ARIPUC VOL. 11.

ANNUAL REPORT

of the
Institute of Phonetics
University of Copenhagen

COPENHAGEN 1977

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KØBENHAVNS UNIVERSITET
REPRO. AFDELINGEN

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PERSONNEL OF THE INSTITUTE OF PHONETICS IN 1976

Professor: Eli Fischer-Jørgensen (director of the Institute)

Associate professors:

Børge Frøkjær-Jensen, cand.mag. (seconded to Audiologopedics Research Group from September 1, 1975)

Jørgen Rischel, dr.phil.

Oluf Thorsen, cand.mag.

Assistant professors:

Peter Holtse, cand.phil. (until February 29)

Birgit Hutters, cand.mag.

Niels Reinholt Petersen, cand.phil. (from May 15, temporarily appointed)

Nina Thorsen, cand.phil.

Research fellow:

Peter Holtse, cand.phil. (from March 1)

Teaching assistants:

Kaare Dalhoff, M.A.

Peter Molbæk Hansen, stud.mag.

Mimi Jacobsen, stud.mag.

John Jørgensen, stud.mag.

Ellen Pedersen, stud.mag.

Pia Riber Petersen, cand.mag.

Torben Poulsen, M.sc.

Engineers:

Preben Dømler, B.sc. (returned from leave March 1)

Mogens Møller, M.sc.

Jens Holger Stellinger, M.Sc. (until February 29, temporarily appointed)

Technician:

Svend-Erik Lystlund

Secretary:

Else Parkmann

Teachers from other institutes, lecturing at the Institute of Phonetics:

Esther Dinsen (Institute for Applied and Mathematical Linguistics)

Steffen Heger (Institute for Nordic Philology)

Henning Spang-Hanssen (Institute for Applied and Mathematical Linguistics)

PUBLICATIONS BY STAFF MEMBERS:

Eli Fischer-Jørgensen	"Perception of German and Danish vowels with special reference to the German lax vowels", Auditory Analysis and Perception of Speech (eds. G. Fant and M.A.A. Tatham), London 1975
Børge Frøkjær-Jensen and Svend Prytz	"Registration of voice quality", Brüel & Kjær Technical Review, 3
Peter Holtse	"Datamaskinel behandling af fonetiske målinger", Publication 10 Symposium for Scandinavian Students of Phonetics on the Doctoral Level, Umeå, September 24-25, 1976 (eds. C.-C. Elert and Thorvald Wictorsson), p. 45-49
Birgit Hutters	"Problemer omkring den fotoelektriske glottograf", Publication 10 Symposium for Scandinavian Students of Phonetics on the Doctoral Level, Umeå, September 24-25, 1976 (eds. C.-C. Elert and Thorvald Wictorsson), p. 54-57
Niels Reinholt Petersen	"Intrinsik F_0 i danske vokaler", Publication 10 Symposium for Scandinavian Students of Phonetics on the Doctoral Level, Umeå, September 24-25, 1976 (eds. C.-C. Elert and Thorvald Wictorsson), p. 93-97
Nina Thorsen	"An acoustical investigation of Danish intonation: Preliminary results", Preprints from the 14th Acoustical Conference - Acoustics of Speech and Perception of Sound, Bratislava, October 4-8, 1976, p. 261-264

Nina Thorsen and Oluf Thorsen Lærebog i Fonetik, 2nd revised edition, København, 181 pp.

Oluf Thorsen, Ole Kongsdal Jensen and Karen Landschultz Fransk Fonetik, 6th revised edition, København, 161 pp.

LECTURES AND COURSES IN 1976:

1. Elementary courses in general phonetics

One semester courses (two hours a week) in elementary general phonetics (intended for all students of foreign languages except French and English) were given by Peter Molbæk Hansen, Mimi Jacobsen, John Jørgensen, Jørgen Rischel, Ellen Pedersen, Pia Riber Petersen, and Nina Thorsen. There was one class in the spring semester and nine parallel classes in the autumn semester.

Courses in general and French phonetics including practical exercises in the language laboratory (three hours a week) were given through 1976 by Oluf Thorsen.

Kaare Dalhoff and Jørgen Rischel gave courses (three hours a week) in general linguistics for students of English in the autumn semester.

2. Practical exercises in sound perception and transcription

Steffen Heger gave a course for more advanced students (two hours a week) in the spring semester.

Birgit Hutters gave a course for beginners (two hours a week) in the autumn semester.

Oluf Thorsen gave a course for advanced students (two hours a week) in the autumn semester.

These courses form a cycle of three semesters, and are based on tape recordings, as well as work with informants (on the advanced level).

3. Phonology

Eli Fischer-Jørgensen gave a course for beginners (two hours a week) in the spring semester.

Jørgen Rischel gave a course for advanced students (two hours a week) in the spring semester, and a course in Danish phonetics with emphasis on the phonological aspect (two hours a week) in the autumn semester.

Eli Fischer-Jørgensen and Jørgen Rischel gave a course in phonology for advanced students on the topic: trends in phonological theory (two hours a week) in the autumn semester.

4. The physiology of speech

Birgit Hutters gave a course in instrumental physiological phonetics (two hours a week, plus individual exercises) in the spring semester, and a course in the physiology of speech (two hours a week) in the autumn semester.

5. The acoustics of speech

Niels Reinholt Petersen gave a course in instrumental acoustic phonetics (four hours a week, plus individual exercises) in the autumn semester.

Torben Poulsen gave a course in elementary mathematics and electronics (two hours a week) in the spring semester.

Nina Thorsen gave a course in the acoustics of speech (two hours a week) in the autumn semester.

6. Other courses

Esther Dinsen (Institute of Applied and Mathematical Linguistics) gave a course in the theory and practice of the language laboratory (two hours a week) in the autumn semester.

Eli Fischer-Jørgensen presided at a series of seminars for advanced students on topics in experimental phonetics (two hours a week) in the spring semester.

Peter Holtse gave a course in English phonetics (two hours a week) in the autumn semester.

Peter Holtse gave an introductory course to the operating system of the laboratory computer (fifteen hours) in September, 1976.

Henning Spang-Hanssen (Institute for Applied and Mathematical Linguistics) gave a course in elementary statistics (two hours a week) in the autumn semester.

Nina Thorsen and Oluf Thorsen presided at a series of seminars for language teachers of the language teaching department of the Danish Refugee Council (four hours every two weeks) in the autumn semester.

7. Seminars

Peter Molbæk Hansen gave an account of 'stød' and syllable in a Danish dialect.

Nina Thorsen presented some preliminary results of her investigation of Danish intonation.

Nina Thorsen and Oluf Thorsen gave an account of the Symposium on Linguistics and Language Teaching in Stockholm, May 1976.

Peter Holtse, Birgit Hutters and Niels Reinholt Petersen presented papers to be read at the Symposium for Scandinavian Students of Phonetics on the Doctoral Level at Umeå, September 1976.

Jørgen Rischel gave an account of some field work observations on sound change in Eskimo.

8. Participation in congresses, symposia, meetings, etc.

Eli Fischer-Jørgensen lectured in July and August at the Linguistic Summer Institute, Oswego, USA. In October and November she visited and lectured at the following institutions of speech research in Japan (invited by the Research Institute of Logopedics and Phoniatrics, Tokyo): Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, University of Tokyo; Institute of Electrical Engineering, University of Tokyo; Osaka University of Foreign Languages; Tsuda College, Tokhai University, and Research Institute of Electrical Communication, Tohuku University, Sendai.

Børge Frøkjær-Jensen has participated in follow-up courses in logopedics and phoniatrics in April and November, and has arranged a number of interdisciplinary seminars on audio-logopedic topics.

Jørgen Rischel gave guest lectures on Danish stress at the University of Odense, and on problems in Greenlandic dialectology at Aarhus University. He participated in the 3rd International Conference on Nordic and General Linguistics in Austin, Texas, in April and gave an invited paper: "The contribution of Louis Hjelmslev".

Nina Thorsen gave guest lectures on Danish intonation at the University of Lund in June, and at the University of Kiel in October.

At seminars on language teaching and phonetics held at the Department of General Phonetics, University of Lund, Oluf Thorsen gave an account of pronunciation exercises in French, and Niels Reinholt Petersen presented an analysis of phonetic and phonological errors in Danish spoken by an American English talker.

Nina Thorsen and Peter Holtse participated in the 14th Acoustical Conference - Acoustics of Speech and Perception of Sound, Bratislava, October 4-8, and Nina Thorsen gave a paper: "An acoustical investigation of Danish intonation: preliminary results".

Nina Thorsen and Oluf Thorsen participated in the symposium on linguistics and language teaching in Stockholm, May 19-20.

Peter Holtse, Birgit Hutters, Niels Reinholt Petersen, Nina Thorsen and Oluf Thorsen participated in the symposium for

Scandinavian students of phonetics on the doctoral level at Umeå, September, and the following papers were given: Peter Holtse: "A system for the computer processing of phonetic measurements", Birgit Hutters: "Problems concerning the photo-electric glottograph", and Niels Reinholt Petersen: "Intrinsic fundamental frequency of Danish vowels".

INSTRUMENTAL EQUIPMENT OF THE LABORATORY

The following is a list of the instruments that have been purchased or built since January 1, 1976.

1. Instrumentation for speech analysis

   1 fundamental frequency meter, type FFM 650

2. Tape recorders

   2 semi-professional recorders, Revox, type A77

3. Microphones

   2 dynamic microphones, Sennheiser, type MD21

4. Loudspeakers

   8 loudspeakers, Philips, type RH 541 MFB

5. Outfit for photography

   1 timer, Kaiser, type 4033

   1 enlarger, Durst, type A300

6. Equipment for EDP

   1 disk drive, Digital, type RK8J-ED

ABBREVIATIONS EMPLOYED IN REFERENCES:

AJPs.	American Journal of Psychology
AL	Acta Linguistica
ALH	Acta Linguistica Hafniensia
ARIPUC	Annual Report of the Institute of Phonetics, University of Copenhagen
Folia Ph.	Folia Phoniatrica
FRJ	For Roman Jakobson
F&S	Form and Substance (Akademisk forlag), København 1971
Haskins SR	Status Report on Speech Research, Haskins Laboratories
IJAL	International Journal of American Linguistics
IPO APR	IPO Annual Progress Report
JASA	Journal of the Acoustical Society of America
JL	Journal of Linguistics
JPh.	Journal of Phonetics
JSHD	Journal of Speech and Hearing Disorders
JSHR	Journal of Speech and Hearing Research
Lg.	Language
Ling.	Linguistics
LS	Language and Speech
MIT QPR	M.I.T. Quarterly Progress Report
NTTS	Nordisk Tidsskrift for Tale og Stemme
Proc.Acoust. ...	Proceedings of the ... International Congress on Acoustics
Proc. Ling. ...	Proceedings of the ... International Congress of Linguists
Proc. Phon. ...	Proceedings of the ... International Congress of Phonetic Sciences
STL-QPSR	Speech Transmission Laboratory, Quarterly Progress and Status Report, Royal Institute of Technology, Stockholm
SL	Studia Linguistica
SPE	The Sound Pattern of English, Chomsky & Halle, 1968

TCLC	Travaux du Cercle Linguistique de Copenhague
TCLP	Travaux du Cercle Linguistique de Prague
UCLA WPP	Working Papers in Phonetics, University of California, Los Angeles
Zs.f.Ph.	Zeitschrift für Phonetik, Sprachwissenschaft und Kommunikationsforschung.

(ARIPUC 11, 1977)

ON THE INTERPRETATION OF RAW FUNDAMENTAL FREQUENCY TRACINGS[1]

Nina Thorsen

Abstract: This paper describes a procedure with which complex raw fundamental frequency (Fo) tracings can be dissolved into their constituent components, namely 1) the intonation contour of the sentence, 2) the Fo patterns associated with stress groups, 3) Fo movements pertaining to individual segments (vowels), 4) intrinsic Fo differences between segments (vowels), and 5) coarticulatory Fo variations. The problems inherent in such a procedure are discussed as are assumptions of underlying physiological production models of and perceptual correlates to the physical signal.

A phonetic investigation of fundamental frequency (F_o) may concern phenomena at various levels, such as the over-all intonation contour(s) of sentences, the F_o patterns associated with stressed and unstressed syllables (in languages where stress and F_o are interrelated), intrinsic F_o differences between segments, F_o movements associated with individual segments, and F_o variations arising from the interaction between neighbouring segments (coarticulatory variations). The contributions from each one of these phenomena may vary between languages, between dialects, and between speakers but, to some extent, they all interfere with each other to make for the rather complex F_o courses we observe in the outputs of our analyzers, and thus, no matter what the focal point of interest may be, the effect of the others upon it should be accounted for, in order to arrive at a stringent and relevant description and also to create a certain simplicity in the frequency dimension.

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1) Paper read at VIII[èmes] journées d'étude sur la parole, Aix-en-Provence, 25-27 Mai 1977.

We may attain simplicity in the time dimension by disregarding parts of the F_o course, which presupposes a reliable delimitation. Segmentation is also necessary to create line-up points for the averaging of several repetitions of a given utterance and is in itself a problem which, however, is not considered any further here.

The outcome of the processing of F_o tracings is often (tacitly) assumed to reflect either an underlying physiological production model or a perceptual correlate to the physical signal - but, clearly, either of these goals can only be approached in a roundabout fashion which involves guess-work and inferences made from observations of similarities and dissimilarities among and between sounds in various environments.

I shall try to exemplify some of the problems inherent in separating, in raw F_o tracings, the contributions from each of the factors mentioned in the first paragraph, stressing the fact that they are relevant to "manual" as well as to computerized treatment of data. The problems are the experimenter's and the answers to them can only be supplied by him.

In a recent investigation (Thorsen 1976) of Danish intonation (in non-emphatic, non-emotional speech) - which was also to illuminate the relationship between linguistic stress and F_o - it was found necessary, first of all, for the averaging of repetitions of the same utterance, to line up the traces to each new beginning of a stretch of voicing in the sentence. The time-axis is thus, of course, distorted.

Only the F_o course of vowels and (voiced) sonorants were included in the subsequent treatment, assuming that the F_o course in voiced obstruents is irrelevant for the perception of pitch patterns and -contours (associated with stress groups and sentences, respectively), the ultimate goal of the investigation being a description as close to the perceived pitch course as possible.

The assumption of the irrelevance of the course of F_o in voiced obstruents will have to be tested in perceptual experiments, but it seems justified in the light of a case like the one below (which is but one out of many): The word stavelserne ('the syllables' (the stress is on the first syllable)) may appear in any of the three shapes depicted in Fig. 1. (Note that Danish does not have an opposition between unvoiced and voiced alveolar fricative, but /s/ may be voiced between voiced sounds, especially in rapid speech.)

(a) a rise in the first two syllables, continuing through the [s̬], followed by a fall in the last two syllables,

(b) a rise in the first two syllables, a fall and a rise in the [s̬], and a fall in the last two syllables, which corresponds to the fall in (a),

(c) a rise in the first two syllables, 'silence' during the [s], a jump upwards to the fall in the last two syllables, which corresponds to (a) and (b).

The basic production model might look somewhat like (a) and is realised as such (in rapid speech) when the glottis remains "closed" and the vocal cords vibrate during the [s] and, probably, when at the same time the constriction at the alveolar ridge is fairly loose. It is modified as in (b) when the vocal cords vibrate around a somewhat more open position during the [s], a modification which is not voluntary but due to mechanico-acoustico-aerodynamical factors. Finally, the model may be realised as in (c) if the glottis is wide open during the [s], impeding vocal cord vibrations. Unless one's attention is specifically drawn towards the detection of voicing in an /s/, the three editions are likely to be perceived in the same fashion, i.e. there is as much information for the listener in (c) as in (a), and the F_o course in the (voiced) obstruent is thus irrelevant in the sense that it passes unnoticed - and (c) may thus be an approximation to the perceptual model.

In vowels one often finds, after an aspirated stop or an [s] or [f], i.e. unvoiced consonants produced with an open glottis and with forceful airflow, one or two vibrations which are

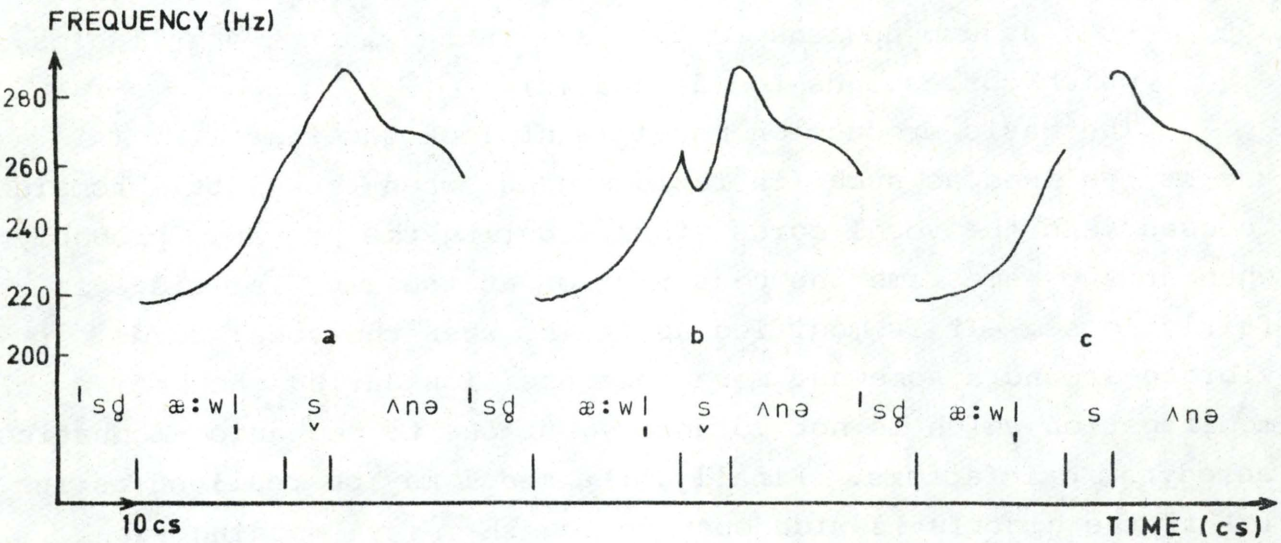

Figure 1

F_o tracings of three recordings of the word stavelserne (female subject) between 10 and 40 Hz above the succeeding ones. Such vibrations were left out, cf. the line of argument above for /s/.

The pruning of the F_o course is, regrettably, not uncontroversial. How much of a movement in a vowel surrounded by (voiced and unvoiced) consonants can be ascribed to influence from these consonants? In other words, what does the intended F_o course - the production model - look like before it is superimposed by involuntary modifications? And, once again, what are the perceptual correlates (which are not necessarily identical to the production model)? To my knowledge, there is no sure way to compensate accurately for such coarticulatory F_o variations since, as yet, too little is known about the physiological and aerodynamic mechanisms involved to allow us to quantify these variations. - But there are ways around this problem. One (which I chose to follow) is to disregard those portions of the F_o course where coarticulatory variations occur, i.e. mainly at the boundaries between sounds of the obstruent and sonorant classes, and prune away the obstruents plus bits of the adjoining sonorants (but how large bits is difficult to decide). This is probably permissible if the outcome of the processing is to reflect a perceptual correlate to the signal. Another possibility is to interpolate an F_o course through all voiced obstruents so as to smoothly connect the courses in the adjoining sonorants and thus approach what may be the underlying production model.

The F_o patterns associated with stressed and unstressed syllables were attacked next - on the basis of a material of reference words of two and three syllables ([b̥ʰib̥ʰi(b̥ʰi)]) where only the position of the main stress varied (they are nonsense words but they are all possible words in Danish). These words were embedded, in various positions, in declarative sentences. By employing the same consonants and vowels in the reference words, observed differences in F_o courses must be due to different stress distributions. (It turned out that a stressed syllable and all succeeding unstressed syllables in the same non-compound sentence, irrespective of intervening morphological and syntactical boundaries, constitute the unit for an F_0 pattern, which can then be described as a low stressed syllable followed by a tail of higher and falling unstressed syllables, cf. the dotted line in Fig. 2,d.) But the problem remains to demonstrate that words of different and varying segmental structures exhibit the same F_0 patterns as do the reference words, since intrinsic and coarticulatory F_0 variations interfere.

A tabulation of intrinsic F_0 differences between segments (vowels) must be performed for each individual in an experiment since the magnitude of these differences varies. It may be as large as 35 Hz for females, and as small as 10 Hz for males, between [i:] and [ɑ:], cf. Reinholt Petersen (1976). But the magnitude of these differences seemingly also varies with degree of stress (being much larger in stressed syllables), with the short/long distinction (being larger in long vowels), and with position on the intonation contour (being larger at the top than at the bottom of the contour).

Once these intrinsic differences in various conditions have been established for each subject, it becomes possible, in sentences consisting solely of short vowels and unvoiced consonants, to simply move the F_0 course in a given vowel up or down the frequency axis, as the case might be, - and only then does the similarity to the F_0 patterns of the reference words become apparent. - But sentences consisting also of words of long vowels and of vowels surrounded by sonorants, which exhibit longer stretches of voicing (abbreviated "voiced words" in the following) have to be dealt with as well. It is possible to reduce the long continuous stretches of voicing in "voiced words" to a succession of shorter ones if we assume that identical tonal patterns shall recur in "voiced words" and reference words. (This assumption must of course be verified or falsified in perception experiments.) One can compare (under identical conditions) the F_0 courses in "voiced words" and reference words with identical stress patterns <u>after</u> corrections for intrinsic F_o differences have been performed. Parts of the F_o courses in the "voiced words" are then concurrent with the F_o courses in the reference words, and if the remainder of the F_o courses in the "voiced words" is disregarded, "voiced words" are seen to follow the same F_o patterns as exhibited by the reference words (and other words with short vowels and unvoiced consonants). (This is in itself an indirect support of the assumption of the recurrence of identical tonal patterns in reference words and "voiced words".)

<u>F_o movement</u> associated with individual segments (vowels) must be accounted for, but in this case results will probably be valid for the whole ensemble of speakers of the same dialect. (In Advanced Standard Copenhagen Danish all short vowels exhibit falling movements and all long vowels exhibit falling-rising movements, but the fall is of greater extent than the rise. The only exception seems to be the first stressed syllable in a sentence, which may be rising. The direction of the movement is unaffected by surrounding consonants, but the extent of the fall is slightly greater after aspirated stops and unvoiced fricatives than after unaspirated stops and sonorants, cf. Reinholt Petersen (1976).) If a movement is not heard as such, but rather as a level pitch, it can be represented as such, but should the level then correspond to the beginning, the middle, or the end of the movement? This is, of course, a problem which has engaged phoneticians for years, cf. e.g. Rossi (1971). - If a movement is perceived as a movement, it may be preferable to preserve it in the description, especially if it is to serve comparative purposes. Different vowel F_o movements may well be one of the important prosodic distinctions between different Danish dialects.

When F_o patterns associated with stress groups are recurrent entities (allowing, however, for context dependent modifications, as long as they are predictable), the <u>intonation contour</u> can be defined narrowly as the course described by the stressed syllables alone, cf. the "crossed" line in Fig. 2,d.

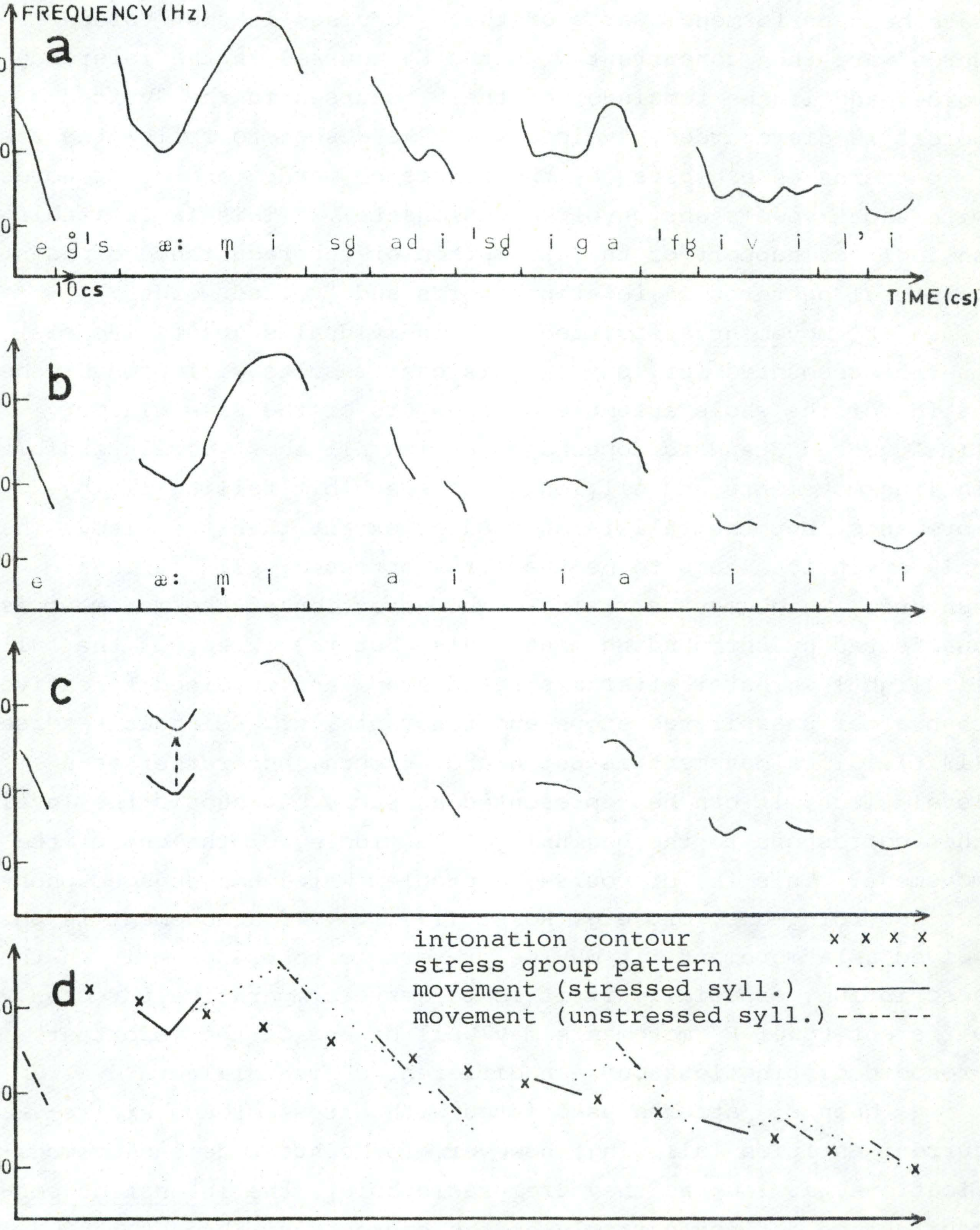

Figure 2

F_o tracing of a sentence Eksamen i statistik er frivillig ('The examination in statistics is non-compulsory') (Male subject.) a: raw signal, b: pruned signal, c: reduced and corrected signal, d: stylized signal.

Given the results of experiments and considerations as outlined above, a raw F_o tracing can be broken down into constituent components, as illustrated in Fig. 2. First "irrelevant" passages (cf. above) are pruned away (b). Corrections for intrinsic F_o differences between (stressed) vowels are performed and, simultaneously, longer voiced stretches are reduced (via comparisons with reference words in identical context) to a succession of shorter ones (c). In this case movements associated with individual vowels are preserved but it may be justified to reduce them to level courses. Finally, the tracings may be stylized (d).

On the basis of a relatively comprehensive material it has been possible, following the procedure just described, to postulate a preliminary model (Fig. 3) for F_o in various types of short sentences in Advanced Standard Copenhagen Danish.

A scale has been tentatively indicated. For X equal to one it would fit a rather low male voice. For other speakers, X will have to be determined, which is probably not a simple procedure. A very coarse approximation is $X = \frac{a}{100}$ where 'a' is the frequency in Hz of the second (of three) stressed syllable(s) in a declarative sentence. This value of X, however, predicts too high values for the highest unstressed syllables for female voices.

The model is supposedly predictive as well as descriptive. Given a sentence with a certain intonation contour (determined by the syntactical and semantical nature of the sentence) the stress group patterns are superimposed on the contour and the appropriate vowel movements are added (if they are not prescribed by the model). The result is modified by intrinsic F_o differences pertaining to individual segments (vowels) and, finally, is turned into a continuous course by smoothly connecting the vowels, with interruptions, of course, for unvoiced consonants (and with dips for voiced obstruents, but this last step needs further clarification). For a more detailed account, see Thorsen (1976).

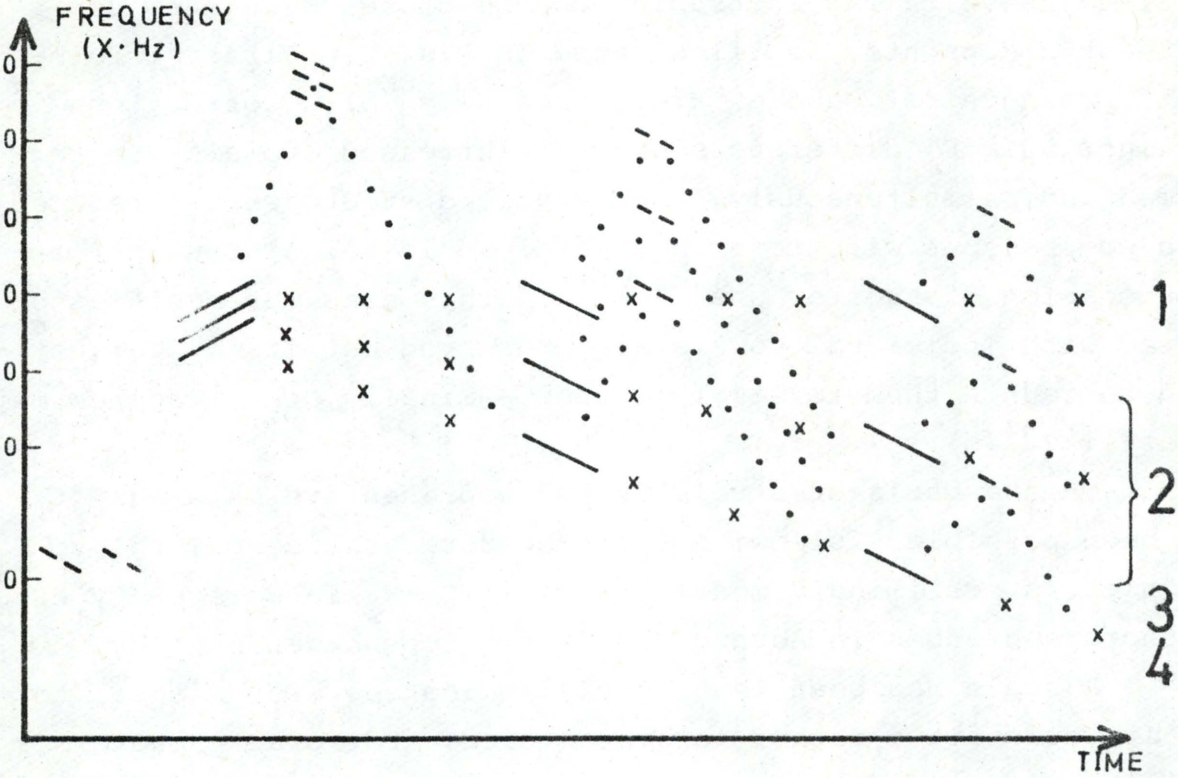

Figure 3

Model for F_o in short sentences in Advanced Standard Copenhagen Danish. 1: Intonation questions, 2: Questions with word order inversion and Non-terminal periods (variable), 3: Questions with interrogative particle, 4: Declarative sentences. See further the legend to fig. 2,d.

