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THE INFLUENCE OF ACOUSTIC AND PHYSIOLOGICAL FACTORS ON SOME VOWEL CHANGES IN DANISH

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1. Introduction

The investigation reported in the present article is concerned with the development of the short vowels /ɛ/ and /a/ in the Copenhagen dialect. Some of the problems discussed seem to be relevant to the study of sound change in general[1].

Our main source of historical data is a recent work by Brink and Lund on the development of the pronunciation of Danish since 1840 (Brink and Lund 1975). According to these authors, the phonemes[2] /ɛ/ and /a/ were pronounced as indicated below about 1840:

	after [ʁ]	elsewhere
/ɛ/	[æ]	[ɛ]
/a/	[ɑ]	

During the period 1840-1900 the following change gradually spread in the Copenhagen dialect (and in Standard Danish):

(1) [ɑ] → [æ] before alveolar consonants (except when preceded by [ʁ]), e.g. [nɑt] → [næt]. In idiolects characterized by (1), the distribution of allophones of /ɛ/ and /a/ after the change is as shown below:

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1) We are grateful to Eli Fischer-Jørgensen for urging us to take up this investigation and for valuable criticism.

2) The term phoneme is used in a diachronic sense here.

	after [ʁ]	elsewhere	
		before alveolars	before labials and dorsals
/ɛ/	[æ]	[ɛ]	[ɛ]
/a/	[ɑ]	[æ]	[ɑ]

This is roughly the situation in modern Standard Danish. In the Copenhagen dialect, however, the following change is reported to have spread at least since the beginning of this century:

(2) [æ] → [ɑ] after [ʁ] before alveolars,

e.g. [ʁæt] → [ʁɑt]. In idiolects characterized by (2), even the following change is gaining ground:

(3) [æ] → [ɑ] after [ʁ] before labials,

e.g. [sgʁæmə] → [sgʁɑmə]. Both (2) and (3) are favoured by the younger generation; (3) is characteristic of the lower social classes (cf. Brink and Lund 1975, vol. 1, p. 128-132).

One phonological consequence of (2) and (3) is a merger of words like /brɛnə/-/branə/ and of words like /skrɛpə/-/skrapə/, both types of words being pronounced with an [ɑ]-like vowel. No [æ]-retraction after [ʁ] is reported to have taken place before dorsals, i.e. words like /brɛk/-/brak/ have remained clearly distinguishable (being usually transcribed [bʁæg]-[bʁɑg]). In the remainder of this article we shall refer to words like /brɛk/, /rɛt/, /skrɛpə/, etc. as /rɛ/-words, and to words like /brak/, /rat/, /skrapə/, etc. as /ra/-words. Although the changes (1), (2), and (3) are obviously phonetically conditioned, some problems arise if we compare them: In (1) a back vowel is fronted before alveolar consonants, whereas in (2) a front vowel is retracted before alveolar consonants. Moreover, in (1) alveolars are opposed to labials and dorsals as regards the effect on a preceding /a/; in (3) dorsals are opposed to alveolars and labials as regards the effect on a preceding /ɛ/. Although ʁ-colouring must somehow be involved in (2) and (3), it seems difficult to explain these facts.

On this background we have concerned ourselves with the following problems: (I) Is the /rɛ/-/ra/ merger before alveolars (and labials) a true merger in the sense that no systematic acoustic differences are found between /rɛ/-words and /ra/-words in the pronunciation of speakers who appear to be representative of these mergers? (for a detailed discussion of various aspects of the concept of merger, see Labov 1972). (II) is it possible to explain the fact that /rɛ/- and /ra/-words have remained clearly distinguishable when the postvocalic consonant is dorsal? - (III) is it possible to explain the fact that the change (3) is less frequent than (2) and seems to presuppose the latter?

With the aim of contributing to a solution of these problems we have investigated the acoustic characteristics of some typical /rɛ/- and /ra/-words as spoken by five speakers of the Copenhagen dialect representing different social classes and different age groups.

2. Subjects and Material

The investigation was based upon sound spectrograms. In order to obtain an optimal ratio between the bandwidth of the spectrograph and the F_o of the subjects, only male subjects were chosen. The subjects were:

FR
Age: 22
Occupation: craftsman (temporarily unemployed)
Social background: parents uneducated workers.

BJ
Age: 22
Occupation: craftsman (temporarily unemployed)
Social background: parents uneducated workers.

JS
Age: 39
Occupation: various jobs, now a university student
Social background: parents uneducated workers.

SN
Age: 25
Occupation: dentist
Social background: father a skilled worker, mother uneducated.

PO
Age: 22
Occupation: university student
Social background: parents university graduates.

In order to facilitate the delimitation of segments on the spectrograms we used words in which [ʁ] is preceded by (s +) an unaspirated stop and the vowel is followed by a stop or a nasal. Only mono- and bisyllabic words were used. Thus the words to be compared directly formed minimal or subminimal pairs each consisting of a /rɛ/-word and a /ra/-word. The test words are listed below in their orthographical form and in the traditional IPA transcription of Standard Danish:

skrappe	[sgʁɑbə]	skramme	[sgʁɑmə]	bratte	[bʁɑdə]
skræppe	[sgʁæbə]	skræmme	[sgʁæmə]	brættet	[bʁædəð]
brande	[bʁɑnə]	brak	[bʁɑg]	Strange	[sdʁɑŋə]
brænde	[bʁænə]	bræk	[bʁæg]	strenge	[sdʁæŋə]

The test words were placed in frame sentences according to the following criteria: (i) The syllable containing the vowels under investigation should have a full sentence stress, (ii) the words which were to be compared directly, i.e. the members of each minimal pair, should have the same placement in the rhythmical structure of their respective sentences and these sentences should be of the same rhythmical structure. Each test word should be sentence final, if possible. For instance, the words <u>bræk</u> and <u>brak</u> (/brɛk/ and /brak/) appeared in the sentences "Så gik de ud på bræk" and "Naboens jord lå brak", respectively.

