

læser *læser* *piber* *piber*

[lɛ:sɒ lɛ:ʼsɒ pʰi:bɒ pʰi:ʼbɒ]

(see list 1) plus:

man	[man]	'one' (indef. pron.)
mand	[manʼ]	'man'
pedal	[pʰeˈdæ:ʼl]	'pedal'
betale	[beˈtʰæ:ʼlə]	'to pay'
pagaj	[pʰaˈgai̯ʼ]	'paddle'
bakkant	[baˈkʰan̂ʼt]	'bacchant'
purist	[pʰuˈʁist]	'purist'
buddhist	[buˈdist]	'buddhist'

List 5b = 5a plus:

man	[mæ:ʼn]	'urge!' imper. of mane
manden	[manʼn̩]	'the man', def. form of mand.

kæle *kæler* *kælder* *Keller* *huen* *huen*

[kʰɛ:lə kʰɛ:ʼlɒ kʰɛlɒ kʰɛlʼɒ hu(:)ən hu:ʼən

(see list 1)

List 6 1977

taler	[tʰæ:lɒ]	nomen agentis of the verb *tale* 'to
taler	[tʰæ:ʼlɒ]	pres. of the verb *tale* speak'
pæn	[pʰɛ:ʼn]	'pretty'
pæne	[pʰɛ:nə]	'pretty' (pl.)
pen	[pʰɛnʼ]	'pen'

plus:

læser *læser* *kæle* *kæler* *kælder* *Keller*
[lɛ:sɒ lɛ:ʼsɒ kʰɛ:lə kʰɛ:ʼlɒ kʰɛlɒ kʰɛlʼɒ]

(see list 1)

Kan du sige Anna?	[kʰa du si: ˈana]	'can you say Anna?'
" " " "	[kʰa du si: ˈʔana]	" " " "
Kan du sige Hanna?	[kʰa du si: ˈhana]	'can you say Hanna?'
Kan du lide Nana?	[kʰa du ˈli:ʼ ˈnana]	'do you like Nana?'
Han gik lige i seng	[han gig ˈli: i ˈsɛŋʼ]	'he went straight to bed'
" " " " "	[han gig ˈli: ʔi ˈsɛŋʼ]	" " " "
Der er et lig i sengen	[dɑ:.d ˈli:ʼ i ˈsɛŋʼn̩]	'there is a corpse in the bed'

List 7 1981 (frame: de vil sige ... igén)

mile	[mi:lə]	'mile' (pl.)
mil	[mi:'l]	'mile' (sg.)
mild	[mil']	'soft'
sile	[si:lə]	'to pour'
sil	[si:'l]	imperative of *sile*
sild	[sil']	'herring'
diset	[di:səð]	'hazy'
disen	[di:'sən]	'the haze', def. form of *dis*
Sanddalen	['san,dæ:'lən]	a place name
sandalen	[san'dæ:'lən]	'the sandal'

List 8a 1985 (frame: jeg kan gődt sige ... til Pálle)

All words from list 1, except *væn* and *Vænern*, plus:

buse	[bu:sə]	'to rush'
buser	[bu:'sɒ]	present of *buse*
duen	[du:ən]	'the dove', def. form of *due*
dugen	[du:'ən]	'the table-cloth', def. form of *dug*
taget	[tʰæ:əð]	'taken', part.perf. of *tage*
taget	[tʰæ:'əð]	'the roof', def. form of *tag*
sejlet	[sai̯ləð]	part.perf. of *sejle* 'to sail'
sejlet	[sai̯'ləð]	'the sail', def. form of *sejl*
fældes	[fɛləs]	'is felled', passiv of *fælde*
fælles	[fɛl'əs]	'common'
gæller	[gɛlɒ]	'gills', pl. of *gælle*
gælder	[gɛl'ɒ]	'is valid', pres. of *gælde*
føl	[føl]	'foal'
føl	[fø:'l]	'feel!', imper. of *føle*
pib	[pʰib]	'chirp'
pib	[pʰi:'b]	'squeak!', imper. of *pibe*
tag	[tʰa]	'take!', imper. of *tage* } variants
tag	[tʰæ:']	'take!', " " " } variants

(both also short forms of the infinitive)

List 8b 1985 (frame: jeg kan gődt sige ... til Pálle)

All words from list 1, except *væn* and *Vænern* plus:

buse	[bu:sə]	'to rush'
buser	[bu:'sɒ]	present of *buse*
file	[fi:lə]	'to file'
filer	[fi:'lɒ]	pres. of *file*

bene	[be:nə]	'to leg it'
benet	[be:'nəð]	'the leg', def. form of *ben*
tabe	[tʰæ:bə]	'to lose'
tabet	[tʰæ:'bəð]	'the loss', def. form of *tab*
gabe	[gæ:bə]	'to yawn'
gabet	[gæ:'bəð]	'the yawning', def. form of *gab*
sale	[sæ:lə]	'halls', pl. of *sal*
salen	[sæ:'lən]	'the hall', def. form of *sal*
tag	[tʰa]	'take!'
tag	[tʰæ:']	" (see 8a).

List 9 1986 (frame: Jeg kan lět sige .... fém gånge)

maler	[mæ:lɒ]	'painter', nomen agentis of the verb *male*
maler	[mæ:'lɒ]	'paints', pres. of *male*
spiser	[sbi:sɒ]	'dishes', pl. of *spise*
spiser	[sbi:ˀsɒ]	'eats', pres. of the verb *spise*
musen	[mu:sən]	'the Muse', def. form of *muse*
musen	[mu:'sən]	'the mouse', def. form of *mus*
posen	[pʰo:sən]	'the bag', def. form of *pose*
Posen	[pʰo:'sən]	Place name.

List 10 1986

'far renser 'piber i 'aften [pʰi:bɒ]
'musene 'piber på 'loftet [pʰi:'bɒ]

'børnene elsker at 'kæle med 'hunden [kʰɛ:lə]
'børnene 'sidder og 'kæler med 'hunden [kʰɛ:'lɒ]

'bogens 'læser vil 'undre sig [lɛ:sɒ]
'drengen 'læser om 'aftenen [lɛ:'sɒ]

List 11 1986

Der 'står en 'maler på 'stigen [mæ:lɒ]
Han 'står og 'maler på 'stigen [mæ:'lɒ]

'Digteren 'påkaldte 'Musen for'gæves [mu:sən]
'Bageren 'fangede 'musen i 'fælden [mu:'sən]

Der var 'mange 'lækre 'spiser på 'bordet [sbi:sɒ]
Hun har 'spurgt om 'Peter 'spiser på 'skolen [sbi:'sɒ]

List 12 1986

Der 'står en 'maler på 'stigen [mæ:lɒ]
Han 'står og 'maler på 'stigen [mæ:'lɒ]

Han 'viste en 'valen 'holdning [væ:lən]
Han 'fjernede 'hvalens 'finner [væ:'ləns]

Der 'sidder en 'måler på 'væggen	[må:lɒ]
Han 'sidder og 'måler på 'kurven	[må:'lɒ]
'Bogens 'læser vil 'undre sig	[lɛ:sɒ]
'Drengen 'læser om 'aftenen	[lɛ:'sɒ]

List 13 1986

mile	[mi:lə]	'miles'
milen	[mi:'lən]	'the mile'
pile	[pʰi:lə]	'arrows, willows'
pilen	[pʰi:'lən]	'the arrow, the willow'
bile	[bi:lə]	'to go by motor car'
bilen	[bi:'lən]	'the motor car'
lime	[li:mə]	'to glue'
limen	[li:'mən]	'the glue'

B. The subjects

BF born 1935 in Ribe, West Jutland, since 1953 in Copenhagen. He speaks Standard Danish on a Jutlandic basis but also with some influence from Modern Copenhagen speech.

BH born 1946 in Copenhagen; has spent all her life in Copenhagen, speaks "Advanced Standard Copenhagen" (ASC).

BM born 1947 in Grenaa, Eastern Jutland, but moved to Copenhagen at the age of seven; has still some reminiscences of non-Copenhagen pronunciation.

BRP (= Pia Riber Petersen's subject No. 22) born 1933 in Copenhagen and has spent all his life here; speaks ASC.

FJ born 1911 in Nakskov, Lolland; grew up in South Funen but has never spoken dialect. Since 1929 in Copenhagen, speaks a slightly conservative Standard Danish, but influenced by Copenhagen intonation.

HU born 1945 in Copenhagen; has spent all her life in Copenhagen and speaks ASC.

JJ born 1949 in Hornbæk, North Zealand; spoke regional Zealandish Standard as a child, now ASC. Has lived in Copenhagen since 1969.

JR born 1934 in West Funen; spoke Standard Danish with his parents, speaks a slightly conservative Standard Danish but with influence from Copenhagen intonation.

LG born 1946 in Copenhagen; has lived in North Zealand (Snekkersten) since his early childhood. Speaks ASC.

MF born 1939 in North Zealand, from 1946-57 in South Zealand, from 1957 in Copenhagen; speaks Standard Danish

ND born 1950 in Hellerup, Northern Copenhagen; has spent all his life here.

NR born 1943 in Gammel Holte, North Zealand, since 1964 in Copenhagen; speaks ASC.

OB born 1946 in East Jutland; lived until 1965 in various East Jutlandish towns, the last seven years in Århus, from 1965 in Copenhagen; speaks ASC on a Jutlandish basis.

PD born 1950 in Southern Zealand; lived in various Zealandish towns until 1969, from then on in Copenhagen; speaks ASC.

PM born 1946 in Himmerland, East Jutland; spoke dialect until the age of ten, then also regional standard. Lives in Copenhagen since 1967. He has adopted the Copenhagen intonation, but he has a perceptible Jutlandish rhythm.

Two subjects from the Haskins investigation have been included in some cases:

PMi born 1942 in Copenhagen, has lived in Roskilde and Copenhagen; speaks ASC.

TB born 1937, spent his childhood in southern Jutland, since 1955 in Copenhagen; speaks Standard Danish.

APPENDIX II

Duration

1. Survey of material used for measurements of duration.

a. Long vowel with and without stød

List	Year	Number of word pairs	Subjects and (average) number of repetitions				
1	1974	3	BF 10	HU 12	NR 6		
			BH 8	JJ 12			
			BM 10	JR 3			
	1977a-b	3 3	BF 12 11				
	1979a-b	3 3	BF 12 17				
3	1974	4	JR 10				
		3	BM 9	JJ 9			
5a	1972	2	TB 16	PMI 16			
6	1977	3	FJ 18				
7	1981	1	FJ 12				
8a	1985	4	FJ 8				
8b	1985	9	HU 8	JR 8	NR 8		
9	1986	4	ND 10	NR 10	PM 10	PD 10	OB 10
10	1986	3	HU 8	NR 8			
11	1986	3	OB 8				
12	1986	3	BRP 8				

b. Short vowel with and without following stød

List	Year	Number of word pairs	Subjects and (average) number of repetitions		
1	1974	3	same as a,1		
	1977 a-b	3	BF 12	11	
	1979 a-b	3	BF 12	18	
8a	1985	5	FJ 7		
8b		3	HU 8	JR 8	NR 8

c. Consonant after long vowel with and without stød

List	Year	Number of word pairs	Subjects and (average) number of repetitions		
1	1974	1	BM 10	HU 12	
		3	BF 10		
1	1977	2	BF 12	11	
8a	1985	5	FJ 8		
8b	1985	3	HU 8	JR 8	NR 8

d. Consonant after short vowel with and without stød

List	Year	Number of word pairs	Subjects and (average) number of repetitions		
1	1974	1	BF 12	BM 10 JR 3	HU 12 NR 6
		2	JJ 12		
8a	1985	5	FJ 7		
8b	1985	3	HU 8	JR 8	NR 8

2a. Duration (in cs) of V: and V:', and V:' in percentage of V:

List 1 (significance: * < 5%, ** < 1%, *** < 0.1%)

	BF 1974		1977a		1977b		1979a		1979b	
N	11		12		11		12		17	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
p^{h}i:bɒ	14.4	1.5	15.6	2.8	16.8	1.1	14.8	1.5	16.3	1.2
p^{h}i:'bɒ	11.9	2.0	12.0	1.1	13.5	1.4	13.6	1.8	14.1	2.0
diff.	2.5**		3.6***		3.3***		1.2		2.2***	
	83%		77%		80%		92%		87%	
k^{h}ɛ:lə	22.8	1.8	21.6	1.6	23.0	1.5	21.4	8.0	23.0	2.3
k^{h}ɛ:'lɒ	18.7	1.6	17.7	1.4	17.9	1.5	16.6	1.1	18.2	1.6
diff.	4.1***		3.9***		5.1***		4.8***		4.8***	
	82%		82%		78%		78%		79%	
lɛ:sɒ	19,7	1.2	19.5	0.9	19.6	1.2	19.3	1.1	18.8	1.3
lɛ:'sɒ	18.7	1.6	17.5	1.1	16.7	1.7	17.9	1.1	18.1	1.5
diff.	1.0		2.0***		2.9***		1.4		0.7	
	95%		90%		85%		93%		96%	

	BH		BM		HU		JJ		JR		NR	
N	10		10		12		12		3		6	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
p^{h}i:bɒ	10.5	1.1	13.9	0.7	17.2	0.9	14.7	1.4	14.5		17.2	0.8
p^{h}i:'bɒ	11.4	1.3	13.6	0.7	14.7	1.2	12.9	1.4	12.5		13.2	1.5
diff.	-0.9		0.3		2.5***		1.8***		2.0		4.0***	
	109%		98%		85%		88%		86%		77%	
k^{h}ɛ:lə	19.8	1.6	19.2	1.6	24.3	1.5	22.3	1.5	23.0		25.5	1.4
k^{h}ɛ:'lɒ	19.4	1.7	19.5	1.6	20.3	1.2	18.4	0.8	20.0		19.0	1.1
diff.	0.4		-0.4		4.0***		3.9***		3.0		6.5***	
	98%		102%		84%		83%		87%		75%	
lɛ:sɒ	20.3	1.7	15.9	0.7	23.2	1.6	20.4	1.3	18.0		20.0	1.1
lɛ:'sɒ	20.0	1.8	16.3	0.8	21.7	1.7	19.5	0.9	17.3		19.0	0.6
diff.	0.3		-0.4		1.5*		0.9		0.7		1.0	
	99%		103%		94%		96%		96%		95%	

2b. Duration (in cs) of V: and V:', and V:' in percentage of V:

List 3 (significance: * < 5%, ** < 1%, *** < 0.1%)

Word No.		JR		BM		JJ	
	N	9		9		9	
		av.	s.d.	av.	s.d.	av.	s.d.
15	ˈbi:biˌbi:bi	18.2	1.5	15.4	0.9	18.1	2.0
17	ˈbi:'biˌbi:bi	17.0	1.7	14.5	1.2	14.4	1.2
	diff.	1.2		0.9		3.7***	
		93%		94%		80%	
16	ˈbi:biˌbi:'bi	18.1	1.9	14.3	1.1	19.3	2.0
18	ˈbi:'biˌbi:'bi	16.1	2.1	14.6	1.2	13.2	1.7
	diff.	2.0*		-0.3		6.1***	
		89%		102%		68%	
7	ˈbibiˈbi:bi	16.6				20.2	3.0
11	ˈbibiˈbi:'bi	15.9				13.4	1.0
	diff.	0.7				6.8***	
		96%				66%	
5	ˈbi:biˌbibi	18.0	2.0	14.8	0.8		
25	ˈbi:'biˌbibi	16.6	1.4	14.0	1.5		
	diff.	1.4		0.8			
		92%		95%			

2c. Duration (in cs) of V: and V:', and V:' in percentage of V:

Lists 5a, 6 and 7 (significance: * < 5%, ** < 1%, *** < 0.1%)

List 5a.	TB	PMi	List 6	FJ	List 7	FJ
N	16	16	N	19	N	12
	av.	av.		av.		av.
pʰi:bɒ	17.6	17.8	tʰæ:lɒ	25.9	di:səð	15.6
pʰi:'bɒ	13.0	13.5	tʰæ:'lɒ	21.8	di:'sən	14.1
diff.	4.6***	4.3***	diff.	4.1***	diff.	1.5***
	74%	76%		84%		90%
lɛ:sɒ	22.0	22.8	kʰɛ:lə	26.3		
lɛ:'sɒ	18.1	21.6	kʰɛ:'lɒ	20.7		
diff.	3.9***	1.2	diff.	5.6***		
	82%	95%		79%		
			lɛ:sɒ	21.8		
			lɛ:'sɒ	19.3		
			diff.	2.5***		
				89%		

2d. Duration (in cs) of V: and V:’, and V:’ in percentage of V:

Lists 8a and 8b (significance: * < 5%, ** < 1%, *** < 0.1%)

	8a		8b					
	FJ		HU		JR		NR	
N	8		8		8		8	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
pʰi:bɒ	14.6	1.0	15.8	1.5	13.0	0.9	14.1	0.7
pʰi:’bɒ	11.4	1.1	13.4	0.8	11.5	0.8	11.2	1.1
diff.	3.2***		2.4**		1.5**		2.9***	
	78%		85%		88%		79%	
kʰɛ:lə	20.7	1.1	24.1	1.5	16.8	1.2	20.9	1.0
kʰɛ:’lɒ	15.6	0.6	18.7	1.3	15.6	1.0	15.2	1.1
diff.	5.1***		5.4***		1.2**		5.7***	
	75%		78%		93%		73%	
lɛ:sɒ	19.6	1.0	22.1	1.3	16.9	0.5	19.8	1.8
lɛ:’sɒ	17.2	0.7	20.5	0.9	13.9	0.8	18.4	1.1
diff.	2.4***		1.6**		3.0***		1.4**	
	88%		93%		82%		93%	
bu:sə	20.3	1.0	22.4	1.0	17.6	0.7	21.4	0.7
bu:’sɒ	16.1	0.7	18.6	0.4	15.6	0.4	17.0	1.1
diff.	4.2***		3.8***		2.0***		4.4***	
	79%		83%		89%		79%	
gæ:bə			23.9	1.2	19.3	1.0	21.4	0.9
gæ:’bəð			20.8	1.0	18.3	0.9	19.3	1.0
diff.			3.1***		1.0*		2.1**	
			87%		95%		90%	
tʰæ:bə			21.6	0.7	17.0	0.5	20.1	0.9
tʰæ:’bəð			18.3	0.7	15.8	1.1	16.3	0.9
diff.			3.3***		1.2*		3.8***	
			85%		93%		81%	
be:nɒ			22.5	1.6	18.2	0.9	18.6	0.9
be:’nəð			18.2	0.9	15.9	1.0	14.8	1.0
diff.			4.3***		2.3**		3.8***	
			81%		87%		80%	
sæ:lə			26.4	1.2	20.3	0.8	21.7	0.8
sæ:’lən			23.5	1.1	17.7	1.4	18.4	0.9
diff.			2.9***		2.6***		3.3***	
			89%		87%		85%	
fi:lə			20.9	1.1	15.8	0.6	17.3	0.8
fi:’lɒ			15.7	1.7	14.7	1.2	12.8	1.0
diff.			5.2***		1.1*		4.5***	
			75%		93%		74%	

2e. Duration (in cs) of V: and V:', and V:' in percentage of V:

List 9 (significance: * < 5%, ** < 1%, *** < 0.1%)

	ND		PD		PM		OB		NR
N	10		10		10		10		10
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.
mæ:lɒ	29.3	1.8	18.7	1.5	15.6	0.8	17.9		20.1
mæ:'lɒ	23.3	1.6	16.6	1.2	14.0	0.9	16.1		18.0
diff.	6.0***		2.1**		1.6***		1.8**		2.1***
	80%		89%		90%		90%		90%
sbi:sɒ	20.9	0.9	14.4	1.2	13.7	0.8	16.3		15.0
sbi:'sɒ	16.0	1.0	11.8	0.7	10.8	0.5	14.1		15.1
diff.	4.9***		2.6***		2.9***		2.2**		-0.1
	77%		82%		79%		87%		101%
mu:sən	25.4	1.1	17.9	1.3	16.9	0.9	19.1		17.2
mu:'sən	21.6	1.7	14.7	1.0	15.1	0.6	16.9		15.3
diff.	3.8***		3.2***		1.8***		2.2**		1.9***
	85%		82%		89%		88%		89%
pʰo:sən	26.2	1.9	19.1	1.2	16.6	0.7	18.2		18.3
pʰo:'sən	20.7	1.6	14.6	1.1	14.8	1.1	15.9		16.2
diff.	5.5***		4.5***		1.8***		2.3**		2.1***
	79%		76%		89%		87%		89%

2f. Duration (in cs) of V: and V:', and V:' in percentage of V:

	HU	NR		OB		BRP
N	8	8		8		8
	av.	av.		av.		av.
kʰɛ:lə	12.8	15.6	mæ:lɒ	12.9	mæ:lɒ	19.9
kʰɛ:'lɒ	13.7	13.6	mæ:'lɒ	12.4	mæ:'lɒ	15.8
diff.	-0.9	2.0**		0.5		4.1***
	107%	87%		96%		79%
pʰi:bɒ	11.4	12.2	sbi:sɒ	11.6	må:lɒ	21.0
pʰi:'bɒ	9.8	9.8	sbi:'sɒ	10.3	må:'lɒ	16.4
diff.	1.6**	2.4***		1.3**		4.6***
	86%	80%		89%		78%
lɛ:sɒ	15.9	15.2	mu:sən	14.0	lɛ:sɒ	18.6
lɛ:'sɒ	15.6	16.1	mu:'sən	13.2	lɛ:'sɒ	19.1
diff.	0.3	-0.9		0.8*		-0.5
	98%	106%		94%		103%

3a. Duration (in cs) of short vowels with and without following stød.