References

Reinholt Petersen, N. 1976: "Intrinsic fundamental frequency of Danish vowels", ARIPUC 10, p. 1-28 (also to be published in JPh.6)

Rossi, M. 1971: "Le seuil de glissando ou seuil de perception des variations tonales pour les sons de la parole", Phonetica 23, p. 1-33

Thorsen, N. 1976: "An acoustical investigation of Danish intonation: preliminary results", ARIPUC 10, p. 85-148 (also to be published in JPh.6, in a slightly revised form)

ON THE NOTION "STRENGTH" OF COARTICULATION

R. A. W. Bladon[1]

It has been suggested elsewhere (Bladon and Al-Bamerni 1976) that the numerous factors which constrain the domain and the direction of coarticulatory effects in speech can best be described by postulating the notion of "coarticulation resistance" (CR) as the relevant principle of articulatory control. The speech production mechanism is hypothesized to have continuous access to CR information, which can be considered to be initially stored linguistically as a scalar feature specification [n CR] attaching to each extrinsic allophone and boundary condition. Thus it has been demonstrated, for example, that British (RP) English dark syllabic [ɫ̩] is highly resistant to coarticulation, while clear nonsyllabic [l] is much more susceptible, and we propose initially to provide those allophones with specifications such as [5 CR] and [2 CR], respectively. The numerical value of the CR index is re-computed at a level of articulatory planning by what might be termed a CR compiler to take account of a wide range of constraints imposed by motor compatibility, by the structure of the phonetic system, etc. It is further suggested that coarticulation may proceed freely in either direction (left-to-right or right-to-left) in time, until impeded by a specification of CR on some segment.

One advantage of this formulation is that it enables us to refine our ideas about the degree of coarticulation a segment shows, and to quantify the terms "weak coarticulation" and

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1) Department of Linguistics, University College of North Wales, Bangor LL57 2DG, U.K.

"strong coarticulation" which tend to be used informally (e.g. "segment [A] is weakly coarticulated with the following segment [N] in respect of feature F"). Two kinds of condition can produce a "weak" realization of F on [A]. Firstly, if [A] has a moderately high specification of CR, and provided F is itself reasonably "strong", coarticulation on [A] will not be impeded altogether, but "weakened". [A] can be said to show weak coarticulation, and this can be expressed in appropriate numerical terms.

Secondly, consider a case where the feature F, spreading into [A], is itself realized only "weakly" on [N] in the first place. According to the observed coarticulation behaviour, two different hypotheses can be entertained. On the one hand, it is possible that a moderate CR index on [A] will nevertheless be sufficient to inhibit coarticulation onto [A] of the now "weak" feature F: in that event the CR compiler must be provided with a means of detecting the "strength" ("weakness") of the original specification of the feature available for coarticulation. On the other hand, it is alternatively possible that [A] may show evidence of coarticulation even with a "weak" feature. In that case, the term "weakly coarticulated" would seem inappropriate (i.e. [A] is weakly nasalized, weakly labialized etc., but not weakly coarticulated), and this would provide evidence that the operation of the CR compiler need not be sensitive to the "strength" of the coarticulated feature.

The present experiment was designed primarily to obtain evidence relating to this question of the possible coarticulation of a weakly specified feature. RP English /r/ provides a test case, being frequently produced with slight labialization, in particular with slight protrusion and rounding of both lips, or sometimes of mainly the lower lip (Ladefoged 1971: 62; Jones 1972: 195). A speech sample was devised containing consonant strings of varying length preceding /r/. Interest centred on how far left into the preceding consonant string (if at all) there would be anticipatory coarticulation of the labialization of /r/.

It is known from other studies (Daniloff and Moll 1968, Gay 1977) that the labialization accompanying /u/, which can be shown (see below) to be an example of a "stronger" articulatory gesture than that accompanying /r/, is coarticulatorily advanced leftwards across all consonants within the CV ("articulatory syllable") unit. Gay found, for example, in sequences of English nonsense strings of the type /utu, ustu, ukstu/, that two separate peaks of electromyographic activity were registered from the orbicularis oris muscle, each peak corresponding to a labialization gesture for an /u/, but that the second peak occurred as early as possible in the consonant string. The behaviour of /r/ in this regard was investigated as follows.

Electromyographic (EMG) activity from the orbicularis oris muscle of two young adult speakers of RP was measured by surface electrodes. One speaker was recorded at the Institute of Phonetics, University of Copenhagen, using solid rectangular disc electrodes made of silver and secured to the upper and lower lips by tape. This speaker was the same person who served as subject for the experiment by Gay (1977). The other speaker was recorded at the Department of Phonetics, Stockholm University, using electrodes of the "paint-on" type, made of a mixture of cement, acetone and fine silver powder (for more details of this method see for instance Allen and Lubker 1972). On both occasions the electrode sites were on the vermilion border of the upper and lower lips just to the subject's right of midline. Mingograph tracings were obtained of the audio signal (duplex oscillogram and intensity curve), of a raw EMG signal from each of the two lips, and of a rectified and integrated ($\underline{t}$ = 20 ms) EMG signal from each lip.

Some sample EMG curves are reproduced as Fig. 1. The recording in the upper part of the figure was made in Copenhagen, that in the lower part in Stockholm (different speakers). All

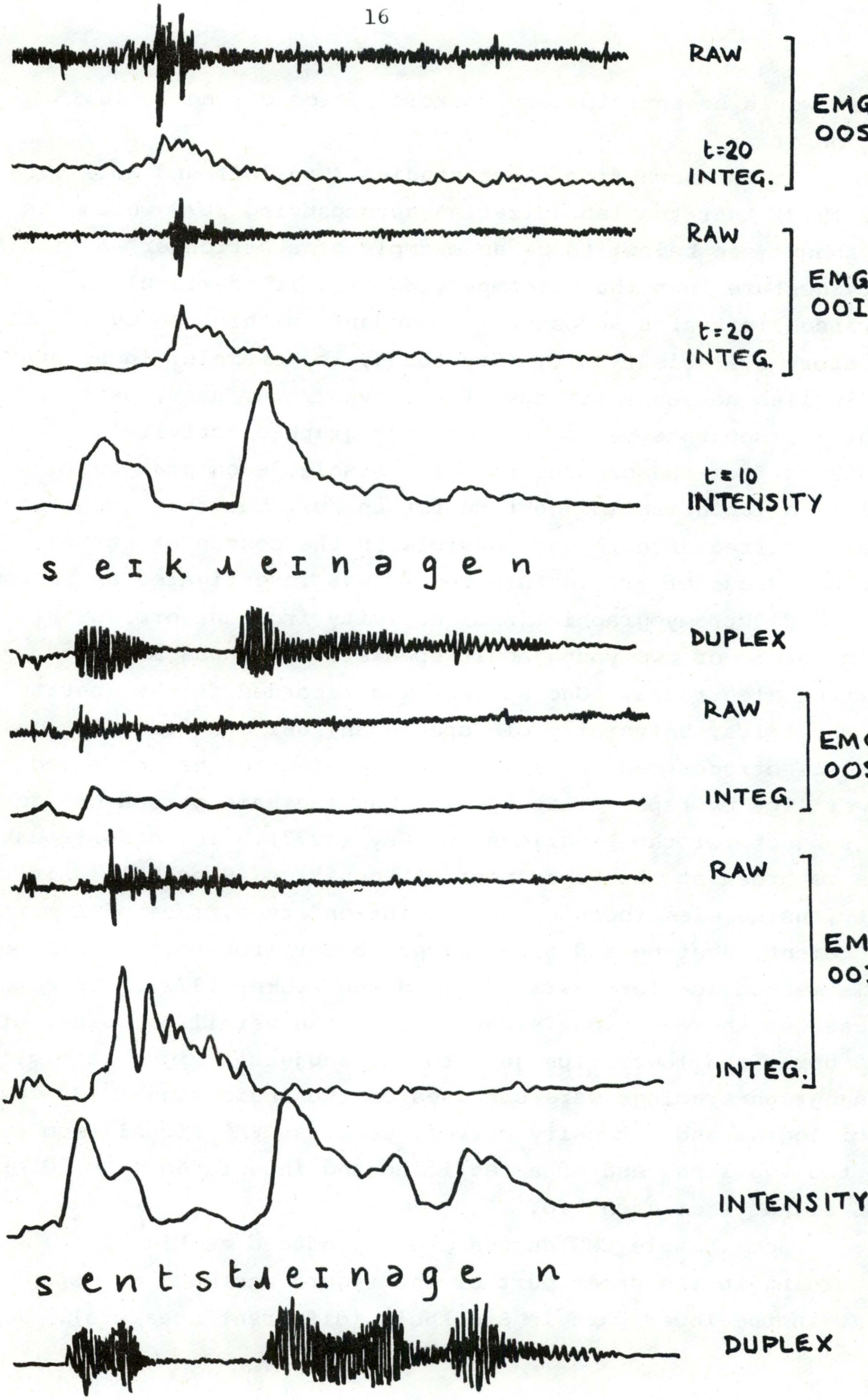

Figure 1

Sample EMG curves of orbicularis oris superior (OOS) and orbicularis oris inferior (OOI), and intensity curves and duplex oscillogram of the audio signal. For further explanation, see text.

the EMG curves were highpass filtered at 100 Hz; the linear intensity curves were highpass filtered at 500 Hz; and integration times of 20 and 10 ms were used for the EMG and intensity curves, respectively.

The speech sample consisted of each of the words listed in Table 1, Columns 2 and 3, embedded into each of the frames shown in Table 1, Column 1, and spoken with a falling intonation nucleus on the word from Column 2 or 3. This corpus was read twice by each of the two speakers, with the intention that the two readings would provide an indication of the variability of data collected by this method (see Appendix for discussion). The purpose of including the items in Column 3 was to obtain control information on the relative "strength" of labialization in /r/ in comparison with other labial or labialized sounds.

Table 1

Items in the speech sample.

1.		2.	3.
Say ... again	(a) /r/	red	bed
See ... again		rat	wed
Set ... again		rain	fed
Sent ... again	(b) /Cr/	train	shed
Do ... again		drain	red
Saw ... again		crane	
Shoot ... again		grain	
	(c) /CCr/	in train	
		engrain	
	(d) /CCr/	strain	
		screen	
	(e) /CCCr/	in strain	
		on screen	
	(f) /CCCCr/	old screen	
		old strip	

The first results to be considered will be those relating to that control group of data in Table 1, Column 3. Fig. 2 shows the peak amplitude of excursion of the rectified and integrated EMG trace, for each of several labial or labialized sounds. Each data point represents the mean value of 14 tokens. From this display of the peak innervation of orbicularis oris, it can be confirmed that labial activity is strongest in those consonants with primary labial approximation /b w f/ and in the rounded vowels /u ɔ/, and weakest in the sounds /ʃ r/ which are traditionally said to have secondary articulation at the lips.

Turning now to the principal results, Fig. 3 summarizes the observed timing relationships between the speech sound segmented from the audio traces and the firing instant for orbicularis oris in both lips. The onsets of /r/ are aligned. These are the findings of interest:

(1) In sentences of the type "Say rain again" (Fig. 3(a)), the firing instant of the orbicularis oris muscle (defined by a steep excursion on the integrated EMG curves) precedes by some 60 to 70 ms the acoustic evidence of the /r/ onset as determined from the audio signal (by a sharply reduced intensity curve and a reduction in the oscillogram amplitude).

This acoustic lag accords well with other investigators' findings for this muscle, and with the time scale cited by Catford (1977: 6) for neuromuscular, organic and aerodynamic phases.

(2) The firing instant for orbicularis oris in /r/ advances progressively through the sequence of environments (a) C_0r to (f) C_4r. That is, right-to-left coarticulated labialization takes place across a sequence of any number of alveolar consonants; but is arrested by a left V boundary. This provides further evidence for the postulation of the "articulatory syllable" (of the form CV, where C is any number of consonants) at whose boundaries coarticulation resistance

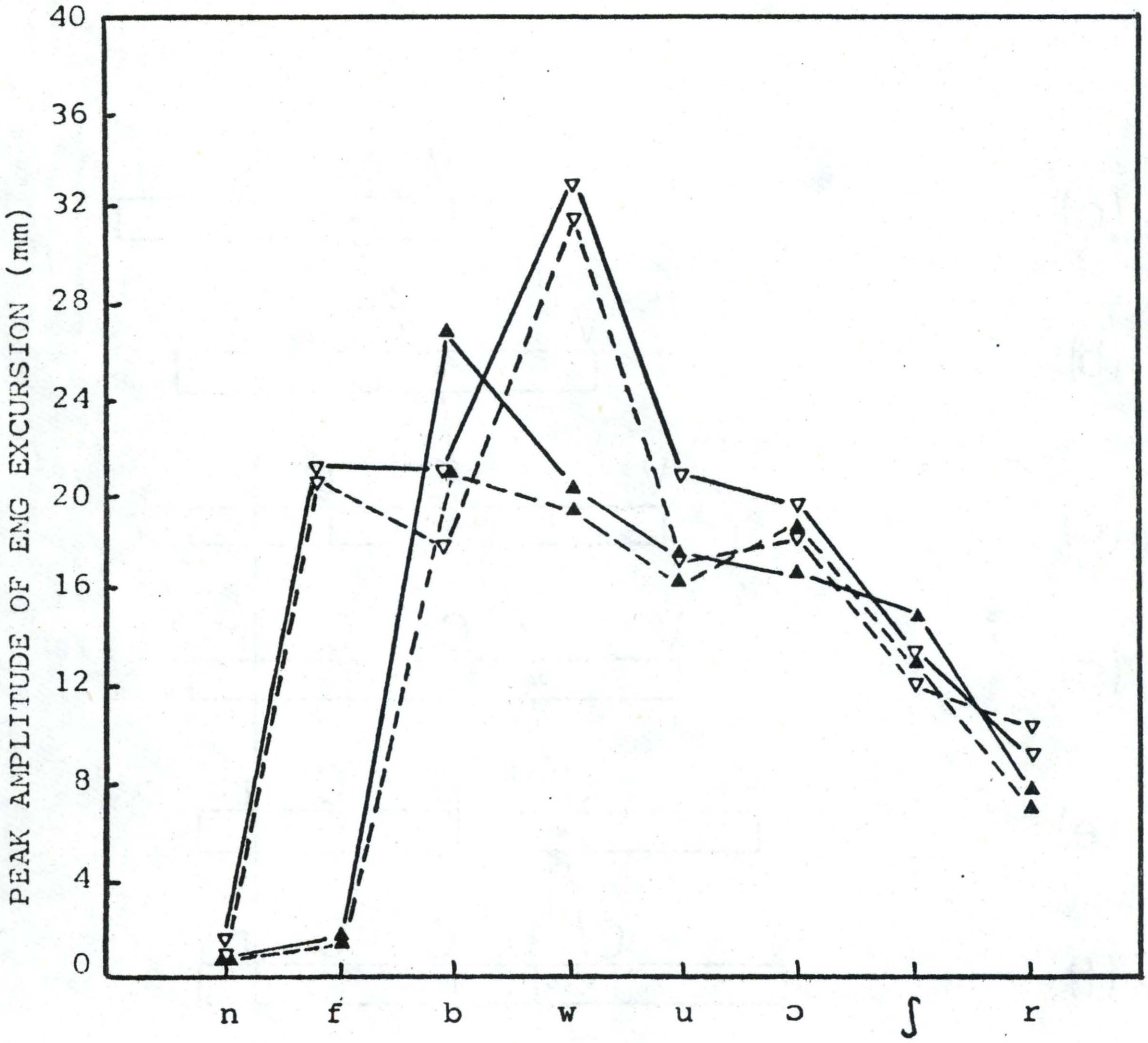

Figure 2

"Strength" of labial activity for various sounds.
Filled triangle (▲): upper lip.
Unfilled triangle (▽): lower lip.
Two speakers represented by —— and ----

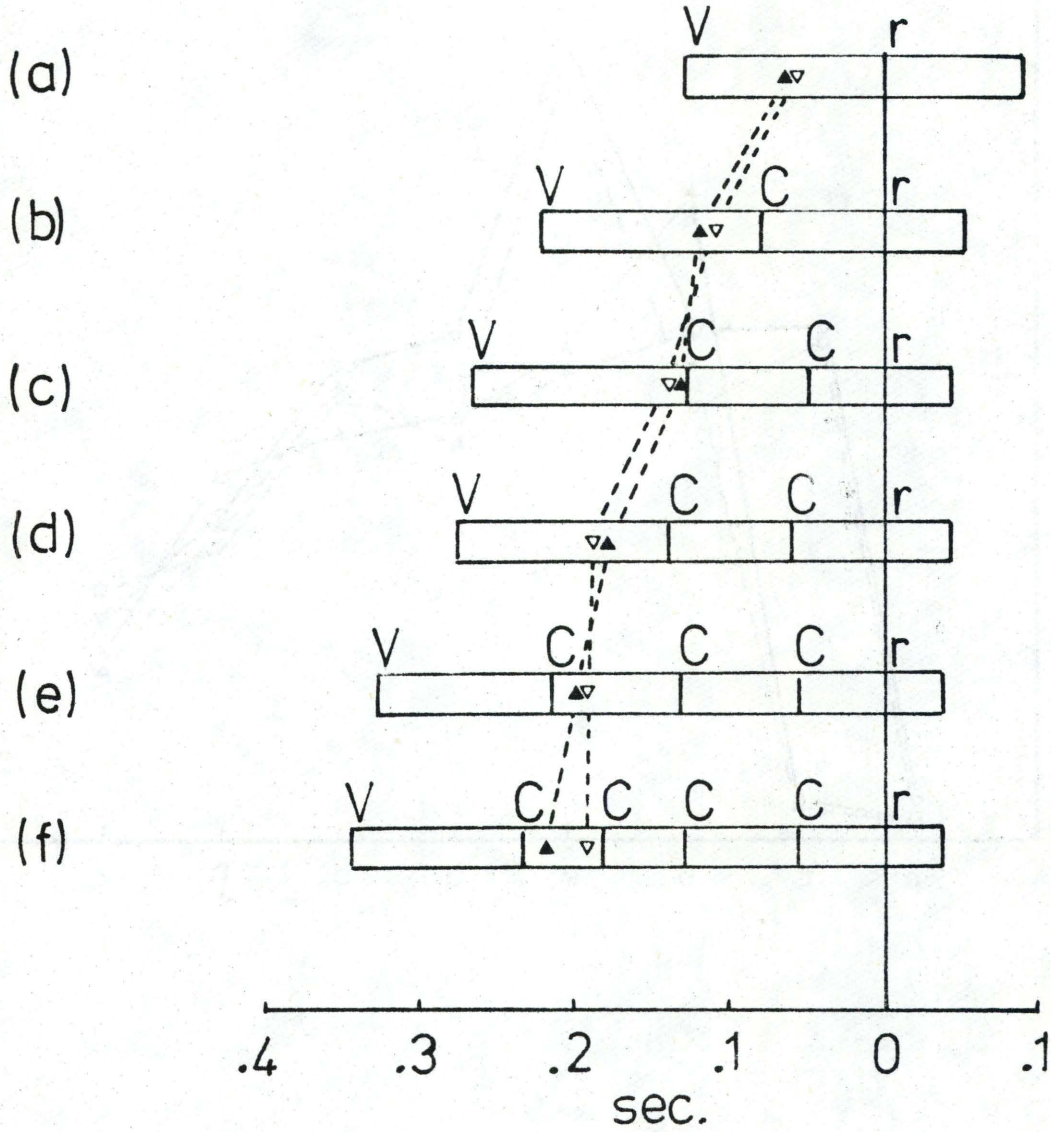

Figure 3

Firing instant of orbicularis oris muscle anticipating /r/, in various environments (a) to (f)- see Table 1 for details.
Filled triangle (▲): upper lip firing instant.
Unfilled triangle (▽): lower lip firing instant.

is high (Kozhevnikov and Chistovich 1965; Bladon and Al-Bamerni 1976).

(3) Following on from finding (2), it is to be noted that coarticulation proceeds in particular unimpeded by an intervening /s/ in the string. This argues against the possibility that English /s/ might have a high overall specification for CR under all conditions; a view speculated upon in Bladon and Nolan (1977) on the evidence of, firstly, the resistance they found in /s, z/ to coarticulatory shifts of laminality towards apicality, and secondly, following Amerman et al. (1970), the inhibition offered by /s/ to coarticulated jaw-opening anticipating English /æ/. Rather, the CR compiler must be sensitive to the 'feature' being coarticulated, allowing /s/ to labialize freely, but not to shift its point of stricture or jaw-opening.

(4) The right-to-left coarticulation takes place over a consonant string irrespective of intervening morpheme boundaries in sentences like "Set train ...", "Sent train ...", "Set strain ...", "Sent strain ...". This is in accordance with similar findings by Daniloff and Moll (1968: 714) and others. But in those cases where a morpheme boundary occurs in Fig. 3, namely (c), (e) and (f), there is some suggestion that coarticulation begins slightly later, in or near to the first C.

The evidence of (2), (3) and (4) above indicates that the "weak" labialization accompanying English /r/ is coarticulated anticipatorily over no smaller a domain of segments than was the "stronger" labialization accompanying /u/. It is probably the case that a given specification to coarticulated labialization anticipating /u/, would at the same time never be so high that it would prevent coarticulation with /r/. More generally, it may then <u>not</u> be necessary to build into the CR compiler, in a model of speech production control, a mechanism for assessing the articulatory "strength" of the coarticulated feature.

The CR compiler will, however, have to be constrained by numerous disparate articulatory and linguistic properties, and while it seems from the above experiment that it may not be necessary to include among them a sensitivity to feature-"strength" in an articulatory sense, it may be worthwhile summarizing here those properties known from other work to be relevant:

(a) "universal" marking conventions - which, for example, will assign a universally high CR index to the intonation-group boundary;
(b) language-specific properties - such as the fact cited by Ladefoged (1967: 62-4) that while French and English both show a /k/ coarticulatorily advanced before an /i/ vowel, only French shows the similar effect after /i/;
(c) dialect-specific properties - British English shows less anticipatory nasalization of a vowel before a nasal than does American English;
(d) speaker-specific properties - according to Su, Li and Fu (1974), coarticulated vowel-quality in a nasal may well be speaker-identifying;
(e) properties of the phonetic system - Irish (with three laterals in its system) shows much less coarticulated vowel-quality in a lateral than does British Englih (with two) which in turn shows less than American English (with one);
(f) properties of phonological structure - CV ("articulatory syllable") boundaries, as mentioned, seem to have high CR;
(g) properties of motor constraints - jaw-opening is incompatible with /s/ probably because it excessively deforms the friction passage;
(h) properties of the coarticulated feature - English /s/ will allow coarticulation of lip-rounding (as seen above) but not of shift in lower articulator;
(i) idiosyncratic CR specifications for individual segments - such as the high CR of RP [ɫ].

It is safe to assume that the above list is not yet complete. However, it is perhaps a small consolation that, apparently, instances of "weak" versus "strong" coarticulation do not yet justify in themselves further extension of this apparatus.

Acknowledgement

My thanks are due to the Universities of Copenhagen and Stockholm for the use of their facilities, and in particular to Jørgen Rischel, James Lubker and Robert McAllister for their criticism and their kind assistance and advice with the experiment.

Appendix

Some impression of the consistency observed in the EMG curves can be obtained from Table 2. This shows, separately for the two muscles orbicularis oris superior and inferior, and separately for each speaker A and B, the duration of coarticulated labialization measured between the EMG firing instant and the acoustic onset of /r/. From these results it can be seen that rather consistently speaker A's values exceed those of B to a small extent (approximately by 8%). Table 2 also shows the mean of the two speakers' data (shown as $\bar{x}$ and used as the basis for Figure 3), the standard deviation, and the results of a t-test performed to compare the data of the first reading with that of the second. The importance of this comparison lies in the widely observed tendency for EMG signals to show appreciable occasion-to-occasion variation. From the t-values it can be stated that in all cases there is no significant difference between the readings ($p > 0.05$). It should also be noted that our results can be compared fairly directly with those of Gay (1977) for the vowel /u/, since Gay's speaker was the same person as one of our subjects.

Table 2

Firing instant in orbicularis oris superior (OOS) and inferior (OOI) anticipating RP /r/. For explanation, see text in Appendix.

		OOS				OOI				
		spkr A spkr B	$\bar{x}$	s	t	spkr A spkr B	$\bar{x}$	s	t	n
(a)	/r/	65 67	66	12.8	0.76	66 56	61	17.5	0.55	48
(b)	/Cr/	123 105	114	20.3	0.44	118 98	108	25.2	0.49	64
(c)	/nCr/	150 130	140	17.0	0.97	145 141	143	16.6	0.33	32
(d)	/sCr/	197 173	185	30.7	0.29	191 185	188	27.3	0.62	32
(e)	/CCCr/	201 183	192	41.3	0.70	205 187	196	47.1	0.76	32
(f)	/CCCCr/	231 203	217	32.8	1.06	180 199	189	36.0	0.90	32

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RETROFLEX AND DENTAL CONSONANTS IN GUJARATI. A PALATOGRAPHIC AND ACOUSTIC STUDY

Radhekant Dave

Abstract: A palatographic investigation of dental and retroflex consonants of one Gujarati speaker shows the point of articulation of the retroflex consonants to be mostly prepalatal. The main result of the acoustic investigation which is based on one more informant is that retroflex consonants (compared to dental consonants) have a lowering effect on the transitions of F3 and F4 of the preceding vowel (though the effect on i and e is very small), whereas the influence on the following vowel is irregular, but clear for the vowel a. In addition, the burst of retroflex stops shows concentration of energy at a lower frequency than dental stops. The important contribution by Stevens and Blumstein is discussed in the final section.

1. Introduction[1]

1.1 The language

Gujarati is an Indic language belonging to the Indo-Iranian branch of the Indo-European language family. It is spoken by approximately 26 million people, most of whom live in the State of Gujarat in Western India, North of Bombay.

The present article is a somewhat abbreviated version of chapter IV of a doctoral thesis presented to the Graduate School of Cornell University.

The palatograms and spectrograms were taken at the Institute of Phonetics, University of Copenhagen. Most of the material has been recorded during my stay in Copenhagen 1967-68, but some supplementary material was recorded during a shorter stay in 1977. I am grateful for having been admitted at the Institute as a guest research worker. I am particularly indebted to pro-

1.2 The phonological system

Gujarati has 8 clear, oral vowels: /i e ɛ u o ɔ ə ɑ/ (in some dialects no distinction is made between /e/ and /ɛ/, /o/ and /ɔ/, and this is the case in the dialect spoken by the informant in the present investigation). There are further 8 (or 6) murmured vowels: /i̤ e̤ (ɛ̤) ṳ o̤ (ɔ̤) ə̤ ɑ̤/, and 6 nasalized vowels: /ĩ ũ ɛ̃ ɔ̃ ə̃ ɑ̃/. Phonologically, the murmured vowels may be interpreted as clear vowels + /h/, and the nasalized vowels as clear, oral vowels + /N/ (see Pandit 1957 and 1958, and Dave 1967a and 1967b).

It has the following consonantal phonemes:[2]

p	t	ṭ	c	k	
b	d	ḍ	ɟ	g	
ph	th	ṭh	ch	kh	
bh	dh	ḍh	ɟh	gh	
	s		ʃ		h
m	n	ṇ		N	
	r	ṛ			
	l	ḷ			
v			j		

(continued)
fessor Eli Fischer-Jørgensen for her encouragement and help during my studies. My research on Gujarati vowels and consonants has been made under her guidance and supervision, and I could not have completed this research without her active interest and extensive aid at all stages of my work. I am also grateful to Børge Frøkjær-Jensen and to Birgit Hutters for helping me with the palatograms, to Jente Andresen, Uffe Due, and Jørn Dyhr for taking and measuring part of the spectrograms, to Jeanette Gliming for making the graphs, and to Else Parkmann for typing a difficult manuscript. - I also want to express my gratitude to Professor K.N. Stevens, Research Institute of Electronics, MIT, who put his instrumentation for linear prediction analysis at my disposal and who kindly helped me taking the curves. Finally, I am thankful to Professor Linda Waugh, the chairperson of my special committee for the Ph.D. degree for her help and supervision.

2) In this paper a dot below the letter is used to indicate retroflex sounds.

The aspirated stops can be interpreted as stop + h (see Pandit 1957 and 1958). Retroflex [ṣ] is found only before another retroflex consonant and can be interpreted as a variant of /ʃ/. /N/ comprises the variants: [ɲ] (before palatal sounds), [ŋ] (before velar sounds), and nasalization of a preceding vowel (according to Pandit 1957 and 1958). The palatal nasal might be considered a variant of the dental or the retroflex nasal, but it is more natural to group it with the velar nasal. The latter cannot be considered a variant of either /n/ or of /ṇ/, since it is commutable with these before a velar stop. Retroflex /ḍ/ is often pronounced as a flap, thus like /ṛ/, except initially after a retroflex nasal and intervocalically, when the second vowel is followed by a retroflex consonant, but retroflex /ṛ/ is not pronounced as [ḍ]. Retroflex /ṛ/, /ḷ/ and /ṇ/ are not found initially.

2. The palatographic investigation

2.1 Preliminary remarks

Until now an instrumental investigation of Gujarati consonants has not been undertaken, and instrumental studies of retroflex consonants in other languages are rather scarce. N. Ramasubramanian and R.B. Thosar (1971) have undertaken a palatographic and spectrographic investigation of retroflex consonants of Tamil, and P. Nihalani (1974) has investigated Sindhi stops by means of palatography and X-ray. However, the point of articulation of retroflex consonants varies a good deal in different Indic languages, so that no direct conclusions can be drawn for Gujarati from these investigations. According to the traditional description of retroflex consonants they are pronounced with the apex of the tongue curled back to the palatal region; they may, however, also be post-alveolar. Firth (1950b) says that the retroflex consonants in Hindi are not pronounced with curled tongue, but he does not give any positive description. Ladefoged (1971b) considers retroflex sounds of some of the Indic languages to be post-alveolar and calls them retracted (cf., however, Bhat 1974).

It is also well known that American retroflex r may be pronounced in two different ways: either with the tip of the tongue curled back, or with the body of the tongue constricted and bunched up, with an almost identical acoustic effect, viz. a lowering of formant 3. The present writer therefore decided to make a palatographic and spectrographic investigation of the Gujarati retroflex consonants ṭ, ḍ, ṛ, ḷ, and ṇ and the corresponding dentals t, d, r, l, n. As for the stops, the material has been restricted to unaspirated types.

2.2 The method used

For the present investigation the dynamic palatographic method would have been adequate, particularly for the flapped retroflex sounds. But the present writer did not have access to this type of instrumentation. The method used was a more traditional, direct method: The tongue of the subject is painted with a mixture of charcoal, chocolate, water, and liquid glue, the subject taking care not to close his mouth before pronouncing the word to be investigated. Immediately after having pronounced the word he moves his head forward so that an oblique mirror mounted on a frame can be inserted into his mouth as far back as possible. The frame also contains a light source and some reflecting mirrors directing the light into his mouth, and a camera. A picture is taken by a helper. The picture may be slightly distorted if the mirror is not at right angles to the palate.

A normal means of presentation would have been to make paper copies of the photos. Instead, a somewhat different procedure was used: A photo was taken of a cast of the palate; it was then developed in natural size. A number of horizontal and vertical lines were drawn on this photo at a distance of 5 mm from each other. This type of reference lines was preferred to reference lines based on the teeth (see, e.g., Firth 1950b), because it is the absolute size of the cavity which is of importance for the acoustic output, and also because subjects may have defective dentition,and therefore reference lines based on the dentition are not so easily comparable from one subject to the other. The picture of the palate with the reference lines was then produced in a great number of copies, and the areas of contact were drawn on these copies by inserting the negative film in a projector and projecting the pictures onto the diagram of the palate. This drawing can be done with great precision and it combines the advantage of being cheaper than photographic copies with the advantage of having reference lines on each picture. No attempt was made to add the vertical dimension.

Fig. 1 shows this schematic drawing of the palate with the lines numbered from 0 to 10. The center of the alveolar ridge is just slightly above line number 2; the highest point of the palate is reached at line 5, which is considered to be the approximate dividing line between the pre- and the post-palatal regions. The boundary between the hard and the soft palate is approximately at line 10.