In the list presented to the subjects the sentences containing the relevant words occurred in random order, and several irrelevant sentences were interspersed among them. The subjects were asked to say the sentences in a normal tempo and to make a pause between each sentence. 12 recordings were made of FR and BJ each, and 7 recordings were made of JS, SN, and PO each. The recordings were made in the recording studio of the Institute of Phonetics.

3. Spectrographic analysis and quantification problems

In order to keep the rather laborious technical treatment of the material within reasonable time limits we contented ourselves with a selection of 5 out of the total number of recordings of each subject. This selection was, of course, made at random (certain recordings, however, were immediately discarded because they were characterized by clearly unintended pronunciation phenomena: coughing, stuttering, and the like). Thus, for each subject, 5 specimens of each of the relevant words were analyzed.

Danish [ʁ] being in most instances a voiced uvular or uvulo-pharyngeal continuant with little or no friction noise, the [ʁ] + vowel phase of the words under investigation shows a continuous vocalic formant structure on the spectrograms. A preliminary series of measurements of F_1 and F_2 at the beginning of the rV-phase showed no systematic differences between corresponding /rɛ/- and /ra/-words of the same subject. It turned out, however, that F_2 at the beginning of the vocalic phase was highly sensitive to the type of consonant preceding [ʁ]. The mean values of F_2 at this point (calculated for all subjects as a whole) were 1295 cps, 1142 cps, and 922 cps in words with prevocalic [sgʁ], [sdʁ], and [bʁ], respectively. These differences must be ascribed to coarticulation effects, F_2 of [g] being higher than that of [d], and F_2 of [b] being considerably lower than that of [d]. These results (and the formant movements in general) show that the point nearest to [ʁ]-target is only reached some centiseconds after the beginning of the vocalic phase. Consequently, if there is a difference in vowel target between /rɛ/- and /ra/-words it should be noticeable only in the later parts of the vocalic phase. Since a difference between a more [æ]-like and a more [ɑ]-like vowel is mainly one of frontness vs. backness, F_2 in the late part of the vocalic phase must be most sensitive to such a difference.

In quantifying the acoustic properties of the vowel qualities under investigation we therefore looked for the point during the F_2 movement at which the influence of the vowel target is at a maximum. This point is rather well-defined in the words with postvocalic labials. Two extreme types of words within this category are shown in fig. 1. In the most [æ]-like type shown in (a), F_2 rises slightly after the [ʁ]-target. In the most [ɑ]-like type shown in (b), F_2 is straight after the initial [sg]-transition (cf. above). Note that in this type there is no way of delimiting [ʙ] from [ɑ] acoustically. In all these words there is a final (short) negative transition due to the succeding labial. The formant frequencies of F1 and F2 were measured just before the final fall of F2. As both [ʙ] and labials have a lowering effect on F2, this point must be the one nearest to the vowel target.

In the words with postvocalic alveolars the point nearest to the vowel target is not always well-defined on the spectrograms. Some typical formant movements of these words are shown in fig. 2. In the most [æ]-like type shown in (a), F2 is rising after the [ʙ]-target and reaches a late, steady [æ]-state; the transition of the succeding alveolar is straight or slightly falling (as should be expected with a vowel of this type, see e.g. Fischer-Jørgensen 1954). In the most [ɑ]-like type shown in (b), F2 has a prolonged [ʙ]-[ɑ]-phase, as in type (b) of the words with postvocalic labials, fig. 1 (b). However, the transition of the succeding alveolar is positive and somewhat longer than the transition of a labial, since it reflects a tongue movement. These extreme types are thus clearly different. They are not typical, however. In most cases the F2 movement in these words is something in between the movements shown in (a) and (b), so that there is a more or less rising F2 throughout the vocalic phase in the majority of both /rɛ/-words and /ra/-words, as shown in (c) and (d). Such formant movements must reflect a continuous tongue movement from the position of a pharyngealized vowel of [ʙ]-type to the position required by the final coronal articulation. It cannot be decided, with this type of formant movement, at what point the influence of the vowel target is at a maximum. It appears from fig. 2 (e), however, that if we assume a fixed second formant locus of alveolars, a possible systematic difference in F_2 between an [æ]-target and an [ɑ]-target should imply

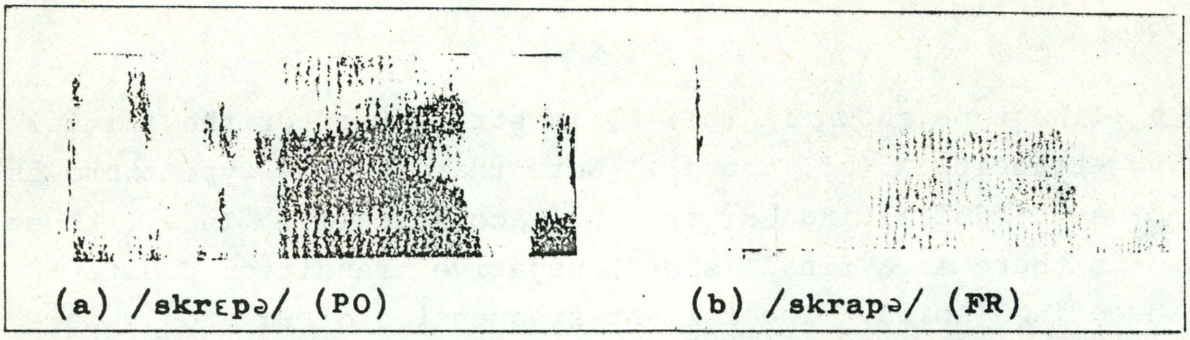

Fig. 1. Spectrograms of words with postvocalic labials, cf. text.