List 1 (significance: * < 5%, ** < 1%, *** < 0.1%)

BF	1974		1977a		1977b		1979a		1979b	
N	12		11		11		17		12	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
kʰɛlɒ	12.8	0.7	12.0	0.9	11.4	1.7	10.2	1.3	10.7	0.6
kʰɛl'ɒ	10.5	1.7	8.8	0.4	8.4	1.2	7.8	1.0	7.9	1.0
diff.	2.3***		3.2***		3.0***		2.4***		2.8***	
sɛn	12.5	1.4	9.1	0.2	10.0	1.4	8.7	1.2	8.2	1.7
sɛn'	11.0	0.9	7.8	1.3	8.7	1.5	8.3	1.3	8.8	1.0
diff.	1.5*		1.3**		1.3*		0.4		-0.6	

	BH		BM		HU		JJ		JR		NR	
N	10		10		12		12		3		6	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
kʰɛlɒ	11.6		12.4	1.0	12.5	0.9	10.5	1.1	10.7		12.1	1.2
kʰɛl'ɒ	11.6		10.5	0.8	11.4	1.3	8.3	0.7	10.0		11.1	0.5
diff.	0		1.9**		1.1		2.2***		0.7		1.0*	
vɛnɒ	12.6	1.1	12.4	1.0	12.3		12.0	1.0	10.3		14.0	1.0
vɛn'n̩	14.1	1.3	10.5	1.1	13.1		10.1	1.3	10.3		12.0	0.8
diff.	-1.5*		1.9**		-0.8		1.9**		0		2.0**	
vɛn	11.1	0.6	10.0	0.8	10.9	0.7	9.1		9.3		9.5	1.0
vɛn'	14.1	1.2	9.9	0.7	12.6	1.2	9.9		10.0		11.2	1.8
diff.	-3.0***		0.1		-1.7**		-0.8		-0.7		-1.7	

3b. Duration (in cs) of short vowels with and without following stød.

List 8 (significance: * < 5%, ** < 1%, *** < 0.1%)

	8a		8b					
	FJ		HU		JR		NR	
N	7		8		8		8	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
kʰɛlɒ	10.8	1.3	10.8	1.1	8.5	0.4	10.9	0.7
kʰɛl'ɒ	8.2	0.8	9.9	0.8	8.7	0.8	9.2	1.1
diff.	2.6***		0.9		-0.2		1.7**	
vɛnɒ	12.3	0.6	11.3	0.8	10.0	0.7	11.2	0.5
vɛn'n̩	10.8	0.9	10.4	0.5	9.6	1.0	9.9	0.5
diff.	1.5**		0.9*		0.4		1.3***	
vɛn	9.8	0.6	9.4	0.9	8.6	0.7	9.2	0.9
vɛn'	9.7	0.9	9.8	0.7	9.9	0.8	8.8	0.6
diff.	0.1		-0.4		-1.3**		0.4	
gɛlɒ	12.8	1.2						
gɛl'ɒ	10.4	0.7						
diff.	2.4***							
fɛləs	12.1	0.3						
fɛl'əs	9.5	0.8						
diff.	2.6***							

4a. Duration (in cs) of consonants with and without stød.

List 1 (significance: * < 5%, ** < 1%, *** < 0.1%)

	BF 1974		BM		HU		JJ		JR	NR	
N	12		10		12		12		4	6	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	av.	s.d.
k^{h}ɛlɒ	6.1	1.1	5.6	1.0	5.9	0.9	6.8	0.9	5.3	6.7	0.8
k^{h}ɛl'ɒ	7.4	1.4	7.2	1.0	7.5	1.1	9.0	1.1	6.0	8.0	0.9
diff.	-1.3*		-1.6**		-1.6**		-2.2***		-0.7	-1.3*	

4b. Duration (in cs) of consonants with and without stød.

List 8 (significance: * < 5%, ** < 1%, *** < 0.1%)

	8a		8b					
	FJ		HU		JR		NR	
N	7		8		8		8	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
k^{h}ɛlɒ	5.8	0.7	6.4	0.6	4.7	0.4	5.3	0.6
k^{h}ɛl'ɒ	8.3	0.9	9.9	1.1	7.3	0.8	6.9	0.6
diff.	-2.5***		-3.5**		-2.6***		-1.6***	
vɛnɒ	5.3	0.8	9.6	1.0	5.8	1.0	5.4	0.8
vɛn'n̩	10.3	1.1	12.1	0.9	8.3	1.0	8.9	0.6
diff.	-5.0***		-2.5***		-2.5***		-3.5***	
vɛn	7.8	1.0	10.5	0.9	5.2	0.4	8.1	0.6
vɛn'	11.7	1.9	13.3	0.8	6.8	0.5	9.4	1.0
diff.	-3.9***		-2.8***		-1.6***		-1.3***	
gɛlɒ	5.9	0.5						
gɛl'ɒ	7.5	1.1						
diff.	-1.6*							
fɛləs	6.4	0.5						
fɛl'əs	8.6	0.7						
diff.	-2.2***							

APPENDIX III

Intensity

Survey of material used for analysis of intensity

List	Year	Number of pairs	Subjects and number of repetitions		
1	1974	7-10	BF 11	HU 12	
			BH 8	JJ 12	
			BM 10	NR 6	
	1977a-b	6-7	BF 12	11	
	1979 a-b		BF 12	17	
3	1974	3-5	JR 10	BM 10	
9	1986	4	ND 10	NR 10	OB 10
			PD 10	PM 10	
10	1986	3	HU 8	NR 8	
11	1986	3	OB 8		
13	1986	3	BRP 8		

Average intensity curves of individual word pairs are shown on the following pages (Figures 1 a-d, and 2 a-b). For reasons of space some pairs which were quite similar to pairs included, were left out: In list 1 three of BF's five recordings, for all subjects the unpaired words and the pairs [đu / đu:'] (with different vowel length) and [vɛnɒ / vɛn'n̩] (which is quite similar to [kʰɛlɒ/kʰɛl'ɒ]), in list 3: 16/18 and 5/25 which are almost identical to 15/17, in list 9: [pʰo:sən/pʰo:'sən].

Lists 1 and 3 were averaged by computer, Lists 9, 10, 11 and 12 manually. In list 1 [pʰi:bɒ] was left out by mistake in the sampling. Therefore averages of [pʰi:bɒ / pʰi:'bɒ] were made manually on the basis of a new mingographic recording (except for BF).

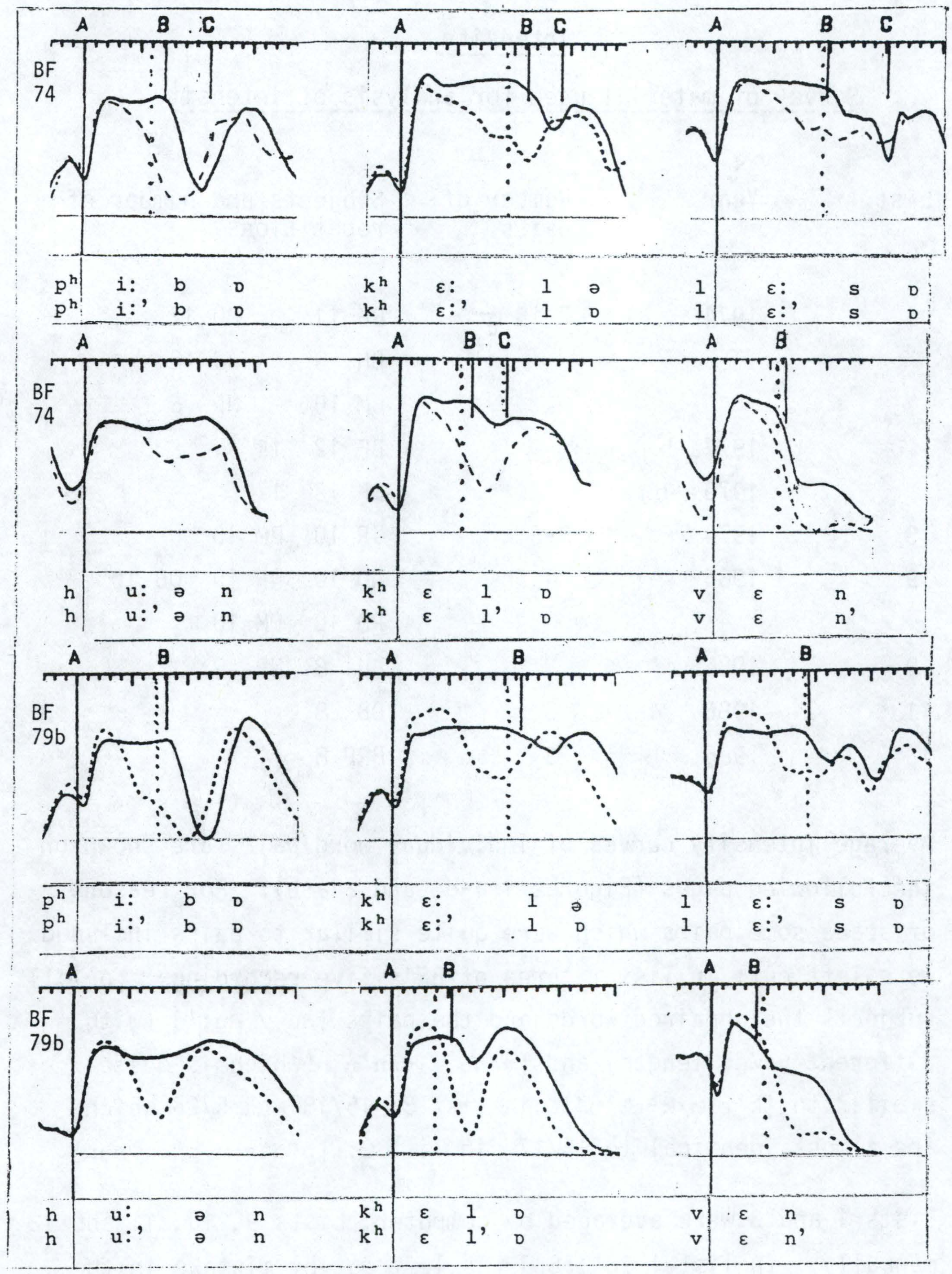


Figure 1a

Intensity average curves 1974 (list 1). Subject BF (N = 11) and BF 1979b (N = 17). —— : no stød. ---- : stød. A: vowel start (line-up point), B: vowel end, C: end of following consonant. | : no stød, ¦ : stød. 10 cs.

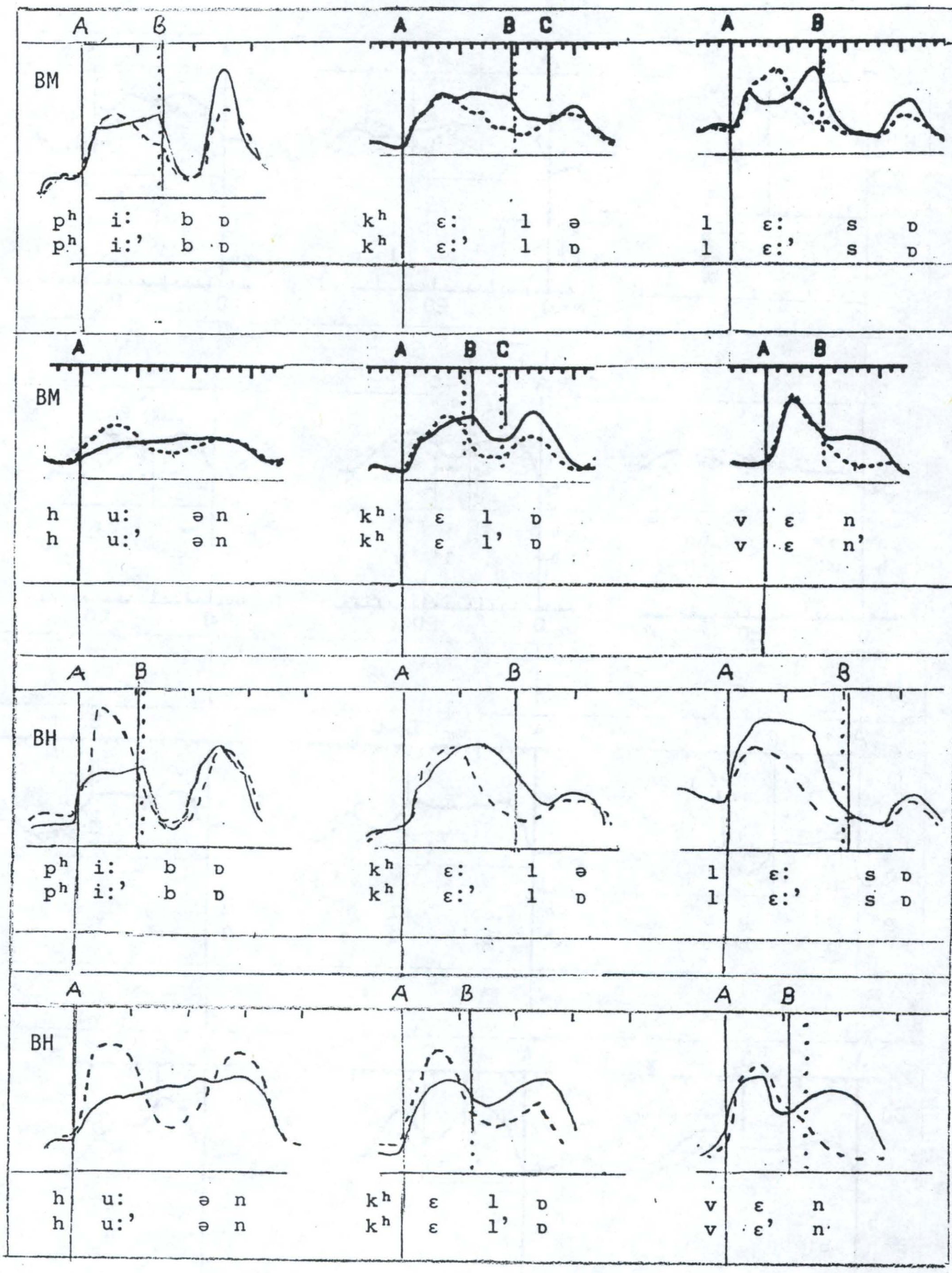


Figure 1b

Intensity average curves 1974 (list 1). BM (N = 10), BH (N = 8). —— : no stød, ---- : stød. See legend to Fig. 1a.

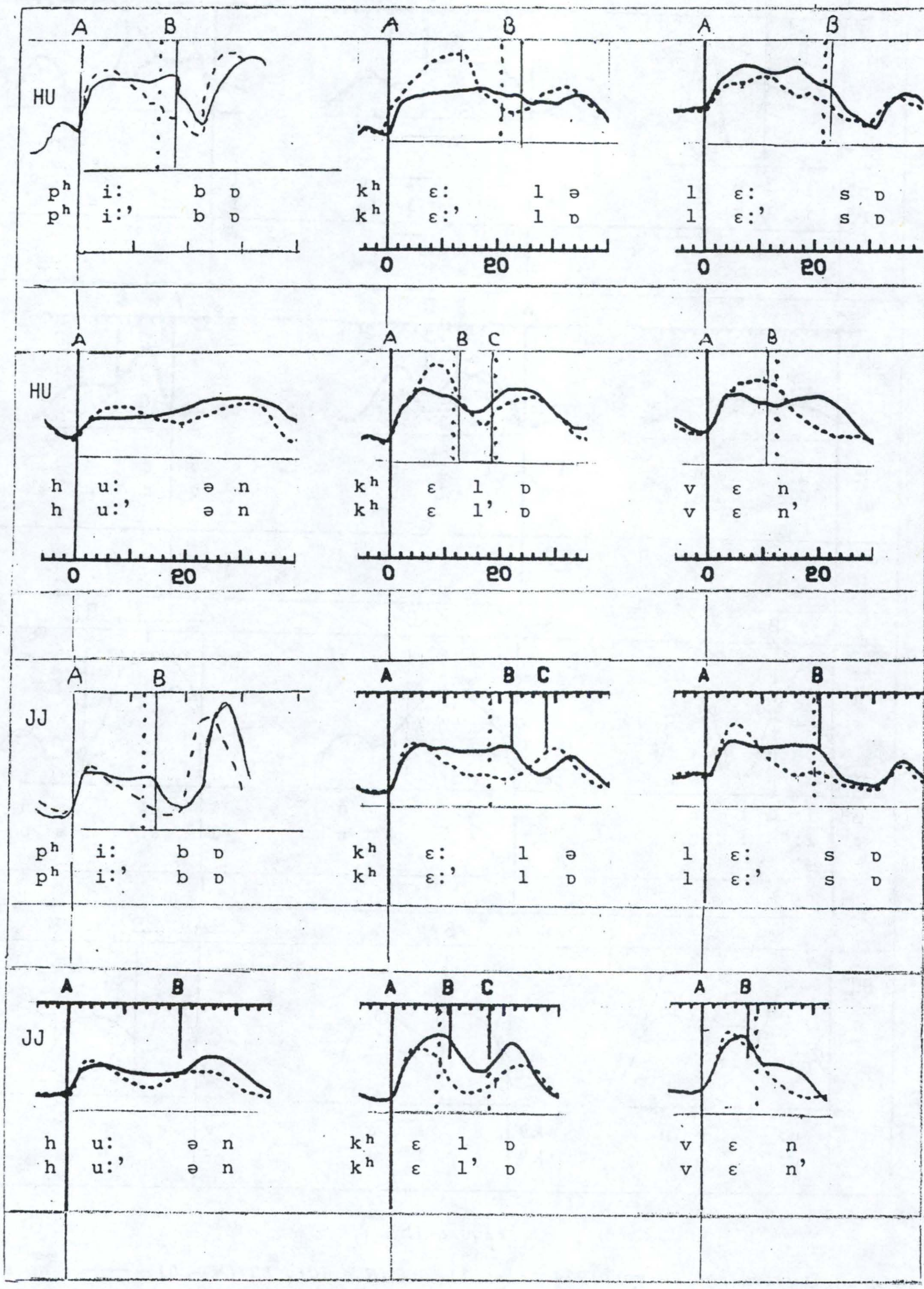


Figure 1c

Intensity average curves 1974 (list 1). HU (N = 12), JJ (N = 12). —— : no stød, --- : stød. See legend to Figure 1a.

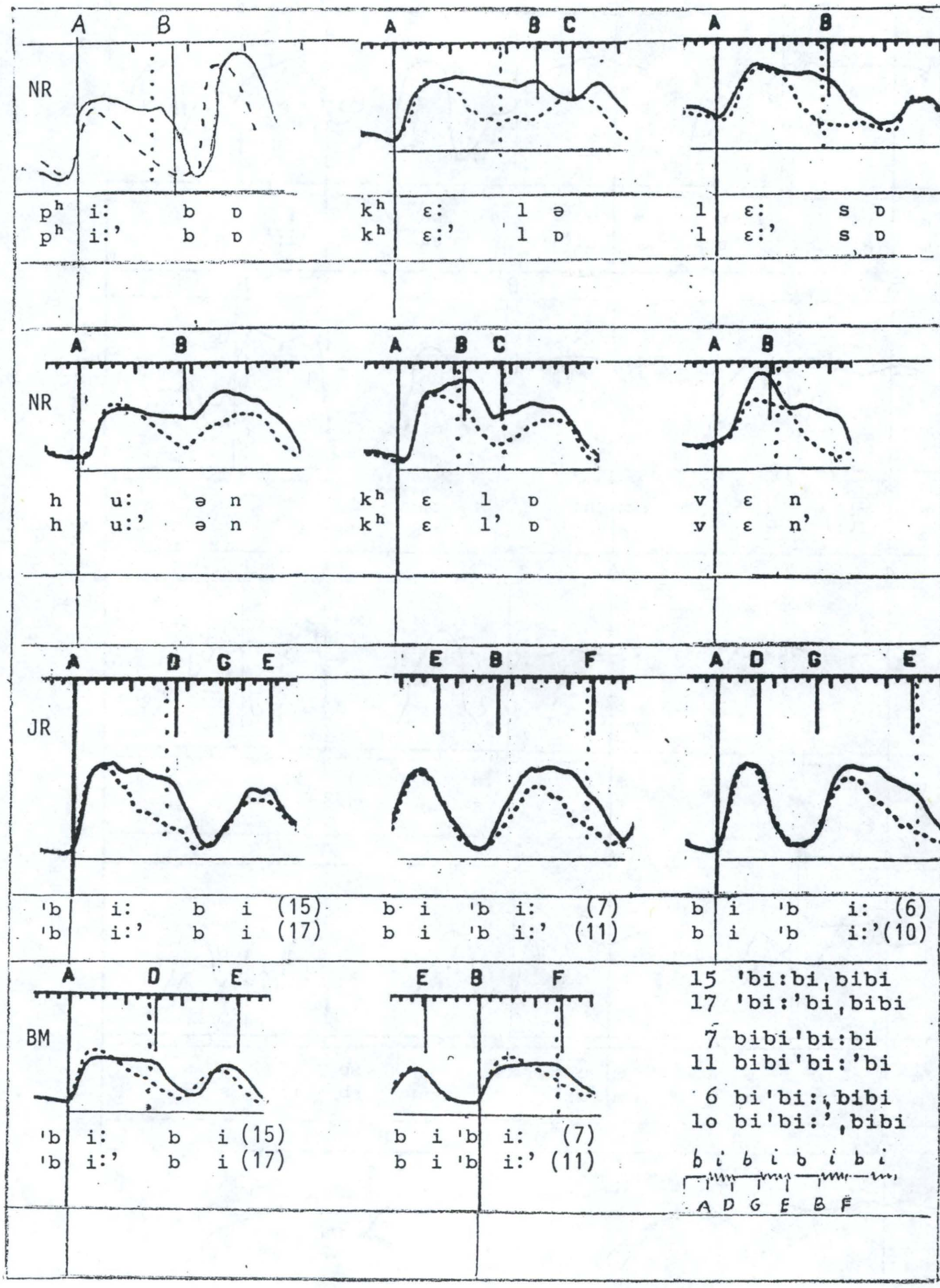


Figure 1d

Intensity average curves 1974 (list 1). NR (N = 6), list 3 JR and BM (N = 10). —— : no stød, --- : stød. See legend to Figure 1a.