Fig. 1 is given here for a general reference to all the following palatograms. Note that the left side of the palate is to the right on the paper, and vice versa.

2.3 The informant

The investigation is based on one informant, RD, who was born in 1928 in Pad-Jari in Gujarat, spent the years 1965-68 in Copenhagen, and has been living in the United States since 1968. He is the author of the present paper. These recordings were made in 1967 and 1977.

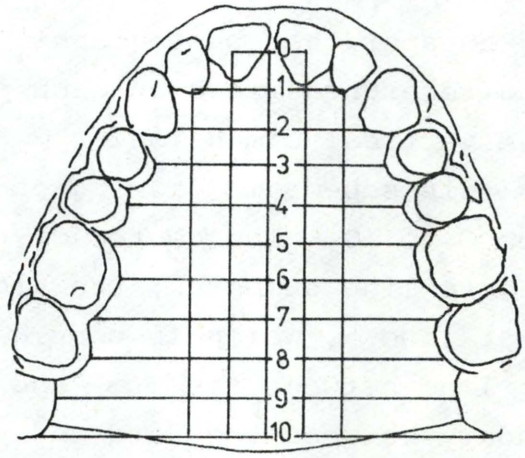


Figure 1

Schematic drawing of the palate with reference lines. Speaker RD.

2.4 The material

A preliminary list (list I) comprised 14 words with the dental and retroflex consonants r, n, l, ṛ, ṇ, ḷ finally after a and medially between a and o, or (for n and ṇ) a and i, and d and ḍ between a and o. The initial consonant was p.

The main list (list II) contained 27 words with all dental and retroflex (unaspirated) consonants in initial, medial, and final position in combination with the vowel a, except for ṛ, ḷ, ṇ in initial position, since (as mentioned above) in Gujarati these consonants occur in medial and final positions only. In this list care has been taken to use words in which only the sound under investigation has contact between the tongue and the palate. For this purpose the vowel a was chosen both as preceding and following vowel. a is a central, low vowel in Gujarati, and it generally does not have contact with the palate; in any case, the contact is so far back that it does not interfere with dental and retroflex consonants. All consonants, except those to be investigated, were labials.

However, it may also be of interest to see whether the place of articulation is influenced by the surrounding vowels. For this purpose a list of words with all dental and retroflex (unaspirated) consonants medially between two i's was set up (list III). Moreover, a few words with u (list IIIa: bhoḍu, uḍũ and moṭũ, kuku) were used. As the vowels u and i have contact between tongue and palate at the sides but not in the middle, it is possible to see whether there is difference between consonants in a-, i- and u-surroundings around the mid line of the palate. A few words with velars before and after a (list IIa) and the words kiki and gəgi (list IIIa) were added for the purpose of comparing retroflex and velar consonants.

Generally 4 to 5 palatograms have been taken with the vowel a in all positions, i.e. before and after a, and intervocally between two a's. In the environment of the vowels o, i, and u-ũ the number is between 2 and 3.

2.5 Results

Figs. 2-54 show tracings of palatograms. The hatched area indicates a typical case, whereas the dotted lines indicate a different example, in principle a rather extreme case, which thus gives a rough idea of the degree of variation. In the following the typical case is referred to as a, the atypical one as b.

2.5.1 The dental and retroflex stops

Palatograms of the voiceless and voiced dental stops together with the retroflex stops are given in Figs. 2-21. Figs. 2-13 show stops in connection with the vowel a.

The contact area for the tongue is the dental region and the foremost part of the alveolar region. The front teeth are almost covered. The contact area generally goes back from line number zero to line number 2 and, in a few cases, to line number 3, which indicates the end of the alveolar region.

As the contact area is predominantly dental, t and d may be described in articulatory terms as apical, dental stops.

The palatograms of the retroflex consonants are presented adjacent to the palatograms of the dental stops, so that they can be easily compared. As mentioned in 3.1, the retroflex stops are traditionally defined as stops articulated with the apex of the tongue curled back and touching the hard palate. As both the upper and lower surface of the tongue had been painted and could have left marks on the palate, it cannot be decided directly on the basis of the palatograms whether the tongue was curled back or not, but the fact that sometimes the tongue has touched farther back in the middle than at the sides seems to indicate that it was curled back, and I have a very clear feeling that I do curl my tongue back. Observation in a mirror bears out this feeling, as do a few experiments in which only the lower surface of the tongue was painted.

The tongue contact is with the hard palate, generally between lines 3 to 6, or 3 to 6.5. Sometimes the contact goes as far back as lines 7 or 8 (see Figs. 3a, 5a, 9a).

The articulatory difference between the dental and the retroflex stops is clear. Their position of articulation is quite different. Similarly, the manner of their articulation is also different. Moreover, the retroflex stops cover more area of the palate than do the dental stops.

The area covered by the tongue in the articulation of d does not differ significantly from the area covered by t. On the average, however, d covers a slightly narrower area than t, but the difference is very small. Sometimes there is no difference at all. Compare, for instance, the palatograms of vat and vad (Figs. 6a and 12a). However, the tongue seems to have contact with a larger area of the palate in the articulation of intervocalic ṭ than in ḍ. See, for instance, paṭa (Fig. 5a) and paḍa (Fig. 11a). But in the initial position the difference is very small or non-existent.

The palatograms of t and d in the environment of the front and back vowels i and u show that the vocalic environment has no influence on the articulation of dental consonants (see Figs. 14-21).

The retroflex stops, unlike the dental stops, seem to be more or less influenced by the vocalic environment. ṭ and ḍ are slightly more fronted with the front vowel i than with the central vowel a or the back vowel u. Compare the palatograms of piṭi (Fig. 15) with paṭa (Fig. 5) and moṭũ (Fig. 19), and similarly iḍər (Fig. 17) with paḍa (Fig. 11) and uḍũ (Fig. 21), but retroflex and dental consonants are still clearly distinguished.

2.5.2 r and ṛ

The articulatory contact for dental r with the vowels a and i is generally in the alveolar region. The apex of the

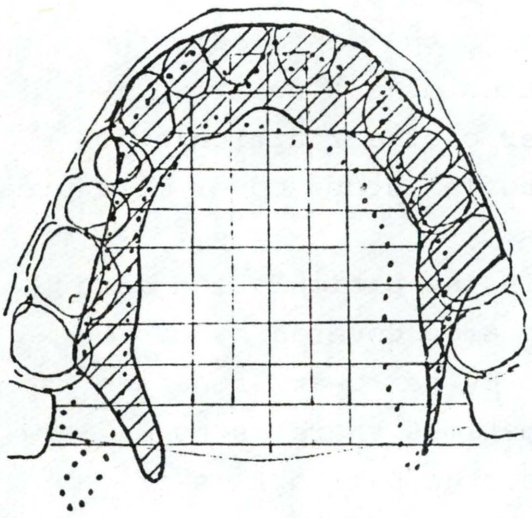


Figure 2ab

[tap]

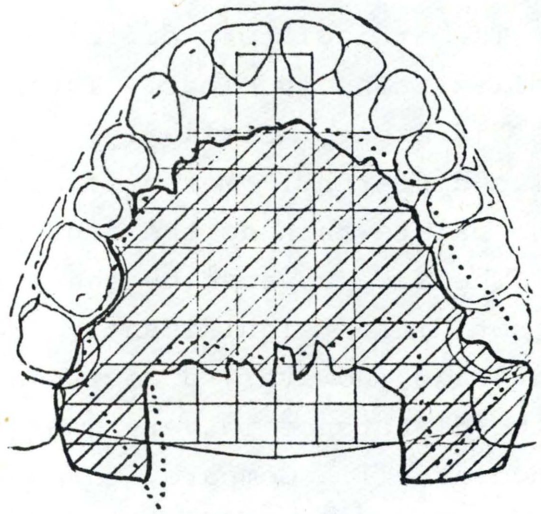


Figure 3ab

[ṭapu]

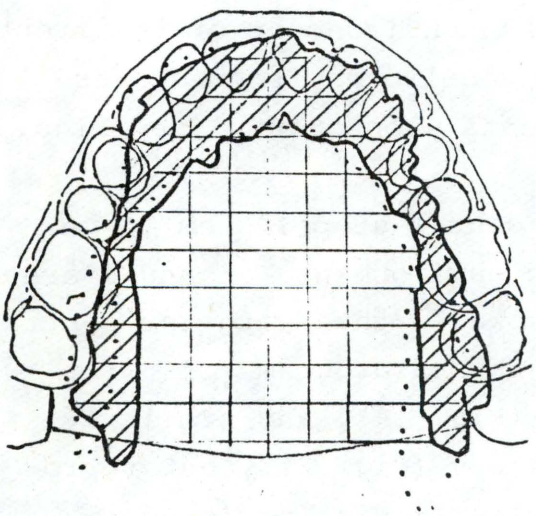


Figure 4ab

[mata]

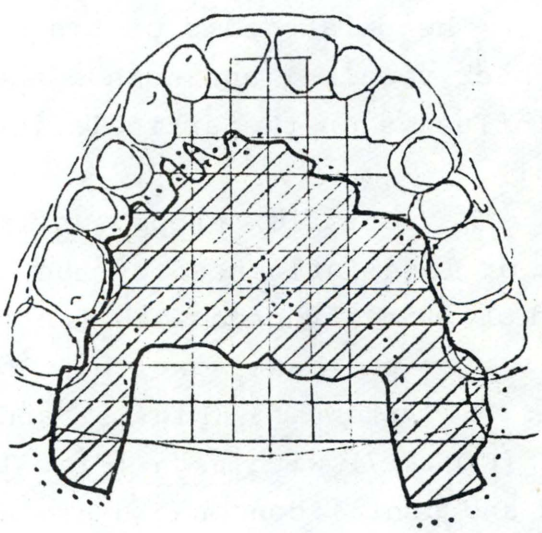


Figure 5ab

[paṭa]

Figures 2-5

Palatograms of speaker RD. The hatched area represents a typical case. The area enclosed by the dotted line represents a different, more extreme case.

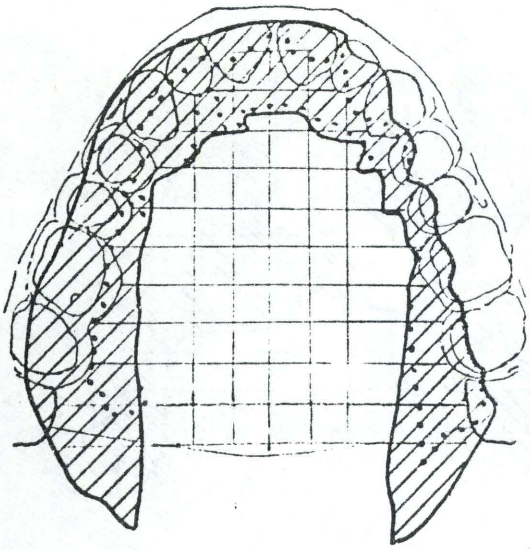


Figure 6ab

[vat]

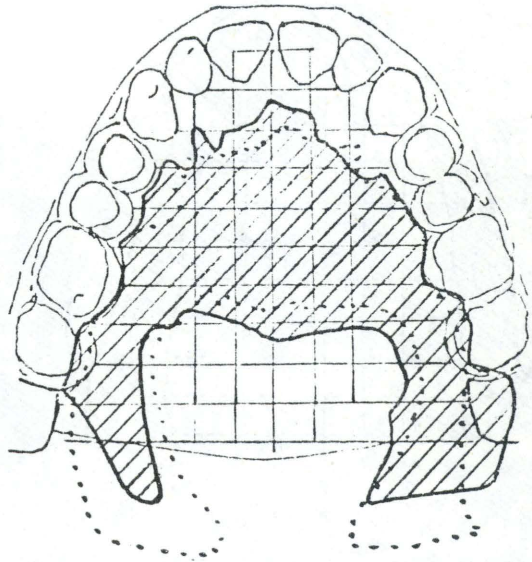


Figure 7ab

[aṭ]

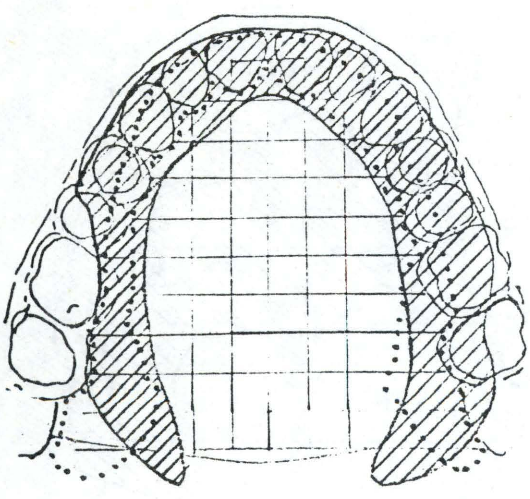


Figure 8ab

[dab]

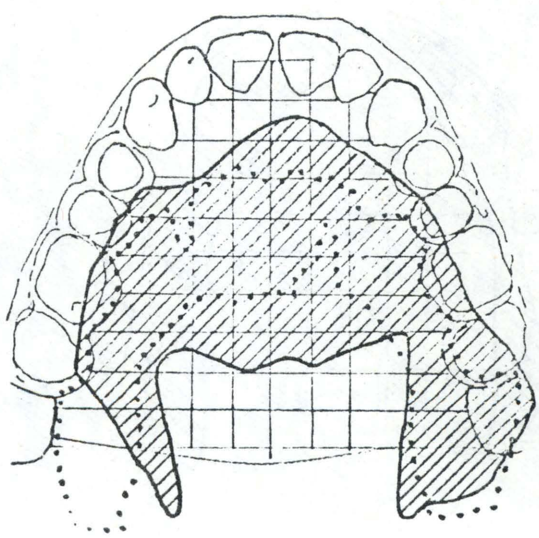


Figure 9ab

[ḍaba]

Figures 6-9

See legend of figs. 2-5.

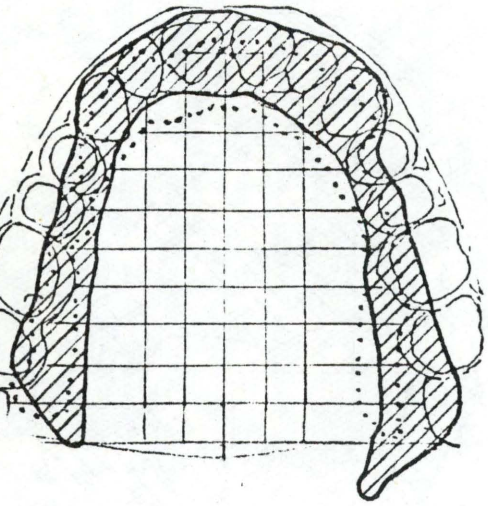


Figure 10ab
[mada]

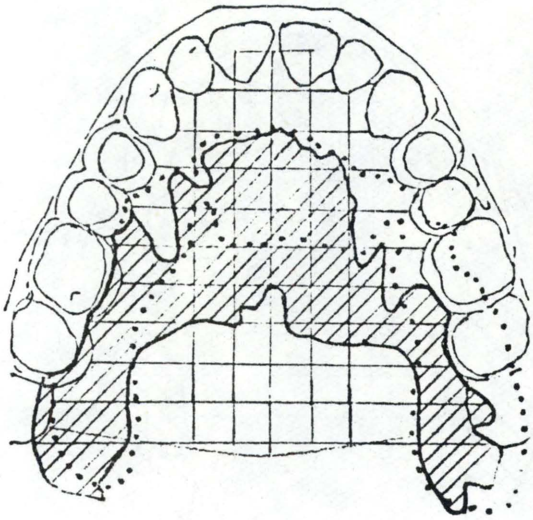


Figure 11ab
[paḍa]

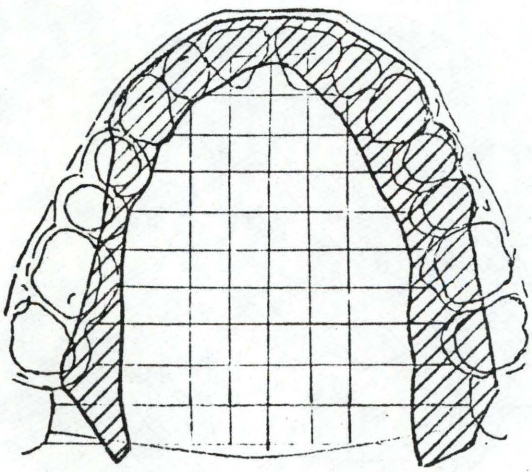


Figure 12a
[vad]

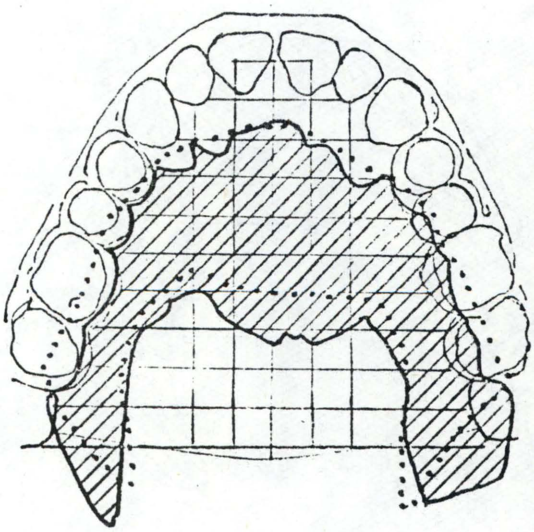


Figure 13ab
[aḍ]

Figures 10-13

See legend of figs. 2-5.

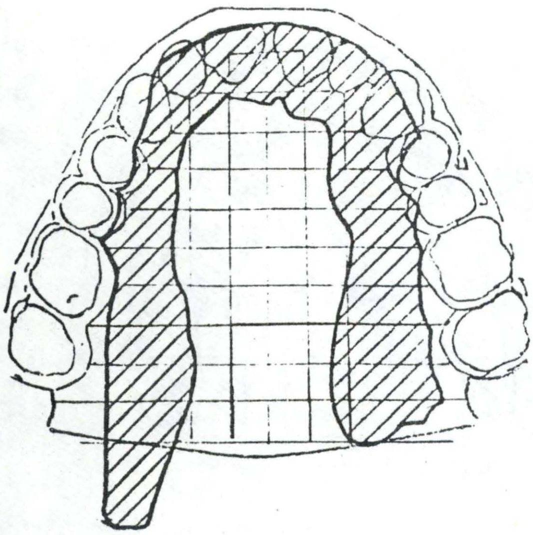


Figure 14
[iti]

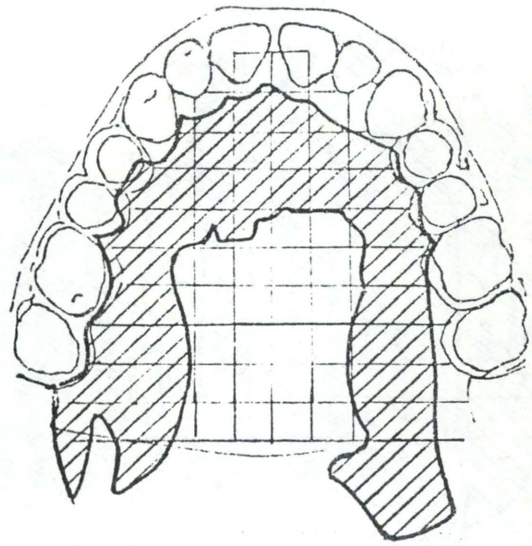


Figure 15
[piṭi]

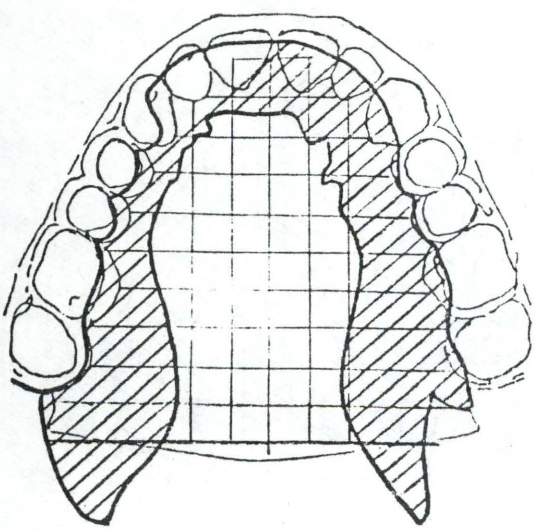


Figure 16
[sidi]

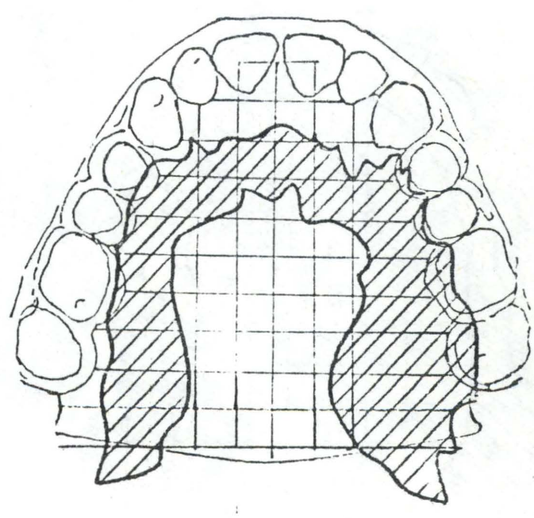


Figure 17
[iḍər]

Figures 14-17
See legend of figs. 2-5.

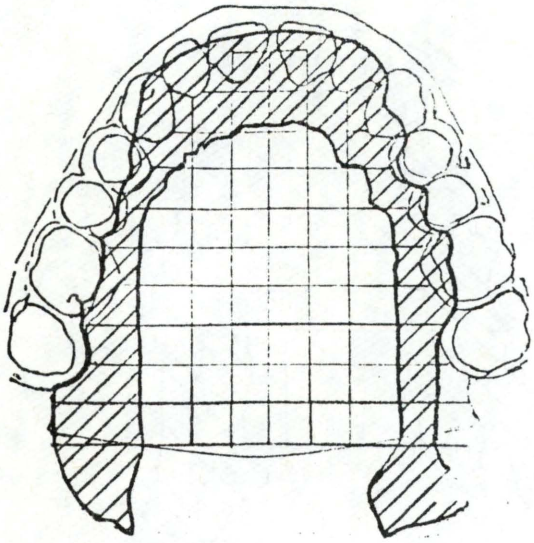


Figure 18

[hututu]

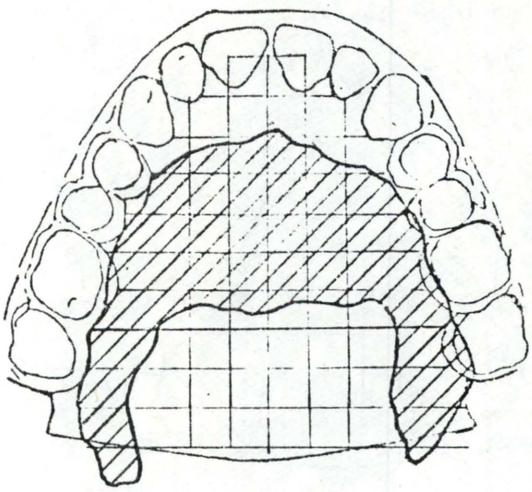


Figure 19

[moṭũ]

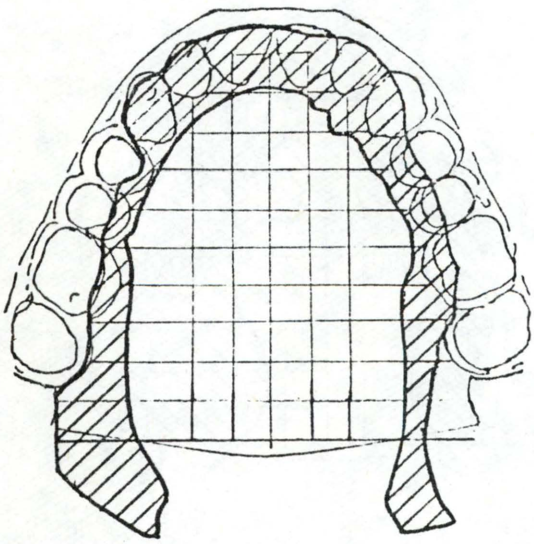


Figure 20

[bhodu]

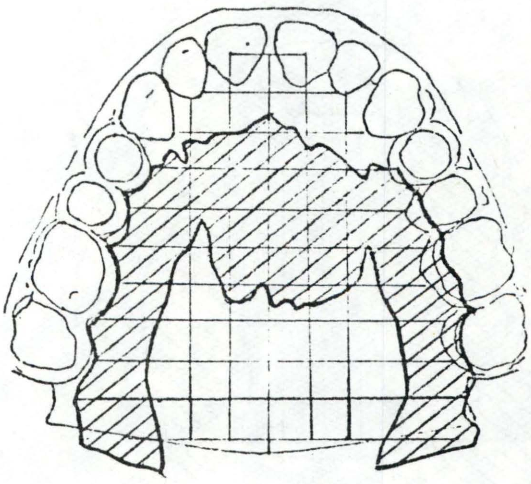


Figure 21

[uḍũ]

Figures 18-21

See legend of figs. 2-5.

tongue, however, covers a very narrow area of the alveolar ridge, approximately 5 millimetres (see Figs. 22a, 24a, 24b, 27a). The tongue contact is generally in the area of line number 2.

Some palatograms also show contact with the dental region. For instance, the word rab (Fig. 26a) shows marks of the tongue on the front teeth. Fig. 27b of the word paro shows a purely dental r.

There are also other variations of r. Sometimes no closure is seen in the palatograms (see Figs. 26b and 28 for rab and əmiri, respectively). The dental r and the r without closure should, however, be considered merely free alternants of the most frequent alveolar r. In other languages r is also generally alveolar. It seems to be difficult to produce a purely dental trill or flap.

The palatograms of ṛ with the vowels a and i have been placed on the same page as those of r for purposes of comparison (see Figs. 22-29). As stated above, ṛ, ḷ, and ṇ occur in medial and final positions only.

ṛ is flapped and the place of articulation for ṛ is the hard palate. The tongue seems to have been curled back obliquely at the left side of the hard palate. The contact area is generally found between the lines 2 to 5, and sometimes between the lines 2 to 6.

The palatogram of the word biṛi (Fig. 29) differs from the other palatograms in two ways: it does not show the oblique contact of the tongue, and there is no complete closure, but a lateral opening at the right side. Such cases are rare.

It should be noted that ṛ in biṛi, although having a small lateral opening, is quite different from the retroflex ḷ (see Figs. 31, 33, 35, 37). The palatograms do not show any effect of the front vowel i on r or ṛ (except for the fact that the contact at the left side seems to be slightly more advanced in əmiri). r and ṛ are quite distinct from each other in the palatograms.

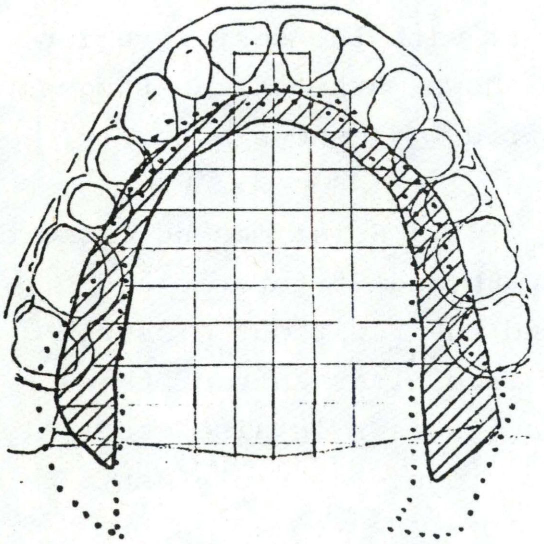


Figure 22ab

[mara]

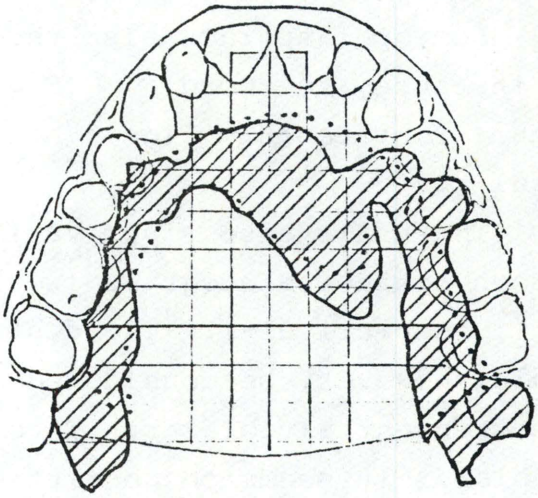


Figure 23ab

[phaṛa]

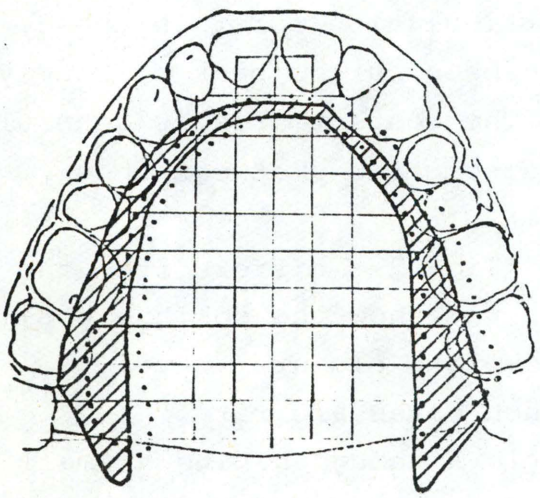


Figure 24ab

[par]

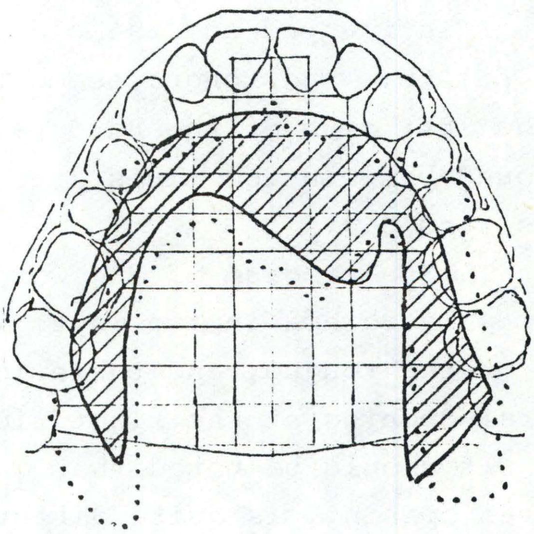


Figure 25ab

[phaṛ]

Figures 22-25

See legend of figs. 2-5.