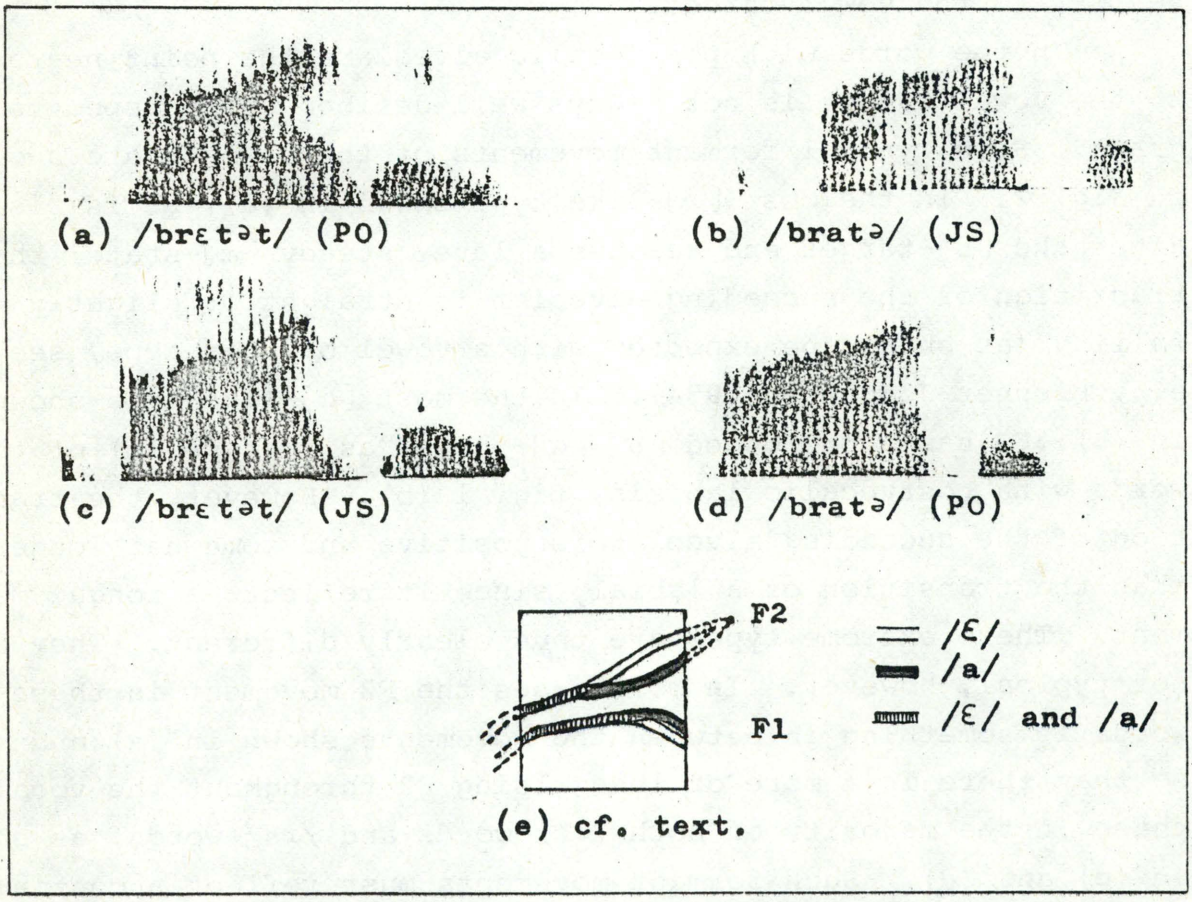

Fig. 2. Spectrograms of words with postvocalic alveolars, cf. text.

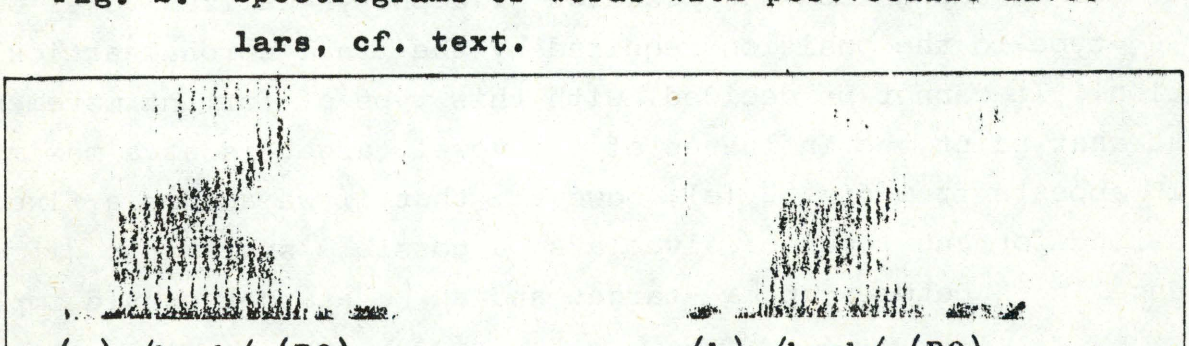

Fig. 3. Spectrograms of words with postvocalic dorsals, cf. text.

a corresponding, though somewhat less marked difference at the end of the vocalic phase. Of course, the formant frequencies at this point are highly influenced by the succeding consonant, but the influence of any intended [æ]- or [ɑ]-target should still be noticeable. We therefore measured the formant frequencies at the end of the vocalic phase in the words with postvocalic alveolars.