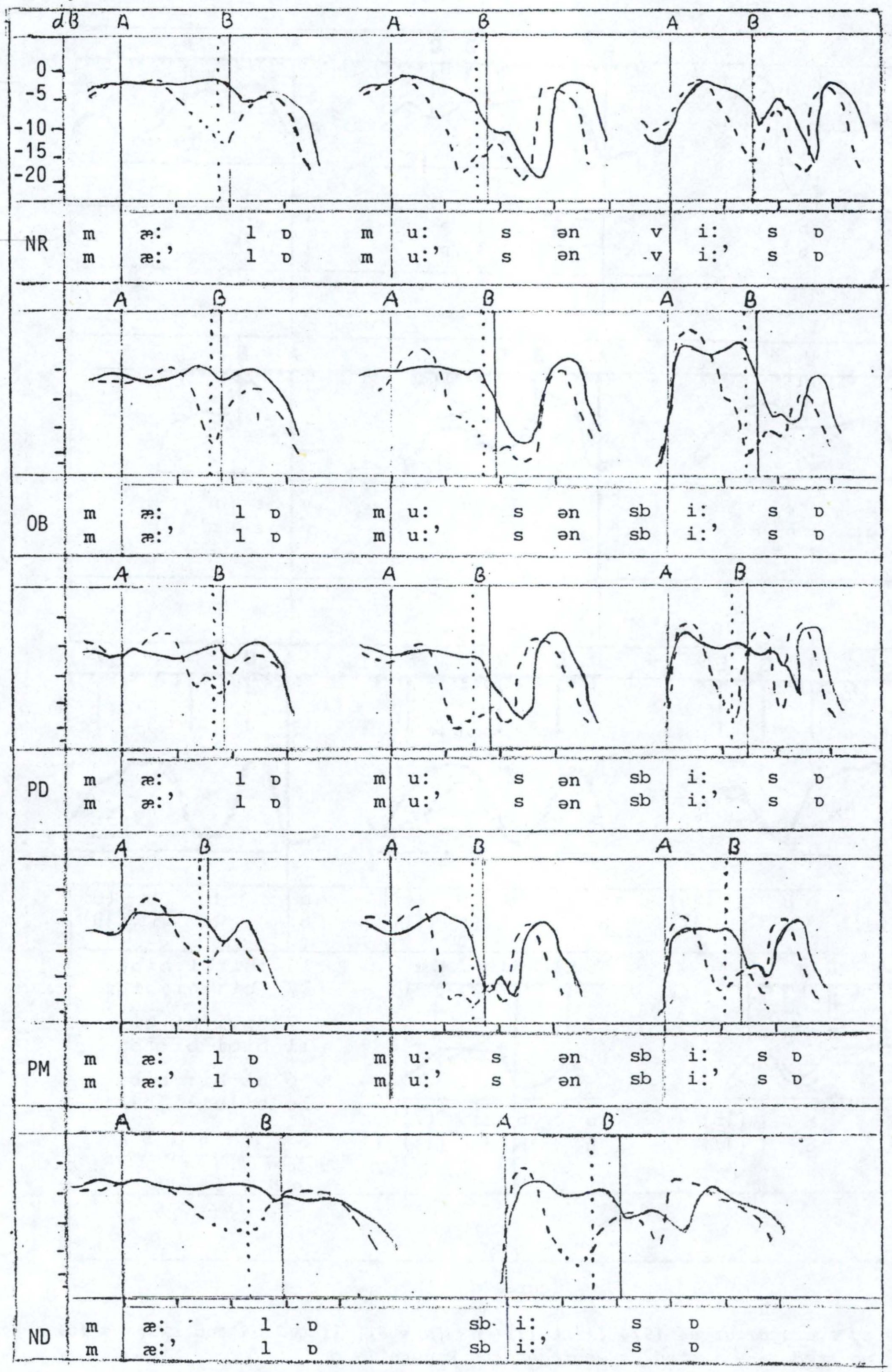


Figure 2a

Intensity average curves 1986 (list 9). NR, OB, PD, PM, ND (N = 10).
—— : no stød, --- : stød. I: 5 dB. See legend to Figure 1a.

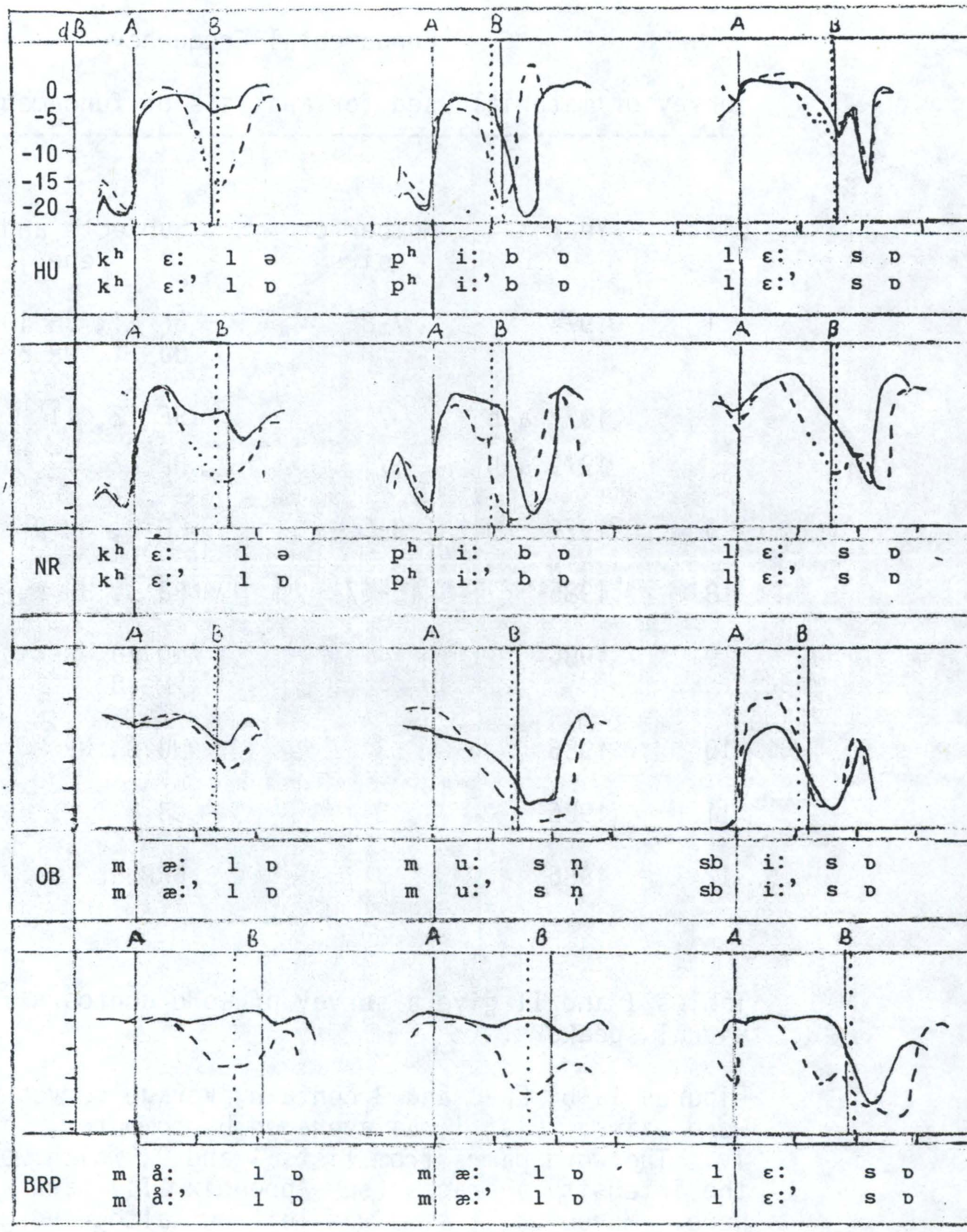


Figure 2b

Intensity average curves 1986 (lists 10 and 11 and 13). HU, NR, OB, BRP (N = 8). —— : no stød, --- : stød. I: 5 dB. See legend to Figure 1a.

APPENDIX IV

Fundamental Frequency

Survey of material used for analysis of fundamental frequency

List	Year	Number of pairs	Subjects and number of repetitions
1	1974	7-8	BF 11, BH 10, BM 10, HU 11, JJ 11, NR 6
	1977 a-b	7	BF 12, 11
	1979 a-b	7	BF 12, 17
3	1974	3-5	BM 9, JR 9
8	1985	15-17	FJ 8, HU 8, JR 8, NR 8
9	1986	4	ND 10, NR 10, OB 10, PD 10, PM 10
10	1986	3	HU 8, NR 8
11	1986	3	OB 8
12	1986	3	BRP 8

Tables I and II give a survey of word contours for the individual speakers.

Figures 1a-b, 2a-c and 3 contain average curves of individual word pairs. List 1 was averaged by computer, lists 8-12 manually. The word pairs from lists 1 and 9, which were left out in the intensity averages (see Appendix III), are also left out here. Moreover, list 3 was left out altogether, and only some of the readings of list 1 are shown, because the average of the stød phase was problematic (see the section on averaging above). The average curves included here are two of BF's five readings, and the two subjects BM and JJ, who had less irregularity than the others, so that it was possible to leave out the tokens with strong irregularity from the averages.

For reasons of space a few word pairs were also left out in list 8.

In the curves averaged manually strong irregularities were skipped. There is thus sometimes only a gap (in list 9, the sensitivity of the pitchmeter was relatively low, and here the individual tokens also generally show a gap). When the average is based on only 2-3 tokens, dots are used instead of broken lines.

Table I

Number of examples with the vowels [i:'], [u:'] and [o:'] which have a lower stressed vowel than the following unstressed vowel (/), both syllables of the same height (- -), or a higher stressed vowel (\ ), for speakers who have \ only in these vowels and not in words with [ɛ:'], [æ:'] or [ɛ] + C'.

	I a												I b								
	HU			NR			ND			PD			BH			BM			FJ		
	/	--	\	/	--	\	/	--	\	/	--	\	/	--	\	/	--	\	/	--	\
p^{h}i:'bɒ	21	3	4	16	3	9							3	1	6	0	0	10	0	0	8
fi:'lɒ	6	2	0	9	0	1															
sbi:'sɒ							7	3	0	10	0	0									
vi:'sɒ				10	0	0															
hu:'ən	19	1	0	14	0	0							4	1	5	2	5	3	1,	2	5
du:'ən																			1	0	7
mu:'sən				10	0	0	8	0	2	7	2	1									
p^{h}o:'sən				10	0	0	4	3	4	7	1	1									
bu:'sɒ	8	0	0	10	0	0													7	2	1
sum	54	6	4	79	3	10	19	6	6	24	3	2	7	2	11	2	5	13	9	4	21

Table II

Number of examples which have a lower stressed vowel than the following unstressed vowel (/), both syllables of the same height (--), or a higher stressed vowel (\), for speakers who may have \ in all types of vowels.

	PM			OB		
sbi:'sɒ	5	1	4	2	2	14
p^{h}e:'dɒ				0	0	8
mu:'sən	5	3	4	5	4	11
p^{h}o:'sən	3	4	3	0	1	9
mæ:'lɒ	5	2	3	11	4	3
sum	18	10	14	18	11	45

	BF		
p^{h}i:'bɒ	6	8	48
hu:'ən	4	5	57
k^{h}ɛl'ɒ	2	4	56
k^{h}ɛ:'lɒ	16	9	37
lɛ:'sɒ	30	6	26
sum	58	32	224

	JR		
hu:'ən	0	3	5
k^{h}ɛ:'lɒ	0	4	4
fi:'lɒ	2	2	4
be:'nəð	2	2	4
p^{h}i:'bɒ	3	1	4
k^{h}ɛl'ɒ	3	2	3
sæ:'lən	4	1	3
vɛn'n̩	6	0	2
lɛ:'sɒ	7	0	1
t^{h}æ:'bəð	7	0	1
gæ:'bəð	8	0	0
bu:'sɒ	8	0	0
sum	50	15	31

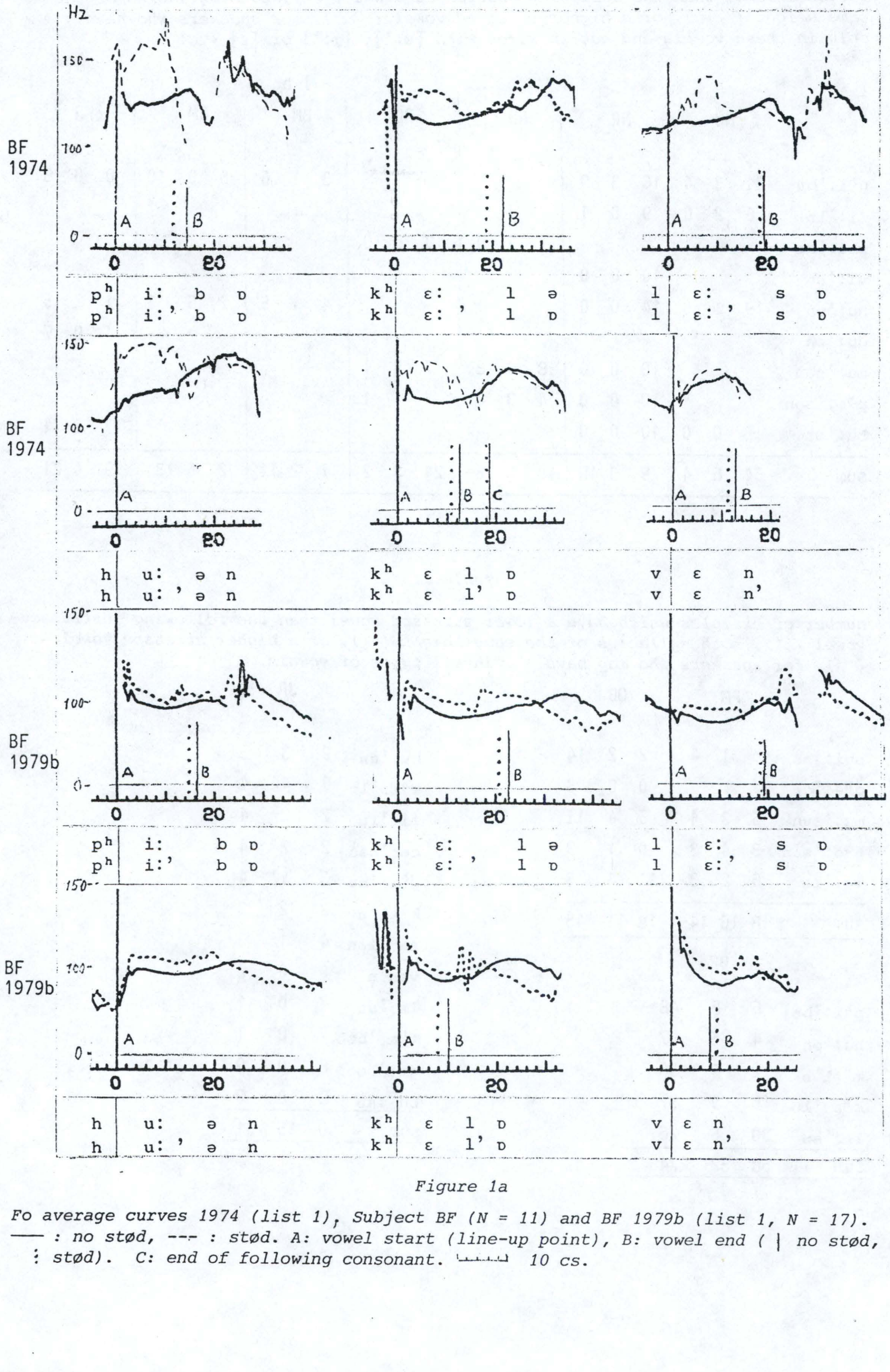


Figure 1a

Fo average curves 1974 (list 1), Subject BF (N = 11) and BF 1979b (list 1, N = 17). —— : no stød, - - - : stød. A: vowel start (line-up point), B: vowel end (| no stød, ⋮ stød). C: end of following consonant. ⊔⊔⊔ 10 cs.

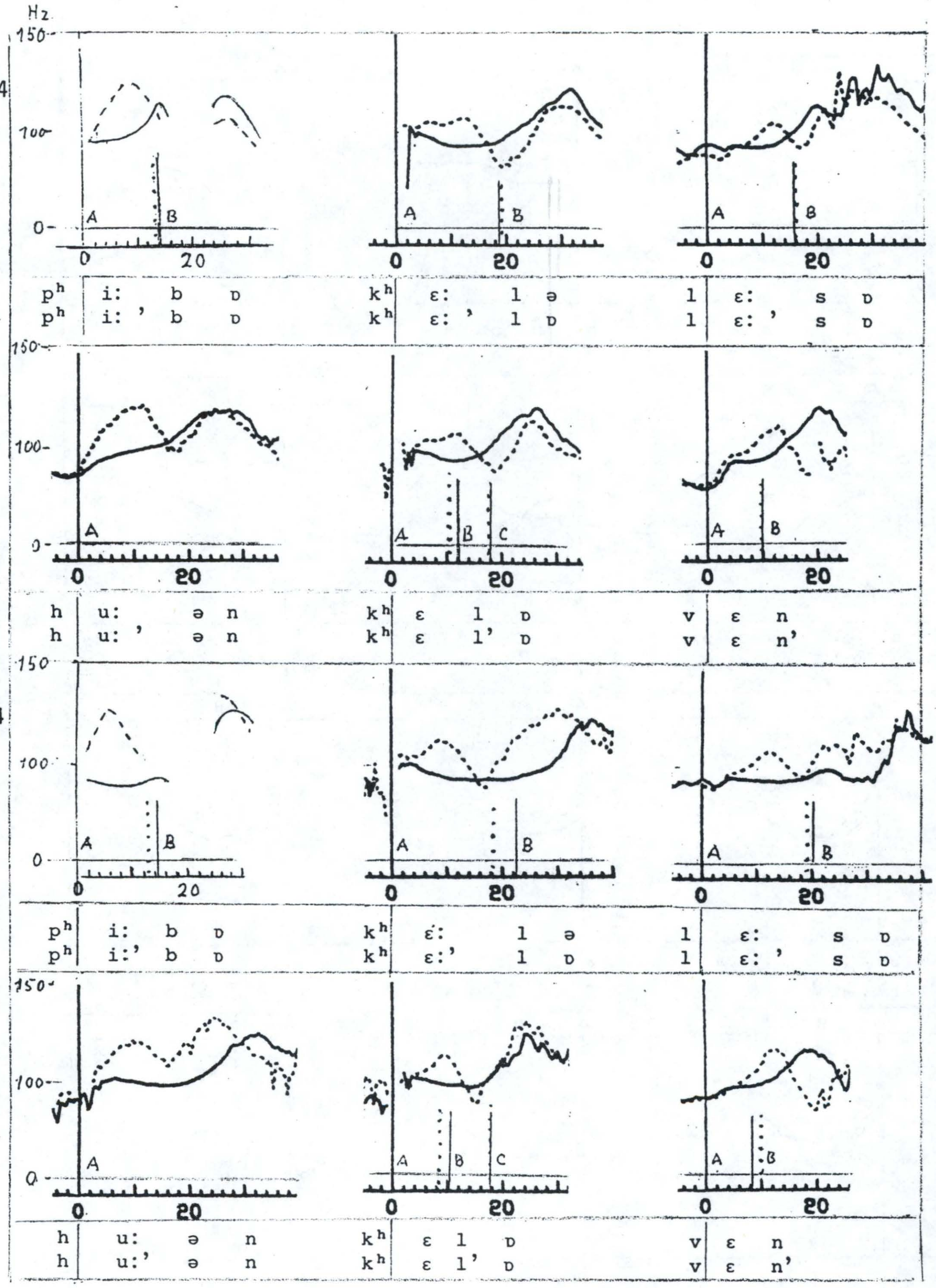


Figure 1b

Fo average curves 1974 (list 1). BM (N = 10) and JJ (N = 12). —— : no stød, --- : stød. See legend to Figure 1a.