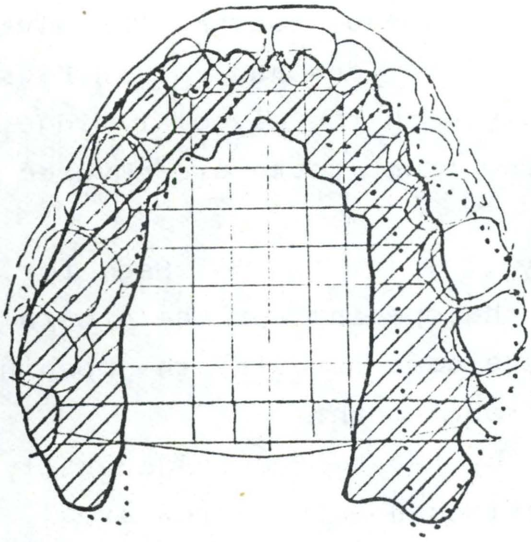


Figure 26ab

[rab]

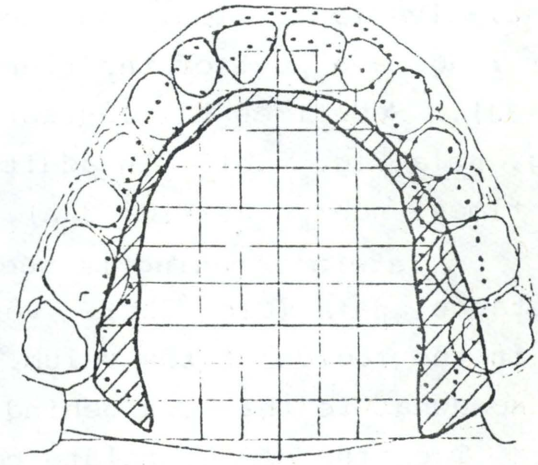


Figure 27ab

[paro]

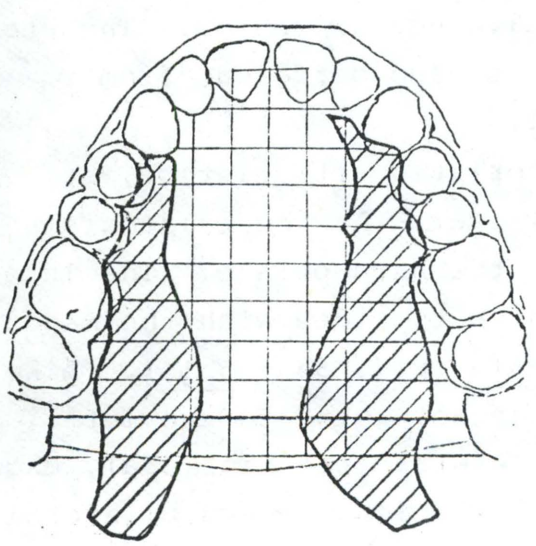


Figure 28

[əmiri]

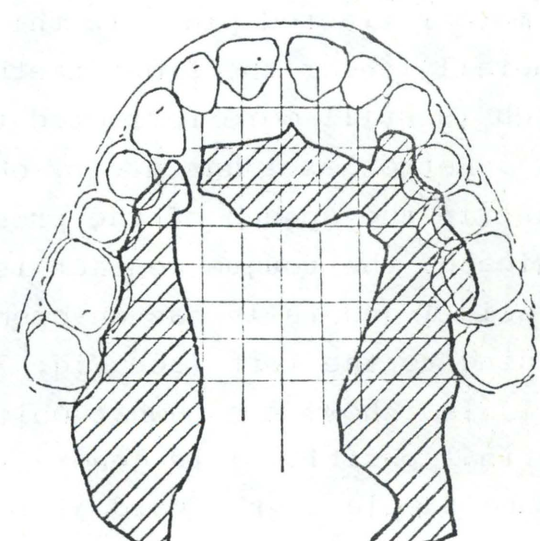


Figure 29

[biṛi]

Figures 26-29

See legend of figs. 2-5.

2.5.3 l and ḷ

The closure for the dental l is, in most cases, in the denti-alveolar region. The apex of the tongue touches the alveolar ridge and part of the front teeth (see labh and pal in Figs. 30-34). Sometimes the contact is only with the alveolar ridge, e.g. pala (Fig. 32b). In addition, the front teeth are covered at times: see pala (Fig. 32a).

A lateral opening is seen only in a few cases. See, for instance, pala (Fig. 32b). Perhaps the opening for the others is in the region of the velum. In the case of pala, the opening is somewhat to the left behind the front teeth.

The area of the palate covered by the tongue is generally between lines zero and one, but sometimes a very narrow area is covered around line number 1 (see pala, Fig. 32a).

l seems to be more fronted in the environment of the vowel i, see pili (Fig. 36). l differs from the dental stops mainly by its laterality, and also by its being articulated at a slightly more retracted place in the dental-alveolar region. The stops generally cover the front teeth. l is also different from r which is still more retracted than l.

Retroflex ḷ has a very characteristic articulation, at least in the speech of the present writer. As the palatograms indicate, the tongue contact is with the hard palate. The intervocalic ḷ generally has an opening at both sides with the major opening to the left (see Fig. 31a: baḷa, Fig. 33a: paḷo). Like ṛ, ḷ also shows a somewhat oblique contact going to the left. In final position ḷ is generally unilateral (see Fig. 35a), except in one sample of the word aḷ (Fig. 35b) which shows a bilateral opening.

The contact area for ḷ is between lines 2 and 7-8, and sometimes goes beyond line 8 (see Fig. 31a, baḷa). The final ḷ generally covers a smaller area, that is, between lines 2 and 5.

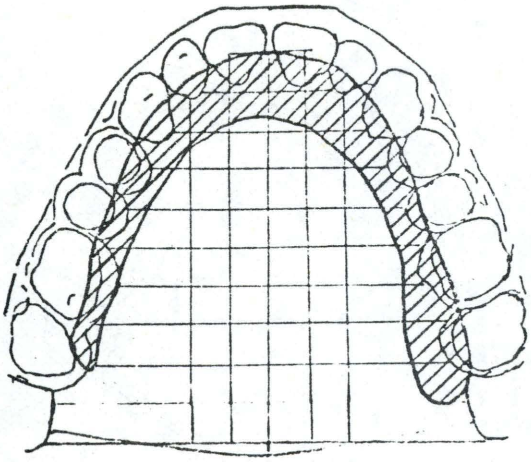


Figure 30

[labh]

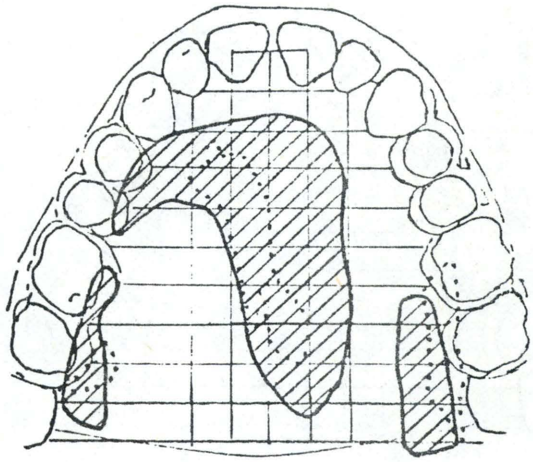


Figure 31ab

[baḷa]

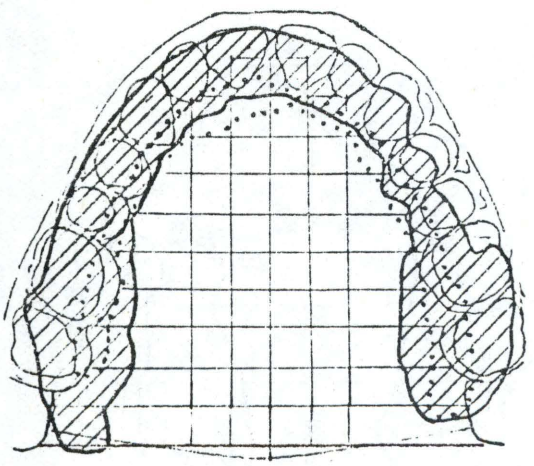


Figure 32ab

[pala]

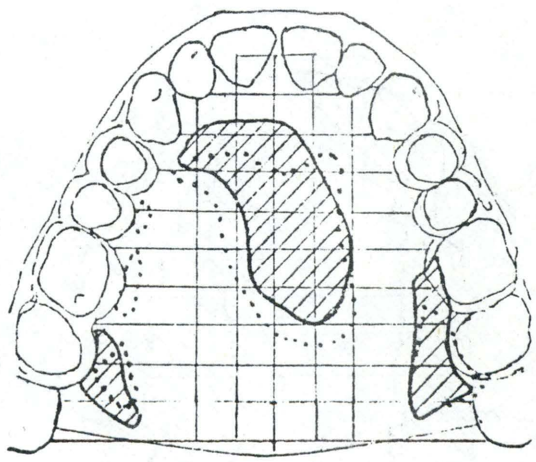


Figure 33ab

[paḷo]

Figures 30-33

See legend of figs. 2-5.

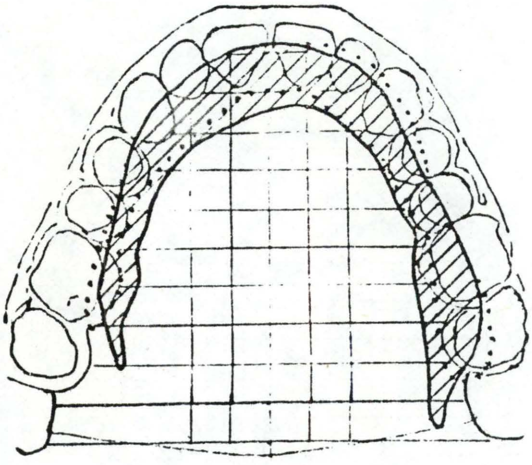


Figure 34ab

a. [pal]
b. [al]

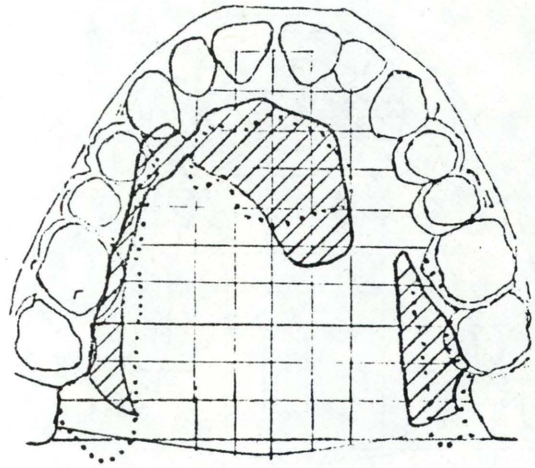


Figure 35ab

a. [paḷ]
b. [aḷ]

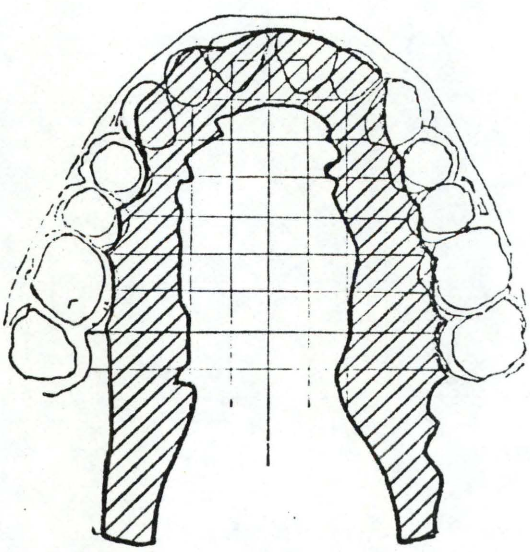


Figure 36

[pili]

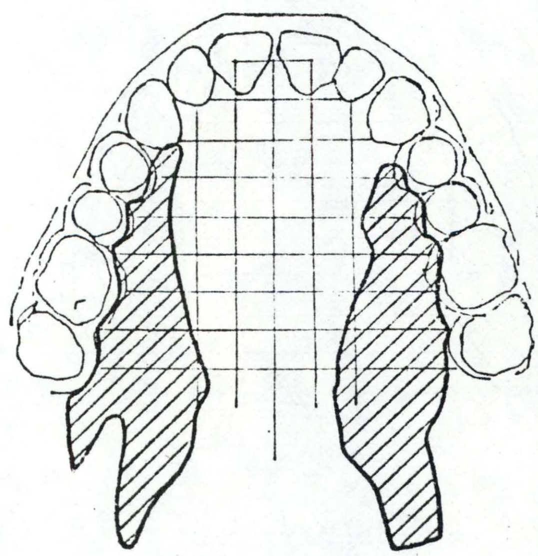


Figure 37

[piḷi]

Figures 34-37

See legend of figs. 2-5.

ḷ seems to be quite different in the palatogram of the word piḷi (Fig. 37). It shows only a slight contact with the prepalatal region. (The contacts at the sides are due to the vowel.) The opening is at the right side. It is also rather fronted. My data is, however, not exhaustive.

Ramasubramaniam et al. (1971) describe the Tamil ṭ, ḍ, ṇ, and ḷ as medio-palatal retroflex consonants. The palatograms of Gujarati ṭ and ḍ look very similar to ṭ and ḍ of Tamil. However, the contact for ṭ and ḍ in Gujarati often extends beyond the mid-palatal region. Gujarati ḷ and ṇ are different from Tamil ḷ and ṇ in that they are flapped. In addition, their contact area generally extends beyond the mid-palatal region (see section 2.5.4 for the discussion of Gujarati ṇ).

2.5.4 n and ṇ

The palatograms of dental n show a rather large variation, with respect to both the place of articulation and the size of the contact area. The place of articulation may be dental, denti-alveolar, or alveolar, but is perhaps most often denti-alveolar. As nasality does not show up in palatograms, n may look very similar to the dental stops or to r and l. When alveolar, it resembles r, when denti-alveolar or dental, it looks more like l and the dental stops (see Figs. 38, 40, 42, 44).

Retroflex ṇ is flapped and the tongue contact is in the palatal region, approximately in the area between lines 2 and 8, sometimes from 2 to 6 (Fig. 43b: aṇ), or even 2 to 4 (Fig. 45: əphiṇi). Often the contact is far back at the hard palate beyond line number 7, and in some cases the ṇ has bilateral opening like l (see paṇa, Fig. 39b and 41b). The retroflexed tip of the tongue comes back to its normal position very swiftly, passing through the palatal region, generally without touching the alveolar or dental zone. At times, however, it does touch the alveolar region, for instance paṇa, or baṇ (Figs. 41a, 43a).

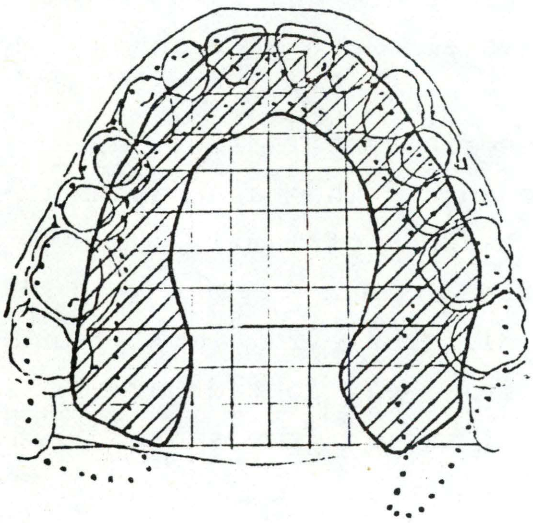


Figure 38ab

a. [nabhi]
b. [nam]

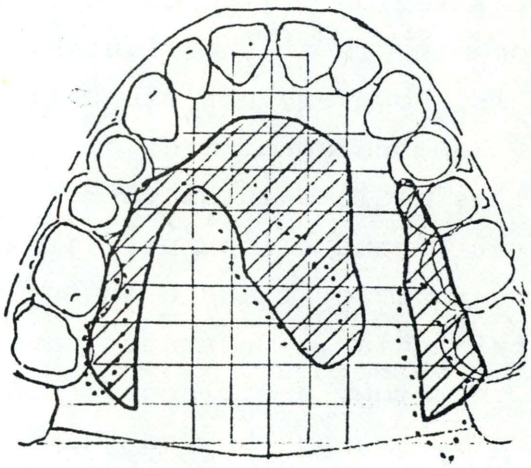


Figure 39ab

[paṇa]

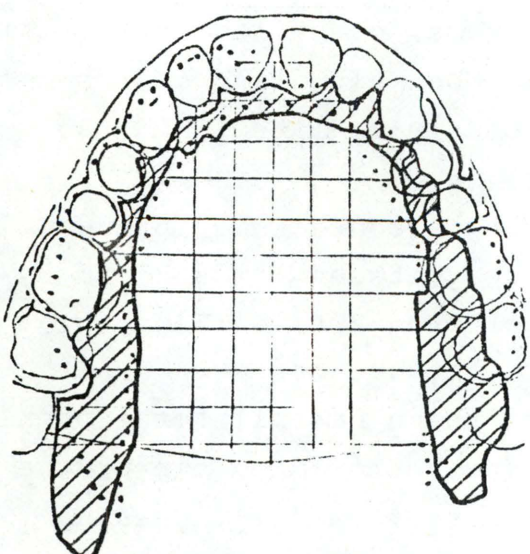


Figure 40ab

[mana]

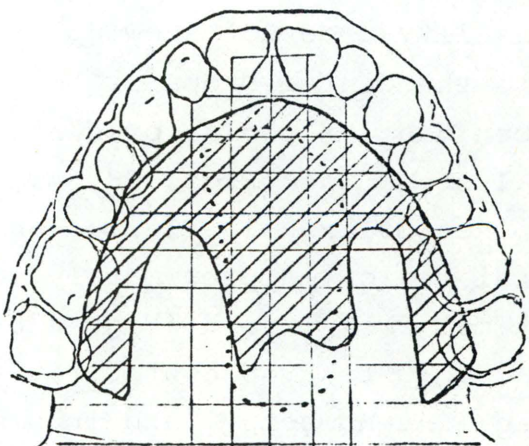


Figure 41ab

[paṇa]

Figures 38-41

See legend of figs. 2-5.

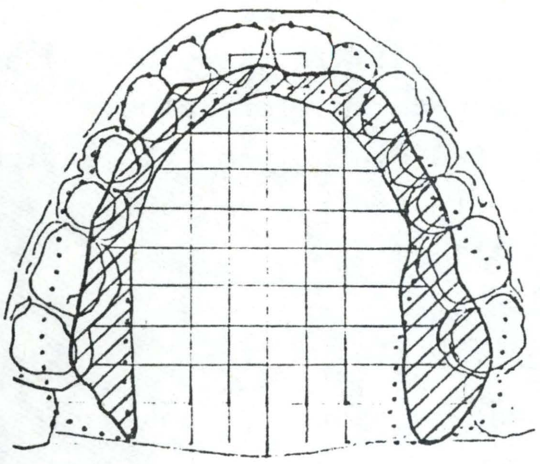


Figure 42ab

a. [an]
b. [ban]

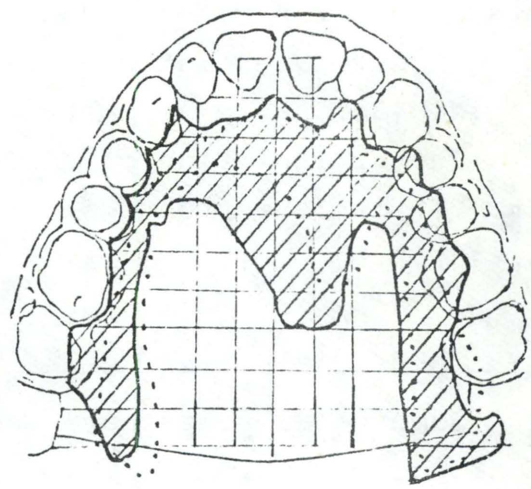


Figure 43ab

a. [baṇ]
b. [aṇ]

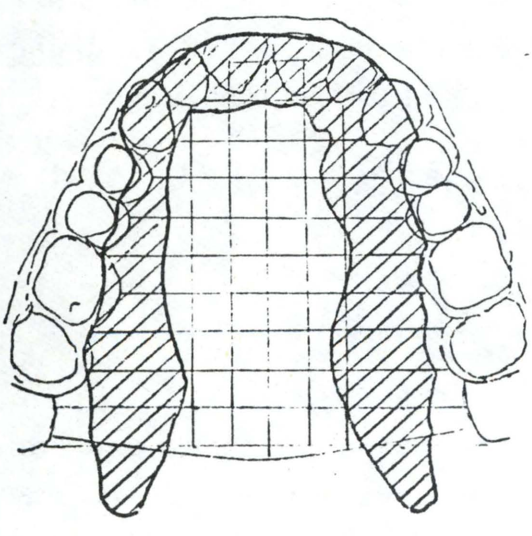


Figure 44

[mini]

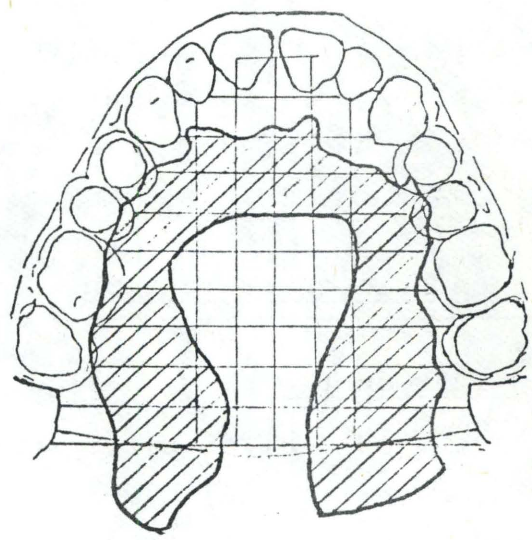


Figure 45

[əphiṇi]

Figures 42-45
See legend of figs. 2-5.

On the whole, the flapped consonants ṛ, ṇ, ḷ, and particularly ṇ and ḷ, seem to be produced with some constriction of the tongue and with a swift movement of the tongue tip, so that the contact is often rather weak.

In several palatograms (cf. paṇa, Fig. 41a, baṇ, Fig. 43a, aṇ, Fig. 43b), ṇ is asymmetric, slanting to the left side.

The articulation of ṇ is influenced by the phonetic environment. It is more fronted in the context with i (see əphiṇi, Fig. 45).

2.5.5 The velar stops (see Figs. 46a - 54)

Some velar stops have been investigated for purposes of comparison.

The contact area for the velar stops is in the velar region. Sometimes there is a slight contact in a small area in the region of the hard palate. Generally both k and g show contact beyond the area of line number 10. It will be clear from the palatograms that g is somewhat more fronted than k, and it also covers a somewhat larger area of the palate.

Both k and g are more fronted in the environment of the front vowel i, showing contact with the hard palate (see kiki and gəgi in Figs. 52-53). Nihalani (1974) notes a similar influence of the vowel i on the Sindhi velar stops.

3. Acoustic investigation

3.1 Introduction

A good deal of perceptual investigations of stops and nasals, and some on liquids, have been published during the last twenty years. Papers based on acoustic analysis of real speech have been fewer in number. We are, however, rather well informed about the acoustic properties of labial, alveolar (and dental) and velar

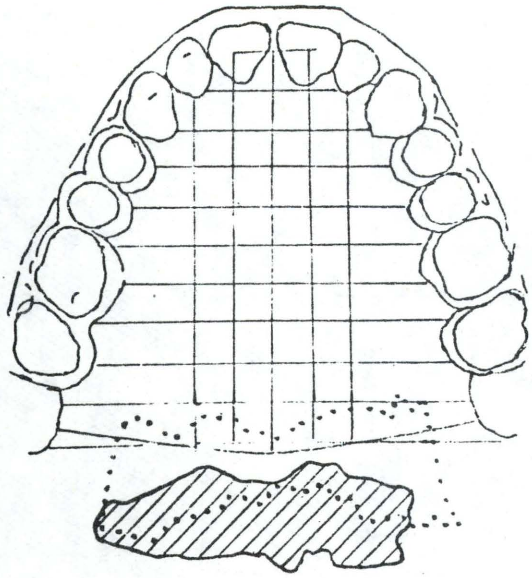


Figure 46ab

[kap]

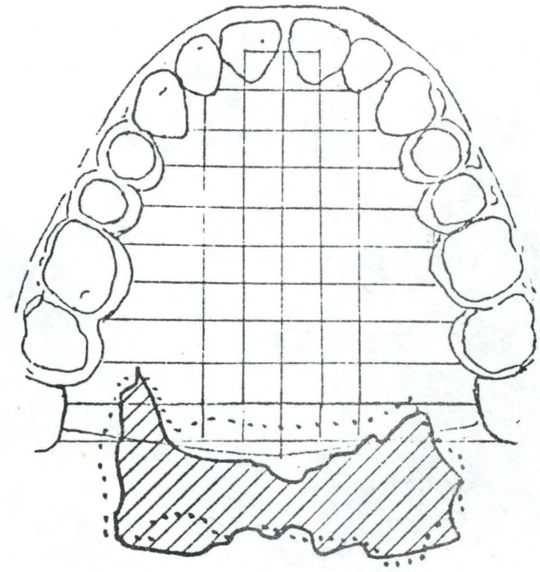


Figure 47ab

[gaw]

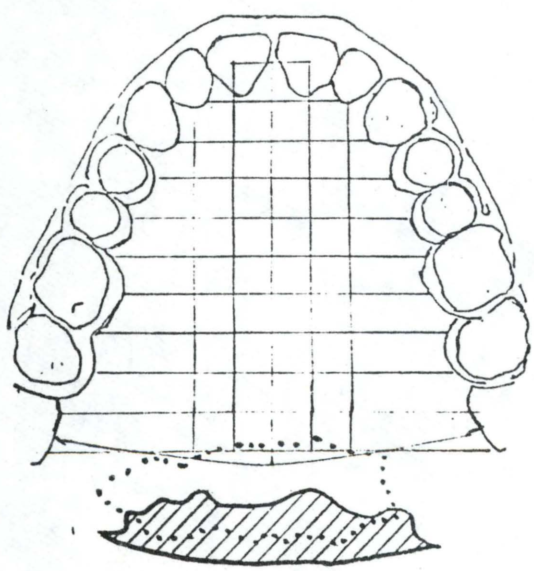


Figure 48ab

[paka]

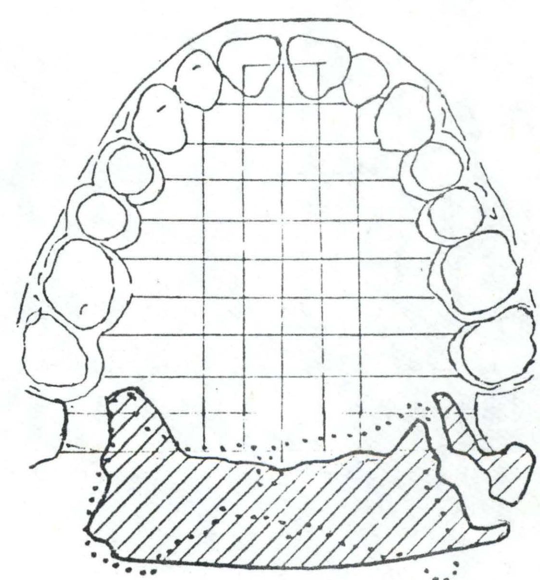


Figure 49ab

[gəga]

Figures 46-49

See legend of figs. 2-5.

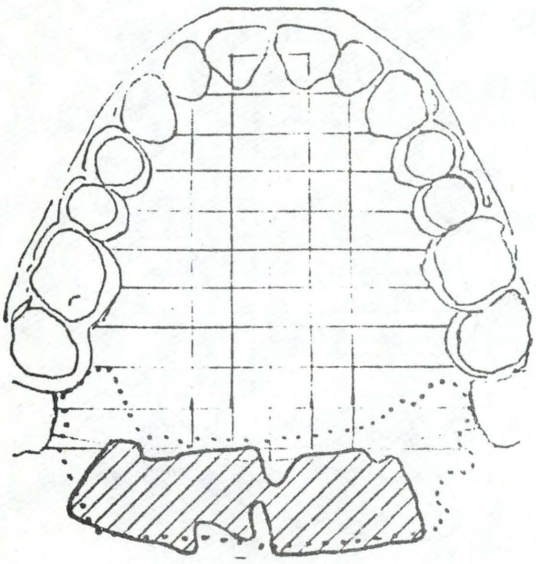


Figure 50ab

[pak]

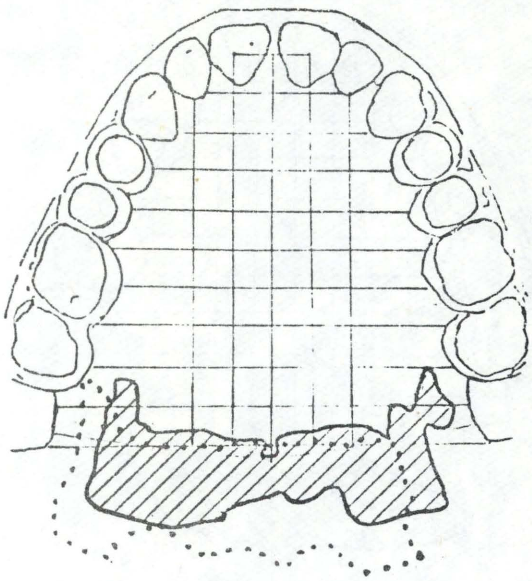


Figure 51ab

[bag]

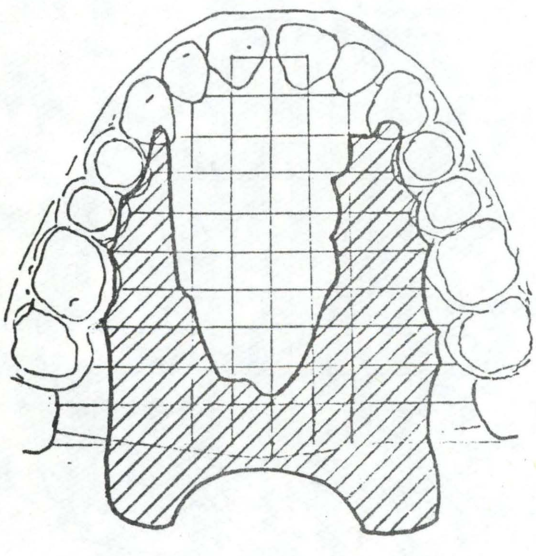


Figure 52

[kiki]

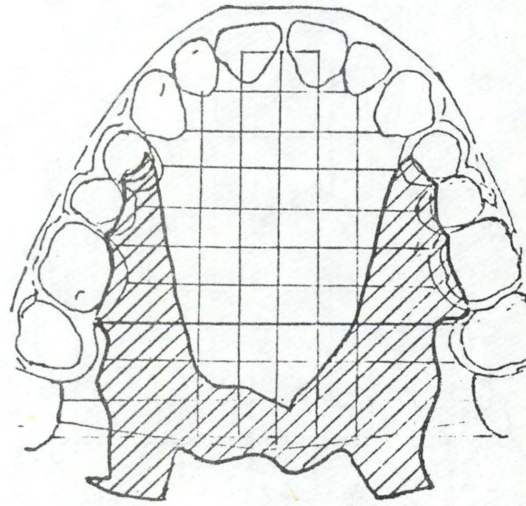


Figure 53

[gəgi]

Figures 50-53

See legend of figs. 2-5.

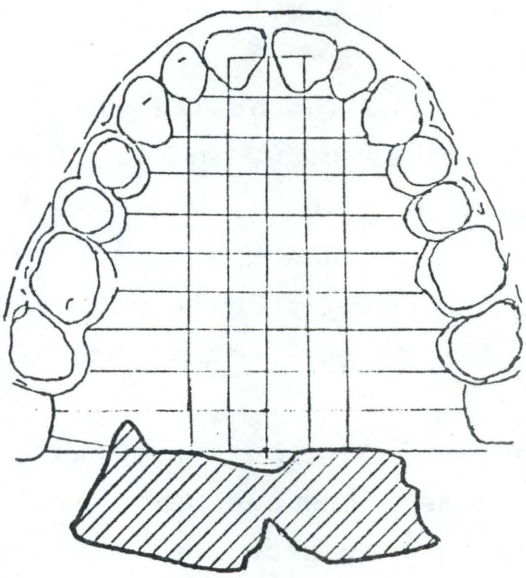


Figure 54
Palatogram of [kuku].

consonants, whereas little has been published on retroflex consonants, except for the retroflex American r and American vowels with retroflex modification, which are generally known to be characterized by a low F3.

Jakobson, Fant, Halle (1952, p. 49) reproduce a spectrogram of Bengali ṣ with the comment that "the retroflex consonant has energy in a lower frequency region and affects the third formant of the following vowel in a downward direction".

Fant (1968, p. 239) remarks very briefly that alveolar retroflex modification has the effect that F4 is lowered and comes close to F3, whereas with a palatal point of articulation F3 is lowered and comes close to F2.

Ramasubramanian and Thosar (1971) have analyzed a restricted number of Tamil retroflex ṭ, ṇ, and ḷ. They give formant values for the steady state of ṇ and ḷ, and have furthermore tried to synthesize retroflex consonants with 3 formants, in combination with i, u, and a, including transitions, and have arrived at some values for the loci. We will return to this investigation in more detail in section 4.1.