In the words with postvocalic dorsals there was always a directly visible difference between /rɛ/-words and /ra/-words. Typical formant movements are shown in fig. 3. There is never a steady [æ]-state in /rɛ/-words, and there is not always a steady [ɑ]-state in /ra/-words. Thus the rather marked difference in formant movements must be ascribed, at least in part, to differences between the postvocalic dorsals of /rɛ/-words and those of /ra/-words. The existence of two types of dorsals in these words is not surprising, since it is a well-known fact that Danish dorsals are very sensitive to the place of articulation of neighbouring vowels. However, this clearly audible difference between a more palatal type and a more velar type of dorsals is traditionally ignored in current types of phonetic transcription of Danish (including the DANIA system used by Brink and Lund) which are otherwise rather narrow. It is obvious that these two types of dorsals are partly responsible for the fact that no merger has taken place between words like /brɛk/ and /brak/ (cf. section 4 below). In the words with postvocalic dorsals we quantified the acoustic qualities in the same way as in the words ending in alveolars, i.e. by measuring the formant frequences at the end of the vocalic phase.

4. Acoustic data

4.1. General remarks

As mentioned above we analyzed 5 recordings of each word. In two minimal pairs, however, we attempted to establish a more solid judgment by analyzing a greater number of items. We thus analyzed 12 items of each of the words /skrɛpə/ and /skrapə/, and 11 items of each of the words /brɛnə/ and /branə/ of FR (we had 12 recordings of FR and BJ at our disposal). For each minimal pair the data of each subject are visualized in the F_1-F_2 diagrams on the following pages. In the diagrams each solid circle represents a /ra/-item, and each triangle represents a /rɛ/-item. It follows from the discussion of measurements that the F_1-F_2 values should not be taken to represent true vowel plots except perhaps in the words with postvocalic labials. Under the circumstances the values only represent the best approximations to the alleged vowel targets.

4.2. Results of the pairs /skrɛpə/-/skrapə/ and /skrɛmə/-/skramə/

It appears from fig. 4 that PO and JS have a clear distinction. This is also true of SN, although one of his /ra/-items is rather [æ]-like. However, an auditive check on this particular item led us to judge it as a mispronunciation. This decision is further supported by the fact that we here observe a forward movement of /a/ which is the reverse of the general tendency. BJ represents the opposite extreme with complete overlapping. The most interesting result is that of FR: Although, as one might expect, the most [æ]-like qualities occur in /rɛ/-words and the most [ɑ]-like qualities occur in /ra/-words, there is more overlapping than one would expect between phonemically different vowels.

4.3. Results of the pairs /brɛtət/-/bratə/ and /brɛnə/-/branə/

As seen from fig. 5, PO shows a relatively clear tendency toward a distinction, whereas BJ and SN show complete overlapping. FR shows no trace of any systematic difference in the pair /brɛtət/-/bratə/; in the other pair he shows a puzzling tendency

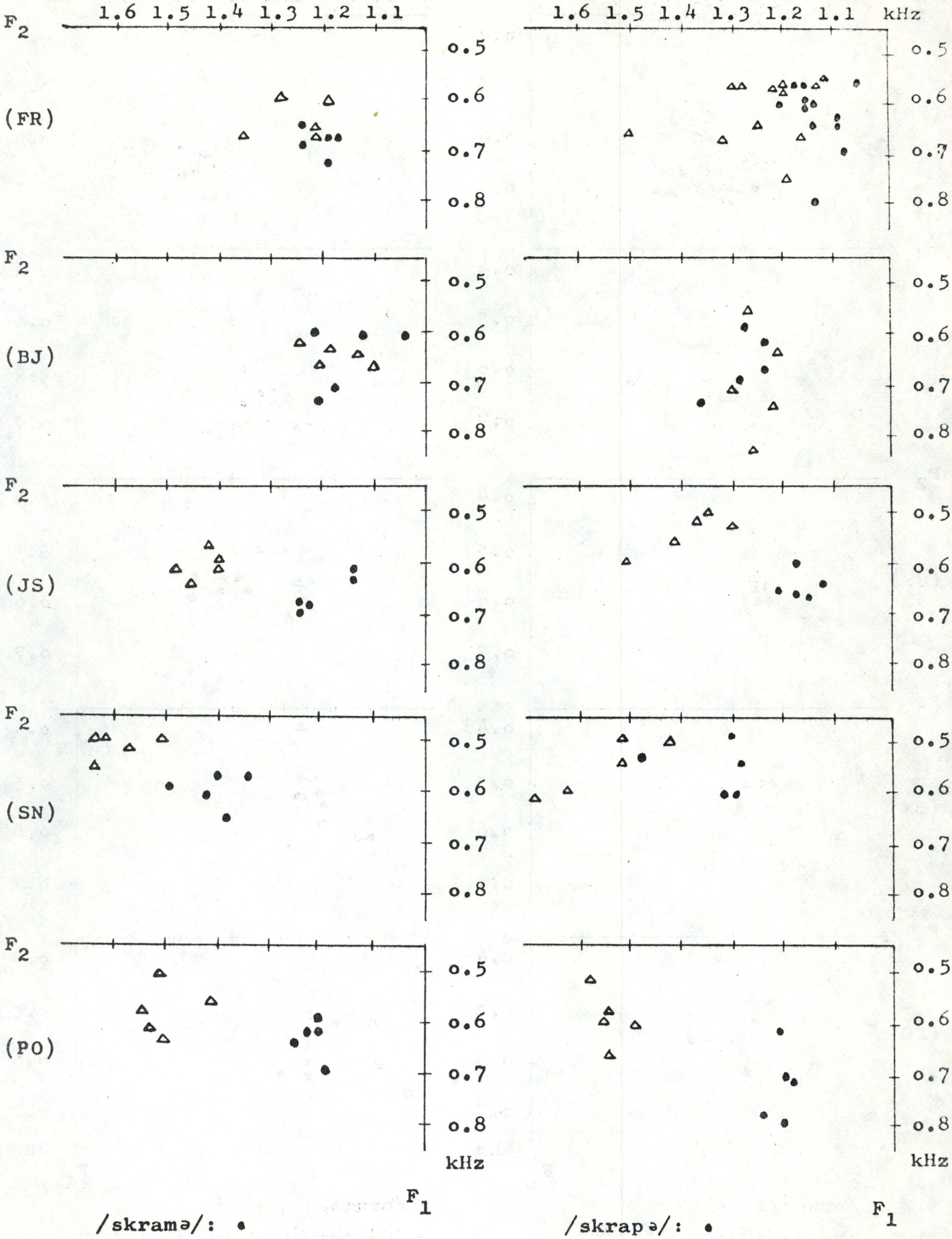

Fig. 4 F_1-F_2 plots of vowels followed by labials, cf. text.