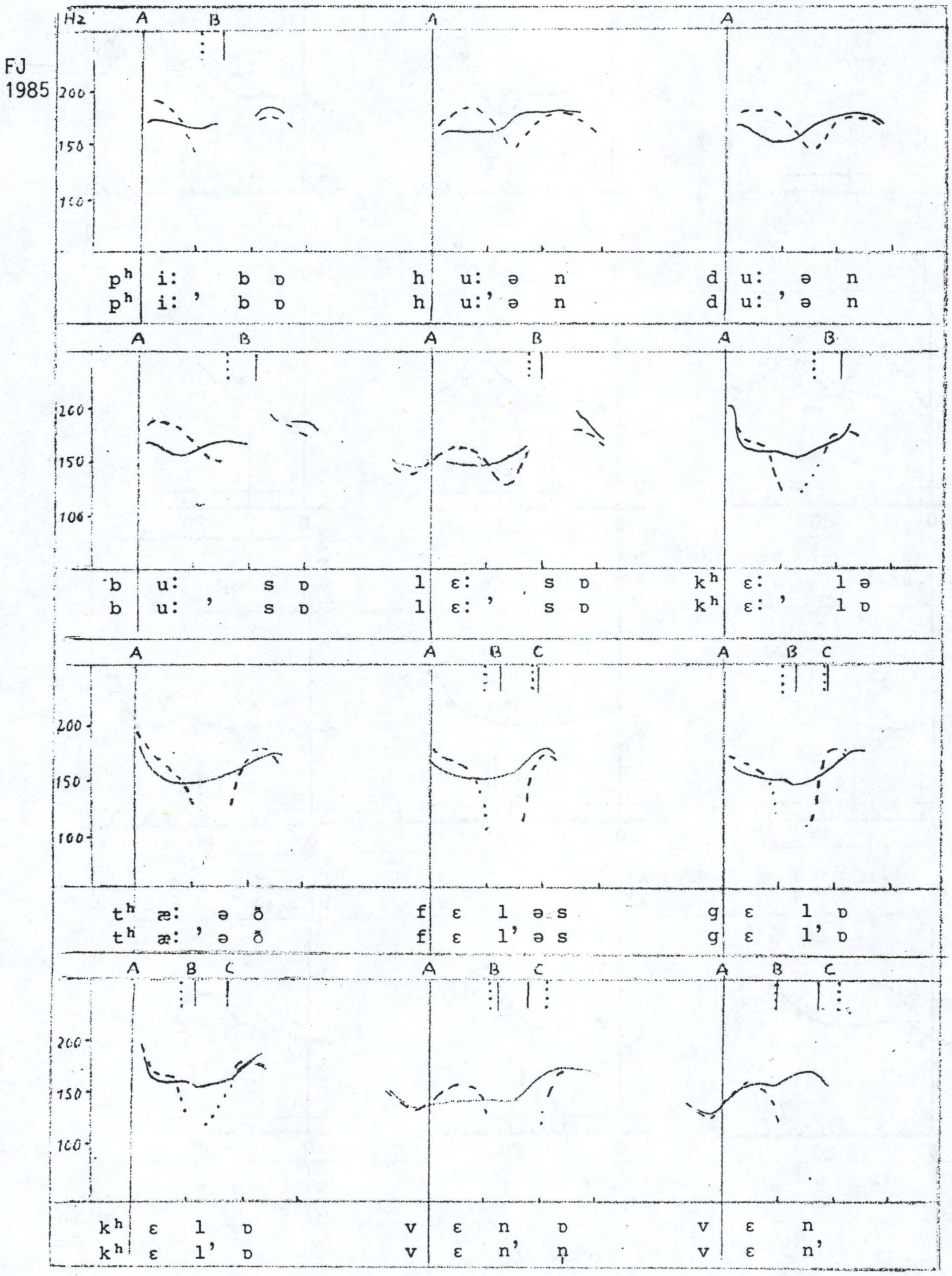


Figure 2a

Fo average curves 1985 (list 8). FJ (N = 8). —— : no stød, --- : stød.
See legend to Figure 1a.

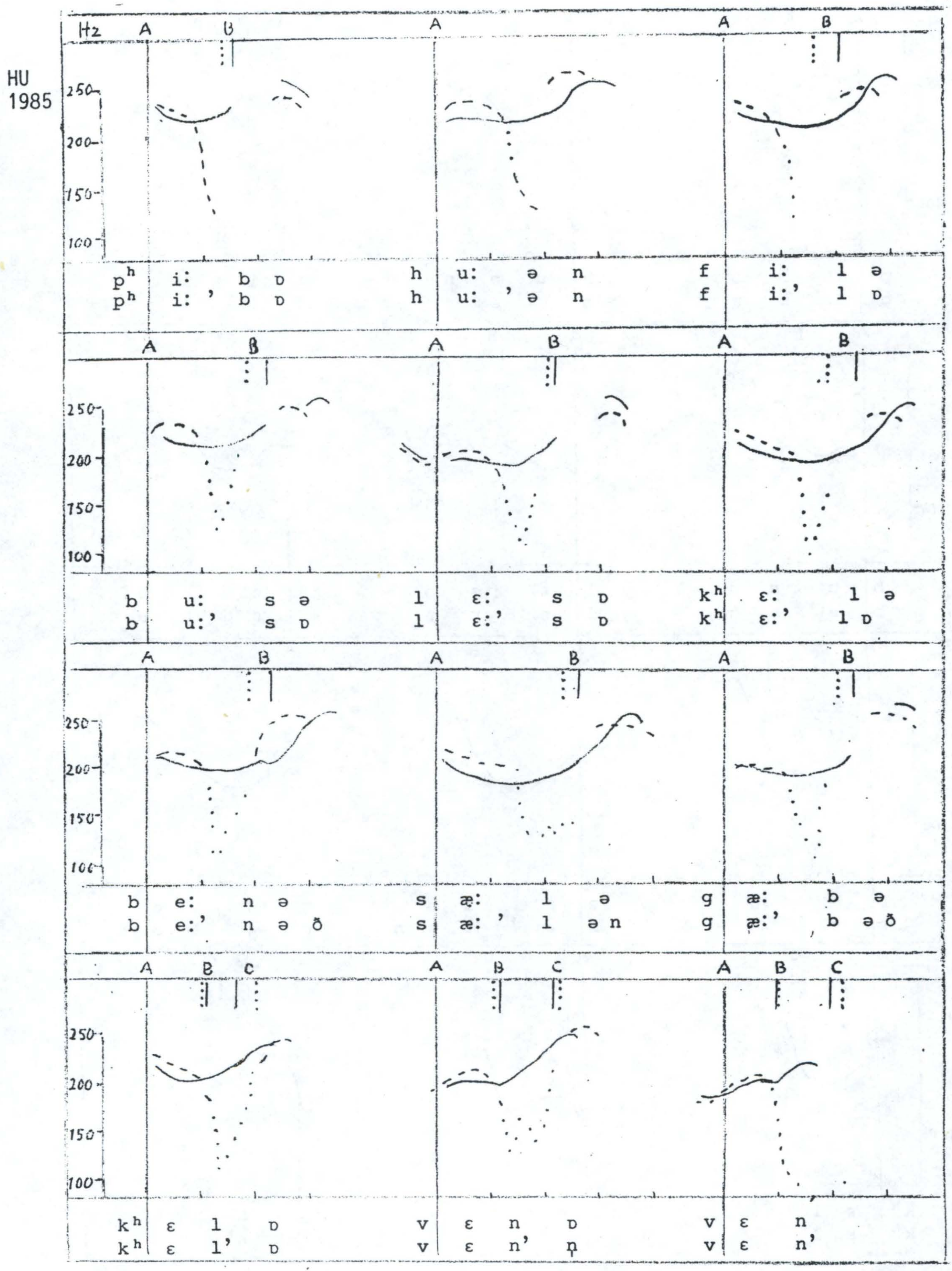


Figure 2b

Fo average curves 1985 (list 8). HU (N = 8). —— : no stød, --- : stød. See legend to Figure 1a.

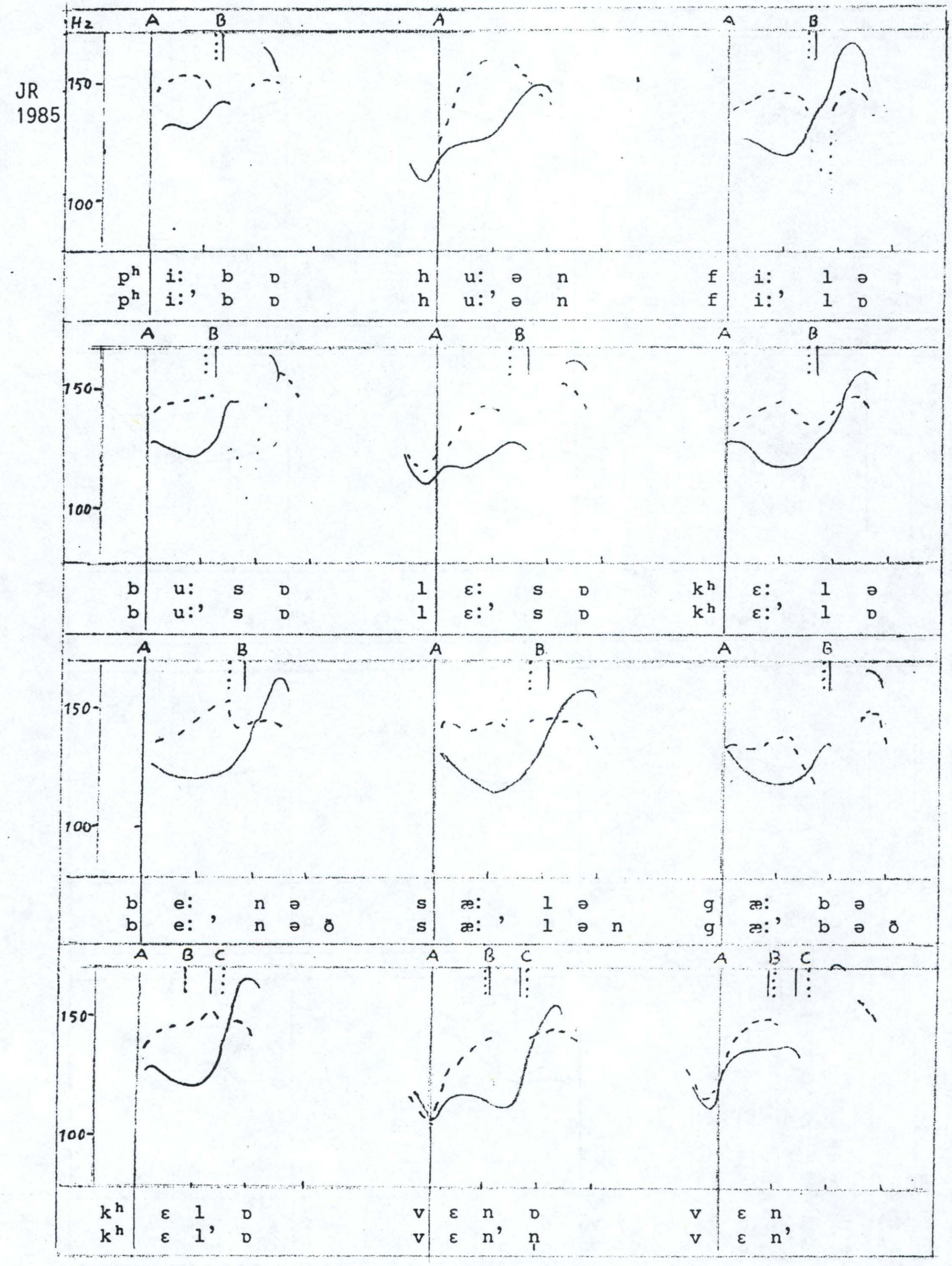


Figure 2c

Fo average curves 1985 (list 8). JR (N = 8). —— : no stød, --- : stød. See legend to Figure 1a.

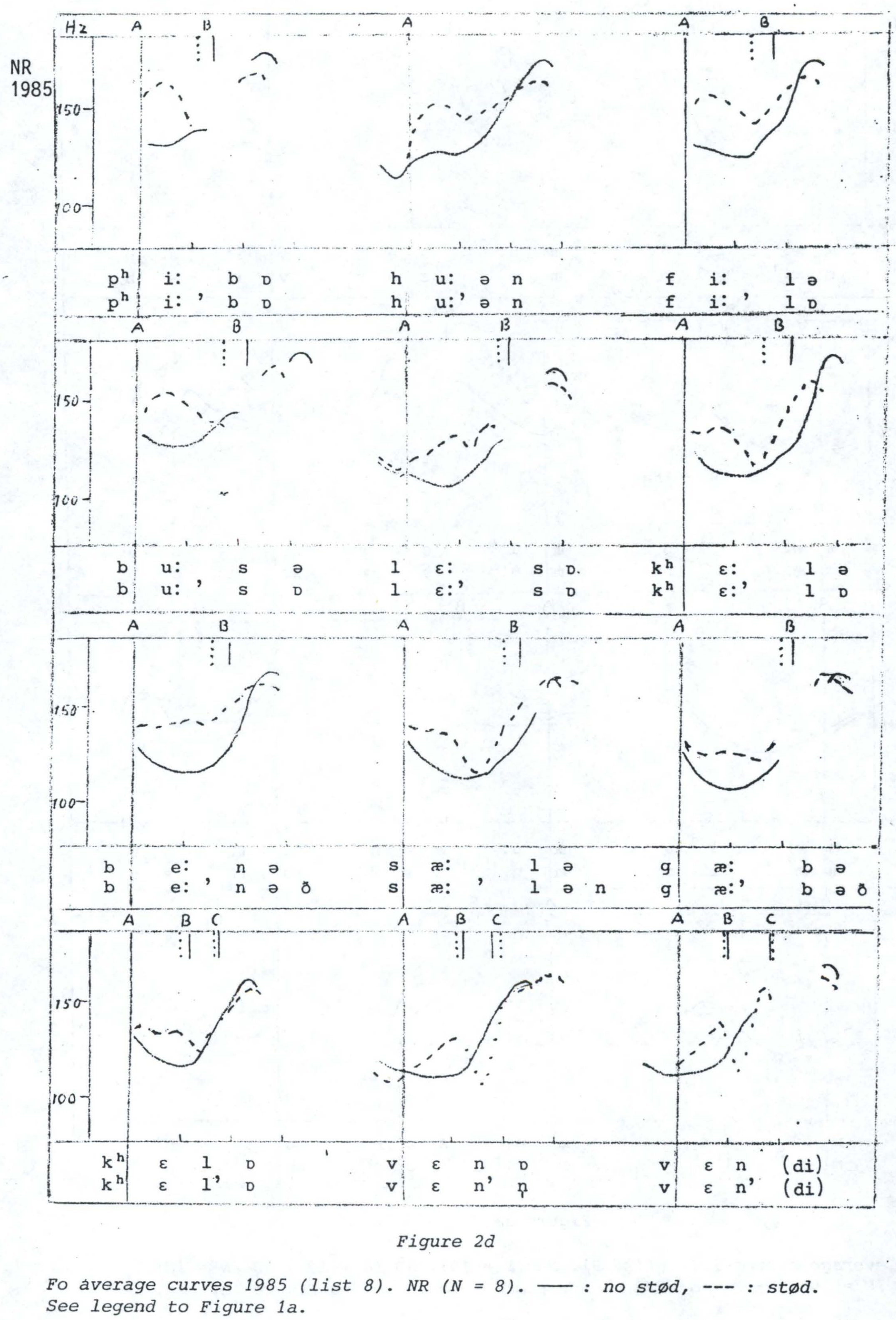


Figure 2d

Fo average curves 1985 (list 8). NR (N = 8). —— : no stød, --- : stød. See legend to Figure 1a.

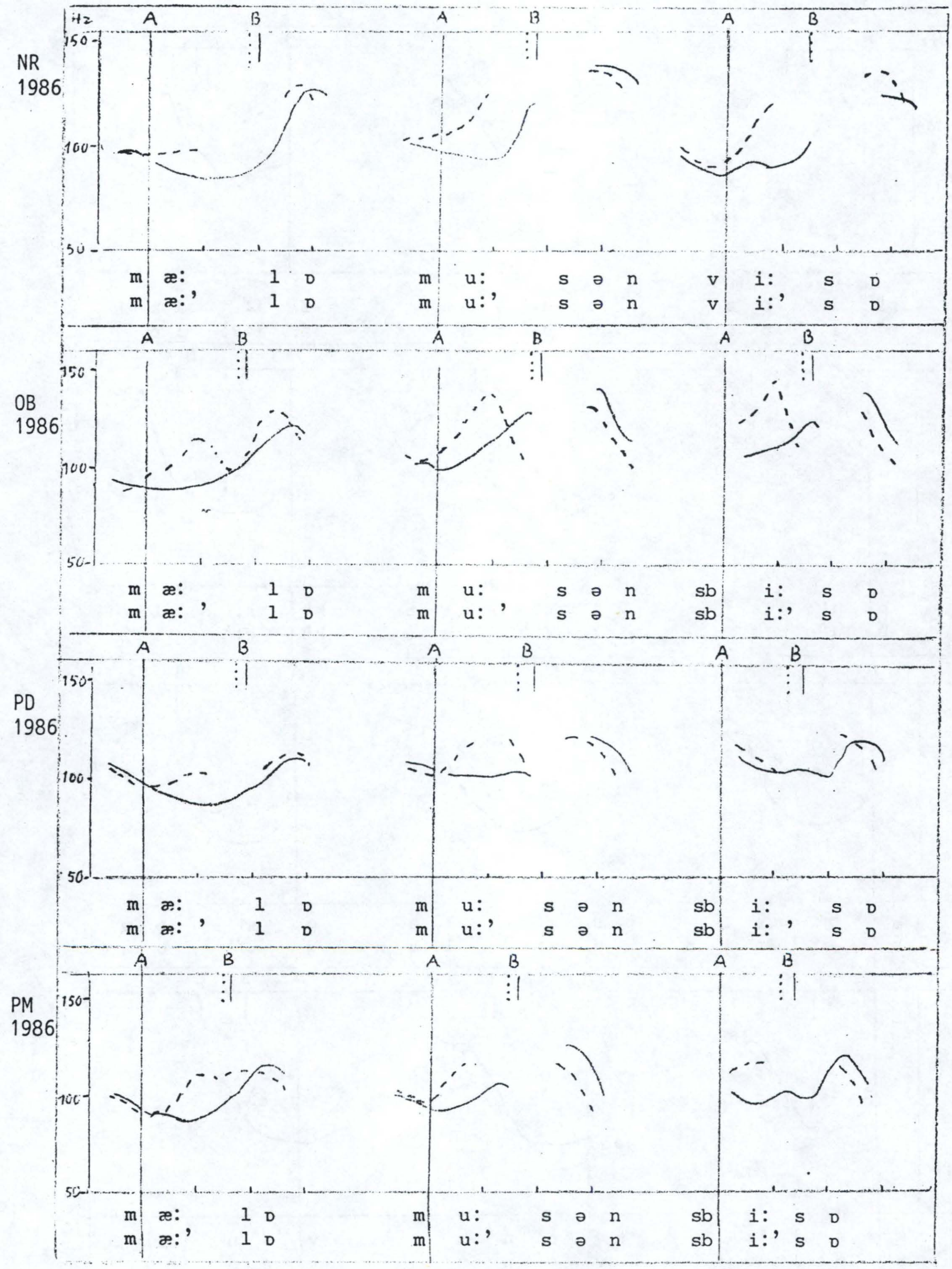


Figure 3a

Fo average curves 1986 (list 9). NR (N = 10), OB (N = 10), PD (N = 10), PM (N = 10). —— : no stød, --- : stød. See legend to Figure 1a.

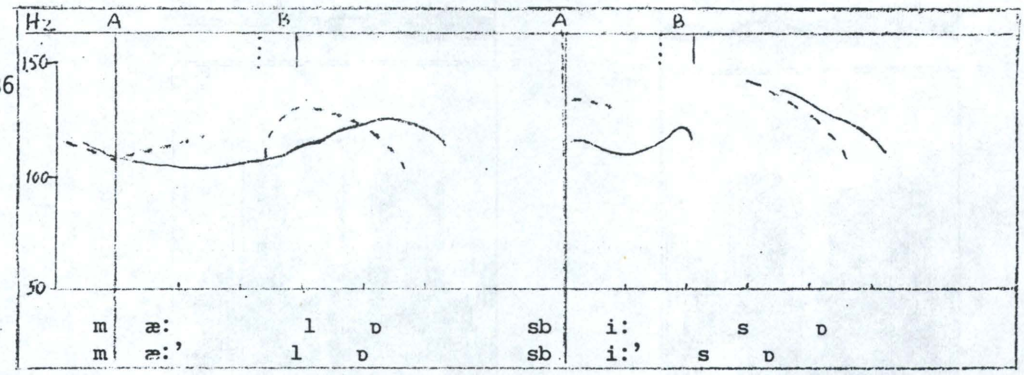


Figure 3b

Fo average curves 1986 (list 9). ND (N = 10). —— : no stød, --- : stød. See legend to Figure 1a.