A very important contribution to the acoustic description of retroflex stop consonants has been given by K.N. Stevens and S. Blumstein (1975). They show spectrograms of the syllable aṭa spoken by three Hindi speakers. In addition, an extensive perceptual test has been made using stimuli changing, in 13 steps, from a dental consonant via a retroflex consonant to a velar consonant. A detailed discussion of this paper is taken up at the end of this article - in sections 4.1 and 4.2.

3.2 Informants

The informants of the present study were RD and RT, RD being the main informant. For his data, see 2.3. RT was born in 1941 in Bombay, and has been living in Copenhagen since 1965. His recordings were made in 1967.

3.3 The material

The material is partly the same as that used for the palatographic investigation, i.e. the preliminary list I, and the main list II containing 27 words with all dental and retroflex (unaspirated) consonants in initial, medial and final position in combination with the vowel a (with the exception of ṛ, ḷ, ṇ in initial position). In addition, for this investigation words with medial and final t, ṭ, d, ḍ, l, ḷ, r, ṛ, and n, ṇ in combination with the vowels i e ə o u (i.e. five lists of 10 words each, called lists III-VII) were analysed. Of these only list III (with the vowel i) was used in the palatographic investigation. In almost all cases the medial consonant has the same vowel on either side. The exceptions were iḍər in list III, eḍi in list IV, and udar, phuṭe, uḍe, sura, and unəp in list VII. It was difficult to find words with u-u. Therefore, list VIIa with the words bhodu, moṭũ, and uḍũ was added. (VIIa was used in the palatographic investigation.) The words with velars (lists IIa and IIIa and the word kuku) were used in the acoustic investigation as well as in the palatographic investigation. Finally, two lists of nonsense syllables were added, namely List VIII comprising 26 CV nonsense syllables with t, ṭ, d, ḍ, k, g before the vowels i, a, u and t, ṭ, d, ḍ before e and o, and List IX comprising 60 CV nonsense syllables containing all unaspirated stop consonants before the vowels i, e, u, o, ə, a.

Lists I-VII were spoken by both informants in Copenhagen in 1967. Lists II, III, and VII were spoken again by RD in Copenhagen in 1977, lists IIa, IIIa, VIIa, and IX were added in Copenhagen in 1977 and spoken by RD only. List VIII was recorded at Cornell University by RD. A list with VCV syllables was also spoken by RD in Copenhagen in 1977, but only a few words from this list were utilized. Lists VIII and IX (which were added in 1977) contain initial stop consonants only. There is thus a larger number of examples with initial stops than with stops in other positions, and the number of examples with nasals and liquids is rather restricted. The reason is that since it was difficult to see a clear difference between dental and retroflex stops in initial position, more such examples were considered necessary. List VIII was recorded specifically for the investigation of bursts.

3.4 Method of analysis

The material was recorded on a professional tape recorder in a sound treated room, and was analysed by means of a Kay Electric Sonagraph. For RD spectrograms were taken of one reading of each list (for lists II, III and VII both the 1967 and the 1977 readings were analysed). For RT a somewhat smaller number of spectrograms were taken, and only stops in initial position were measured, but spectrograms of stops in other positions and of nasals and liquids were inspected visually and compared with the results for RD.

As a rule both a wide band and a narrow band spectrogram were taken of each word. Very often two or three wide band spectrograms with different intensity and different degrees of compression were taken in order to get a clear picture of both formants and bursts in stop consonants.

The spectrograms were used for the measurement of formant transitions. In order to specify the transitions both the frequency of the steady state vowel formants and the end points of the transitions were measured together with the duration of the transition. The measurement of formant 4 was rather difficult because there are cases of split formants or weakened formants. Generally RD has a formant 4 around 3700 Hz and a formant 5 around 4200 Hz, and in some cases of a̲ and o̲ also a (weaker) formant around 3100 Hz. In some cases F5 is too weak to show up in the spectrograms, in other cases this is true of F4, and it is sometimes difficult to decide which one it is, particularly since they may all be lowered in rounded vowels, or be very weak, or missing in these vowels. Moreover, it is not always evident from where the formant transition designated as "F4-transition" starts. There are, therefore, certainly some inconsistencies in the measurements. In some other cases it has also been difficult to decide about the formant number and to exclude possible spurious formants. There have been many points of doubt, but the cases have been carefully considered.

The measurement of the duration of the transition is not exact since the boundary line between transition and steady state is rather arbitrary in many cases; the measurements have been used for the statement of clear differences in transition length (e.g. the rather brief transition of F4), and for the drawing of schematic spectrograms.

A rough analysis of the bursts was also undertaken on the basis of wide band spectrograms. A more precise analysis might have been undertaken by means of sections, but such an analysis would have required segmentation of burst and vowel (electrically or by tape cutting), which would have taken a great deal of time. Instead, an acoustic analysis of the bursts and the start of the vowel was undertaken in the Research Institute of Electronics at MIT, based on a computer directed linear prediction analysis.

A detailed technical description of the computer program is given in V.W. Zue (1976). It is based on a speech production model containing a source and an all-pole filter representing the combined effect of the glottal source, the vocal tract resonances, and radiation losses. The filter is excited either by a periodic impulse train for voiced speech or random noise for unvoiced speech. The zeros found in nasal consonants can be approximated by means of poles. By means of linear prediction (in this case using a form of autocorrelation analysis) a best fit is found between the incoming signal and the smoothed curves generated by the computer. The frequency band analysed is restricted to 5000 Hz, because most of the interesting characteristics of the speech wave are found below 5000 Hz, and because a filter including higher frequencies would lead to a number of complications. The time window was 25.6 ms wide. It is symmetric and has a smooth bell-like shape, which means that signals found at the sides are recorded with decreasing intensity. Because of this shape the effective width of the window is somewhat narrower. See Fig. 55, which is a sketch drawn by professor Stevens.

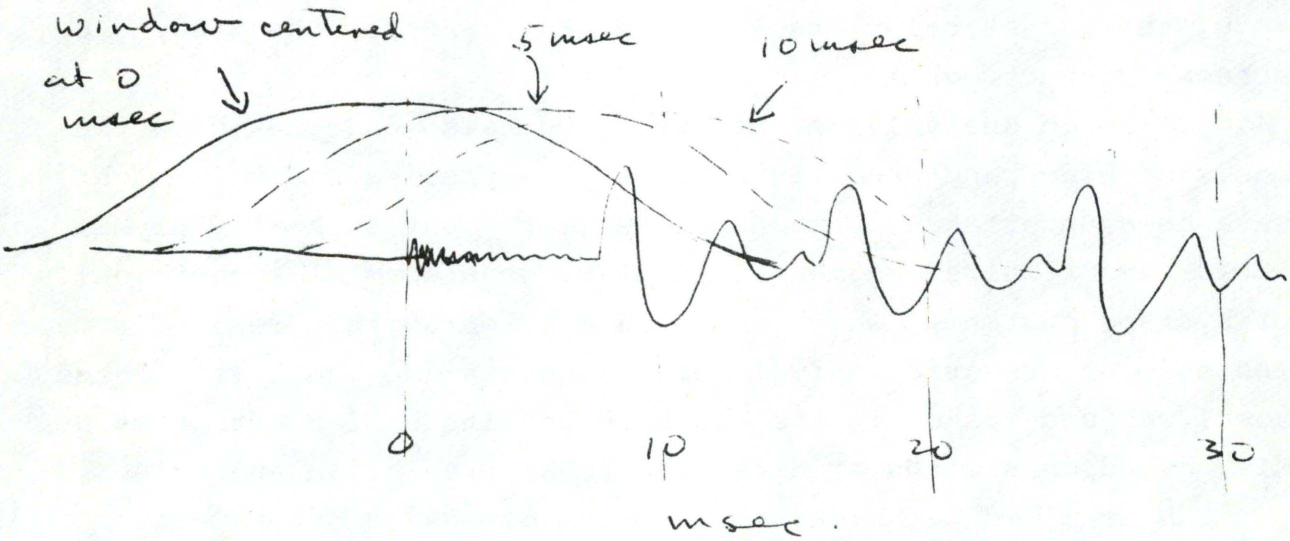


Fig. 55

Sketch of the windows used in the linear prediction analysis (K. Stevens).

The window can be moved in steps of 5 ms. The first point, designated as zero, is placed in such a way that the top of the window is at the start of the burst.

If the distance from burst to vowel is less than half the window, i.e. 12.8 ms, as in this picture, the spectrum will also be somewhat influenced by the start of the vowel formants, and the spectra taken at the following two points (5 and 10 ms) will also be influenced by both burst and vowel, but increasingly by the vowel formants. If the distance is more than 12.8 ms, it is possible to get a separate spectrum of the burst. A hard copy reproduction of the curves can be made, either one curve at a time (as in Fig. 56a), or curves from a number of consecutive points together, as in Fig. 56b. In Fig. 56b (the syllable to) it can be seen that the first two curves (taken at points 0 and 5) have a maximum around 1300 Hz due to the burst, whereas the last (point 10) has a maximum at 550 Hz, corresponding to the first formant of o.

By this method a number of consonants in initial position have been analysed, namely the stops of lists II-VII spoken by RD and RT, and list VIII spoken by RD. In most cases points 0, 5, and 10 have been recorded together. The main purpose was to find the relevant differences between the bursts in dental and retroflex stops. However, due to the length of the time window the zero curve will indicate the burst alone in voiceless stops only where the distance between burst and vowel is sufficiently large. (In some cases of retroflex stops there will be a slight influence from the vowel formants even in voiceless stops, because the distance is somewhat shorter in these stops than in dental stops, see 3.5.2A.) As for the voiced stops, the curve at point zero will always comprise both burst and vowel start. Therefore only the curves of voiceless stops have been utilized for this purpose.

Moreover, the curves taken at point 10 (or sometimes 15) have been compared with the spectrographic measurements of the start of the transition. The agreement is quite good except for the first formant of the high vowels i and u, for which the linear prediction analysis often gives much higher frequencies. For

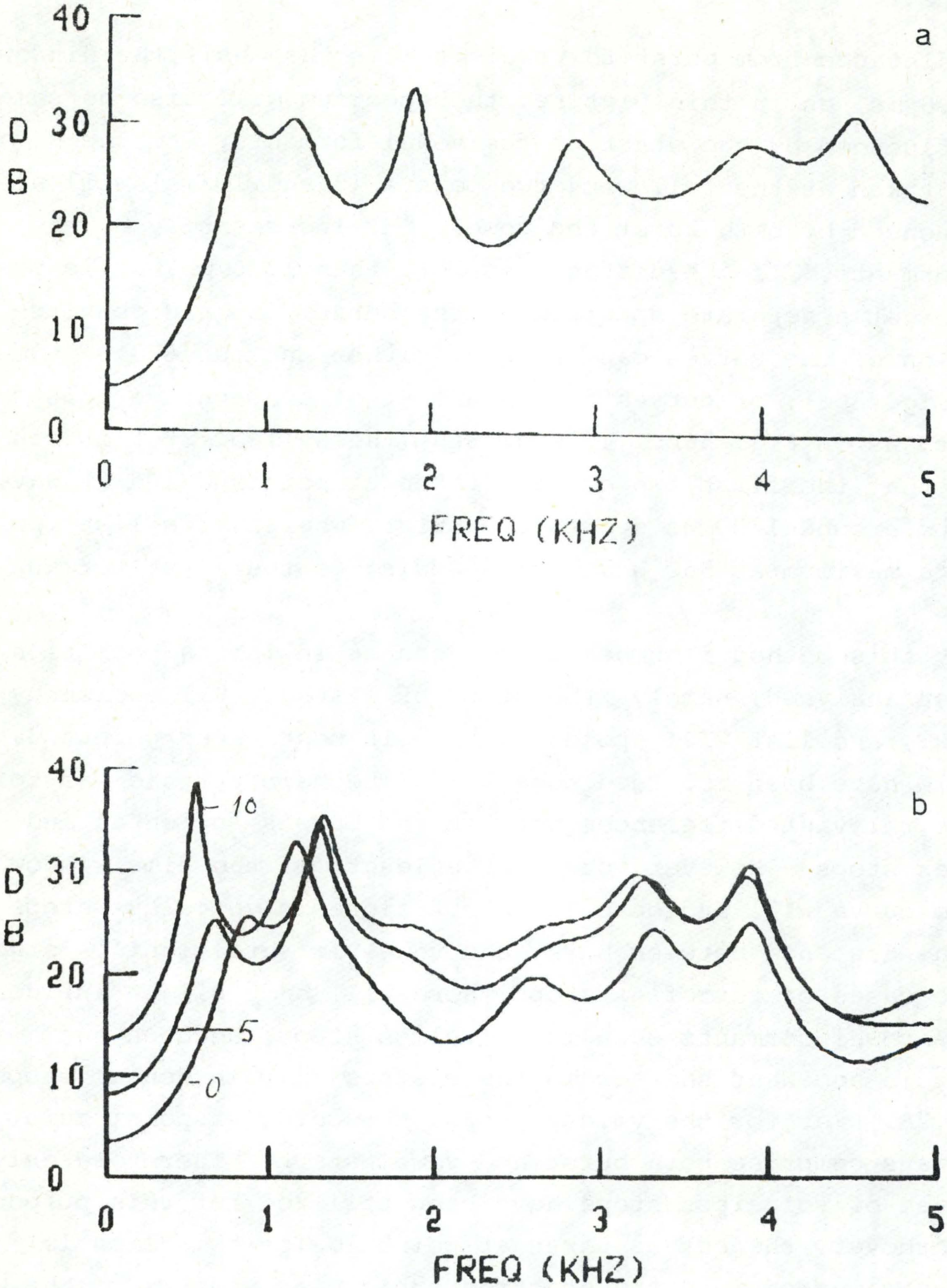


Figure 56

Spectral envelopes obtained by means of the linear prediction technique. a) shows the spectrum corresponding to one position of the time window; b) shows spectra taken at three different (consecutive) positions of the time window.

instance, by the spectrographic analysis the first formant of these vowels was found to have a frequency around 300 Hz, whereas the frequency according to the linear prediction analysis is often 400 Hz. This may partly be due to the fact that spectrographic measurements are based on peaks in the acoustic curve, whereas the linear prediction analysis is based on a theory of poles in the vocal tract. This may give some differences in the results for very low formants. There may, perhaps, also be mistakes in the linear prediction curves, for an F1 of 400 Hz for i seems to be too close to the F1 of e, which is generally 450-500 Hz, corresponding to the results of the spectrographic analysis. There are also some differences in formant 4 and the higher peaks of the bursts. Generally the values obtained by the spectrographic method are somewhat higher.

A binomial pair test has been used to test the significance of the differences between dental and retroflex consonants (see Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences, 1956, table p. 250).

3.5 Results

3.5.1 Liquids and nasals

As mentioned in 1.2, the retroflex liquids and nasals (ṛ, ḷ, and ṇ) are not found initially, so that the contrast to the dentals is restricted to the medial and final positions. - Only RD's consonants have been measured.

3.5.1.1 r and ṛ

A. The consonantal section

Initial r is a one-tap r. There are only two examples in the material (two readings of rab); they have the average formants 550, 1537, and 2450 Hz.

In final position both r and ṛ have a single tap or flap. There are three examples of each, all with a preceding There is a consistent difference in the formants, the second formant of ṛ being slightly higher, and its third formant lower than the corresponding formants of r. The averages are for r: 600, 1442, and 2425; for ṛ: 515, 1572, and 2188. The differences in F1 are not consistent.

Medial r and ṛ are both flaps with a very short closure phase. The average duration is 21 ms for r, and 13 ms for ṛ. During the closure no formants are seen in the spectrograms except for a low resonance around 250 Hz. There are, however, two exceptions: boṛo, which has a second formant of 1250 Hz, and one reading of əmiṛi, with formants at 300(?), 2100, 2630, and 3750 Hz.

B. Formant transitions in adjacent vowels

In the case of medial r and ṛ, the transitions of the adjacent vowels are the only features that are visible in the spectrograms, apart from the short pause. The transitions following initial r (rab) differ from those following medial r by having a very long and extensive transition of F3 (1850-2263, of 120 ms duration). F2 shows a transition of 55 ms duration (1425-1363).

With respect to the transitions preceding the final consonants, there is no difference between them and those preceding the medial consonants: the averages have therefore been combined. Table 1 of the Appendix gives the frequencies of start and end point of the transitions and the extent of the rise or fall (+ and - indicate "positive" and "negative" transitions).

Schematic drawings of the transitions are given in Figs. 57-59, and some specimens of spectrograms in Fig. 60. The averages of vowel transitions of preceding and following a are based on 7 and 6 examples, respectively. For the other vowels there are only 1-2 examples.

It appears from the figures that there are no consistent differences between vowel transitions after r and after ṛ. Both have in most cases a clearly negative F3, and in some cases a negative F4.

The transitions of the preceding vowels are, however, clearly different. Both F3 and F4 are strongly negative before retroflex ṛ. F2 is positive both before r and before ṛ, but it goes somewhat higher up before ṛ. The most relevant measure is probably the frequencies of the end points of the transitions. They differ for all three of the formants 2, 3, and 4, the end points of vowel transitions before retroflex consonants having a higher frequency of formant 2, and a lower frequency of formants 3 and 4 than those before the dental consonants. These differences are very consistent. For F3 and F4 there are no exceptions when the single words are compared in pairs (there are 11 and 12 comparable pairs); for F2 the difference is found in 10 out of 13 comparable pairs. The differences are significant at the 1% level. The frequency of F4 of the steady state part of the vowel preceding retroflex ṛ is also often lower than the steady state part of the vowel preceding dental r, whereas F3 varies. The transitions of F4 in vowels preceding a retroflex ṛ are often very steep and start slightly later than those of F3. In e and i the F3 transition takes place in the middle of the vowel, the F4 transition at the end (see Fig. 60).

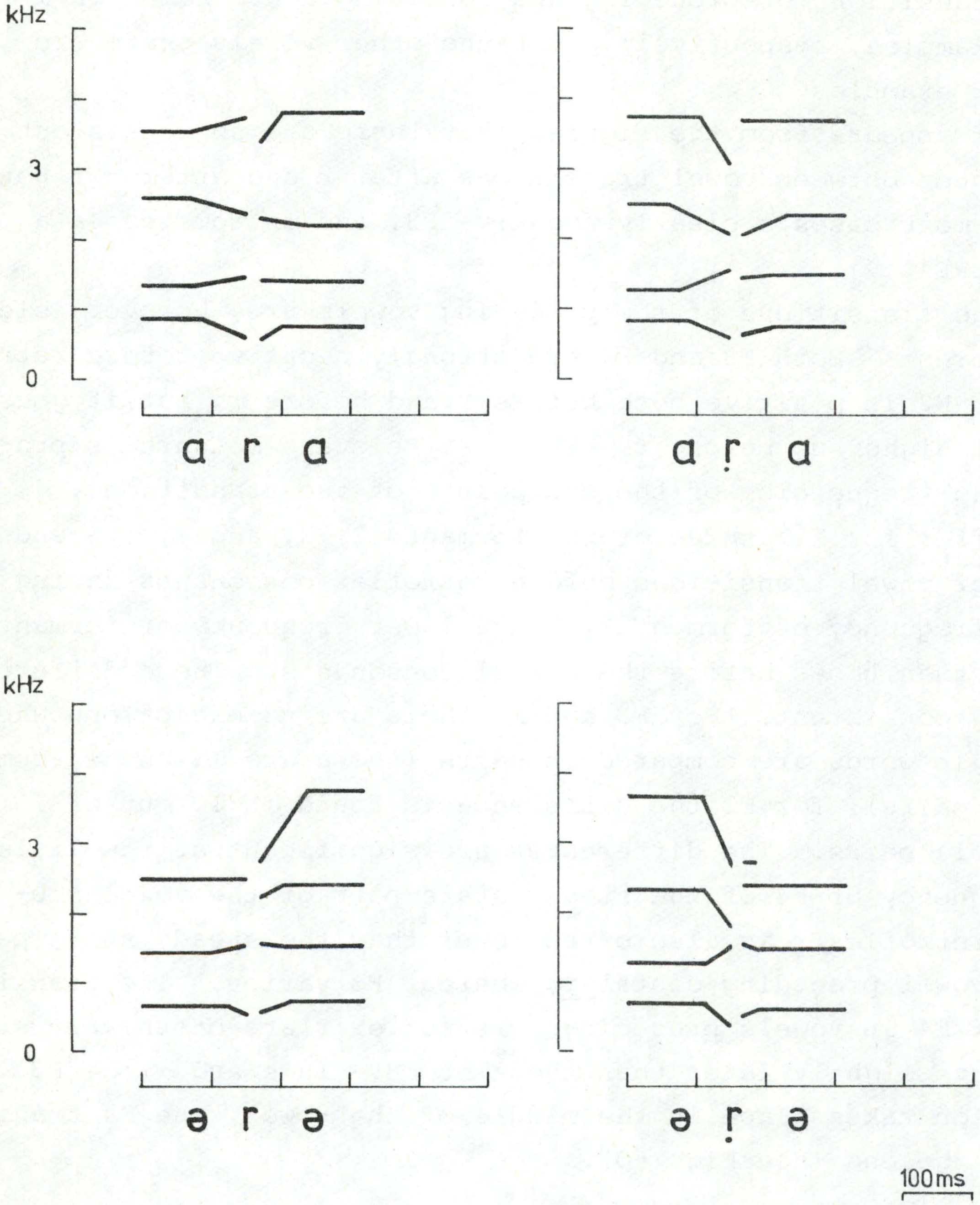


Figure 57

Schematized spectrograms. Speaker RD.

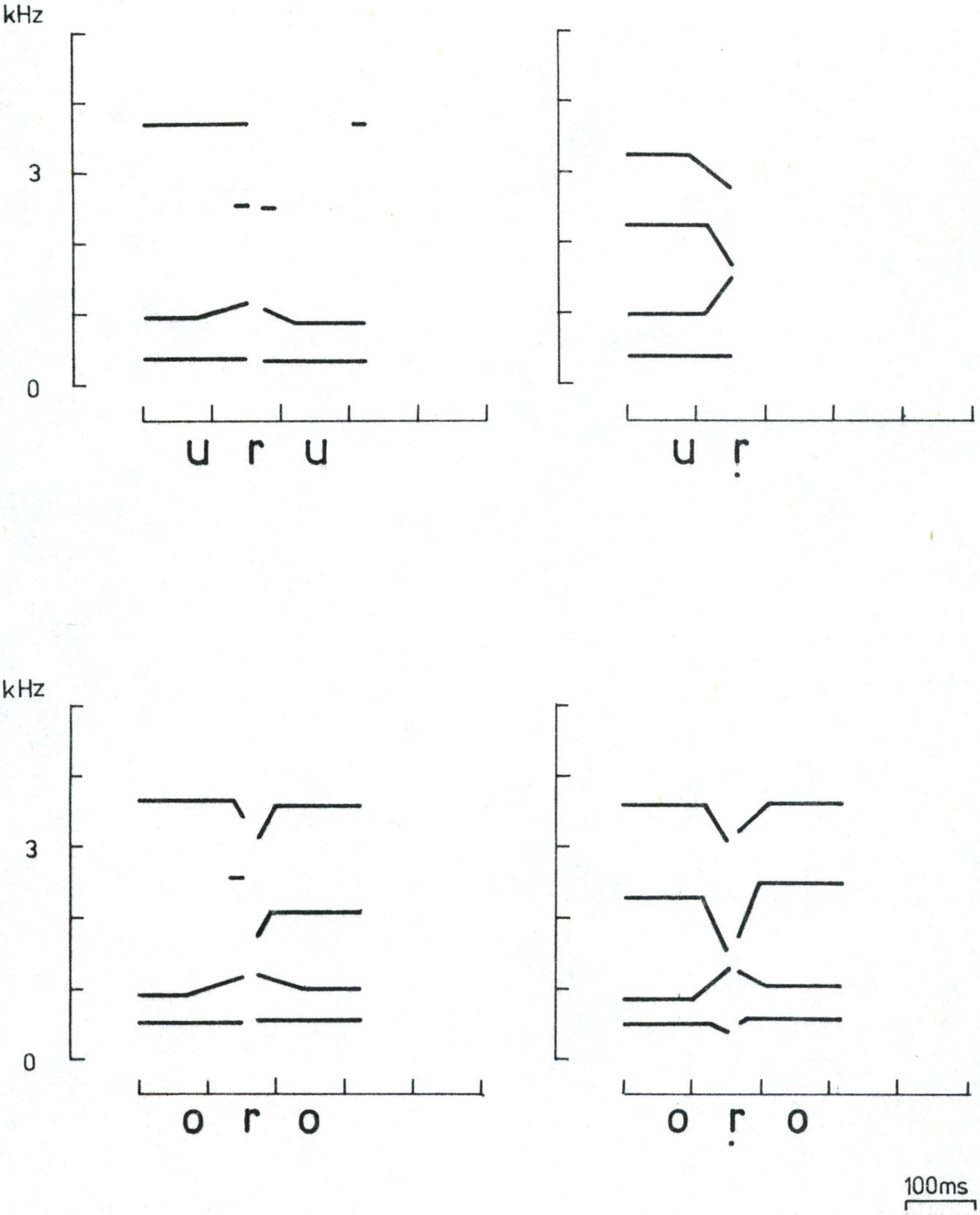


Figure 58

Schematized spectrograms. Speaker RD.

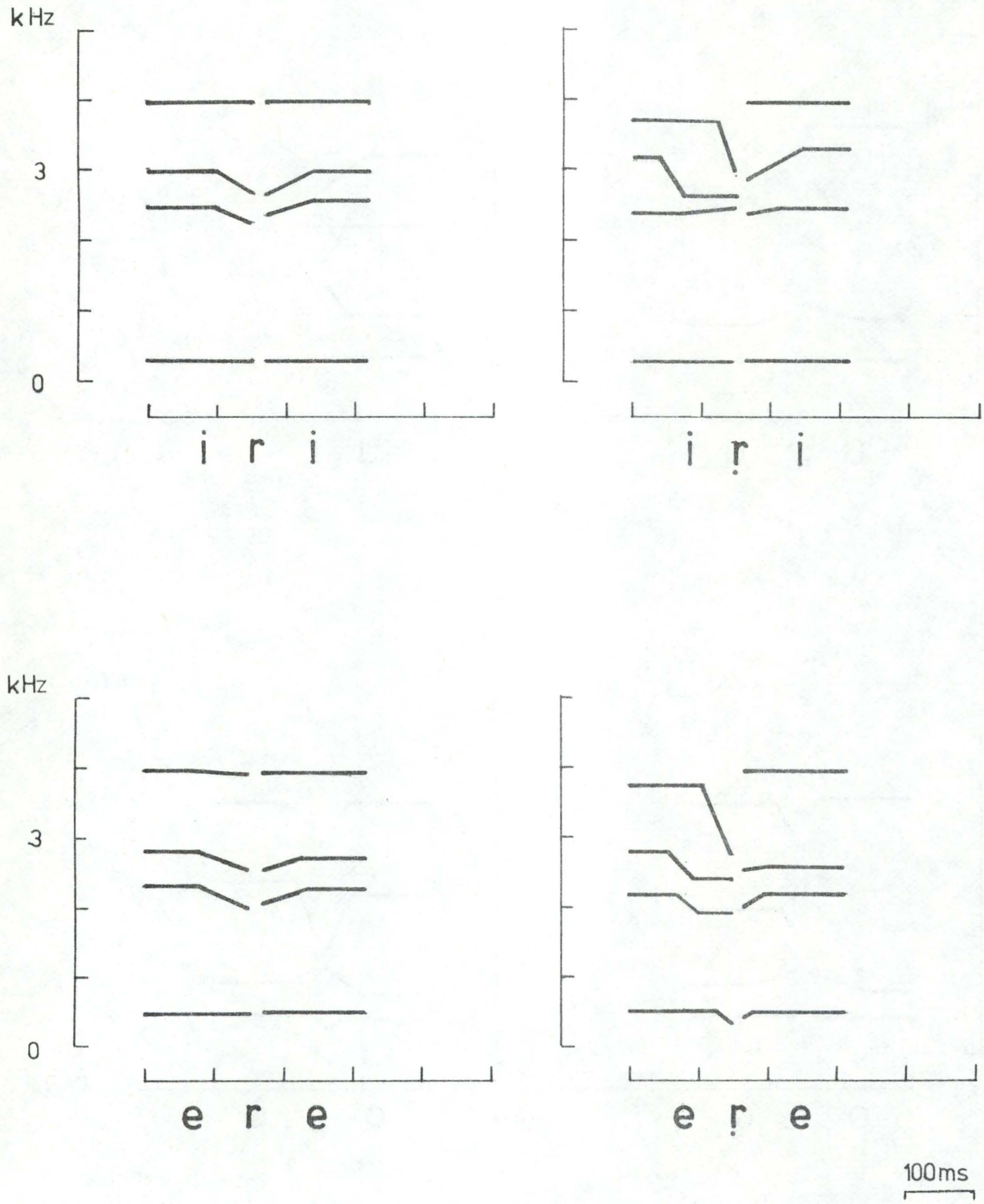
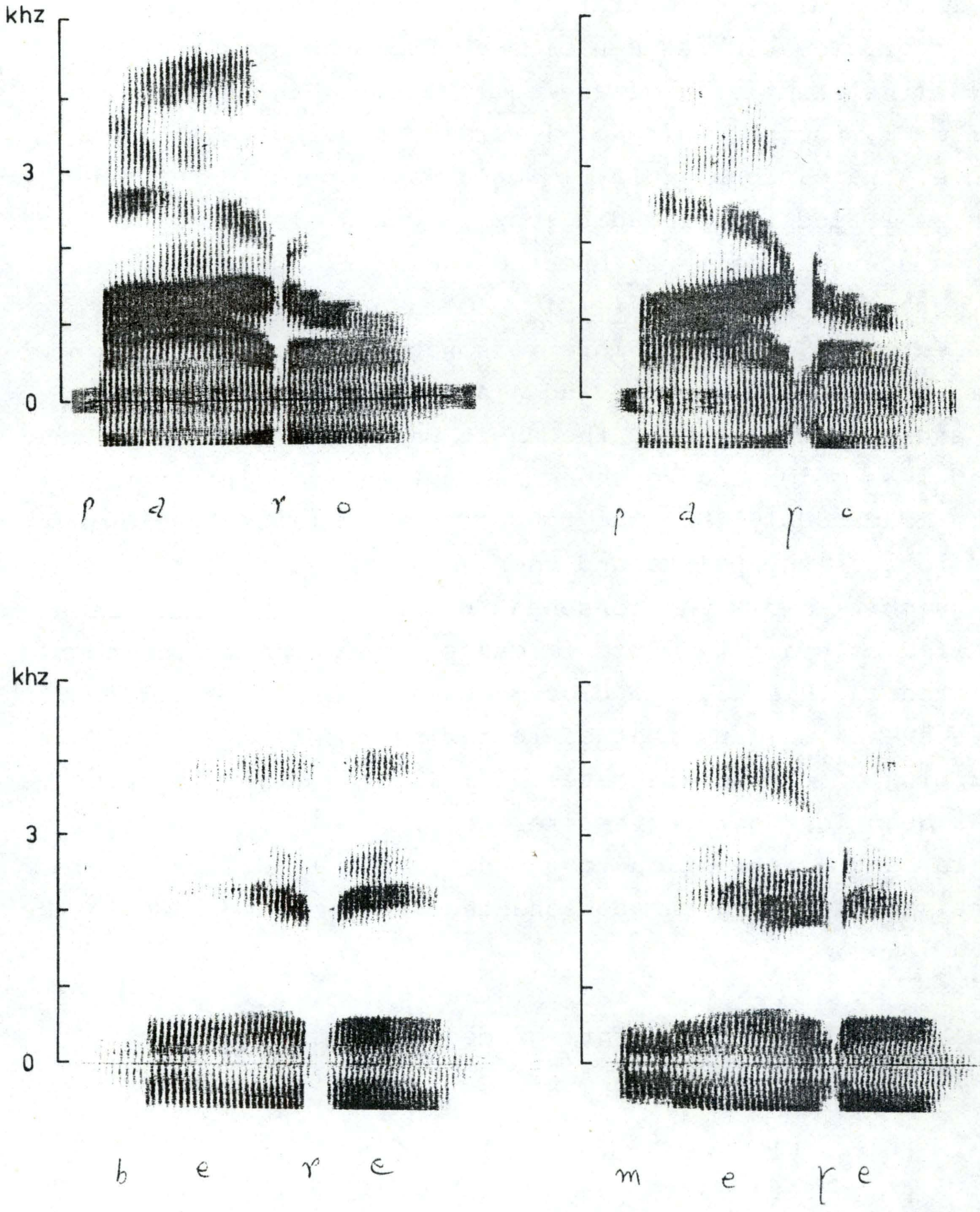


Figure 59
Schematized spectrograms. Speaker RD.