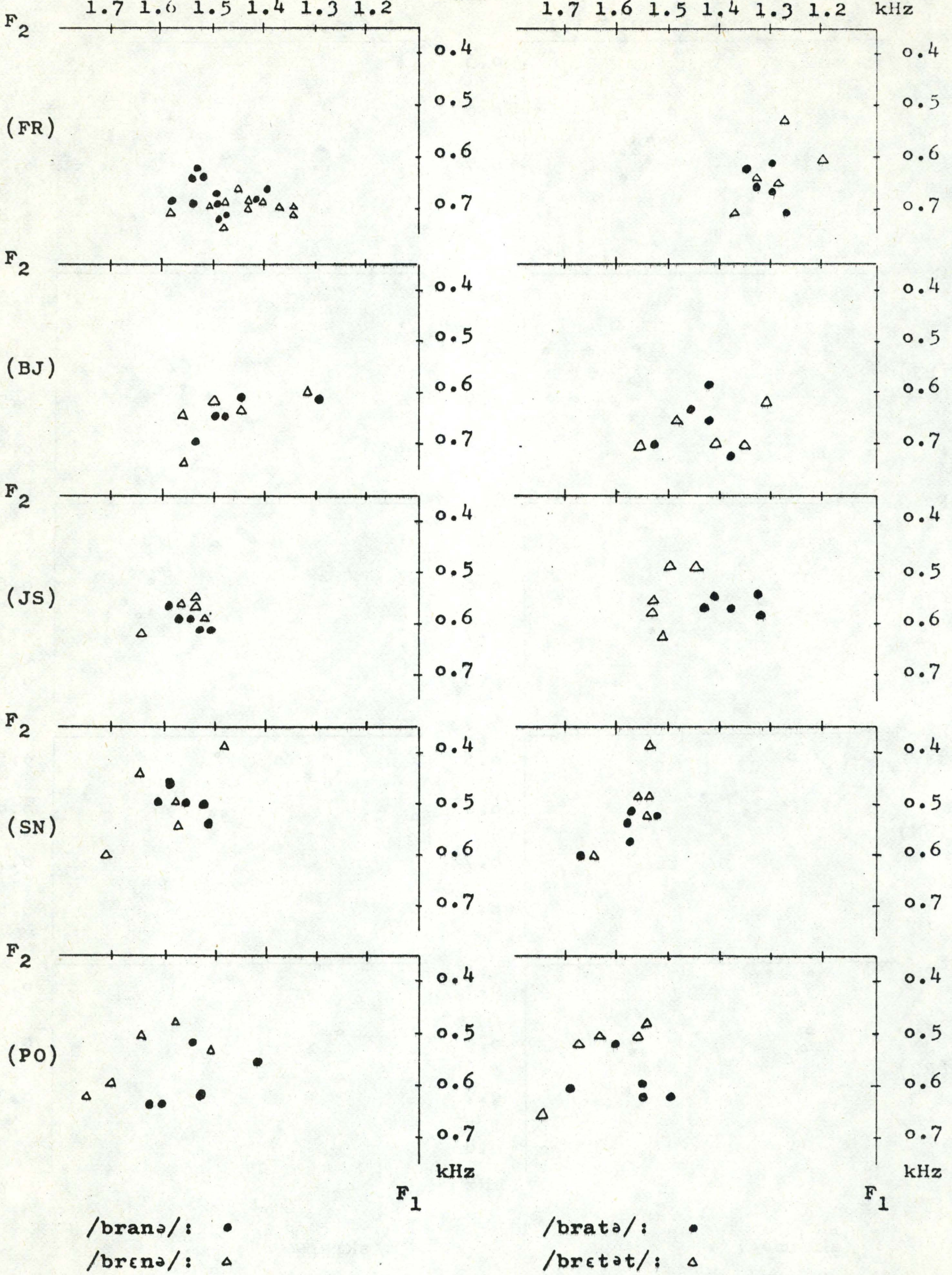

Fig. 5 F_1-F_2 plots of vowels followed by alveolars, cf. text.

to produce the most [æ]-like qualities in /branə/ and the most [ɑ]-like qualities in /brɛnə/. It should be noted, however, that /brɛnə/ and /branə/ are closely related genetically and semantically: /brɛnə/ means 'burn', and /branə/ means 'fires' (sb. pl.). It is probable that these words are felt to be identical by FR.[1] If this is true, what we have called /rɛ/-items and /ra/-items are simply items of the same statistical population. This interpretation (which is not needed to explain the cases of overlapping in general, cf. section 5 below) is supported by the data of JS who has complete overlapping in /brɛnə/-/branə/ and a clear distinction in /brɛtət/-/bratə/.

4.4. Results of the pairs /brɛk/-/brak/ and /strɛŋə/-/straŋə/

These results are not illustrated in F_1-F_2 diagrams. All subjects show a clear difference without overlapping. F_2 of /rɛ/-words is always 400-600 cps higher (at the end of the vocalic phase, cf. section 3 above) than F_2 of /ra/-words, and F_1 is generally lower in /rɛ/-words.