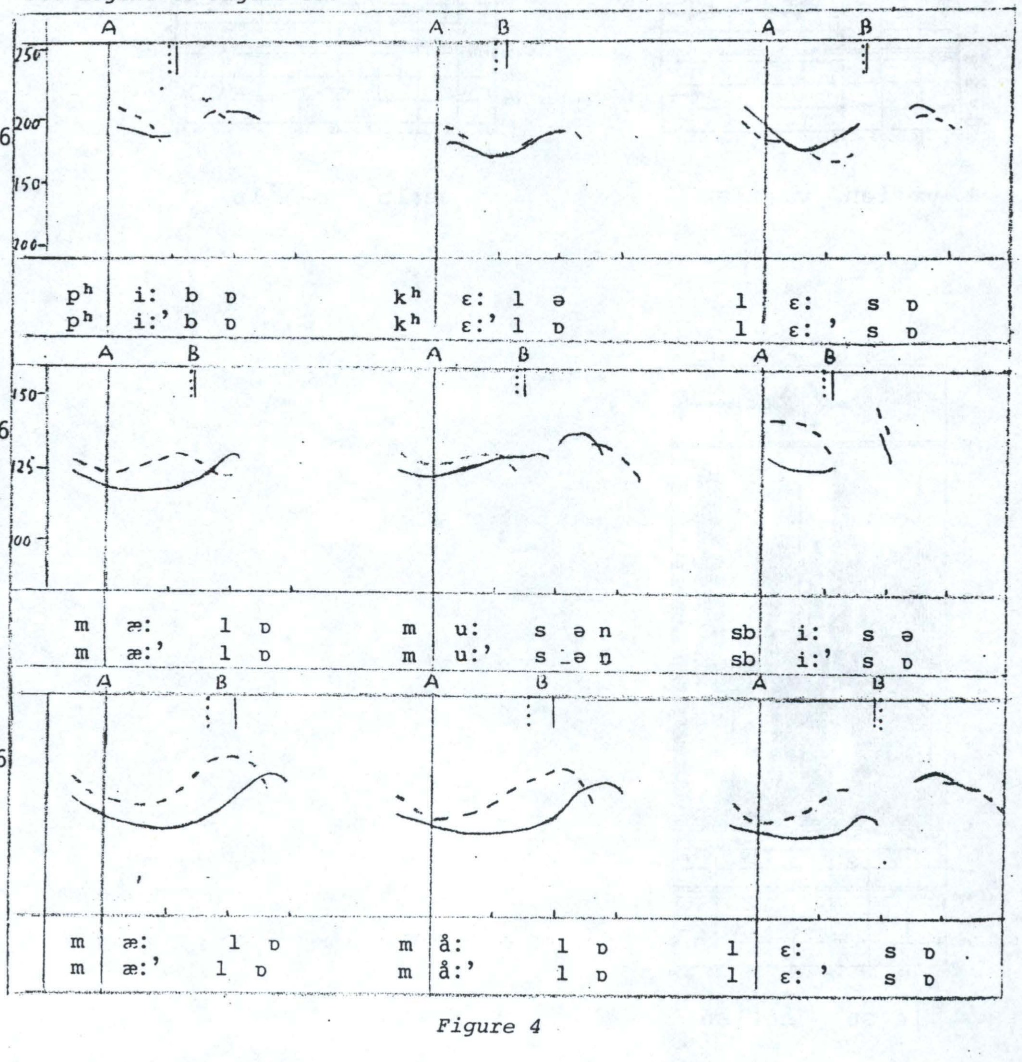
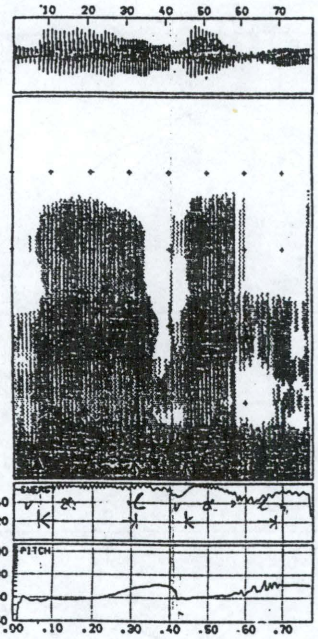
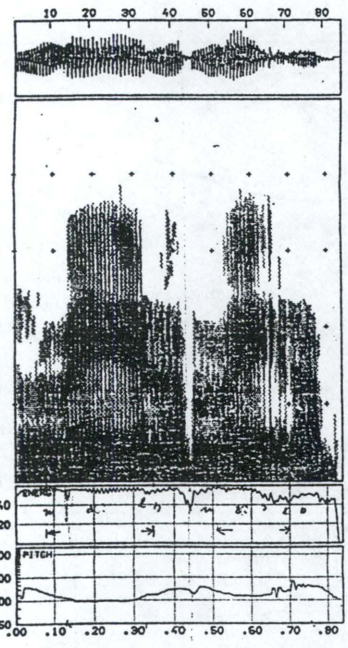


Figure 4

Fo average curves 1986 (lists 10,11,12). HU (N = 8), OB (N = 8), BRP (N = 8). —— : no stød, --- : stød. See legend to Figure 1a.





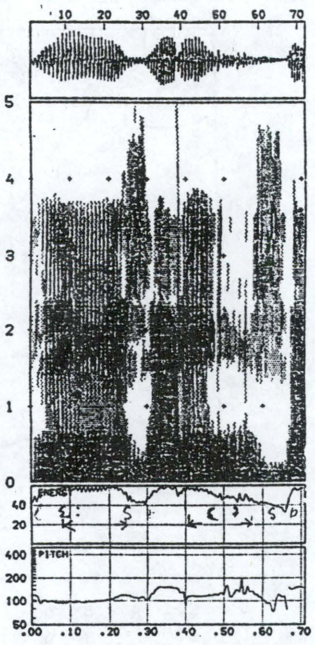
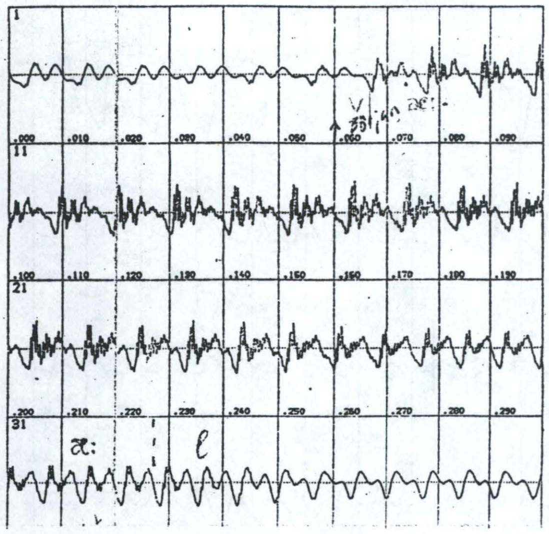
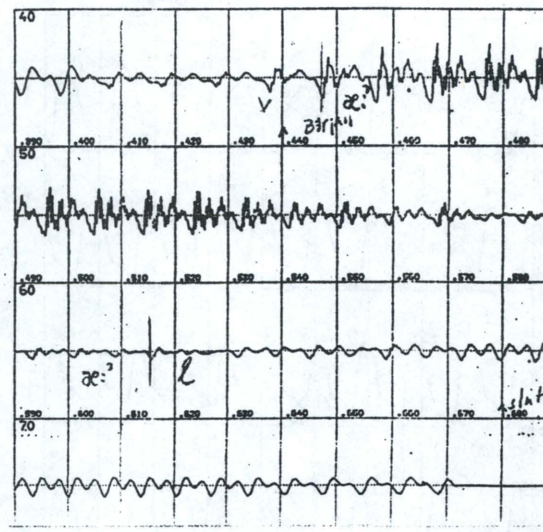


Figure 1

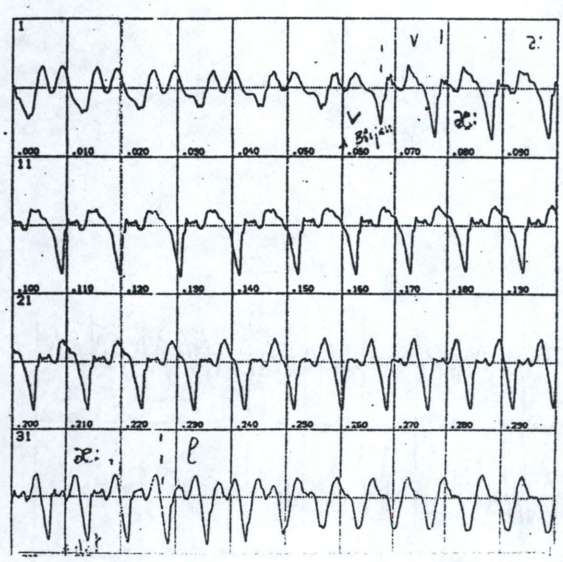
Spectrograms of [væ:lən/væ:'lən], [mæ:lɒ/mæ:'lɒ] *and* [lɛ:sɒ/lɛ:'sɒ] *read by BRP and used for inverse filtering.*



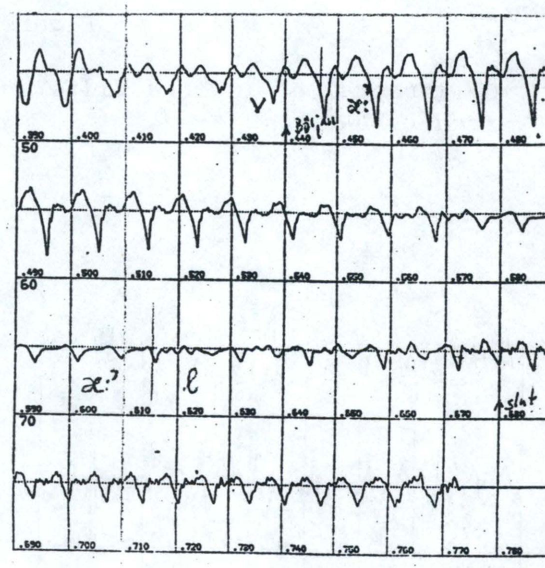
A1 væ:lən



A2 væ:'lən



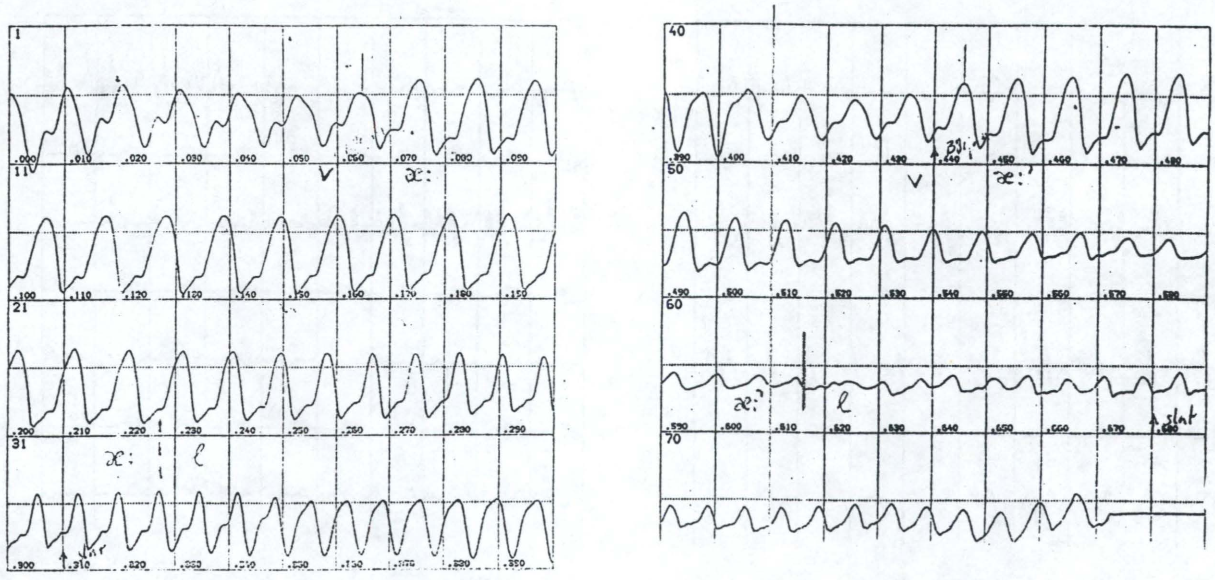
B1 væ:lən



B2 væ:'lən

Figure 2a

A: normal oscillogram and B: inverse filtering, of 1 [væ:lən] *and 2* [væ:'lən], *read by BRP.*

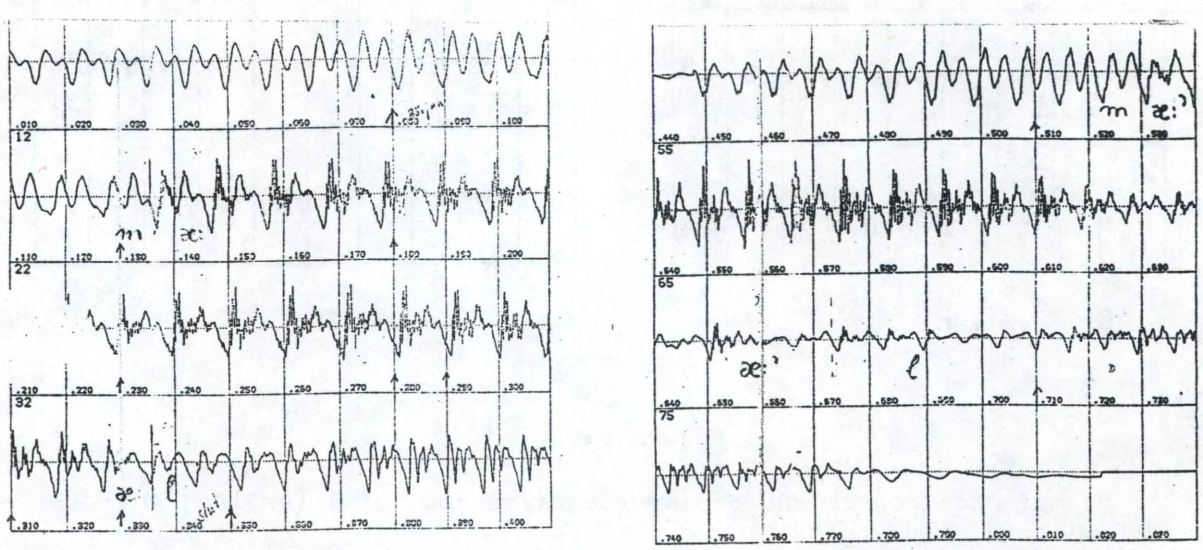


C1 væ:lən

C2 væ:'lən

Figure 2b

C: integral of inverse filtering of 1 [væ:lən] *and 2* [væ:'lən] *read by BRP.*

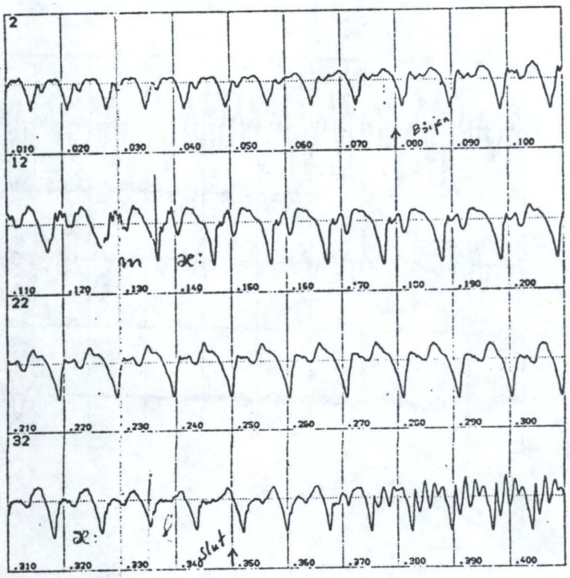


A1 mæ:lɒ

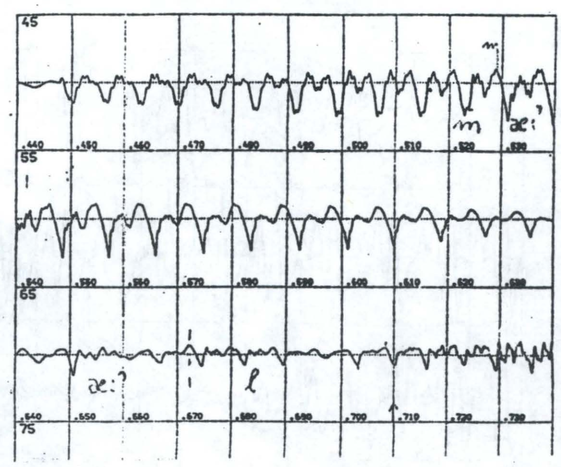
A2 mæ:'lɒ

Figure 3a

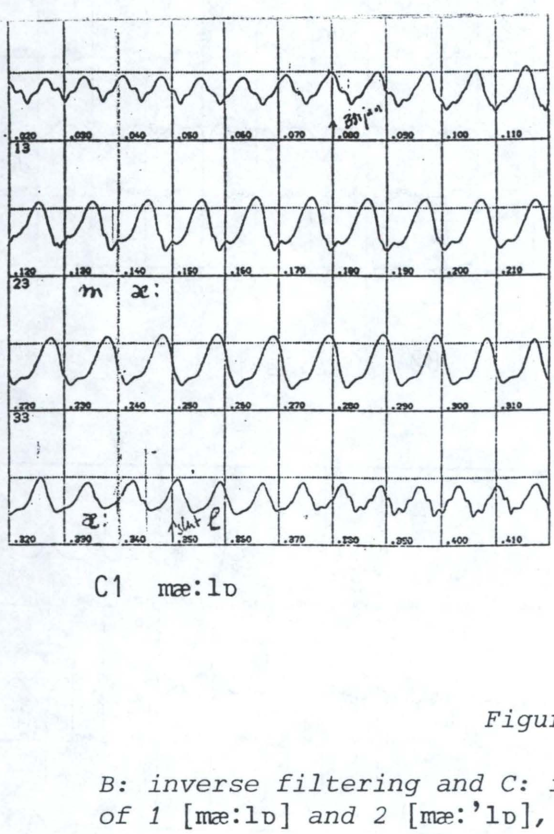
A: normal oscillogram of 1 [mæ:lɒ] *and 2* [mæ:'lɒ], *read by BRP.*



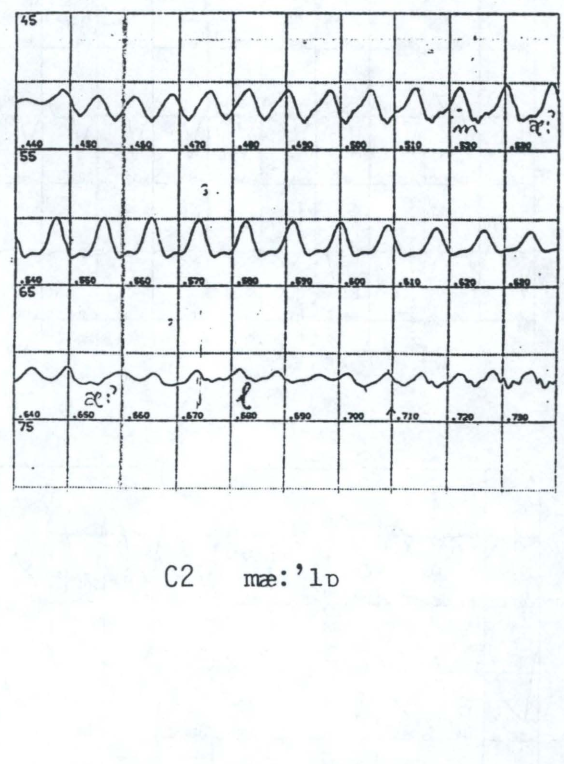
B1 mæ:lɒ



B2 mæ:'lɒ



C1 mæ:lɒ



C2 mæ:'lɒ

Figure 3b

B: inverse filtering and C: integral of inverse filtering of 1 [mæ:lɒ] *and 2* [mæ:'lɒ]*, read by BRP.*

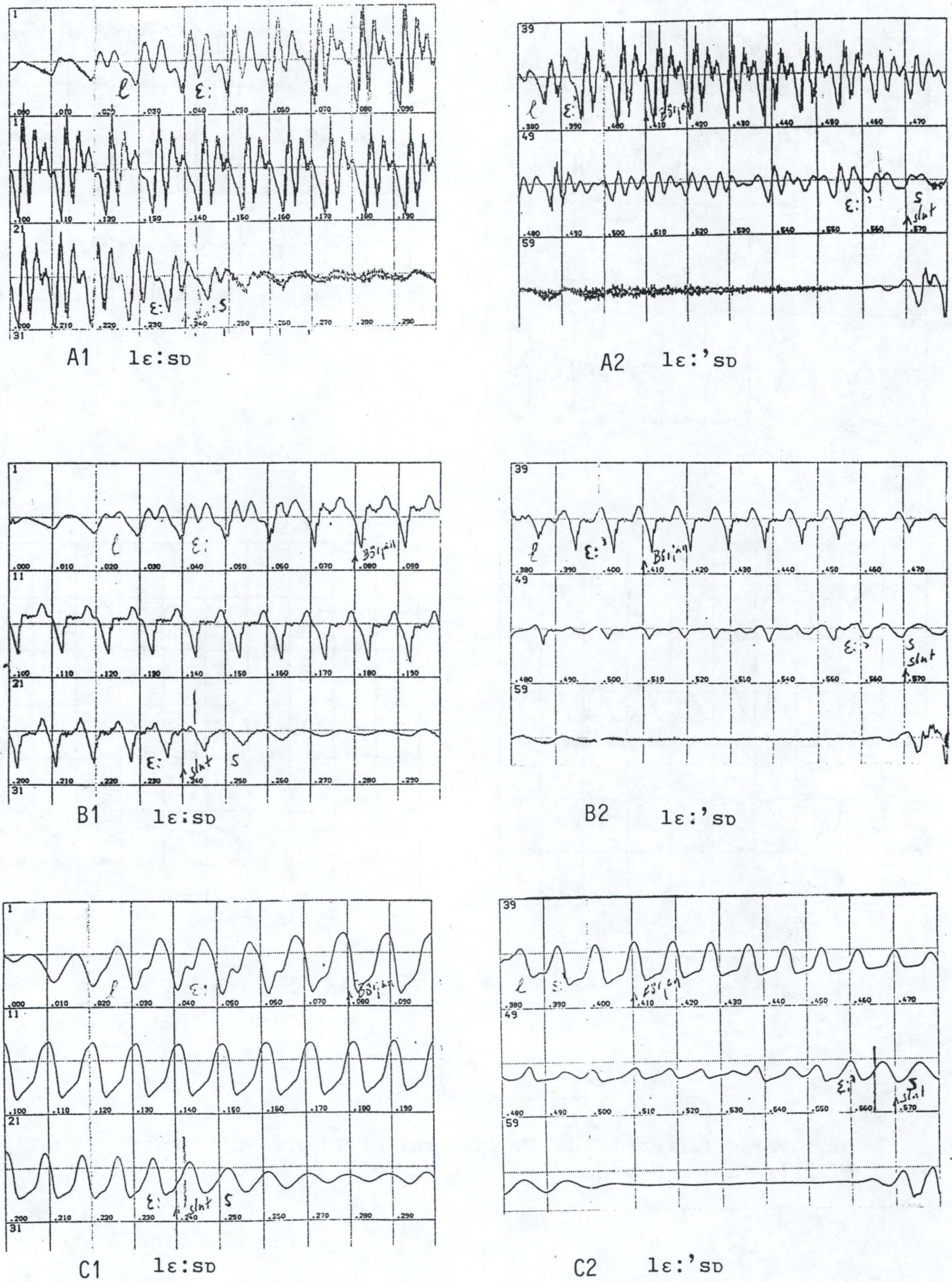


Figure 4

A: normal oscillogram, B: inverse filtering and C: integral of inverse filtering of 1 [lɛ:sɒ], *2* [lɛ:'sɒ], *read by BRP.*

APPENDIX VI

Airflow

Survey of the material used for the analysis of airflow

List	Year	Number of pairs	Subjects and number of repetitions
1	1974	8 (6)	BF 10
8a	1985	17	FJ 8
8b	1985	15	HU 8, JR 8, NR 8

Average airflow curves of individual word pairs are shown on the following pages (Figs. 1-5). Fig. 1 was averaged by computer, the others manually. BF's words with postvocalic nasal are left out, and for lack of space only 12 of the pairs from list 8 are included.