<u>Figure 60</u>

Sample spectrograms. Speaker RD.

3.5.1.2 l and ḷ

A. The consonantal section

The delimitation of retroflex ḷ from the preceding vowel is often problematic, as can be seen from the spectrograms in Fig. 63 (the examples baḷa and eḷe). If, in the examples with retroflex ḷ, the beginning of ḷ were considered to start when the vowel transitions start, ḷ would have approximately the same length as l, and the preceding vowels would also be of the same length. However, if these spectrograms are compared to the spectrograms of retroflex ṛ (Fig. 60) and to spectrograms of retroflex stops, it seems more reasonable to consider the downward movement of formants 3 and 4 as belonging to the preceding vowel and to consider only the short period of closure of the flapped ḷ as belonging to the consonant section proper. What happens is probably that the tongue moves relatively slowly up to the roof of the palate and then, after a very short touch, moves quickly down. The consonant proper has therefore been considered as starting where formants 3 and 4 have come down. Calculated in this way the closure time of dental l will be on the average 86 ms, and that of retroflex ḷ only 27 ms, with no overlapping of the single cases. (l in ullu (185) is a geminate and has been left out in the averages.)

In contradistinction to r and ṛ, both l and ḷ show clear formant values during the consonantal section, as shown in the table below:

Formants of dental l

Adjacent vowels	a	ə	u	o	i	e
N	(8)	(1)	(1)	(1)	(2)	(2)
F_4	3669	3725	3500	3600	3850	3750
F_3	2697	?	2650	2650	2713?	2600
F_2	1281	1300	1350	1150	2563?	1600
F_1	319	350	250	275	275	275

Formants of retroflex ḷ

Adjacent vowels	a	ə	u	o	i	e
N	(2)	(1)	(1)	(1)	(2)	(1)
F_4	3330	3300	3100?	3550	3550	3425
F_3	2280	2500	?	1925	2425	2400
F_2	1400	1425	1100	1050	2000	1800
F_1	710	700	400	550	350	525

There are very clear differences in the formant frequencies between the two types of *l*: retroflex *ḷ* has a higher F1, and in the environment of *a* and *ə* also a higher F2, moreover, in all cases a lower F3 and a lower F4. The differences in F1, F3, and F4 are found in all comparable, single pairs and are significant at the 1% level, and the difference in F2 is consistent for *ə* and *a*.

B. Formant transitions of adjacent vowels

The frequencies of start and end of the vowel transitions are shown in table 2 of the Appendix, and schematic drawings are given in Figs. 61-62.

The averages for the vowel *a* are based on 6 examples before *l* and *ḷ*: 4 examples after *l*, and 2 after *ḷ*. For the other vowels there are only 1-2 examples. As there were no consistent differences between the transitions after initial and medial consonants, nor before final and medial consonants, these examples have been combined into one average.

It appears from the tables and from the schematic drawings in Figs. 61-62 that differences in formant transitions between the dental *l* and the retroflex *l* are found in both the preceding and in the following vowel, but most consistently in the preceding vowel. In *a* and *ə* F1 ends at a higher frequency before *ḷ* than before *l* (and this is true of all 6 examples of *a*), but for the other vowels and in vowels after *l* and *ḷ* there is no consistent difference.

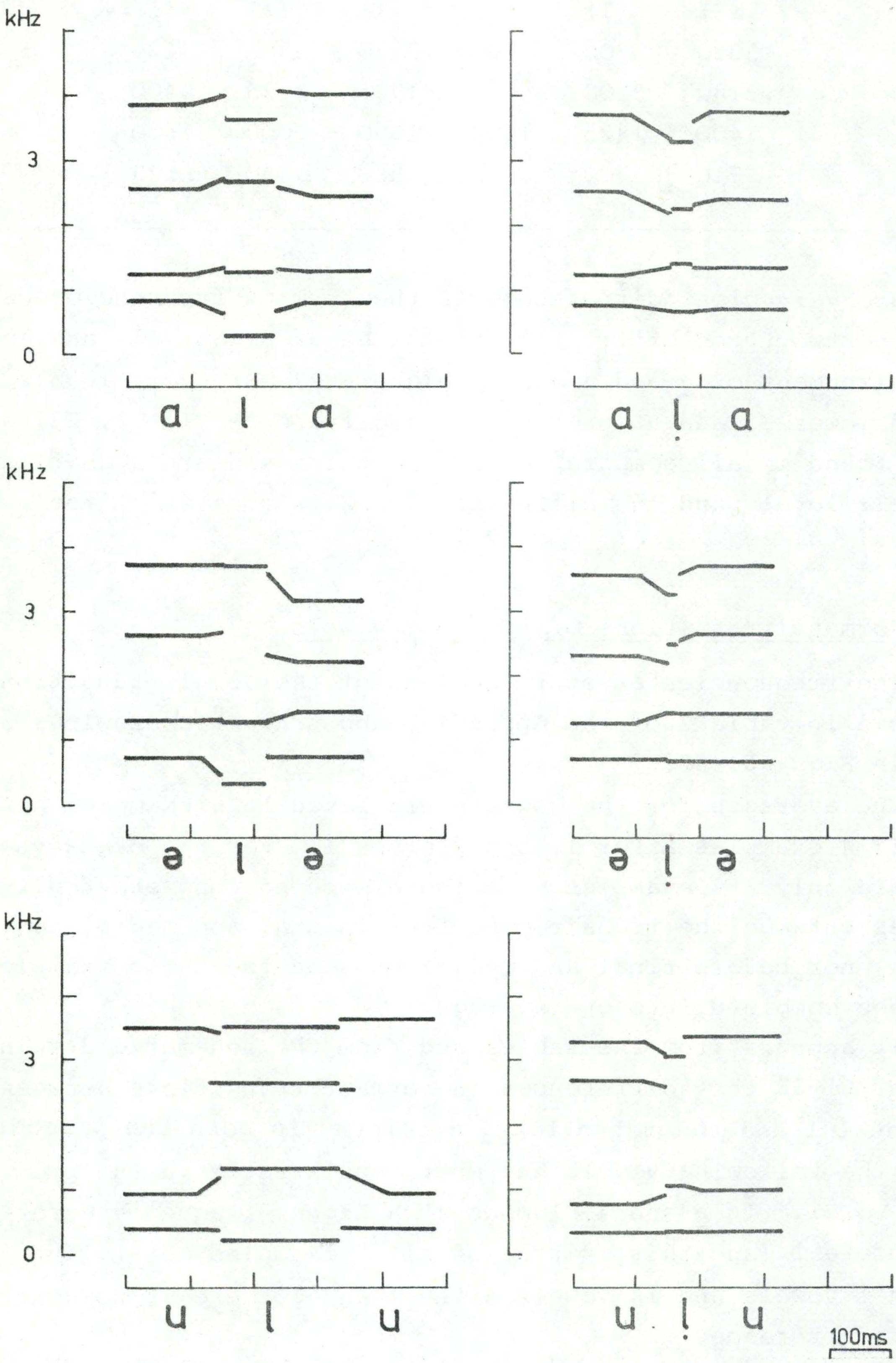


Figure 61
Schematized spectrograms. Speaker RD.

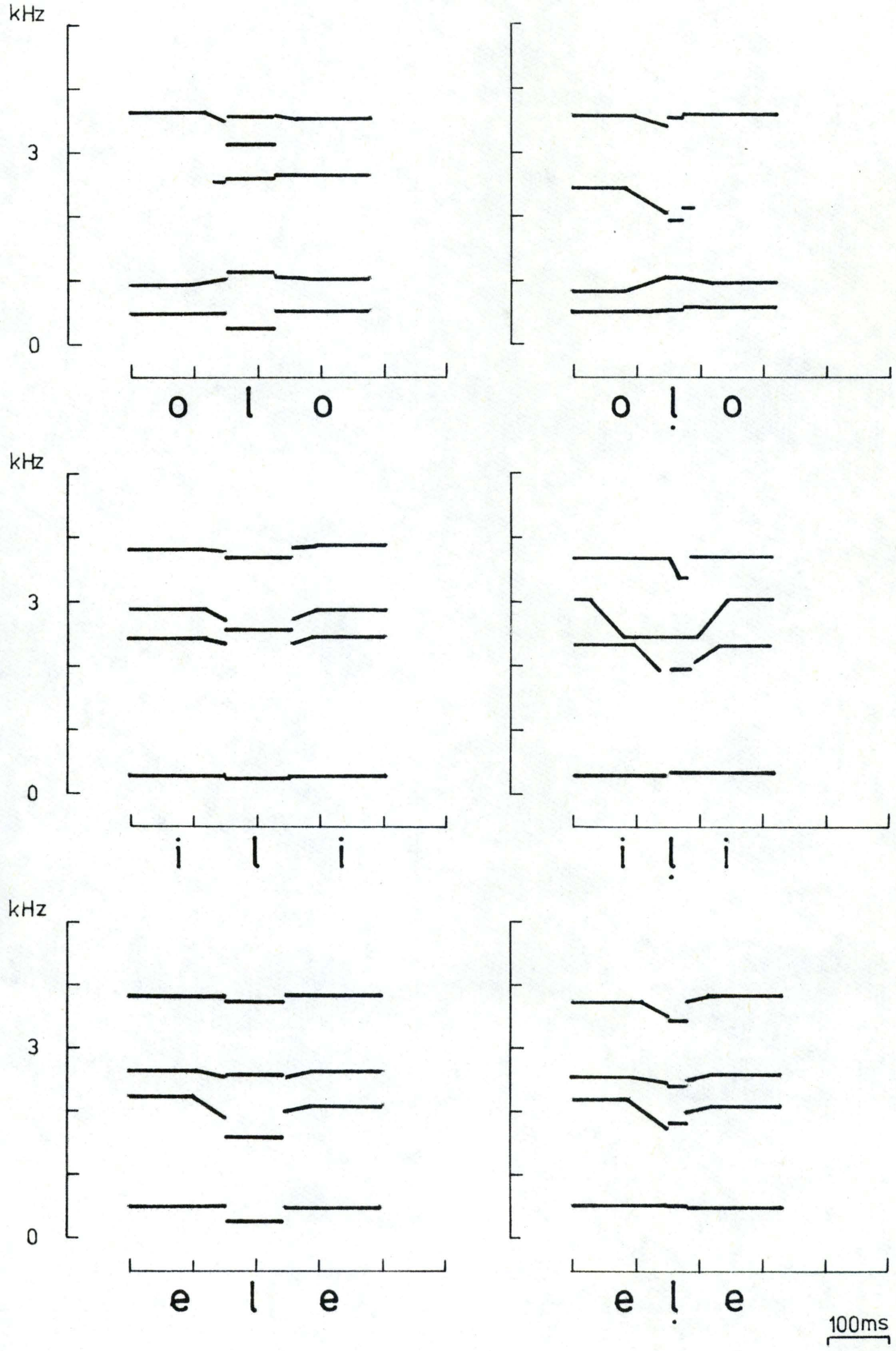


Figure 62

Schematized spectrograms. Speaker RD.

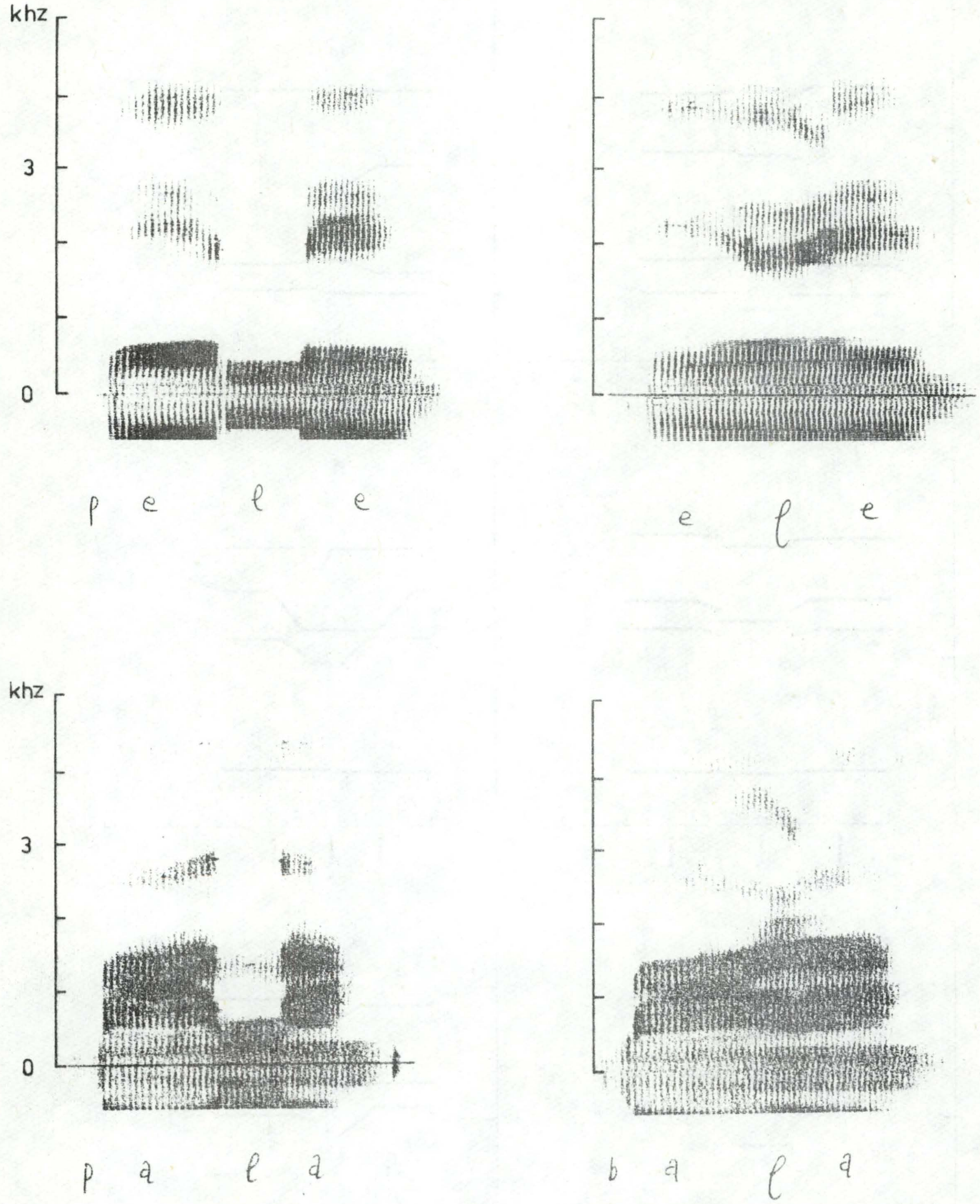


Figure 63
Sample spectrograms. Speaker RD.

The differences in F2 are not consistent. F3 and F4 show much more consistent differences. Particularly the vowel before ḻ shows a more strongly negative transition than the vowel before l̲, and the end points of F3 and F4 are lower before ḻ than before l̲ in all cases (12 comparable pairs), the difference being significant at the 1% level. Similarly, F3 and F4 of the following vowel have a tendency to start at lower frequencies after ḻ than after l̲, but the difference is only found in 6 out of 8 comparable word pairs. The vowel a̲ sometimes has an extra formant around 3000-3300 Hz, particularly before dental l̲. F4 is also consistently lower in the steady state part of a vowel preceding retroflex ḻ than in one preceding dental l̲, whereas F3 varies.

3.5.1.3 n and ṇ

A. The consonantal section

Retroflex ṇ̲ is a flapped consonant like ḻ and ṟ, and the delimitation is not easy, although it is not as difficult as in the case of ḻ. The transitions have been considered to belong to the vowels, and ṇ is thus of very brief duration (see the spectrograms Fig. 66). The average duration of n̲ is 88 ms, and that of ṇ̲ 31 ms, and there is no overlapping (n̲ in unnu has been left out of the average, because it is a geminate (170 ms)).

The formants of nasal consonants are not easy to measure. They are rather irregular, and some may be too weak to appear on spectrograms. Particularly the higher formants are dubious, and the averages for ṇ̲ before i̲ are rather problematic.

Nevertheless, some consistent differences appear from the tables:

Formants of dental n

Adjacent vowels	a	ə	u	o	i	e
N	(6)	(1)	(1)	(1)	(3)	(1)
F_4	4275 (3075)	4400	3700 (2900)		3775	
F_3	2563	2415	2600	2525 }	2680	2575
F_2	1450	1325	1425	1200 }		
F_1	313	275	300	300	300	300

Formants of retroflex ṇ

Adjacent vowels	a	ə	u	o	i	e
N	(6)	(1)	(1)	(1)	(3)	(1)
F_4	3400			3450	3870	
F_x	2625	2800	2800	2900	2867?	2800
F_3	2125	2300	1850	1900	2400	?
F_2	1408	1450	1225	1100	2063?	1900
F_1	250	250	300	225	350	300

There are no consistent differences between F1 or F2 of dental and retroflex nasals. F3 is, however, consistently lower in ṇ than in n. This is true of 12 comparable pairs, and the difference is significant at the 1% level.

Moreover, ṇ has in all positions a formant around 2800 Hz.

B. Formant transitions in adjacent vowels

The frequencies of start and end of the transitions are given in table 3 of the Appendix, and schematic drawings of the transitions are shown in Figs. 64-65. There are no con-

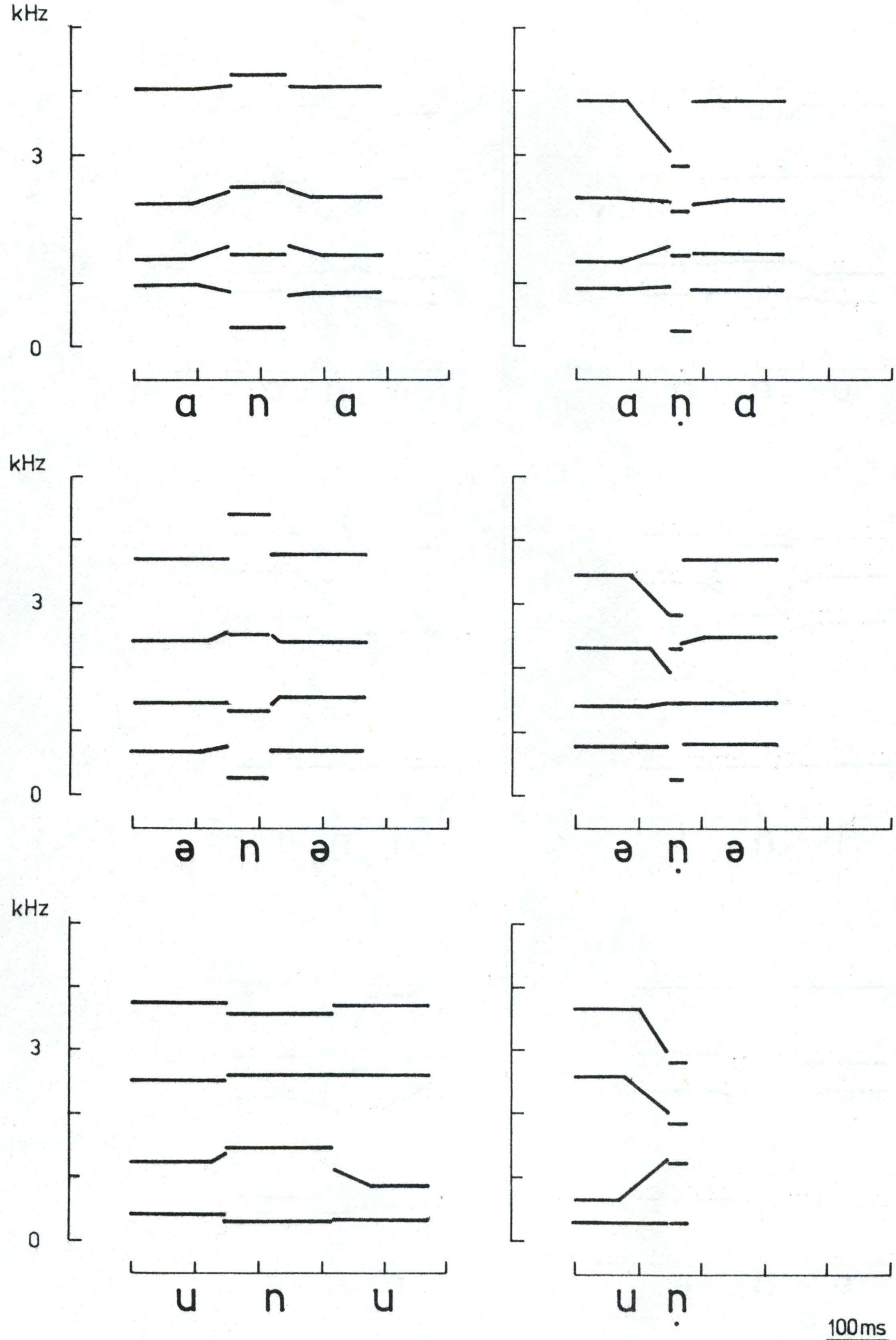


Figure 64

Schematized spectrograms. Speaker RD.

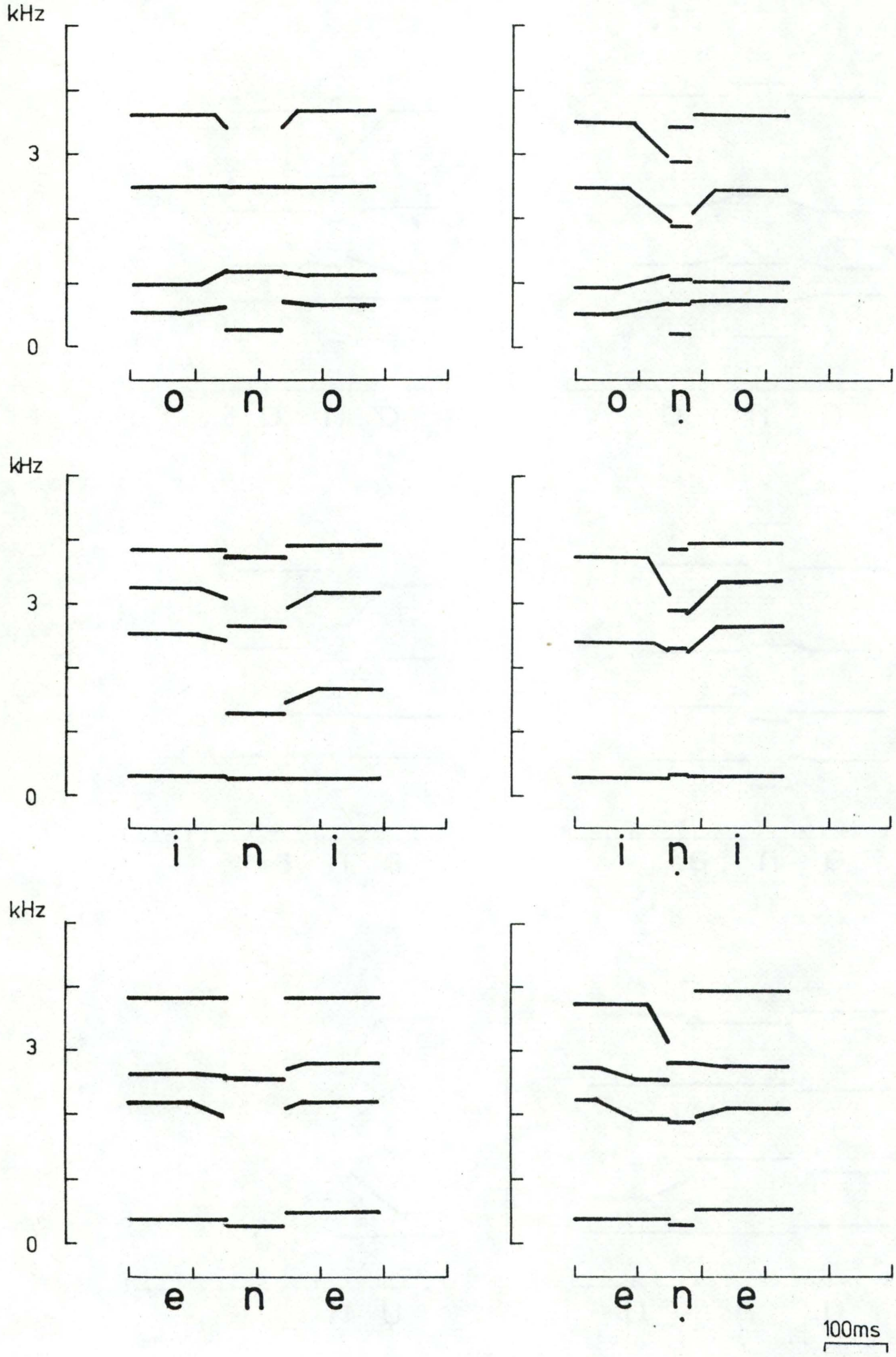


Figure 65

Schematized spectrograms. Speaker RD.

sistent differences between vowel transitions in connection with dental and retroflex consonants in F1 and F2, but there are clear differences in F3 and F4. Vowels before retroflex ṇ have a more pronounced negative transition of F3 and F4 than vowels before dental consonants, and in most cases there is also a difference in the F3 transition after the consonant. F4 has a lower end point of the transition before retroflex ṇ in all 12 comparable pairs, and F3 in all of 10 comparable pairs. In the position after the consonants the same tendency is found, but not consistently (6 out of 8 comparable pairs). F4 in the steady state part of a vowel preceding retroflex ṇ is also consistently lower than in one preceding dental n, whereas F3 is variable.

A further difference between RD's dental and retroflex nasals is that the retroflex consonants tend to nasalize the preceding vowel to a higher degree, cf. Fig. 66. The vowel before ṇ has a higher and weaker F1 and a stronger subformant than the vowel before n.

The common feature for retroflex ṛ, ṇ, and ḷ is thus a lowering of the third and fourth formants of the preceding vowel, and the lowering is also seen in the spectra of the consonantal section of ḷ and ṇ.

3.5.1.4 RT's retroflex liquids and nasals.

The spectrograms of RT show, on the whole, the same differences between dental and retroflex consonants as those found in RD's spectrograms. The lowering of F3 before retroflex consonants is particularly clear. He also has the tendency to higher frequency of F2 before ṛ. As for F4, he has some cases of clearly negative transition before retroflex consonants, but the fall is generally slower than in RD's curves and very often missing. Two pairs of spectrograms reproduced in Fig. 67 from RD and RT show this difference.

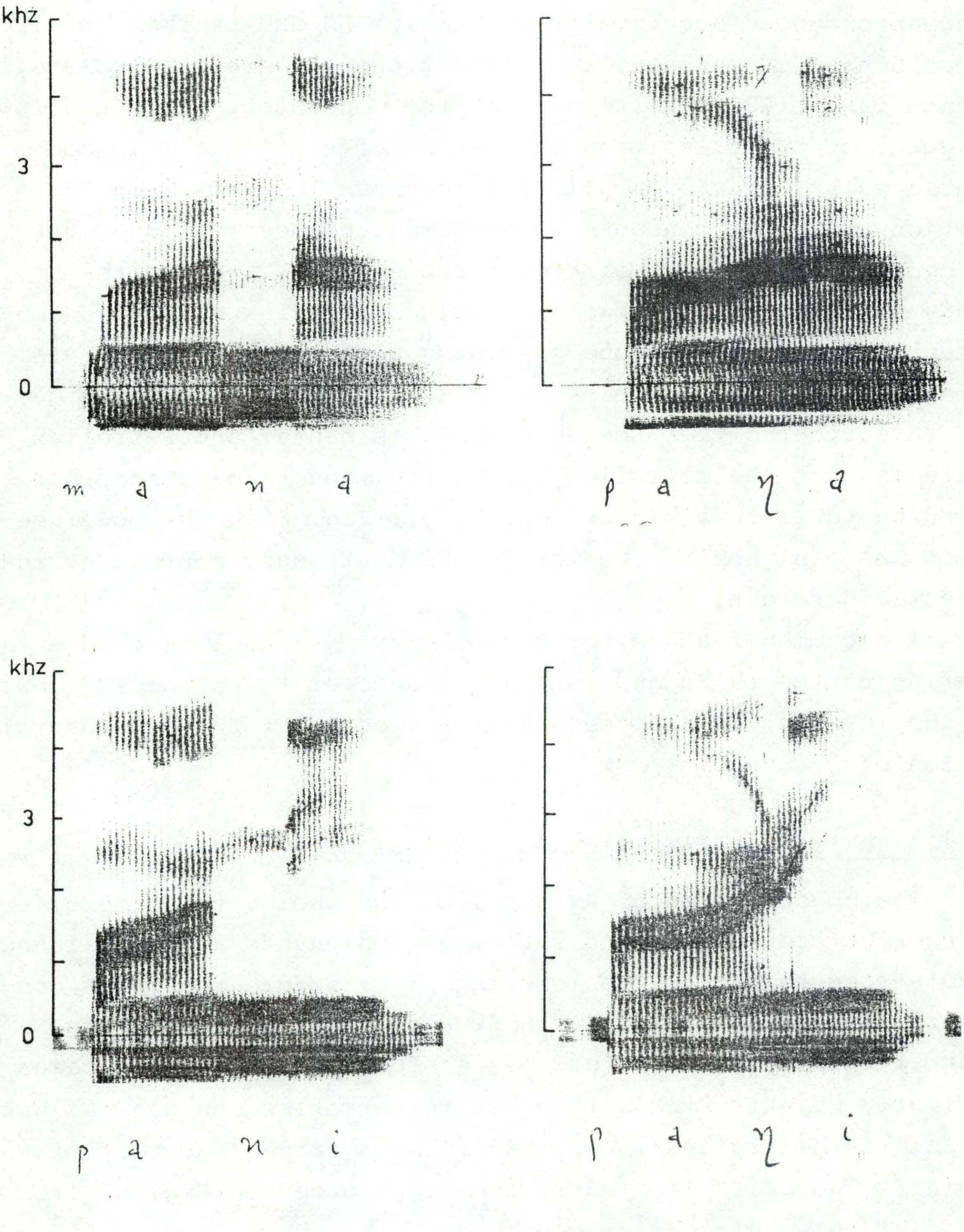


Figure 66

Sample spectrograms. Speaker RD.