4.5. The results in general

As regards /rɛ/-/ra/-merger, there were no cases of discrepancy between our auditive impression and the acoustic results: whenever there was a clear acoustic difference, this difference was clearly audible. Moreover, the results are in agreement with the expected tendencies: (1) No merger before dorsals. (2) Merger before alveolars except for JS and PO (if we interpret the special behaviour of /brɛnə/-/branə/ in the speech of JS and FR as suggested above, i.e. as lexical identification); JS represents the older generation (39 years old), and PO represents the higher social classes (university student, parents university graduates).

1) The difference between /brɛnə/ and /branə/ was originally due to the Germanic umlaut processes. Such differences are now lexicalized.

(3) Merger before labials occurs only in combination with merger before alveolars and is only represented by the lowest social classes (BJ and, less markedly, FR).

5. A simplified model of the development of /rɛ/

Although the non-merger of /rɛ/-/ra/ before dorsals seems to be connected with the existence of two types of dorsals, cf. section 4 above, the problems raised in section 1 (i.e., the different behaviour of /rɛ/ before different types of consonants, and the difference between the effect of alveolars on vowels preceded by [ʁ] and that on vowels not preceded by [ʁ]) on the whole remain unsolved. We shall argue, however, that these facts may be explained as the natural consequences of the acoustic (and articulatory) properties of the sequences involved, under the assumption that the changes were initiated by a single phenomenon, viz. pharyngealization and lengthening of [ʁ]. We shall base this explanation on the following facts: (1) In all types of idiolects the dorsal phonemes have two main allophones; a postpalatal type after (and before) front vowels, and a velar type after (and before) back vowels. It is reasonable to assume that this allophony existed prior to the vowel changes after [ʁ]. (2) Alveolars have a rising F_2-transition in a preceding [ɑ]-like vowel and a straight or slightly falling F_2-transition in a preceding [æ]-like vowel. (3) The F_2-transition of labials is negative in both [ɑ]- and [æ]-like vowels and (if at all present) rather short.

Let us consider a conservative type of the Copenhagen dialect (without any mergers) as represented by PO and JS: The formant movements during the vocalic phase of the words /brɛk/, /brak/, /brɛtət/, /bratə/, /skrɛpə/, and /skrapə/ are shown in a stylized version in fig. 6 along with typical spectrograms of these words from the recordings of PO. The black traces represent the formant movements of /ra/-words, the white traces represent the formant movements of /rɛ/-words, and the hatched traces represent formant movements common to both /ra/- and /rɛ/-words.

In all words there is an initial, relatively short, [ʁ]-like phase. After this phase the following happens: In /brɛk/ F_1 falls and F_2 rises sharply throughout the vocalic phase. The early part of these formant movements must reflect a continuous forward movement of the tongue towards the position of [æ]. However, there seems to be no time for any [æ]-steady state to be reached, and the tongue moves further up towards the position of the postpalatal type of dorsal to follow. In /brak/ there is time for a short [ɑ]-steady state (which is nothing more than a prolonged pharyngeal $ʁ^{ɑ}$-phase) before the final upward movement of the tongue towards the position of the velar type of dorsal to follow (as reflected by the shorter and less steep F_2-rise). Thus the difference is clear and is due partly to different vowel targets, partly to the different types of dorsals. In /brɛtət/ the tongue moves forward (and upward), causing F_2 to rise (and F_1 to fall slightly) until the intended [æ]-position is reached; there is time for a short [æ]-steady state owing to the rather independent final tongue blade articulation which does not influence the formant movements of an [æ]-like vowel (straight transitions); in /bratə/ the $ʁ^{ɑ}$-position (as in /brak/) is held somewhat longer until the forward movement of the tongue body required by the final tongue blade articulation causes F_2 to rise. In /skrɛpə/ and /skrapə/ the formant movements are similar to those of /brɛtət/ and /bratə/, respectively, except, of course, for the final transitions of the labials which are negative and, owing to the independent lip articulation, rather short (if at all present). The /rɛ/-/ra/-difference is thus clear in all three types.