Since the airflow curves are smoothed, the rise is delayed. Therefore the line-up point was moved 2 cs to the right for male speakers and 1 cs for female speakers compared to its place in acoustic curves. This was not, however, done for BF, whose curves were averaged by computer.

Table I

*Number of disyllabic pairs in which the word with stød has a steeper (+), or slower (-) or the same (=) rise in airflow at the start of the word compared to the corresponding word without stød in the same reading. Significance: * < 5%, ** < 1%, *** < 0.1%.*

	A. Aspirated stops				B. Unasp. stops and fricatives				C. Vowels after l,v.				B+C			
	+	=	-	sf.	+	=	-	sf.	+	=	-	sf.	+	=	-	sf.
BF	22	4	5	**(*)	8	0	1	*	13	4	4	*	21	4	5	**
FJ	12	7	5		15	18	11		3	6	7		18	24	18	
HU	19	8	5	*(*)	14	20	14		8	6	2		22	26	16	
JR	18	6	8	(*)	23	10	15		4	10	2		27	20	17	
NR	18	8	6	*	23	19	6	**	11	1	4		34	20	10	**(*)
Sum	89	33	29	***	83	67	47	**	39	27	19	***	122	94	66	***

Table II

*Number of disyllabic pairs in which the word with stød has a higher (+) or lower (-) or the same (=) airflow peak at the start of the word compared to the corresponding word without stød in the same reading. Significance: * <5%, ** <1%, *** < 0.1%.*

	A. Aspirated stops				B. Unasp. stops and fricatives				C. Vowels after l, v				B+C			
	+	=	-	sf.	+	=	-	sf.	+	=	-	sf.	+	=	-	sf.
BF	23	2	6	***	7	2	0	*(*)	12	5	4	*	19	7	4	**
FJ	15	2	7		21	4	19		10	2	4		31	6	23	
HU	24	1	7	**	30	6	12	*	13	2	1	**(*)	43	8	13	***
JR	22	1	9	*	26	5	17		10	3	3	*	36	8	20	*
NR	22	0	10	*	33	7	8	***	11	2	3	*	44	9	11	***
Sum	106	6	39	***	117	24	56	**	56	14	15	***	173	38	71	***

Table III

*Airflow (in l/m) in the second part of long vowels with and without stød in disyllables (measured at the minimum in stød-words) (average of 8 repetitions). Significance: * < 5%, ** < 1%, *** < 0.1%.*

	pʰi:bɒ pʰi:'bɒ	kʰɛ:lə kʰɛ:'lɒ	hu:ən hu:'ən	lɛ:sɒ lɛ:'sɒ	bu:sə bu:'sɒ	gæ:bə gæ:'bəð	be:nə be:'nəð	fi:lə fi:'lɒ	du:ən du:'ən
BF	18.5 13.0	19.5 9.0	17.5 9.0	19.0 9.5					
diff.	5.5***	10.5***	8.5*	9.5***					
FJ	7.5 4.0	6.5 4.0	9.0 3.0	7.0 10.0	6.0 5.0				6.0 2.0
diff.	3.5*	2.5	6.0**	-3.0	1.0*				4.0**
HU	8.0 4.0	7.5 3.0	7.0 2.0	8.5 6.0	6.0 3.5	6.0 1.5	6.0 1.5	6.0 2.5	
diff.	4.0**	4.5**	5.0**	2.5**	2.5**	4.5**	4.5**	3.5**	
JR	22.0 12.0	19.0 12.0	13.0 9.0	23.0 14.0	9.0 6.0	16.0 13.0	22.0 11.0	16.0 8.0	
diff.	10.0**	7.0**	4.0**	9.0**	3.0**	3.0**	11.0**	8.0**	
NR	5.0 4.0	6.5 4.5	6.0 3.5	8.0 7.0	2.5 2.0	10.0 8.0	4.0 2.5	3.5 1.0	
diff.	1.0**	2.0**	2.5*	1.0	0.5	2.0**	1.5*	2.5*	

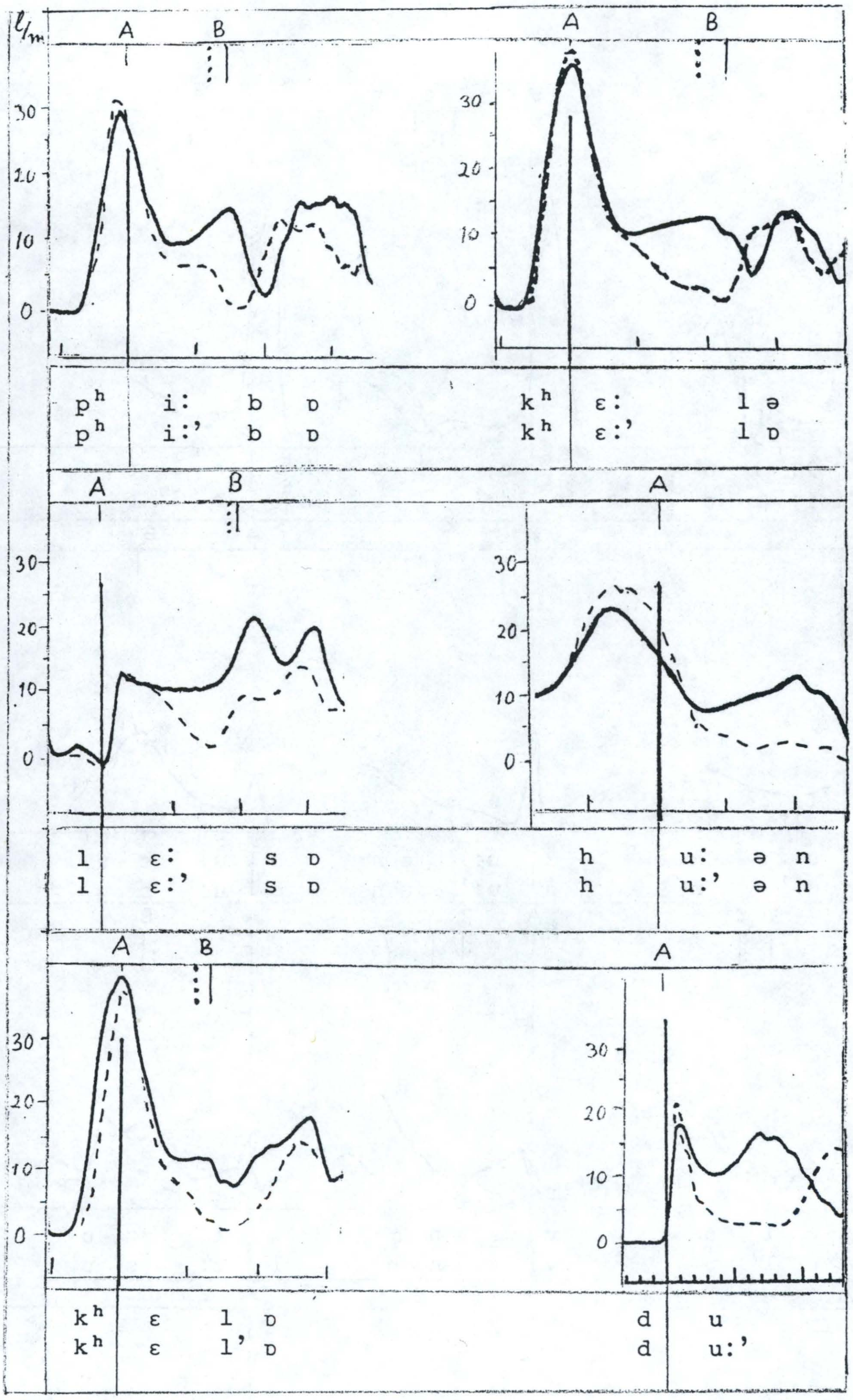


Figure 1

Airflow average curves 1974 (list 1). Subject BF (N = 10). —— : no stød, --- : stød. A: vowel start (line-up point), B: vowel end (| no stød, ⋮ stød), C: end of following consonant. l/m = liter per minute, ⊢—⊣ 10 cs.

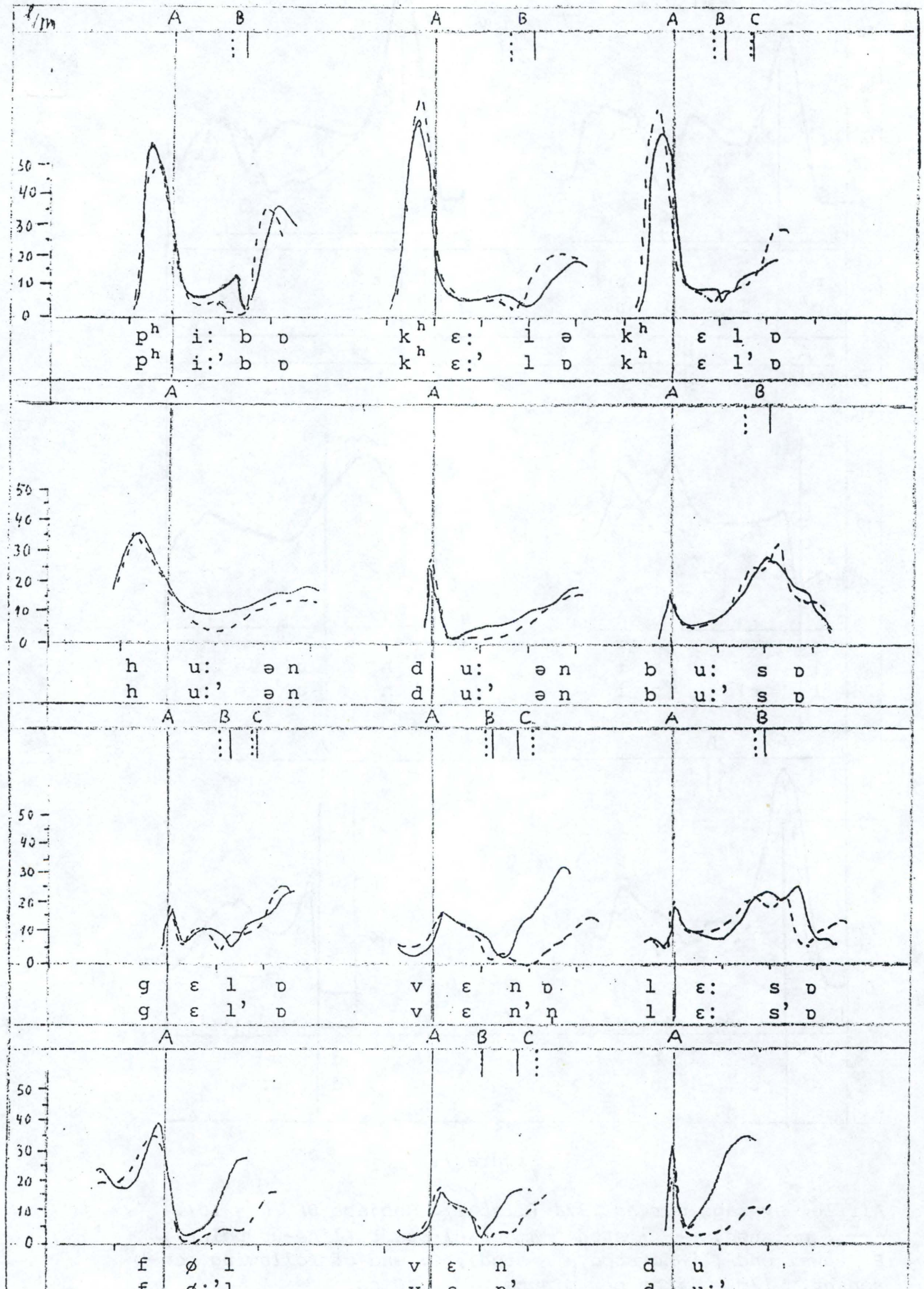


Figure 2

Airflow average curves 1985 (list 8a). Subject FJ (N = 8). —— : no stød, --- : stød. See legend to Figure 1.

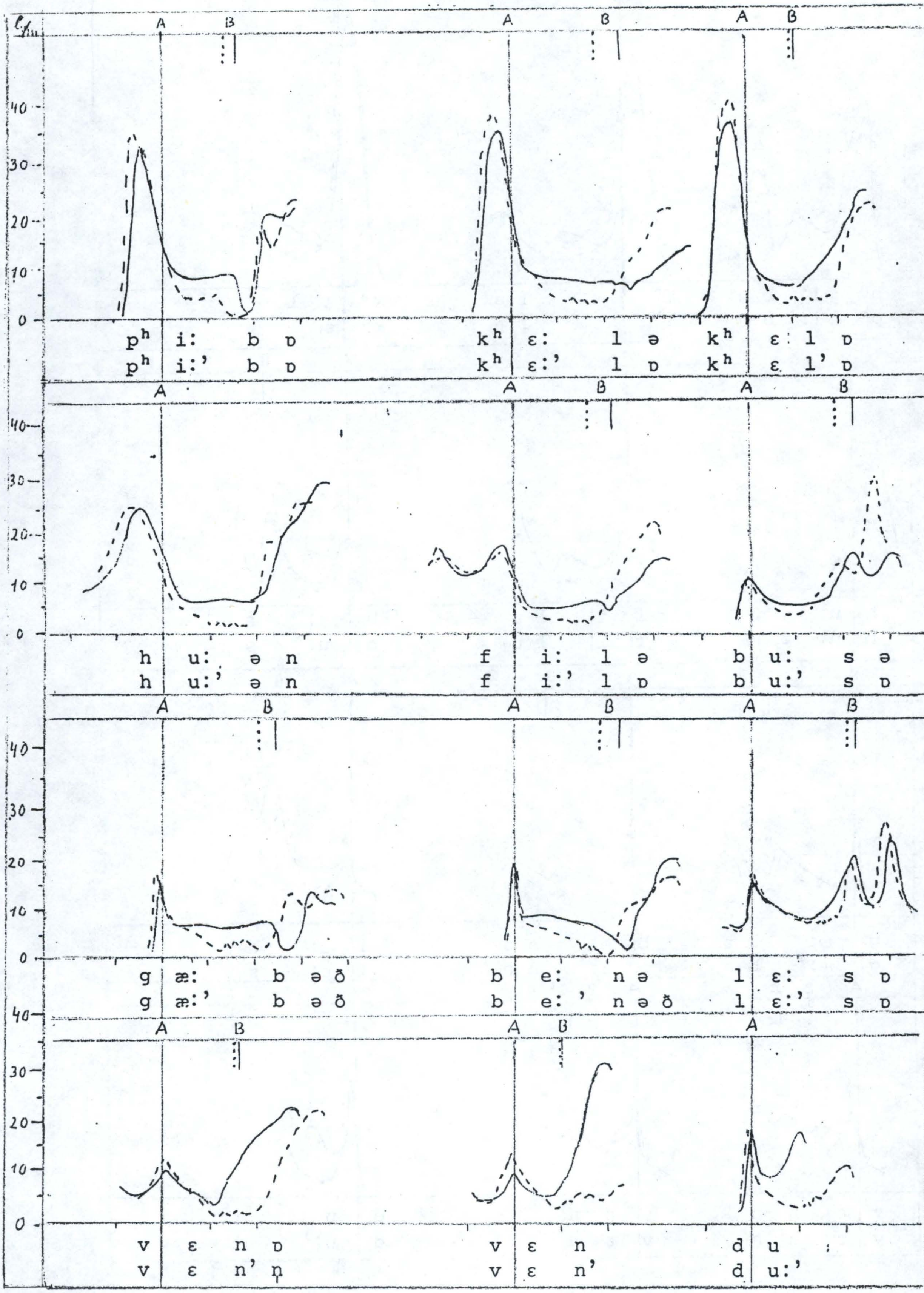


Figure 3

Airflow average curves 1985 (list 8b). Subject HU (N = 8). —— : no stød, --- : stød. See legend to Figure 1.

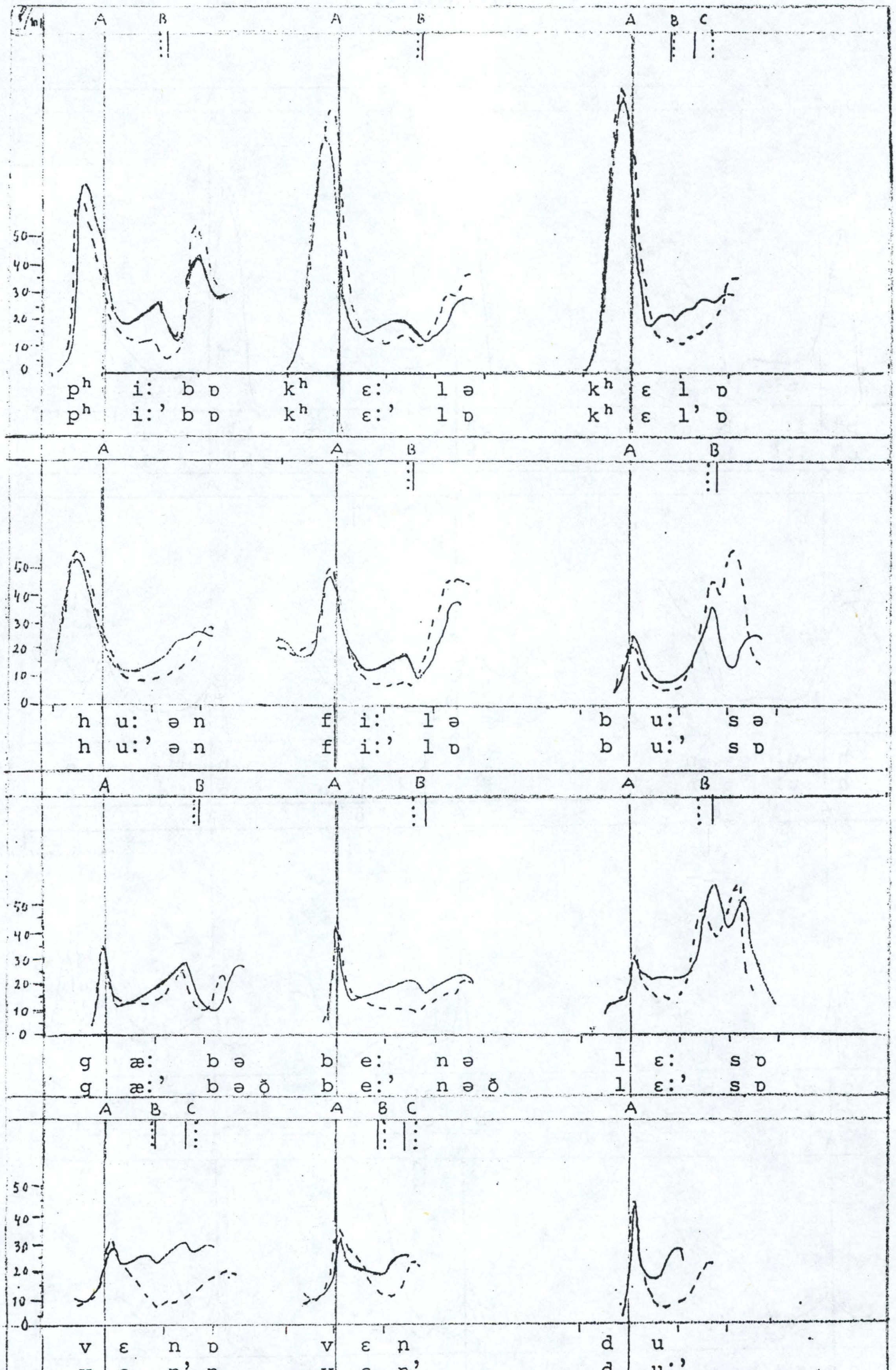


Figure 4

Airflow average curves 1985 (list 8b). Subject JR (N = 8). —— : no stød, --- : stød. See legend to Figure 1.