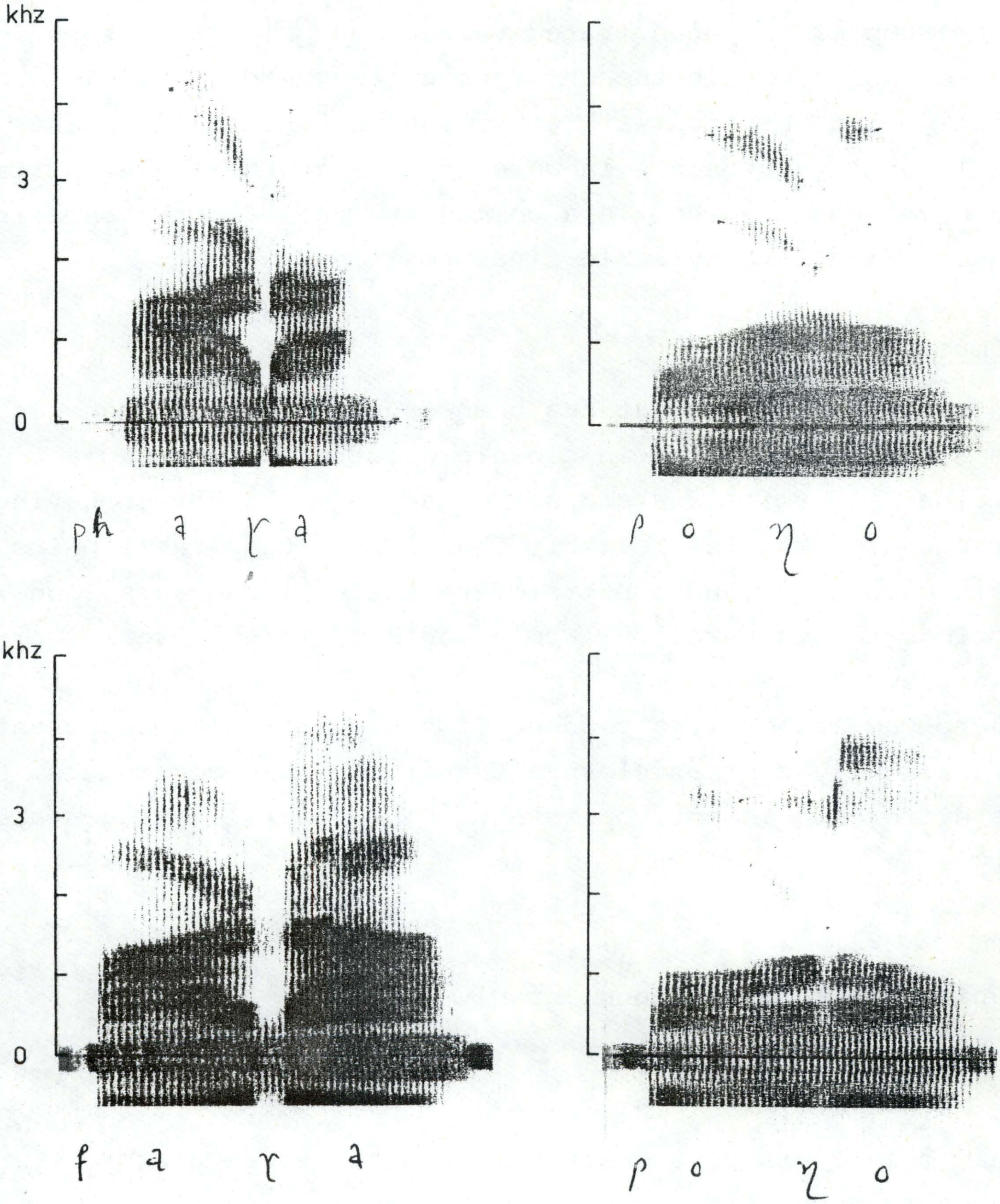


Figure 67

Spectrograms of the two speakers' [ṛ] and [ṇ];
RD above, RT below.

3.5.2 Stops

Both dental and retroflex stops are found in all positions of the word: initially, medially, and finally. Spectrograms have been taken of the unaspirated voiced and voiceless stops in all three positions in the environment a-a, and initially and medially in connection with other vowels. As was the case with the liquids, consonants in word-initial and syllable-initial position have been combined in a common average, and the same is true of word-final and syllable-final position.

A. Temporal relations

In accordance with what has been found in other languages there is a clear difference in closure duration between RD's medial voiced and voiceless stops t ṭ and d ḍ, the former having a longer closure than the latter. There are 8 comparable pairs of dental consonants, and 8 pairs of retroflex consonants, and no exceptions to the durational relationship, which gives significance at the 1% level.

There is, moreover, a tendency for the retroflex consonants to have a slightly shorter closure than the dental consonants, but this difference is not consistent. The general averages are:

t 124 ms, ṭ 114 ms, d 83 ms, ḍ 71 ms.

RT has quite similar relations, namely

t 106 ms, ṭ 103 ms, d 68 ms, ḍ 51 ms.

But he has only 3 examples where ḍ is pronounced as a stop. Normally he pronounces it as a flap.

More important is the difference in distance between burst and vowel start, found in RD's spectrograms. This distance has sometimes been called "open interval" (e.g. by Fant and by Eli Fischer-Jørgensen 1954), but is now commonly called "voice onset time", abbreviated VOT, a term introduced by Lisker and Abramson (1964).

In RD's spectrograms the VOT value is smaller for retroflex consonants than for dental consonants. For the voiced stops the VOT is in any case very short and sometimes difficult to measure, but there is at least a tendency for ḍ to have a few ms shorter VOT than d̲. For the voiceless stops the difference is quite clear. The averages (in ms) are:

	a	ə	u	o	i	e
t	15	15	16	15	24	20
ṭ	9	9	13	10	10	9

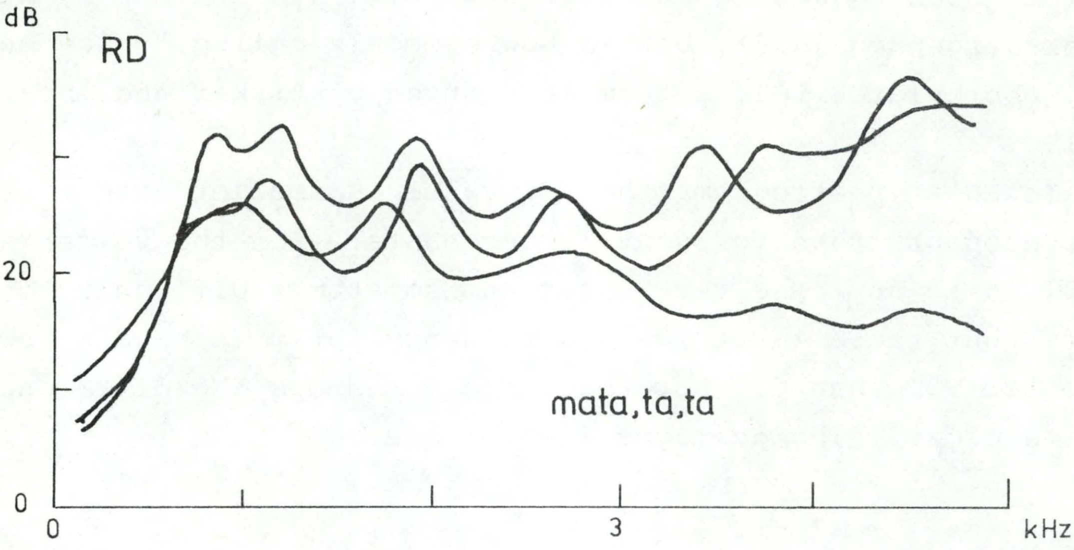
There are 27 examples of t̲ and 25 of ṭ, and of 24 comparable pairs the dental consonant has a longer VOT in 21. This is significant at the 1% level.

However, the other informant (RT) has no such difference between dental and retroflex stops. The VOT of his dental stops is on the average 15 ms, and that of his retroflex stops 16 ms.

B. <u>Burst frequency</u>

The burst frequency has been analysed by the linear prediction method, mentioned in 3.4. When the point for analysis is chosen at point zero, so that the time window has its peak at the start of the burst, the spectrum of the bursts of voiceless stops will, in most cases, be based on the burst alone, except for some cases of retroflex stops where there may be a slight influence from the vowel start.

Figs. 68-73 show such spectra of the bursts of RD. Dental stops are shown at the top and retroflex stops at the bottom of each figure. In most of the drawings 2-3 examples of stops at



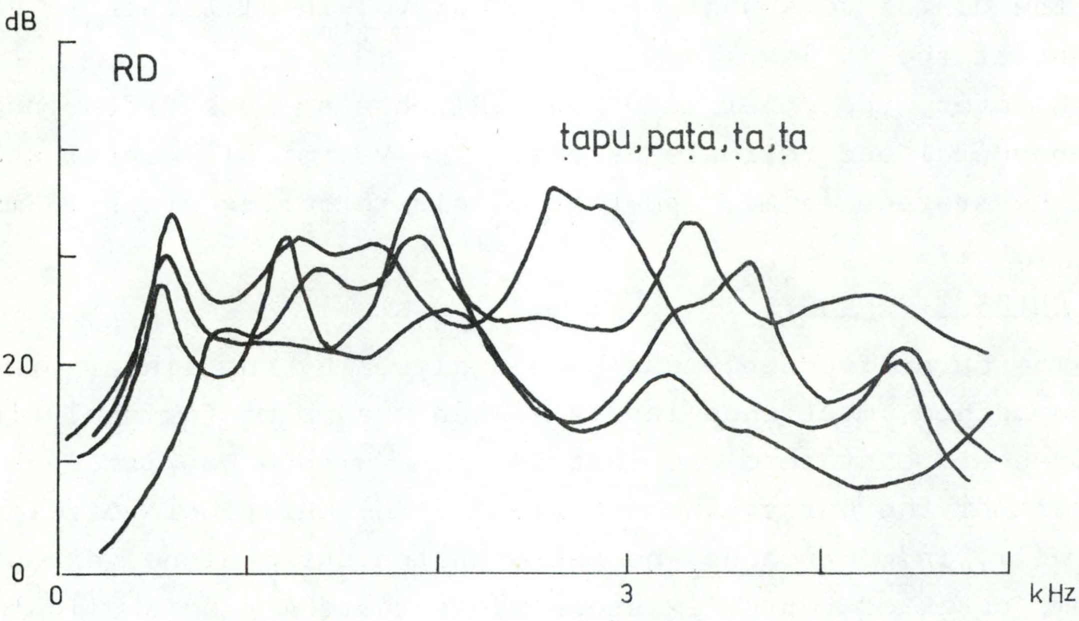
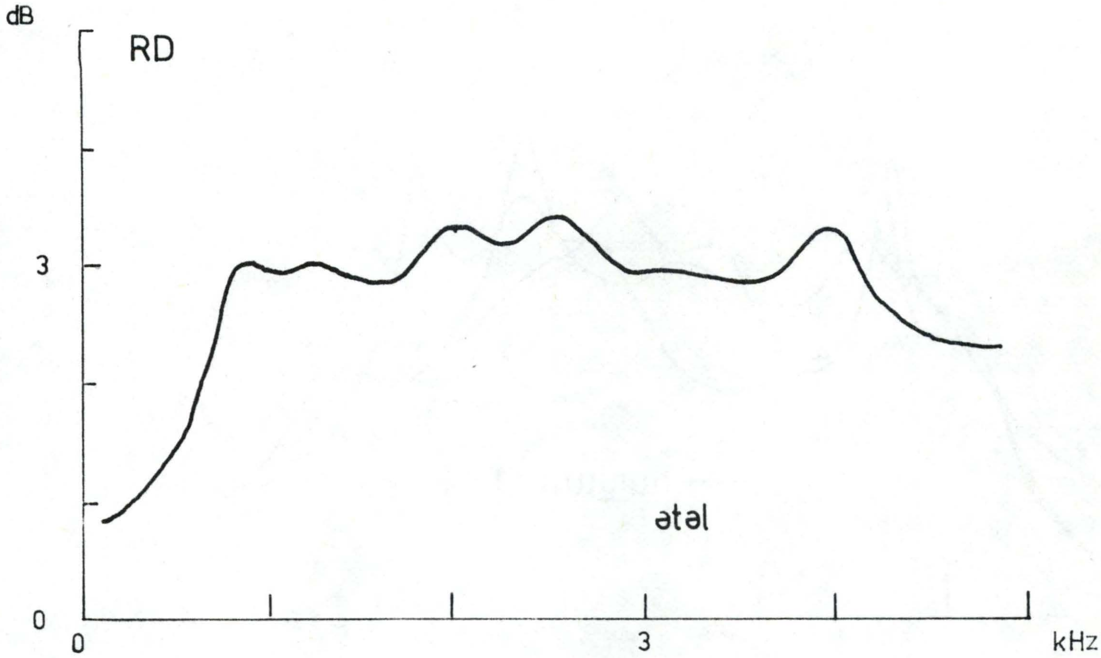


Figure 68

Burst spectra. Speaker RD. The position of the time window was at zero, i.e. the window was placed symmetrically around the burst.



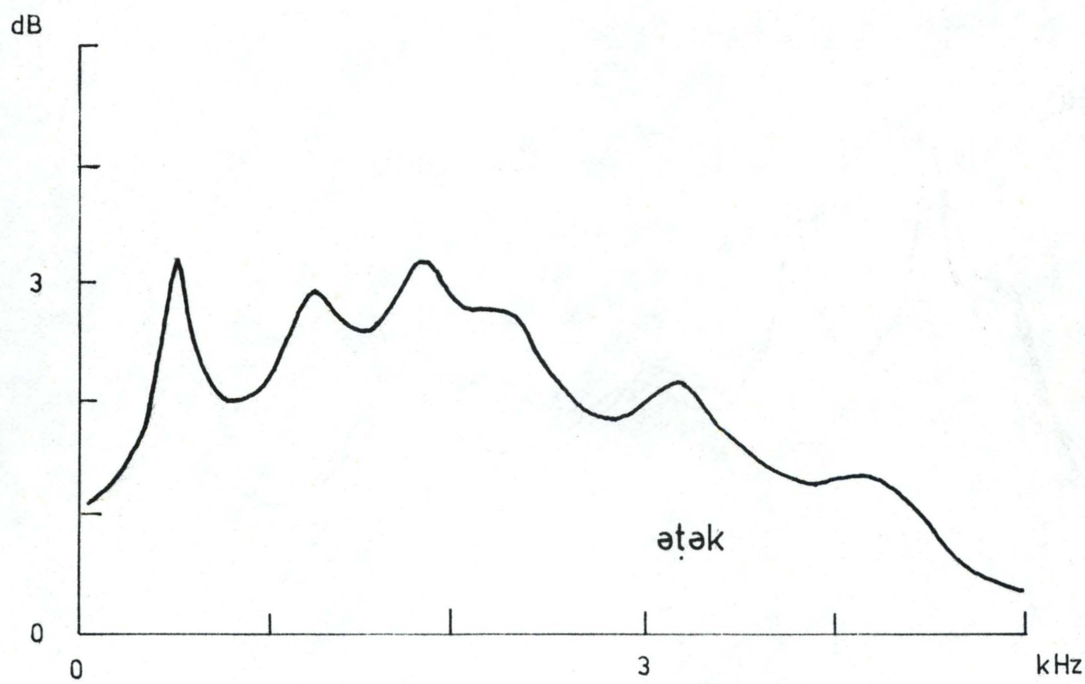


Figure 69

See legend to fig. 68.

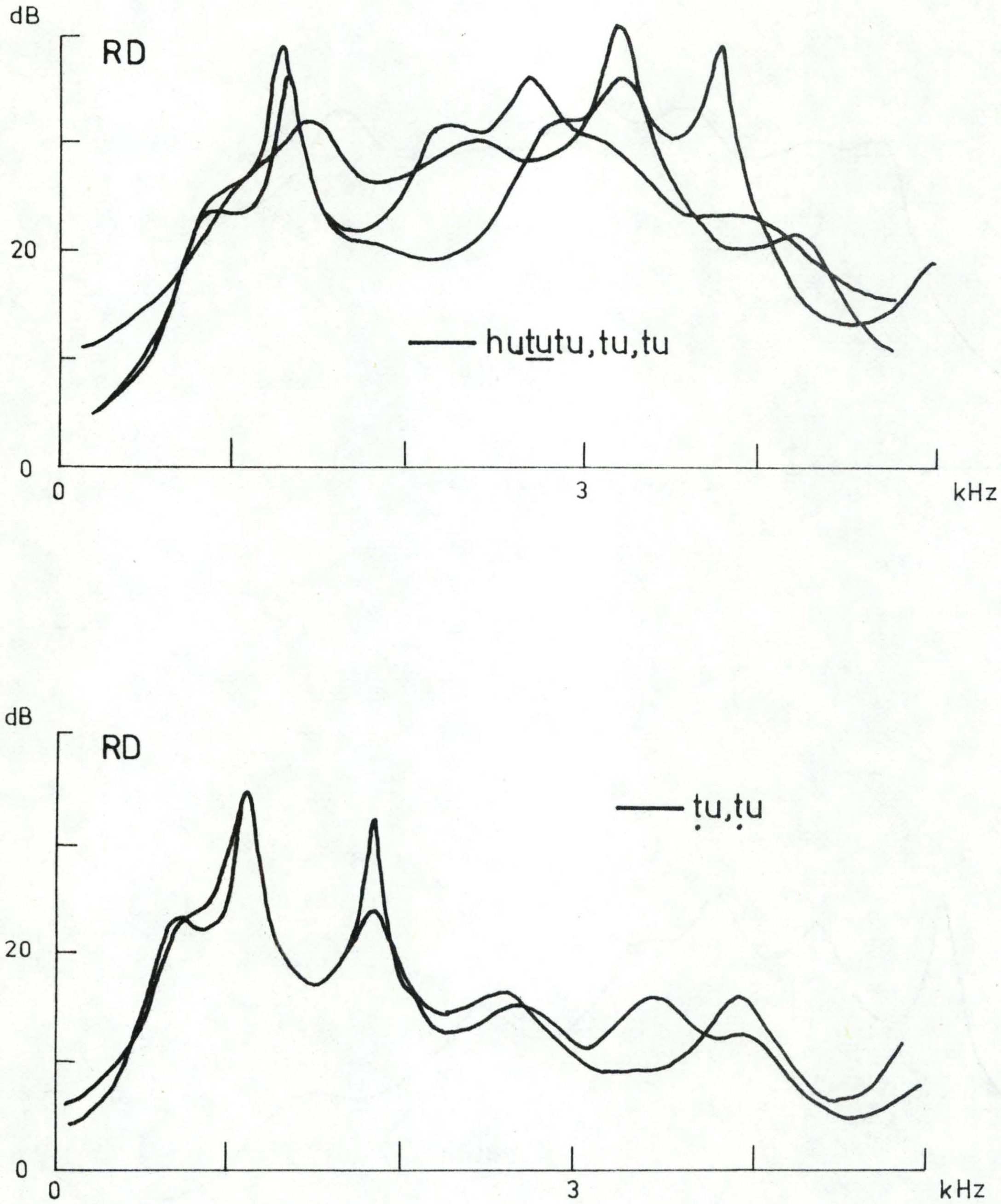


Figure 70

See legend to fig. 68.

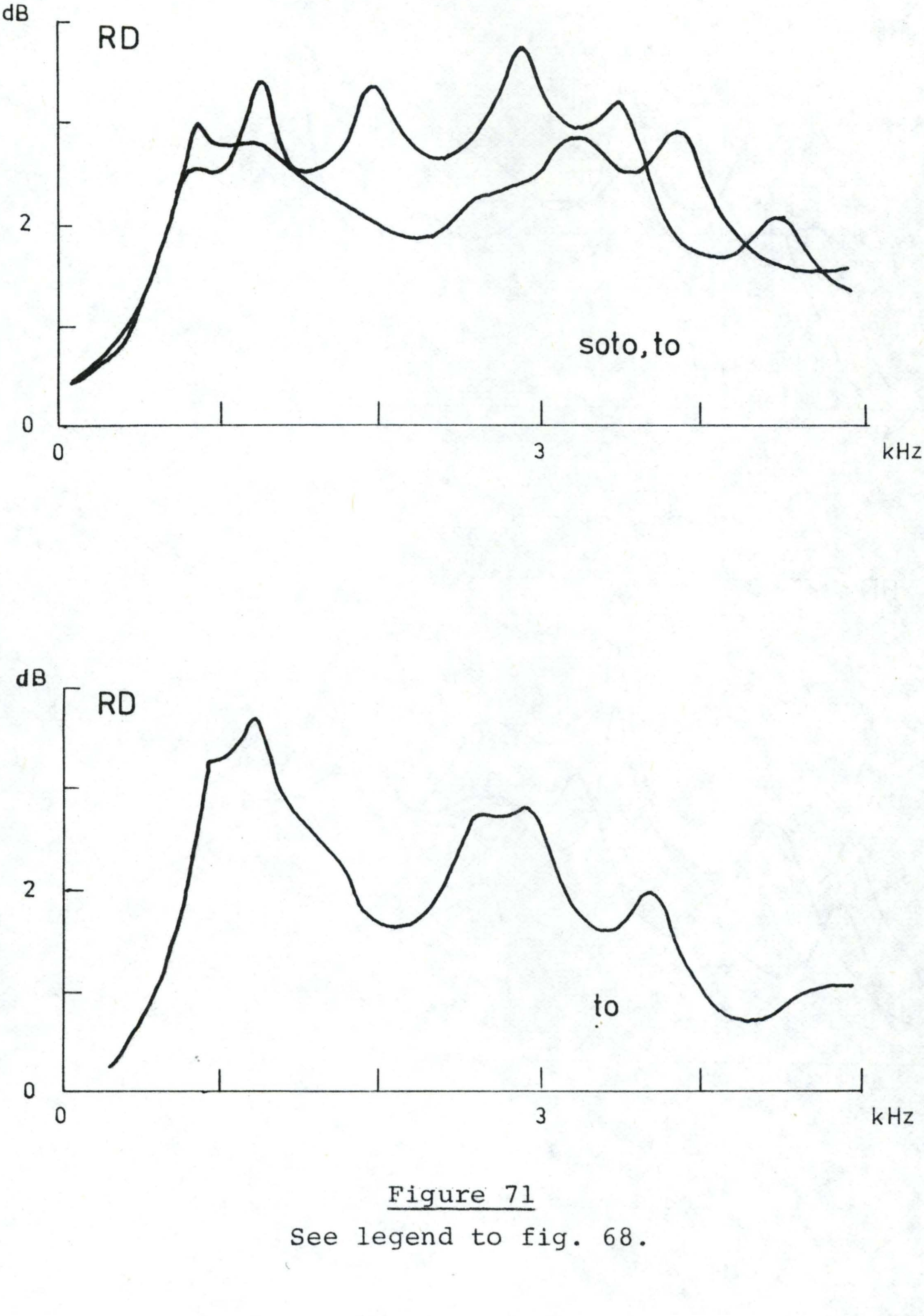


Figure 71

See legend to fig. 68.

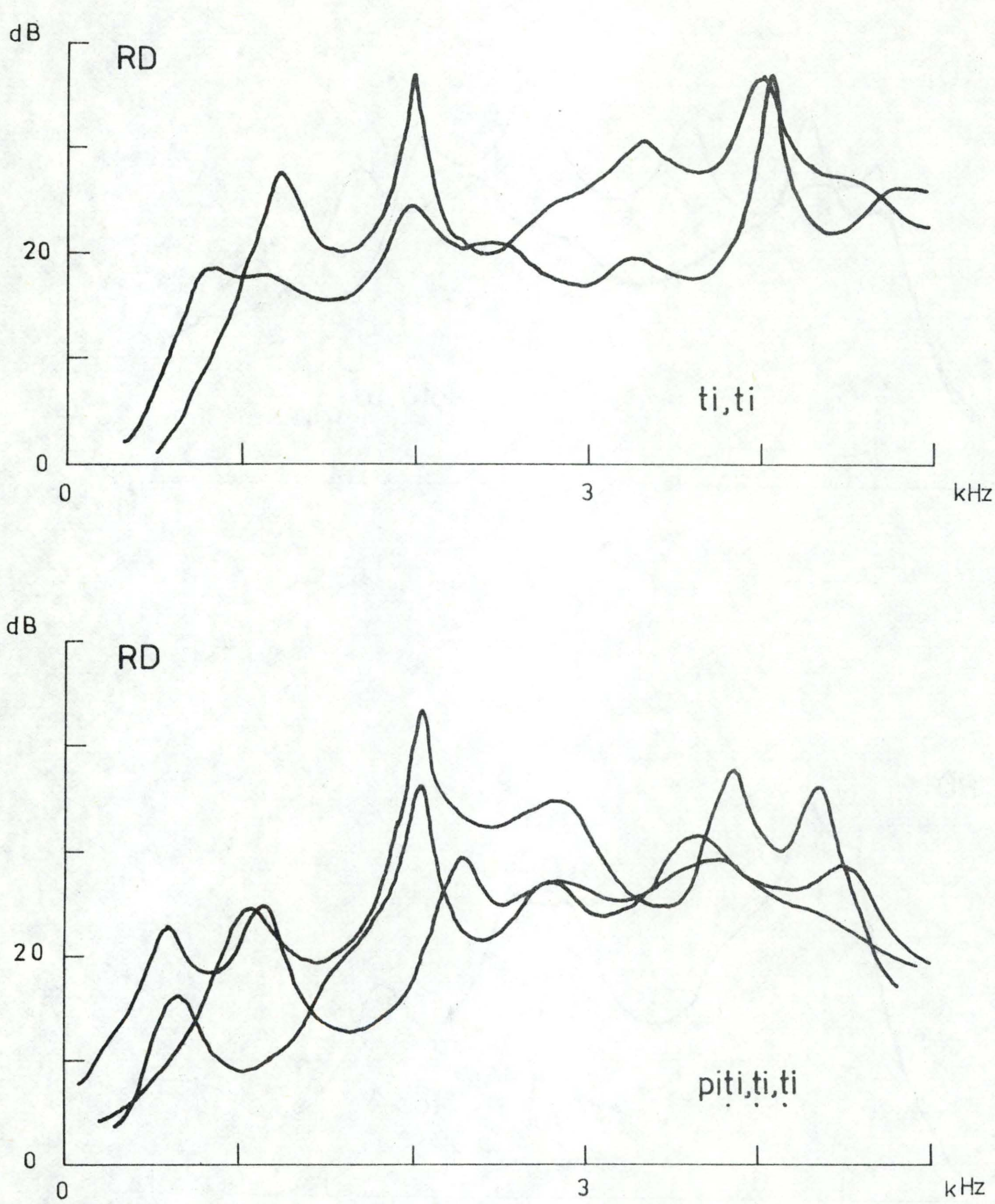
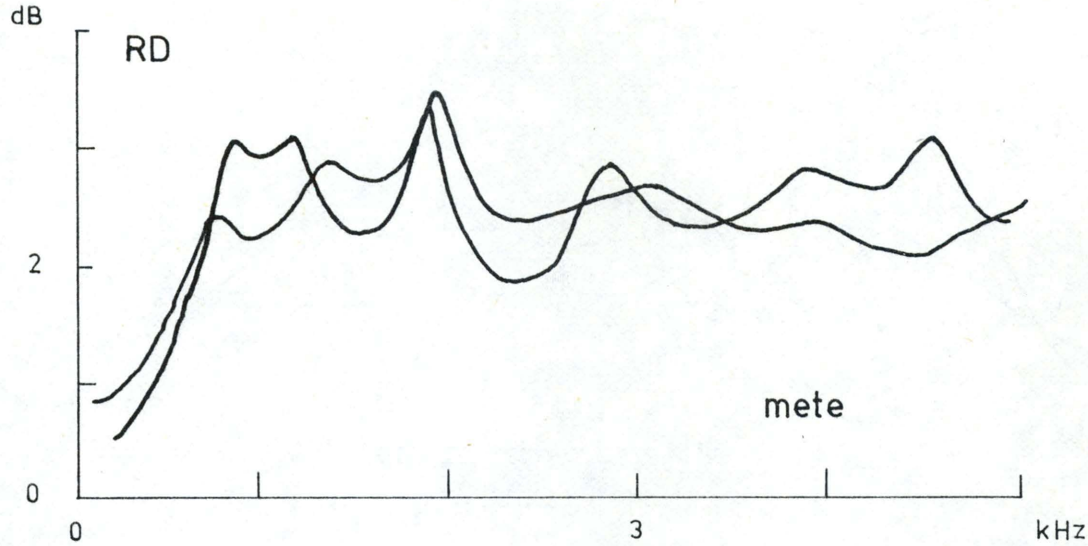


Figure 72

See legend to fig. 68.



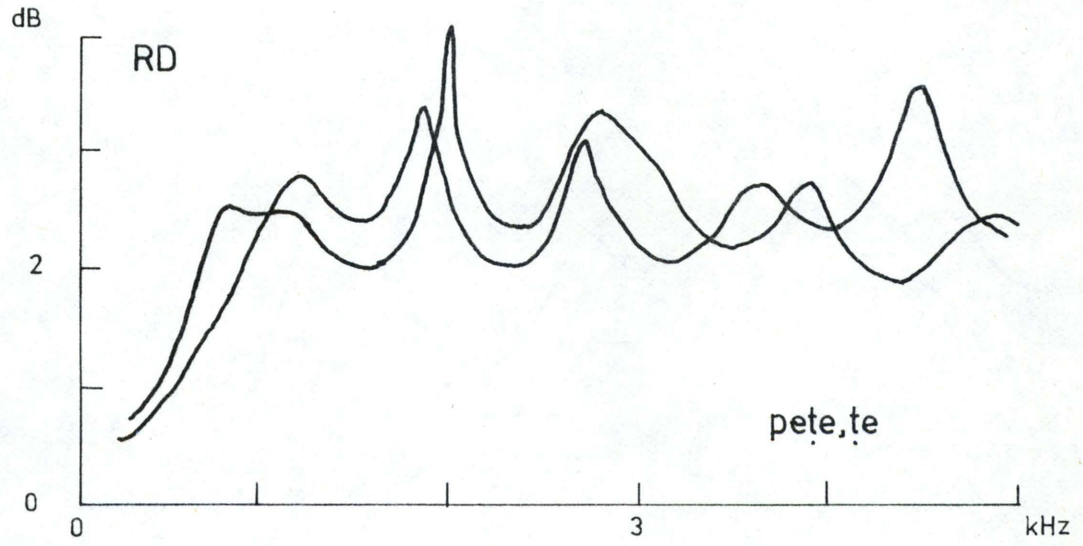


Figure 73
See legend to fig. 68.

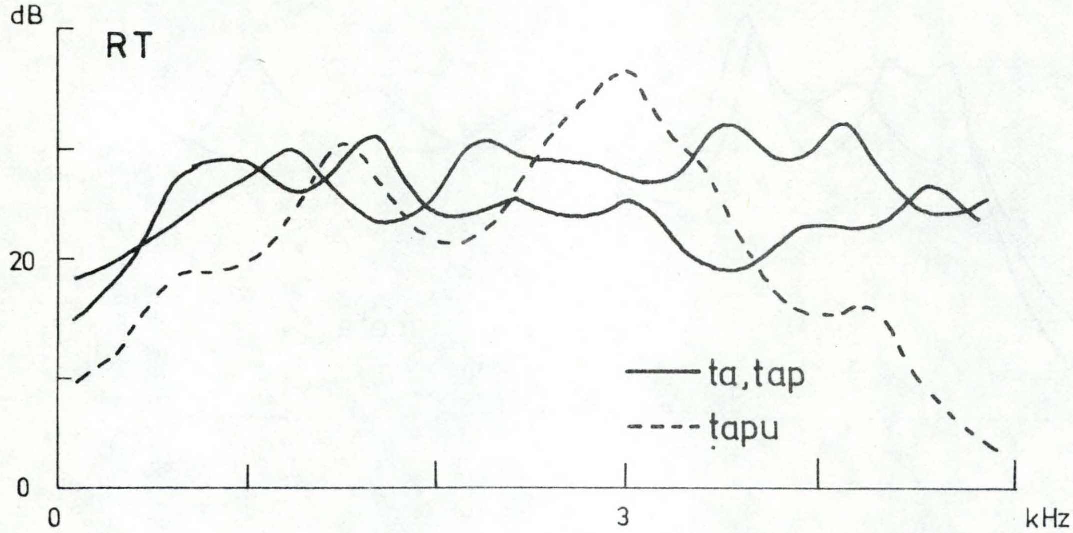


Figure 74
Burst spectra. Speaker RT.