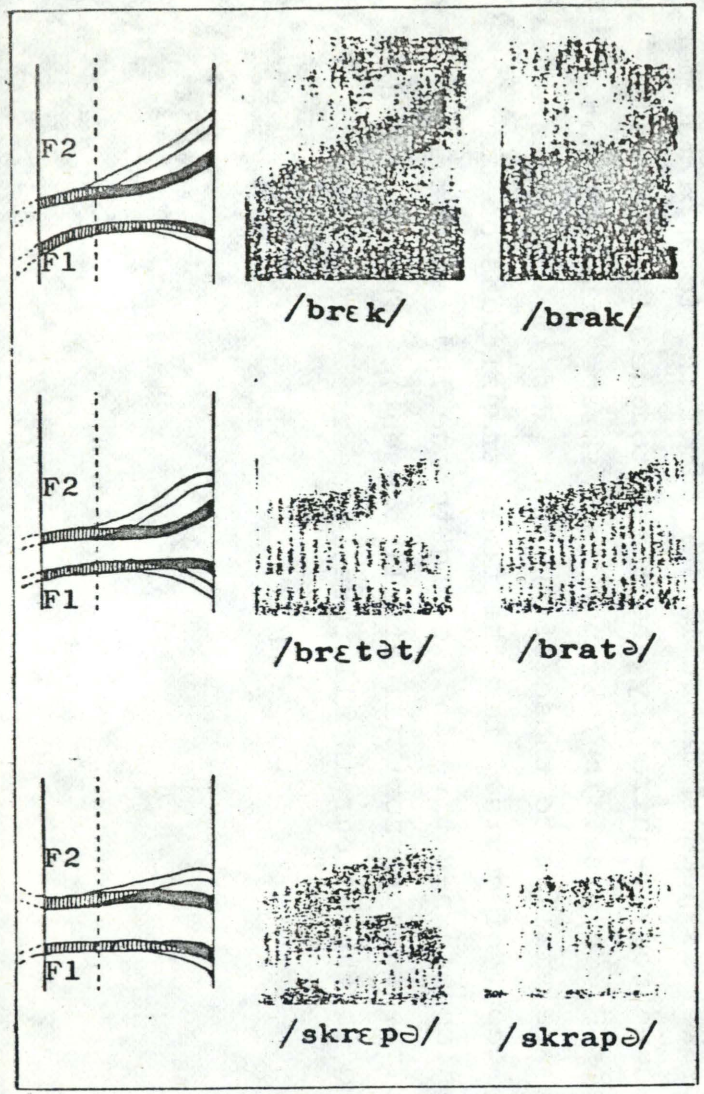

Fig. 6. PO

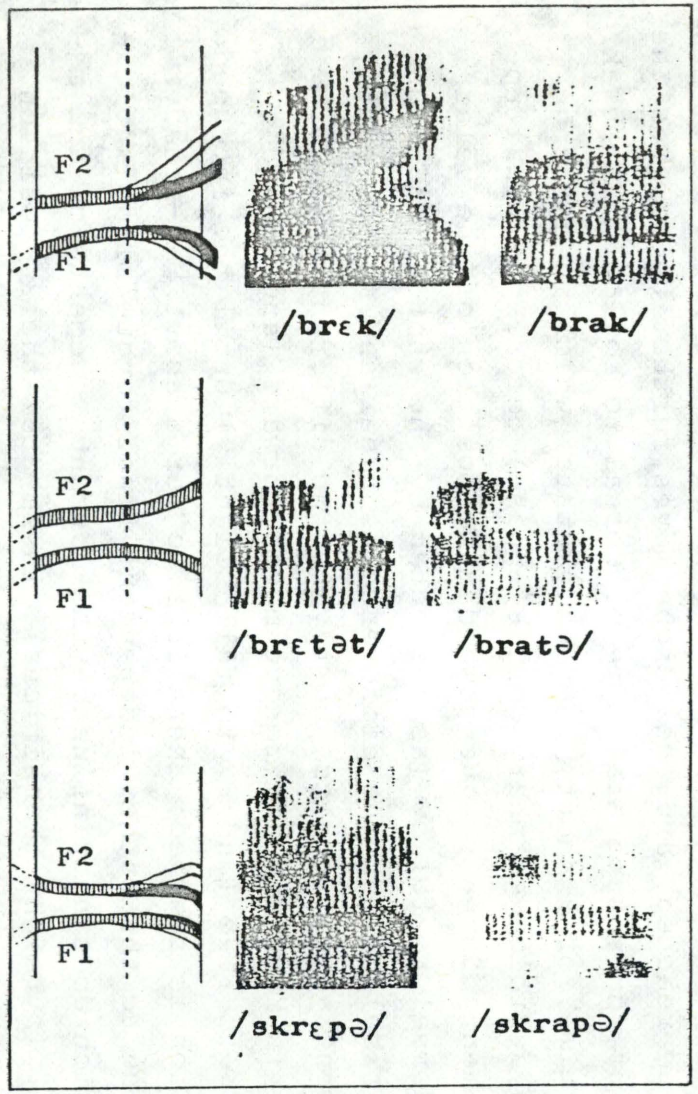

Fig. 7. SN

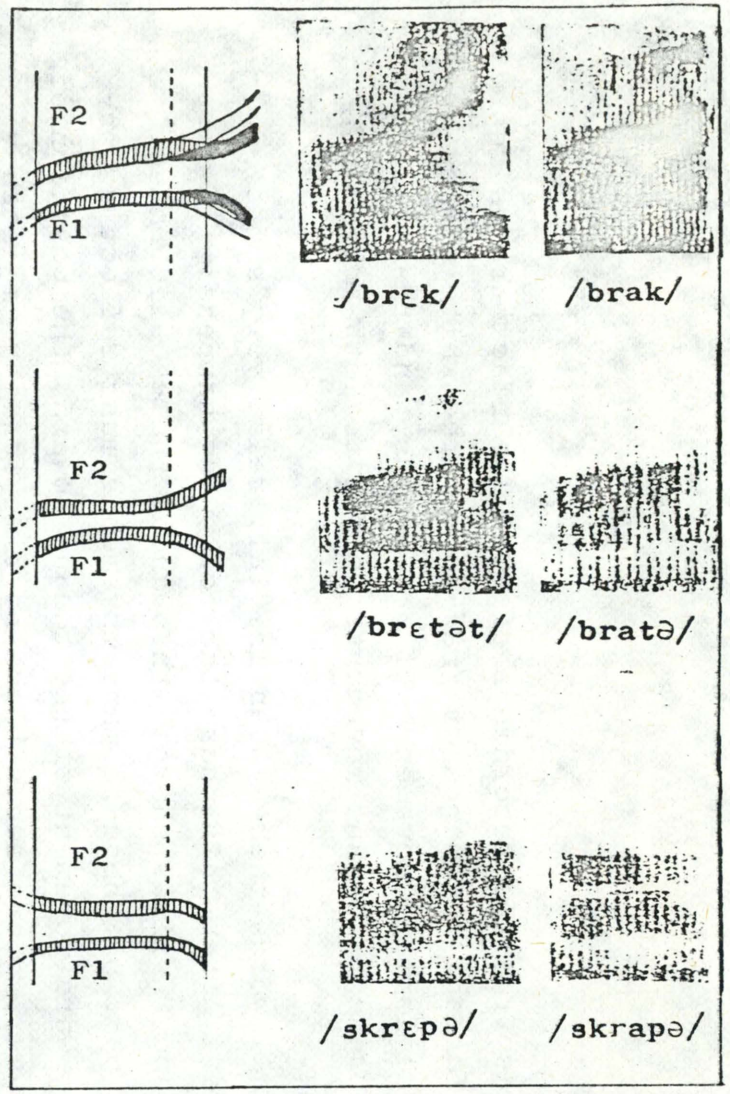

Fig. 8. BJ

Fig. 6-8. Three different stages of [ʁ]-lengthening exemplified by spectrograms of the vocalic phase of different word types and by stylized drawings of the formant movements, cf. text.