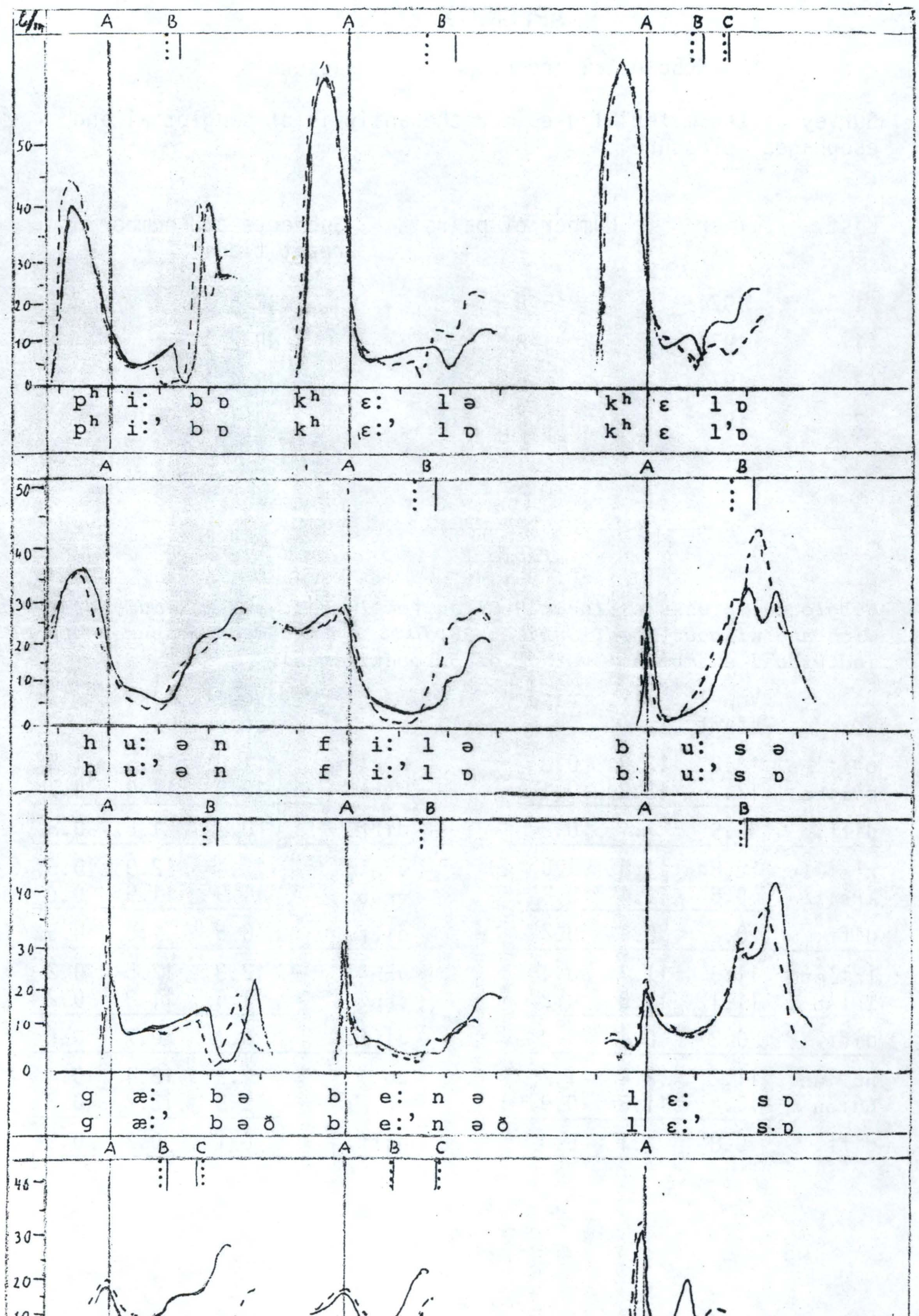


Figure 5

Airflow average curves 1985 (list 8b). Subject NR (N = 8). —— : no stød, --- : stød. See legend to Figure 1.

APPENDIX VII

Subglottal and esophageal pressure

Survey of the material used for the analysis of subglottal and esophageal pressure

List	Year	Number of pairs	Subjects and number of repetitions
1	1974	8	BF 5
(1	1974	8	JR 2)
(3	1974	6	JR 4)
7	1981	4	FJ 12

Table I

Subglottal pressure (in cm H_2O) at vowel start and maximum for words with and without stød. Subject BF. List 1 (based on measurements of individual examples , average of 5 repetitions).

	Vowel start	max.	rise		Vowel start	max.	rise
pʰi:'bɒ	13.0	13.3	0.3	kʰɛl'ɒ	11.0	12.5	1.5
pʰi:bɒ	12.1	12.2	0.1	kʰɛlɒ	10.3	11.0	0.7
diff.	0.9	1.1	0.2	diff.	0.7	1.5	0.8
kʰɛ:'lɒ	10.8	11.8	1.0	vɛn'n̩	12.4	12.9	0.5
kʰɛ:lə	10.6	11.4	0.8	vɛnɒ	11.9	11.9	0.0
diff.	0.2	0.4	0.2	diff.	0.5	1.0	0.5
lɛ:'sɒ	11.3	11.7	0.4	vɛn'	12.3	12.5	0.2
lɛ:sɒ	11.1	11.3	0.2	vɛn	11.6	11.8	0.2
diff.	0.2	0.4	0.2	diff.	0.7	0.7	0.0
hu:'ən	11.2	12.4	1.2	du '	12.9	13.4	0.4
hu:ən	10.4	11.3	0.9	du	12.9	13.2	0.2
diff.	0.8	1.1	0.3	diff.	0.0	0.2	0.2

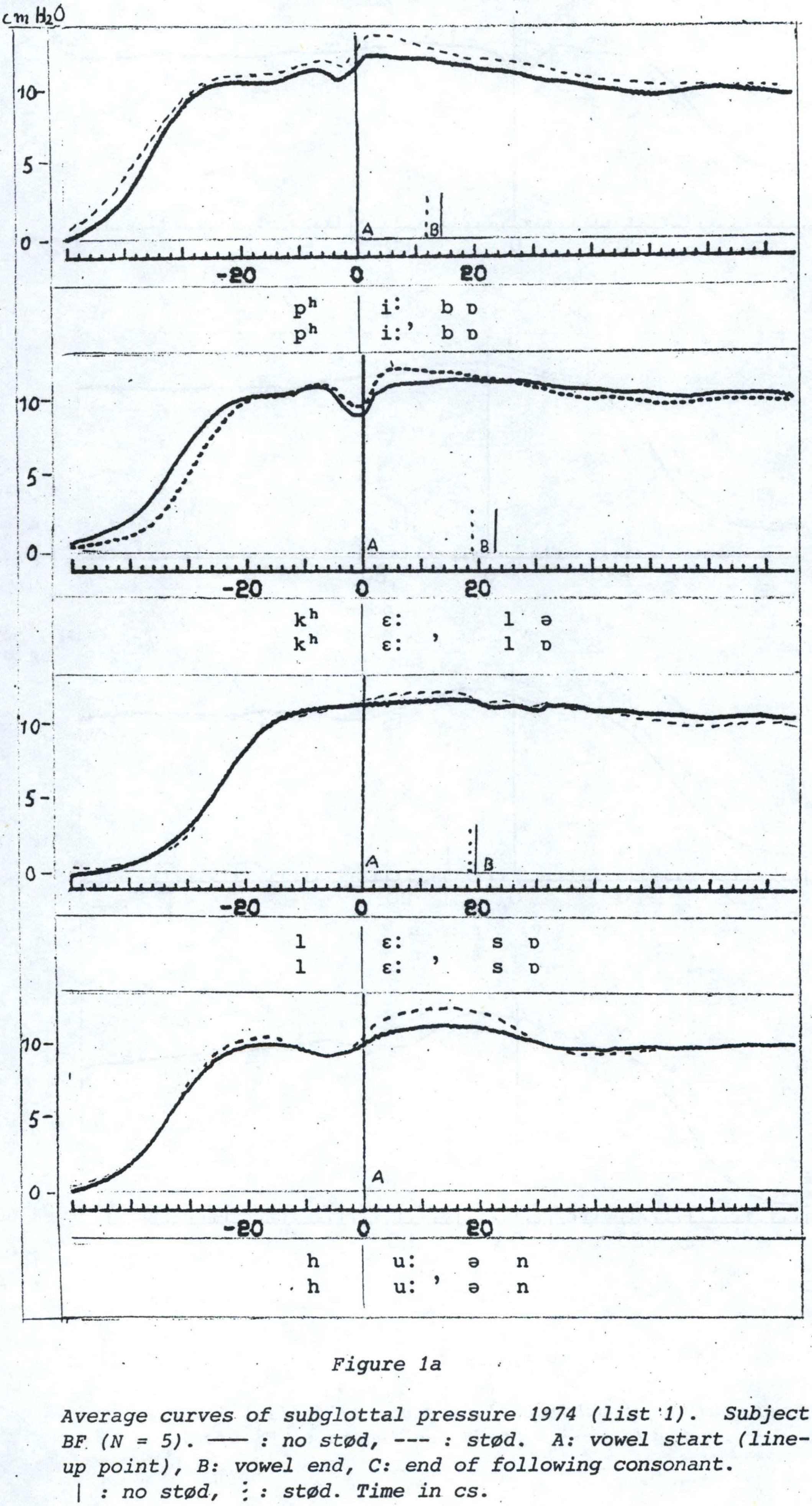


Figure 1a

Average curves of subglottal pressure 1974 (list 1). Subject BF (N = 5). —— : no stød, --- : stød. A: vowel start (line-up point), B: vowel end, C: end of following consonant. | : no stød, ⁝ : stød. Time in cs.

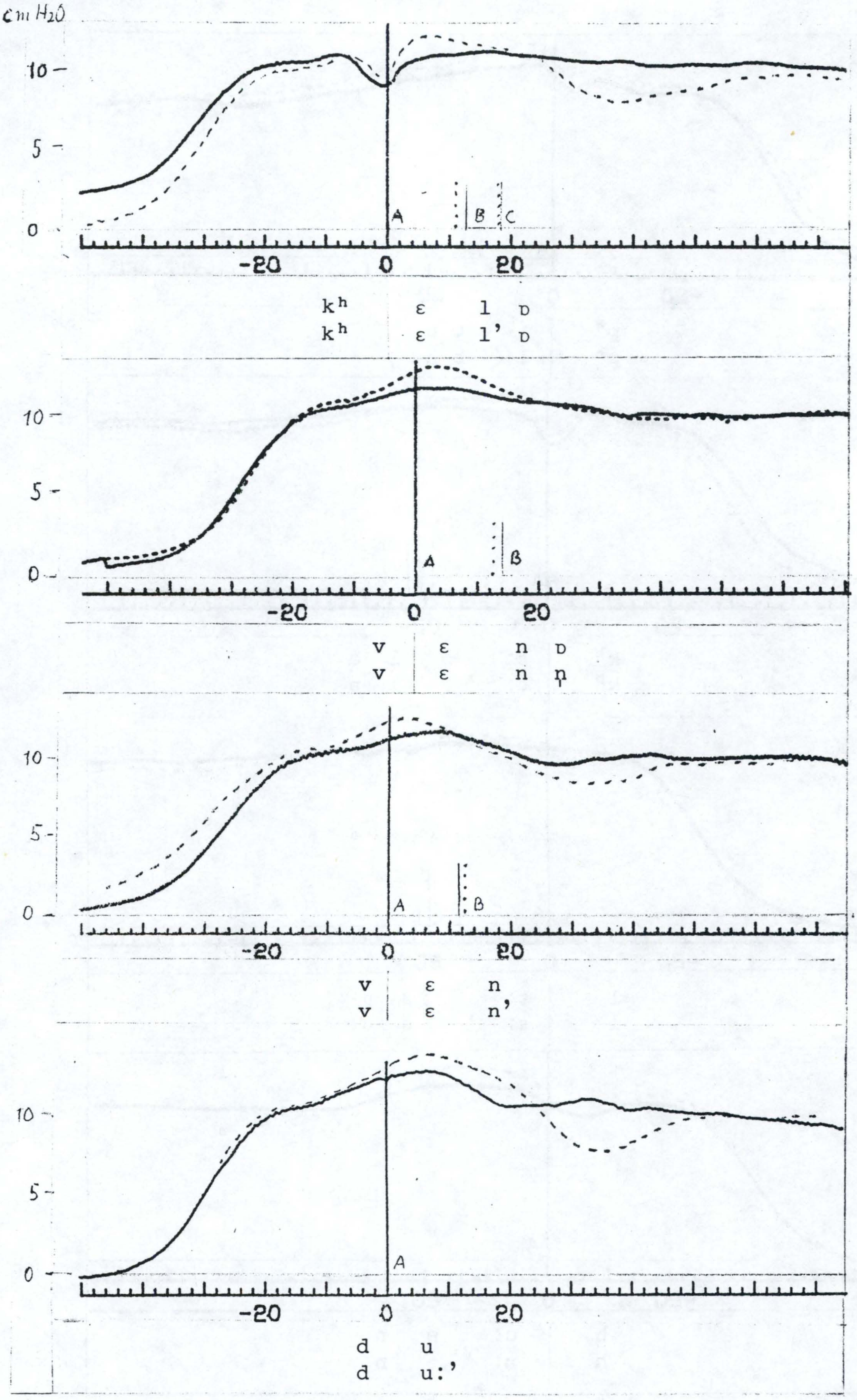


Figure 1b

Average curves of subglottal pressure 1974 (list 1). Subject BF. —— : no stød, --- : stød. See legend to Figure 1a.

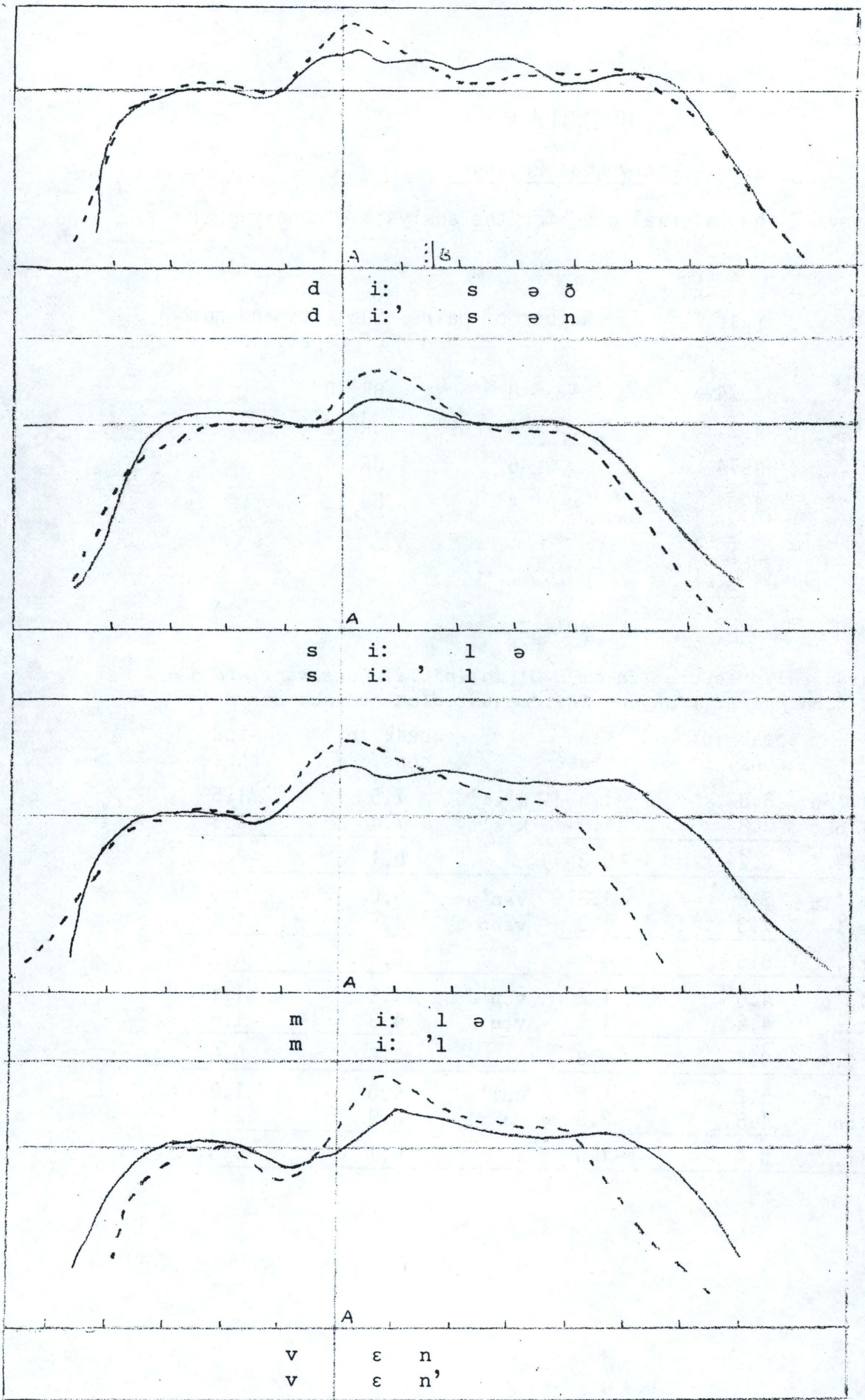


Figure 2

Average curves of œsophageal pressure 1981 (list 7). Subject FJ (N = 12). —— : no stød, --- : stød. See legend to Figure 1a. ⌴ : 10 cs.

APPENDIX VIII

Pharyngeal Pressure

Survey of the material used for the analysis of pharyngeal pressure.

List	Year	Number of pairs	Subjects and number of repetitions
1	1974	8	BF 10
1	1974	8	JR 2
3	1974	6	JR 4
7	1981	4	FJ 12

Table I

Pharyngeal pressure (in cm H_2O) in initial consonant and in the stød phase. (Subject BF), measured on average curves.

	peak in cons.	stød phase		peak in cons.	stød phase
pʰi:'bɒ	8.0	1.5	kʰɛl'ɒ	7.5	1.5
pʰi:bɒ	7.8	1.8	kʰɛlɒ	7.4	2.3
diff.	0.2	-0.3		0.1	-0.8
kʰɛ:'lɒ	7.6	1.3	vɛn'n	5.0	0.9
kʰɛ:lə	7.3	1.3	vɛnɒ	4.5	1.4
diff.	0.3	0.		0.5	-0.5
lɛ:s'ɒ	4.6	1.2	vɛn'	4.8	1.1
lɛ:sɒ	4.2	1.5	vɛn	4.3	1.6
diff.	0.4	-0.3		0.5	-0.5
hu:'ən	5.2	1.5	du:'	4.0	1.8
hu:ən	4.8	2.5	du	3.9	2.1
diff.	0.4	-1.0		0.1	-0.3

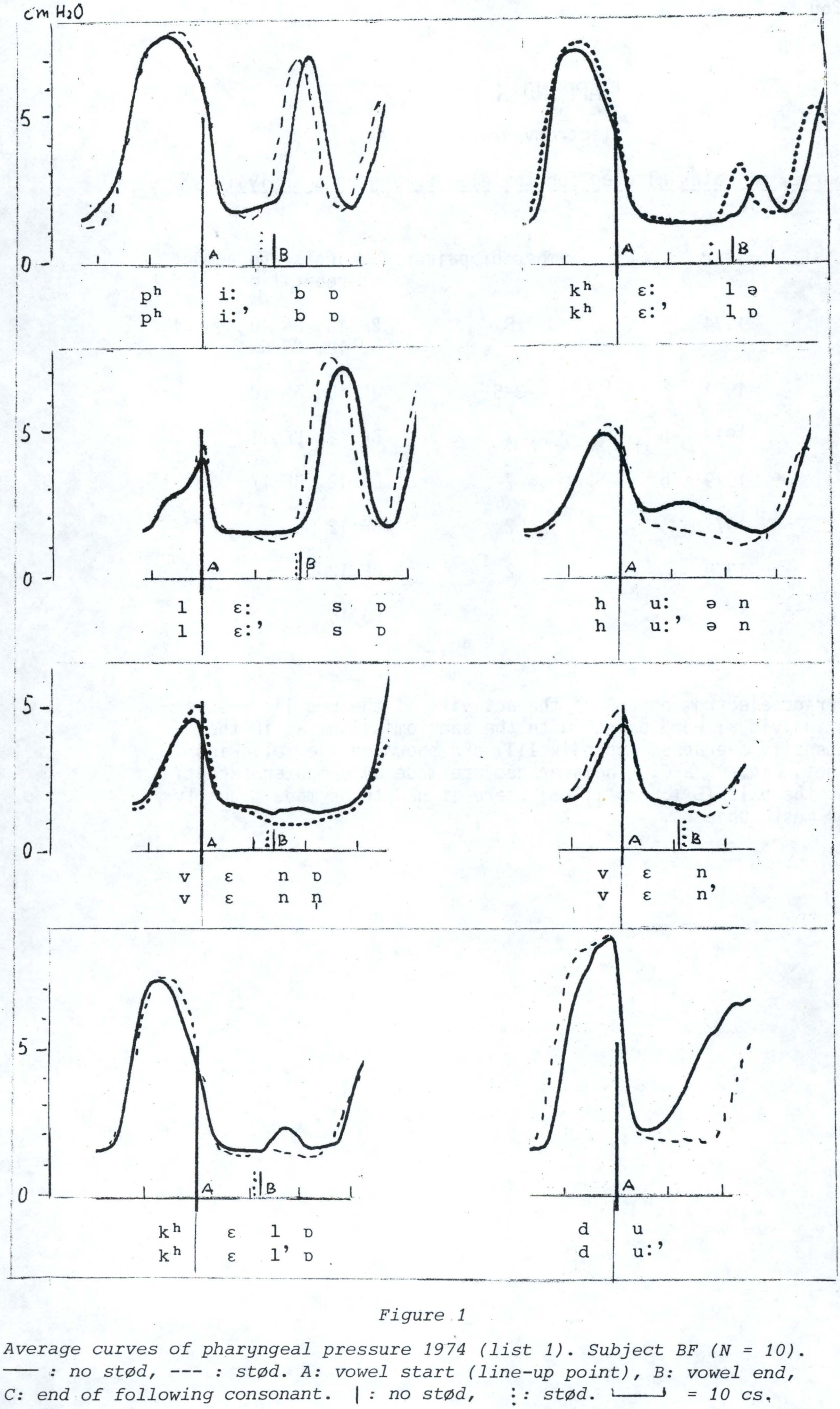


Figure 1

Average curves of pharyngeal pressure 1974 (list 1). Subject BF (N = 10). —— : no stød, --- : stød. A: vowel start (line-up point), B: vowel end, C: end of following consonant. | : no stød, ⁞ : stød. ⌴ = 10 cs.