Consider next the articulatory and acoustic consequences of a moderate ʁ-lengthening, other factors being constant: The situation may now be visualized as in fig. 7. The spectrograms are from the recordings of SN who seems to represent this stage. The formants of both /rɛ/- and /ra/-words now follow the same path for a considerable stretch of time. During (roughly) the last half of the vocalic phase the following happens: If the succeding consonant is dorsal, F_2 of /rɛ/-words, still aiming at the high locus of a postpalatal, rises sharply as before. There is even less time for any [æ]-steady state to be reached, but owing to the different transitional effects of the following consonants (postpalatal vs. velar), the difference between /brɛk/ and /brak/ is maintained. If the succeding consonant is alveolar, the forward movement of the tongue towards the [æ]-position begins too late for any [æ]-steady state to be reached before the tongue blade articulation sets in, and the formant movements (in particular the F_2-rise) simply coincide with the transitions expected between [ɑ] and an alveolar, and is easily perceived as such. If the [ʁ]-lengthening is roughly the same in all types, the situation will be quite different in words with postvocalic labials: owing to the independent lip articulation the movement of the tongue towards the [æ]-position after the $ʁ^{ɑ}$-phase will not coincide with any other expected tongue movement; correspondingly, the late F_2-rise will not be perceived as the transition of a labial, since such a transition is expected to be negative and considerably shorter.

Thus merger before alveolars and no merger before labials and dorsals are the natural articulatory, acoustic, and perceptual consequences of an adequately prolonged $ʁ^{ɑ}$-phase. With an extreme [ʁ]-lengthening as shown in fig. 8 (the spectrograms are from the recordings of BJ who represents this stage), the pharyngeal phase is so long that there is only time for the transitions (needed anyway) of the postvocalic consonants, even in words with postvocalic labials in which the transitions are shortest. (In fig. 6-8 the ʁ$^{\alpha}$-phases of all types are normalized with regard to duration, and the transitions in fig. 7 and 8 are drawn longer in the words with postvocalic tongue consonants so as to give a more realistic picture of the relative durations of different phases; thus, when we speak of other factors being constant, cf. above, we of course disregard durational changes automatically implied by the [ʁ]-lengthening.) In this type of speech the impressionistic vowel quality is very [ɑ]-like in /rɛ/-words ending in alveolars and labials, cf. the apparently complete merger of these words in the speech of BJ. In /rɛ/-words with postvocalic dorsals, i.e. postpalatals, the impressionistic vowel quality is rather diphthongal. The difference between /rɛ/-words and /ra/-words ending in dorsals seems to be exclusively due to the different postvocalic consonants in this type of speech. Thus, if we assume that the changes are initiated by a pharyngealization and lengthening of [ʁ], an articulatory-acoustic model based on our investigation will predict the tendencies reported by Brink and Lund (and others), viz. the following ones: (1) a /rɛ/-/ra/-merger will primarily take place before alveolars, (2) with further [ʁ]-lengthening the merger will eventually extend its domain to incorporate the words with postvocalic labials, (3) no merger will take place before dorsals. It should be noted that our model does not imply that the speakers intend to pronounce /rɛ/- and /ra/-words in the same way. Even if the speakers intend to move the tongue towards an [æ]-position in /rɛ/-words, the acoustic and perceptual fusion will take place for purely mechanical reasons provided that the [ʁ]-lengthening is long enough. If we presuppose, for instance, that FR still intends to pronounce /skrɛpə/ and /skrapə/ differently, this explains the acoustic results mentioned in section 4 above: If the [ʁ]-lengthening of FR is assumed to have reached a stage intermediate between that of SN and that of BJ, it is to be expected that in most instances the difference is clear, whereas there is occasionally an extra-lengthening of the $ʁ^{a}$-phase which is just long enough to obscure the acoustic difference. If this is true, the situation of (at least some of) our subjects seems to be opposite to that of the English-speaking subjects who are reported by Labov (1972) to produce constant acoustic differences which they do not use to distinguish words (and are not themselves capable of perceiving). It seems probable that some of our subjects intend to distinguish words by a constant difference which, in their performance, is obscured owing to the physiological and acoustic properties of the sequences involved.

6. Concluding remarks

If our model is accepted as an explanation of the different behaviour of /rɛ/-words with different types of postvocalic consonants, the series of questions posed by the above-mentioned changes is reduced to one: Why does [ʁ]-lengthening take place? This is probably not a phonetic problem, and of course our model is not explanatory in a narrower sense. The value of a detailed acoustic study of change in progress lies in the fact that it helps to disclose the influence of inherent phonetic factors which may be obscured by traditional statements about sound change considered in terms of segments or features.

References

Fischer-Jørgensen, Eli 1954: "Acoustic Analysis of Stop Consonants", Miscellanea Phonetica II, p. 42-59

Labov, William 1972: "On the Use of the Present to Explain the Past", 11 int. congr. ling., Preprints, p. 1110-1135

Lund, Jørn and Lars Brink 1975: Dansk Rigsmål. Lydudviklingen siden 1840 med særligt henblik på sociolekterne i København (Copenhagen)