APPENDIX IX

Electromyography

Survey of material used for the electromyogrphic analysis

List	Year	Number of pairs	Subjects and number of repetitions
1	1974	8	BF 10, BM 10, HU 11, JJ 12, NR 6
3	1974	3-5	JR 10, BM 10
1	1977 a-b	7	BF 12, BF 11
1	1979 a-b	7	BF 12, BF 17
2	1977	2	BF 12
2	1979	2	BF 12
6	1977		FJ 16

Average electromyograms of the activity of the vocalis muscle in individual word pairs (with the same omissions as in the intensity averages, Appendix III) are shown on the following pages, Fig. 1, a-e. The averages are made by computer except for the pair [pʰi:bɒ/pʰi:'bɒ] where it had to be made manually for most subjects.

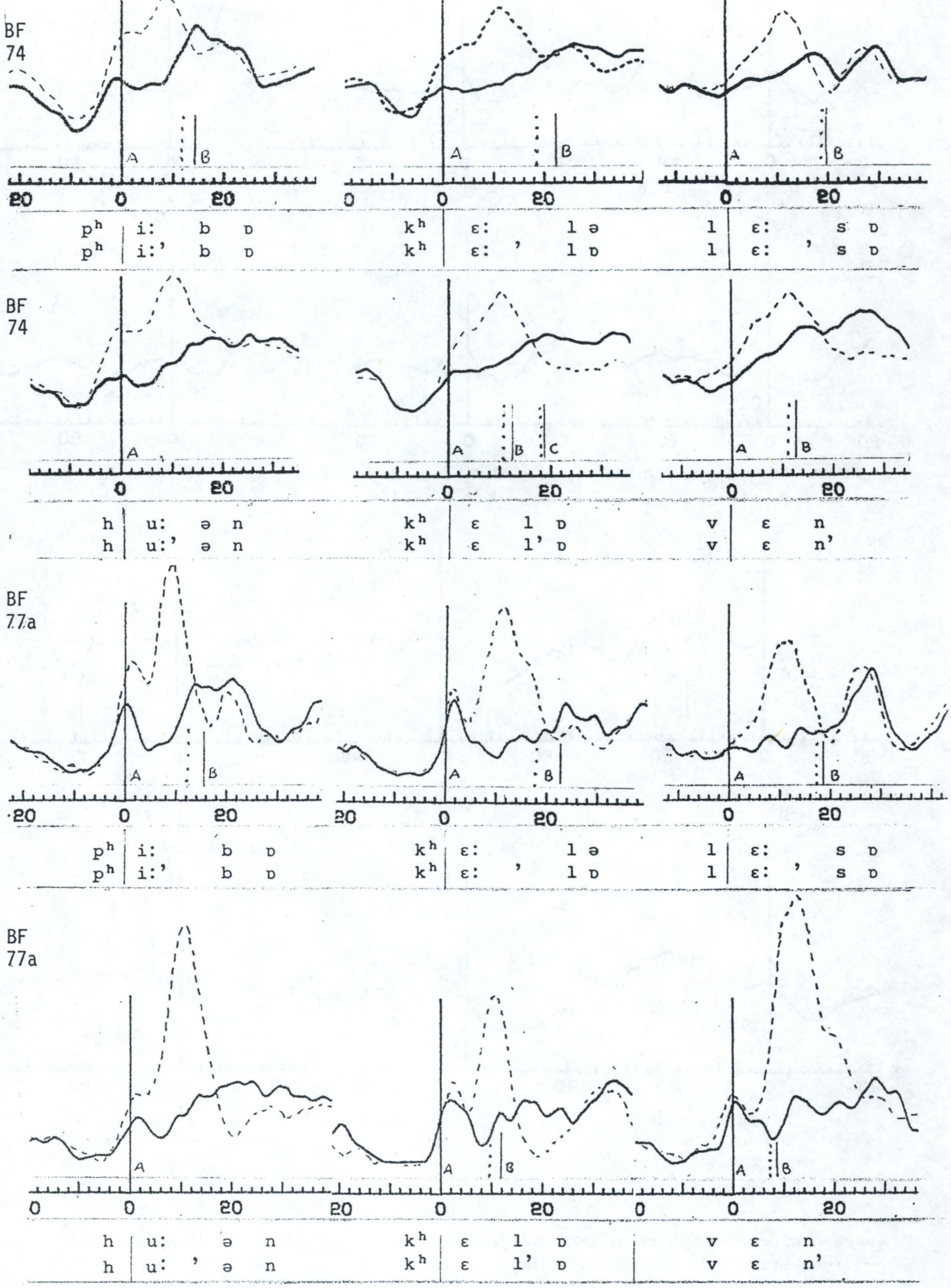


Figure 1a

Average electromyograms of VOC, subject BF 1974 (N = 10) and 1977a (N = 12). —— : no stød, --- : stød. A: vowel start (line-up point), B: vowel end (no stød, stød), C: end of following consonant. 10 cs.

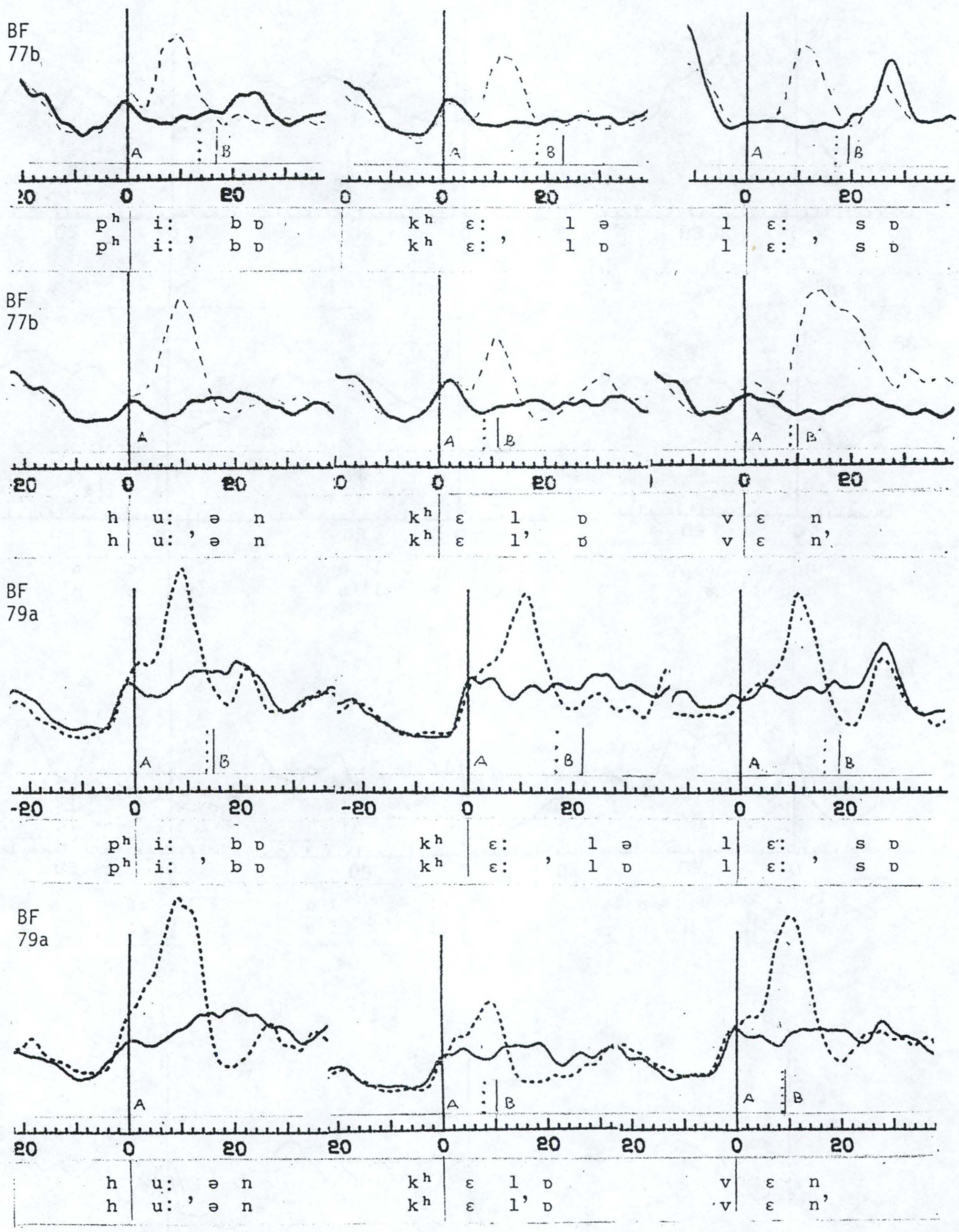


Figure 1b

Average electromyograms of VOC. Subject BF 1977b (N = 11) and 1979a (N = 12).
—— : no stød, --- : stød. See legend to Fig. 1a.

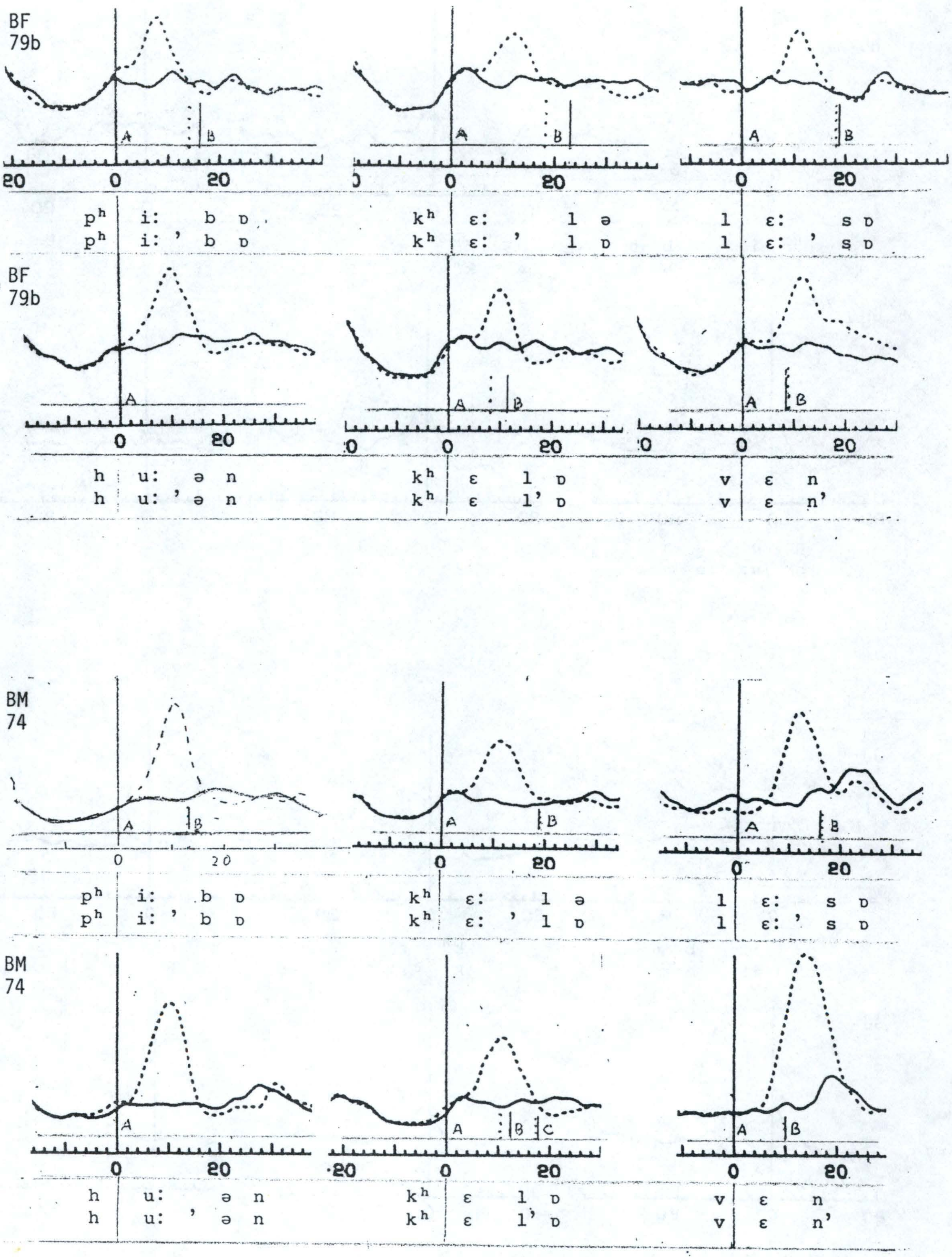


Figure 1c

Average electromyograms of VOC. Subjects BF 1979b (N = 17) and BM 1974 (N = 10). —— : no stød, --- : stød. See legend to Fig. 1a.

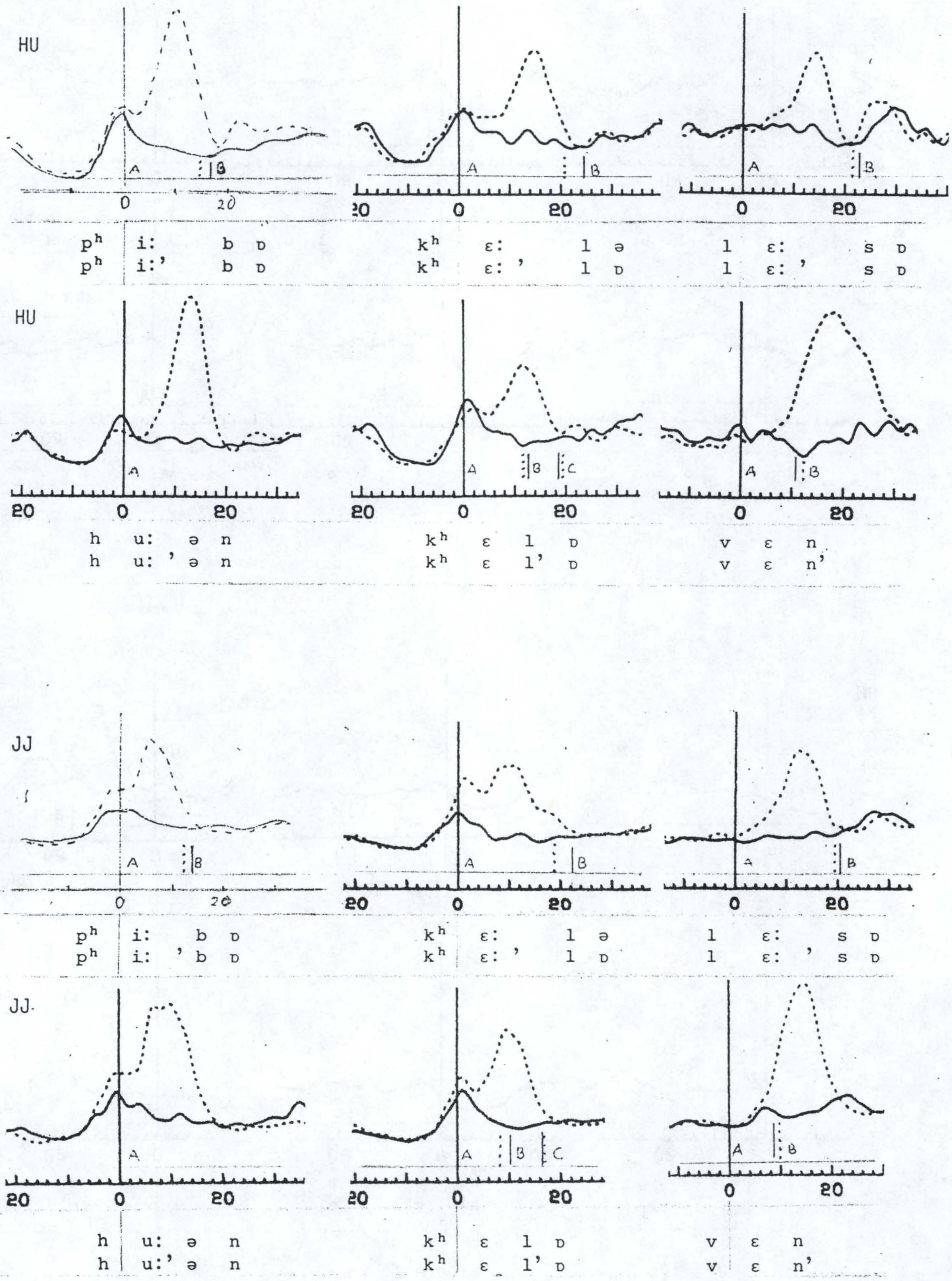


Figure 1d

Average electromyograms of VOC. Subjects HU (N = 11) and JJ (N = 10). —— : no stød, --- : stød. See legend to Fig. 1a.

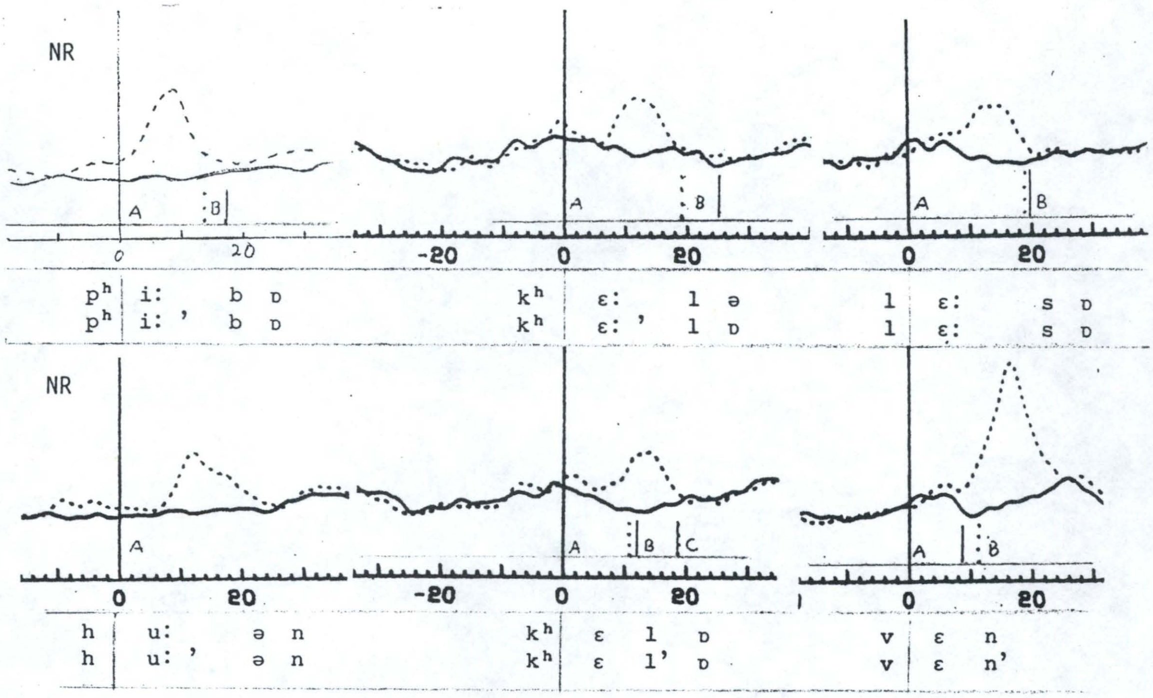


Figure 1e

Average electromyograms of VOC. Subject NR (N = 6). See legend to Fig. 1a.