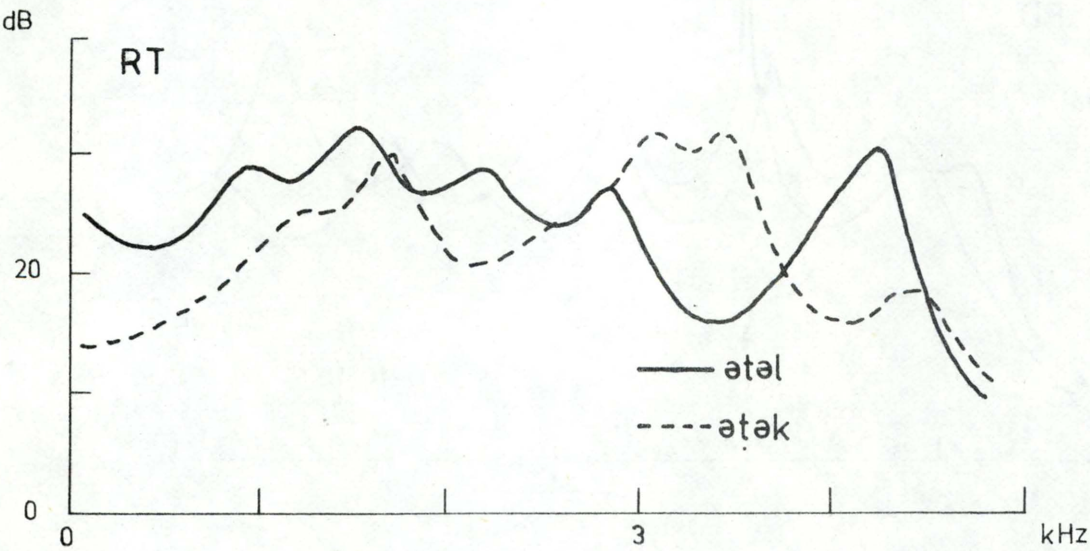


Figure 75
Burst spectra. Speaker RT.

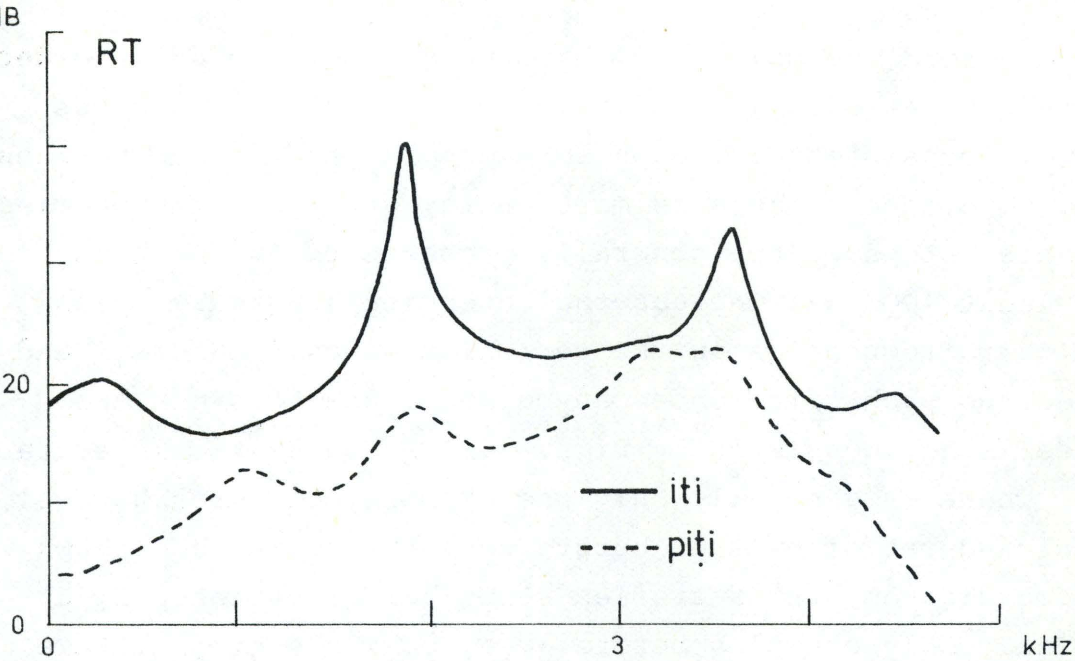


Figure 76
Burst spectra. Speaker RT.

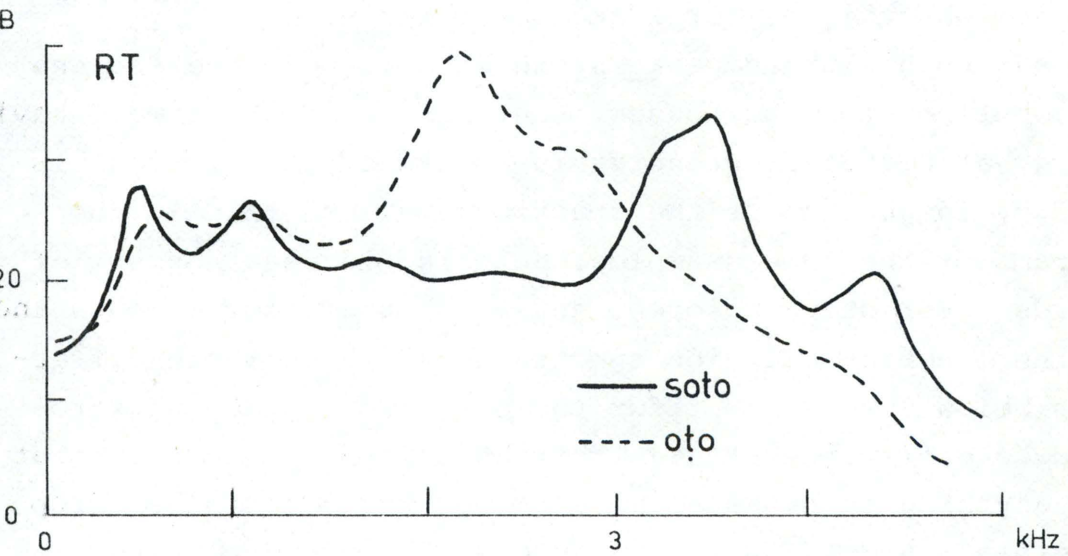


Figure 77
Burst spectra. Speaker RT.

point zero before the same vowel have been superimposed in order to show the variation. The differences between the two types are not very consistent although some general trends can be seen. Before a, u, o, and ə there is more energy at higher frequencies in the dental stops. They generally preserve their intensity up to at least 4000 Hz, whereas the intensity gradually falls off at higher frequencies in the retroflex stops. Before i and e, however, no such difference can be seen, and before a the difference is not consistent. Figs. 74-77 show similar spectra from RT. There is generally only one example before each vowel, and dental and retroflex stop bursts have therefore been shown in the same diagram, the retroflex stops being indicated by a dashed line. Only examples before a, ə, o, i are given (there was no pair before u, and before e it was not possible to distinguish the zero-curve from the other curves on the original picture). RT has a more consistent difference: the bursts of the retroflex consonants seem to have a rather broad peak around 3000 Hz, somewhat higher for i and lower for u.

RD has such a broad peak in one example before a and one before ə, but not in other cases. But RD's tendency toward having more energy at higher frequencies in bursts of dental stops is confirmed by inspection of the spectrograms, not only in the spectrograms of the same examples, but also in spectrograms of other words. For stops before o and u the spectrograms show the same as the linear prediction spectra because the whole difference lies below 5000 Hz, but for the other vowels the spectrograms show a difference at higher frequencies.[1] It is rare that there is anything to be seen above 4-5000 Hz in retroflex stop bursts before a and ə, but dental stops show energy around 5-6500 Hz and sometimes higher (see Fig. 78 showing the differences before ə). As for stops before the front vowels e and i, both may show some energy above 5000 Hz, but the retroflex stops have a concentration of energy from 2500-4500 Hz, whereas the

1) This is not seen in the linear prediction spectra.

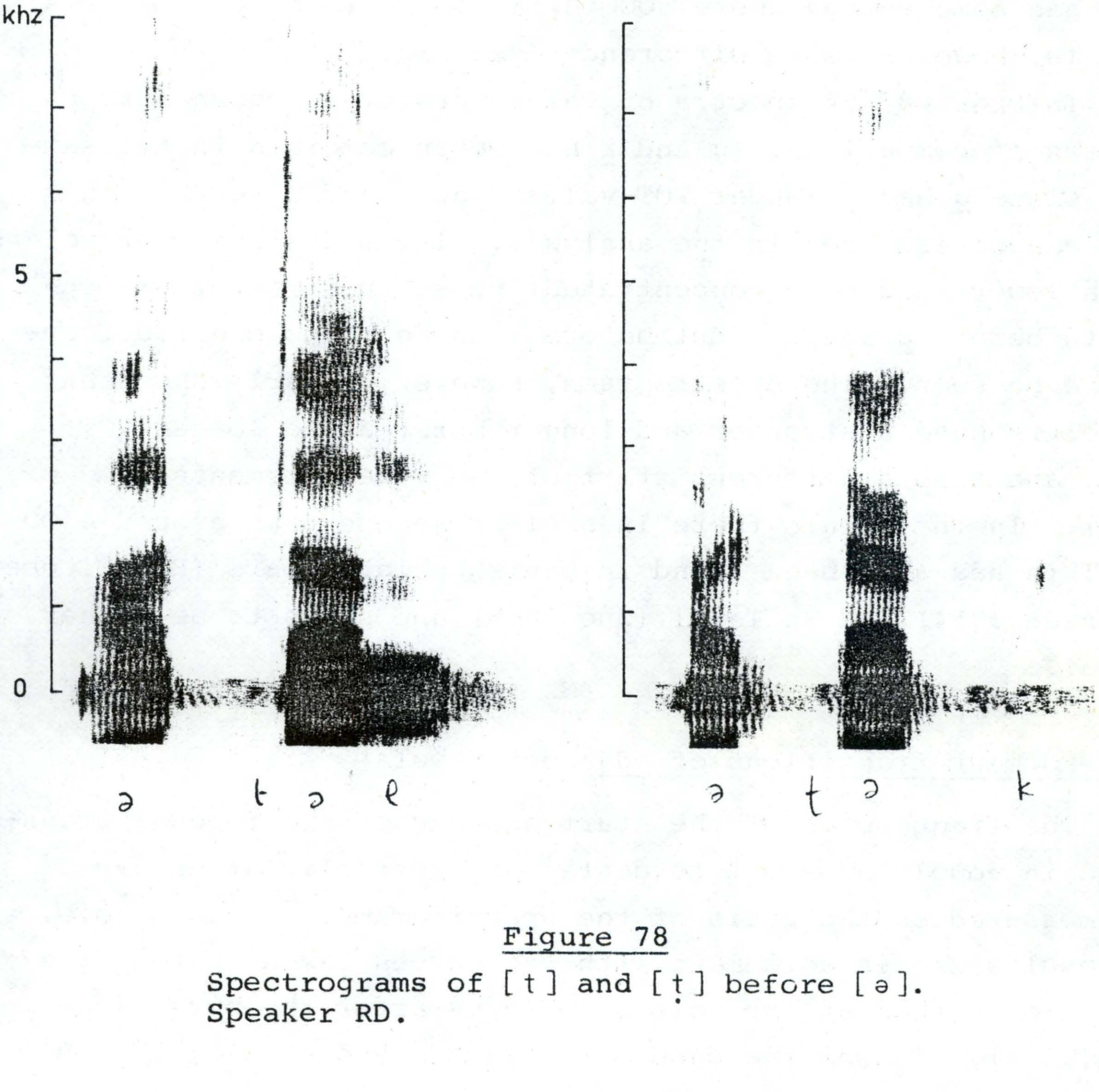


Figure 78
Spectrograms of [t] and [ṭ] before [ə].
Speaker RD.

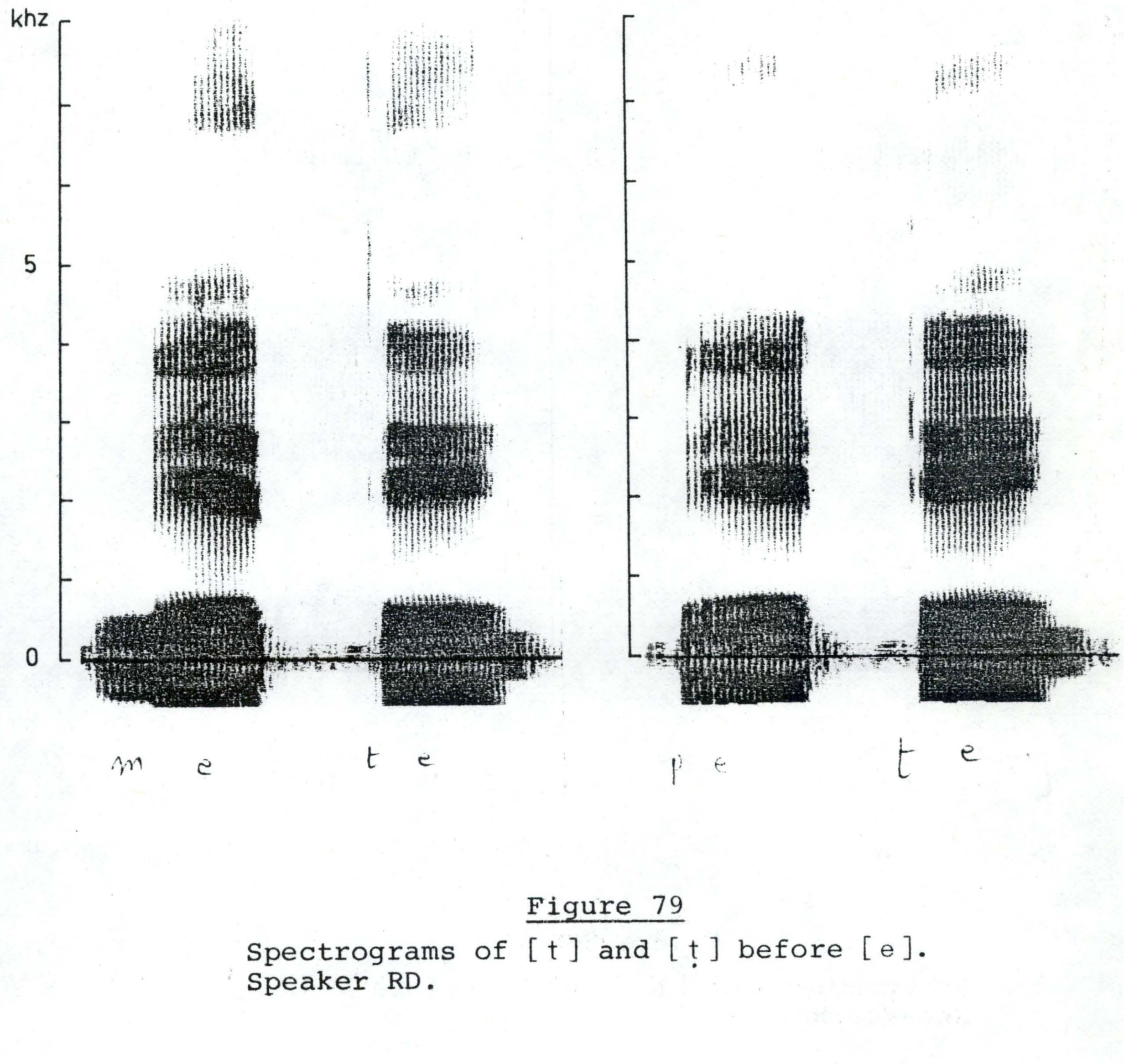
dental stops have more energy at higher frequencies. This is very evident for e (Fig. 79). Before i both have high frequency noise but ti has less energy at the frequencies at which ṭi shows concentration of energy. These differences are rather consistent (see Fig. 80).

In RT's spectrograms the distinction is less clear; he often has some energy above 5000 Hz in the bursts in all cases; there is, however, some difference (see Fig. 81).

In Figs. 82-84 spectra of velar bursts are shown for purposes of comparison. g and k have been combined in the same graph since g has a longer VOT-value than b and d so that the burst can be isolated in the analysis. It is evident that velars have a lower (and more concentrated) burst than retroflex consonants before a and u. But before i there is no clear difference to be seen. The spectrograms, however, clearly show that the velars have a stronger and longer burst and a longer VOT value, and also a different start of the vowel formants (see below). In the velars there is a clear second peak around 4500 Hz. This has also been found in Danish palatovelars (Eli Fischer-Jørgensen 1954) and in Tamil (Zue 1976) and seems to be rather general.

C. Formant transitions of adjacent vowels

The frequencies of the start and end of the formant transitions in vowels adjacent to dental and retroflex stops have been measured on the basis of the spectrograms. On the whole, the results are in agreement with the curves taken by the linear prediction method at the points 10-15 ms after the burst (see above, 3.4). As was the case with liquids and nasals, only RD's spectrograms have been measured, but they have been compared with RT's spectrograms of list I-VII by visual inspection.



<u>Figure 79</u>

Spectrograms of [t] and [ṭ] before [e].
Speaker RD.

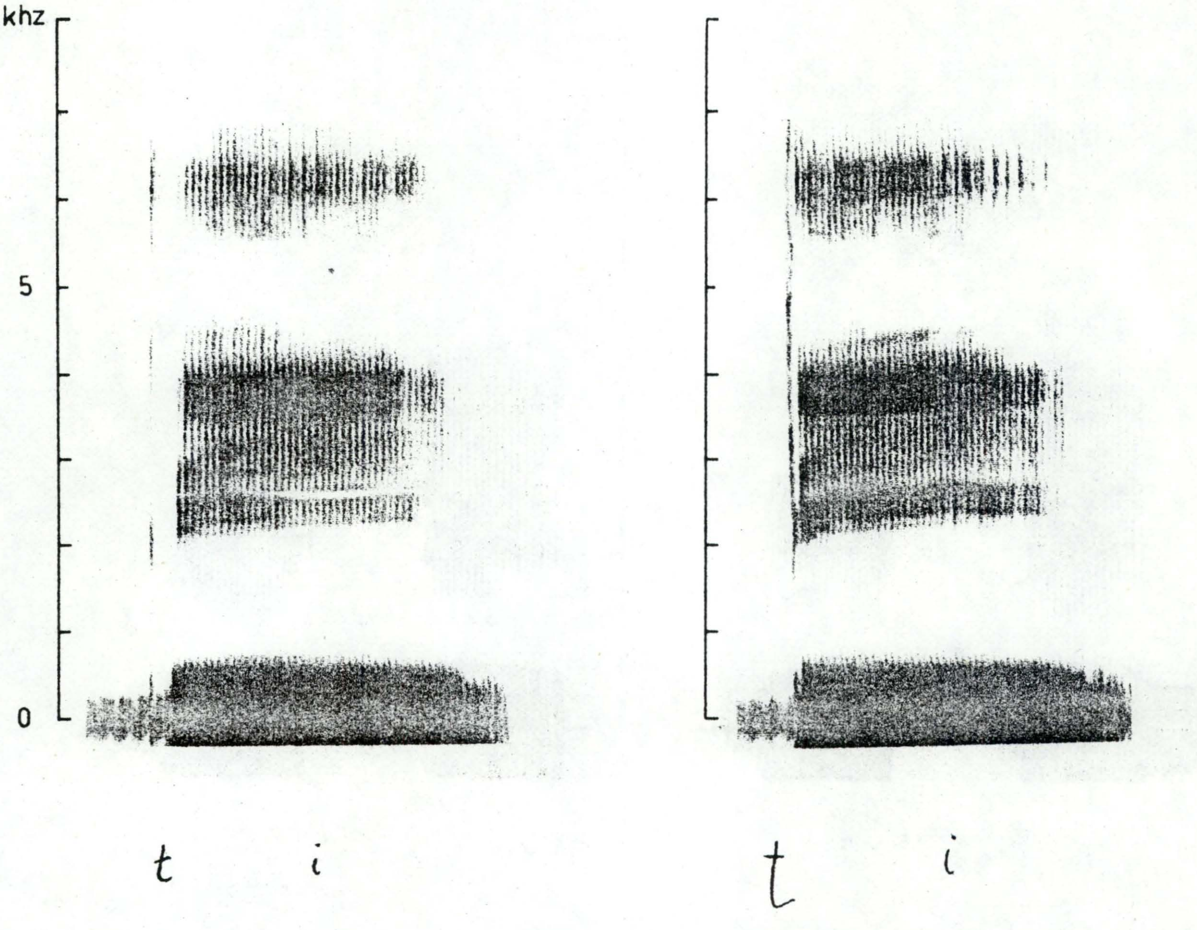


Figure 80

Spectrograms of [t] and [ṭ] before [i].
Speaker RD.

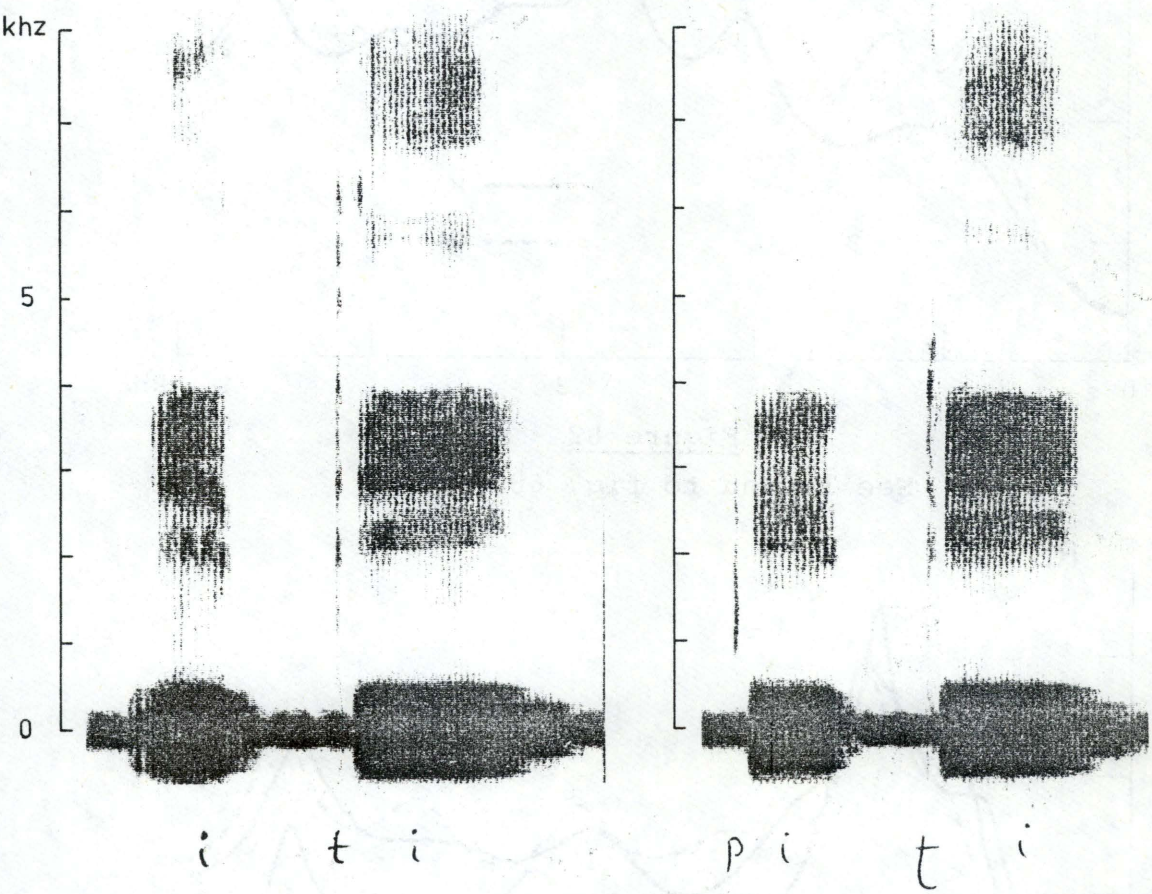


Figure 81

Spectrograms of [t] and [ṭ] before [i].
Speaker RT.

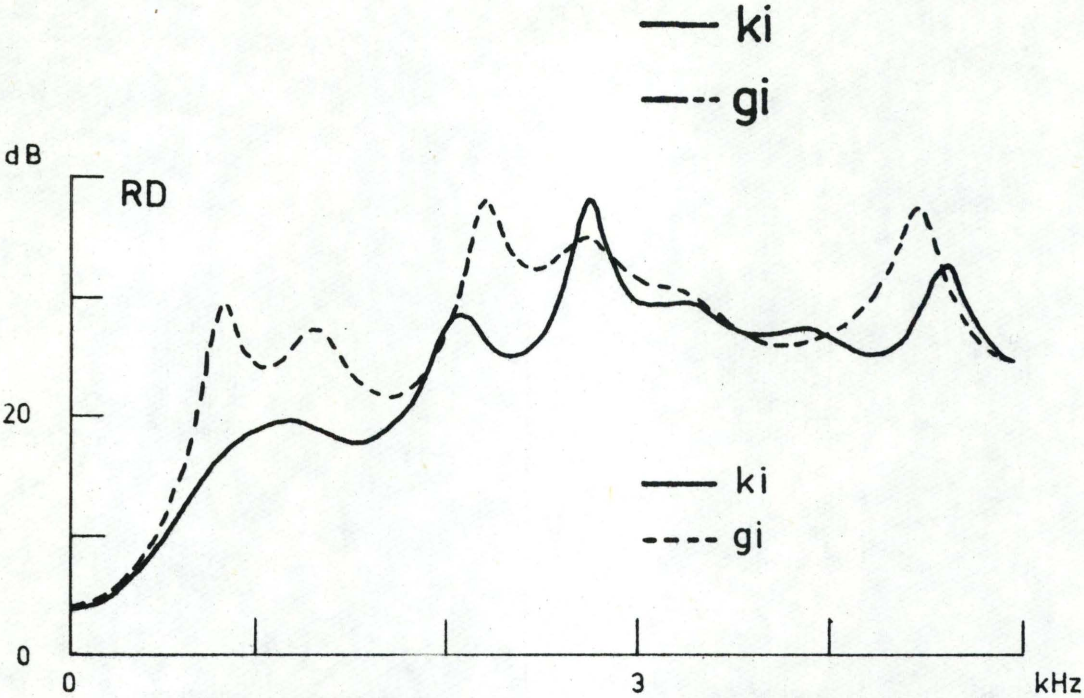


Figure 82

See legend to fig. 68.

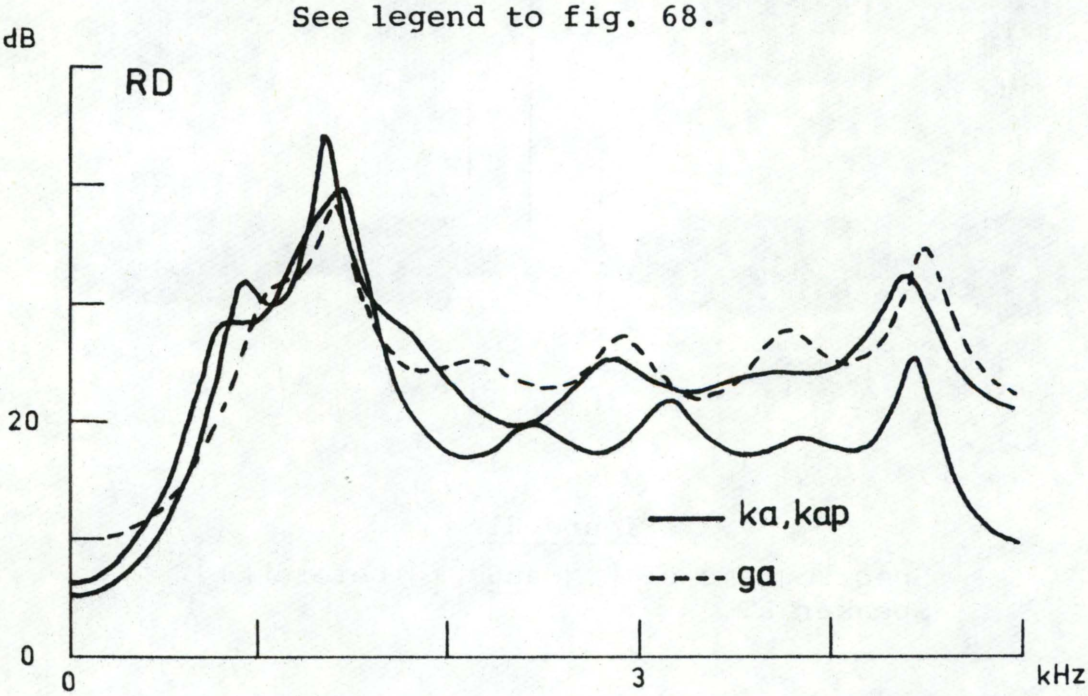


Figure 83

See legend to fig. 68.

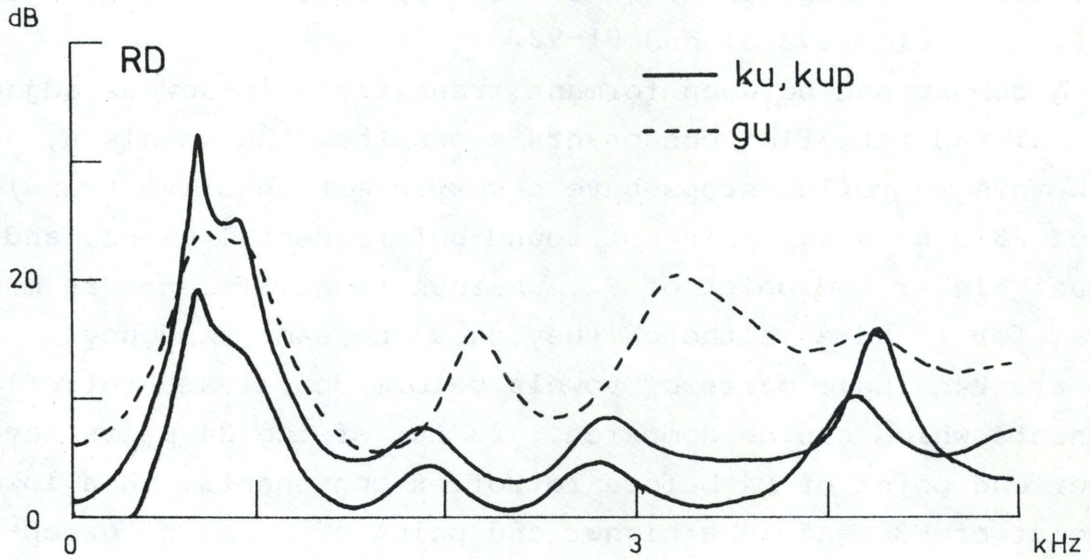


Figure 84
See legend to fig. 68.

The frequencies and extent of the transitions are given in tables 4-9 of the Appendix, and schematic drawings of the transitions are found in Figs. 85-90. Specimens of spectrograms are given in Figs. 78-81 and 91-92.

A comparison between formant transitions in vowels adjacent to dental and retroflex consonants shows that the vowels a, ə, u, o before retroflex stops have a very clear negative transition of F3 and F4 which is not found before dental stops, and a somewhat higher end point of F2, whereas the difference is much smaller for i and e, although they show the same tendency. There are 24 single pairs of vowels before dental and retroflex consonants which can be compared. 22 out of the 24 pairs have a lower end point of F4 before retroflex consonants, 18 a lower end point of F3, and 19 a higher end point of F2. The exceptions for F4 are oḍ and iḍ, for F3 all six examples of i and e, and for F2 uḍ and uṭ. The differences are highly significant for all the vowels taken in one group, but it is evident that the exceptions concerning e and i are systematic. They have negative transitions of F3 like the others, but the transitions do not go as far down. In one case (eḍ) the transition of F3 even goes up, but there was only one example, and in this case the following vowel was not e but i, and the positive transition of F3 is due to coarticulation with the following i, so this figure is misleading.

The lowering of F3 and F4 also affects the steady state frequency of the preceding vowels. This is true in 10 out of 12 averages for both F3 and F4, and this is also valid for e and i. The exceptions for F3 are oṭ and iṭ, for F4 aḍ and oḍ.

The vowels following dental and retroflex consonants do not show any consistent differences except that o has a lower F4 after retroflex consonants, and a a significantly lower F3 and a higher F2 after retroflex consonants.

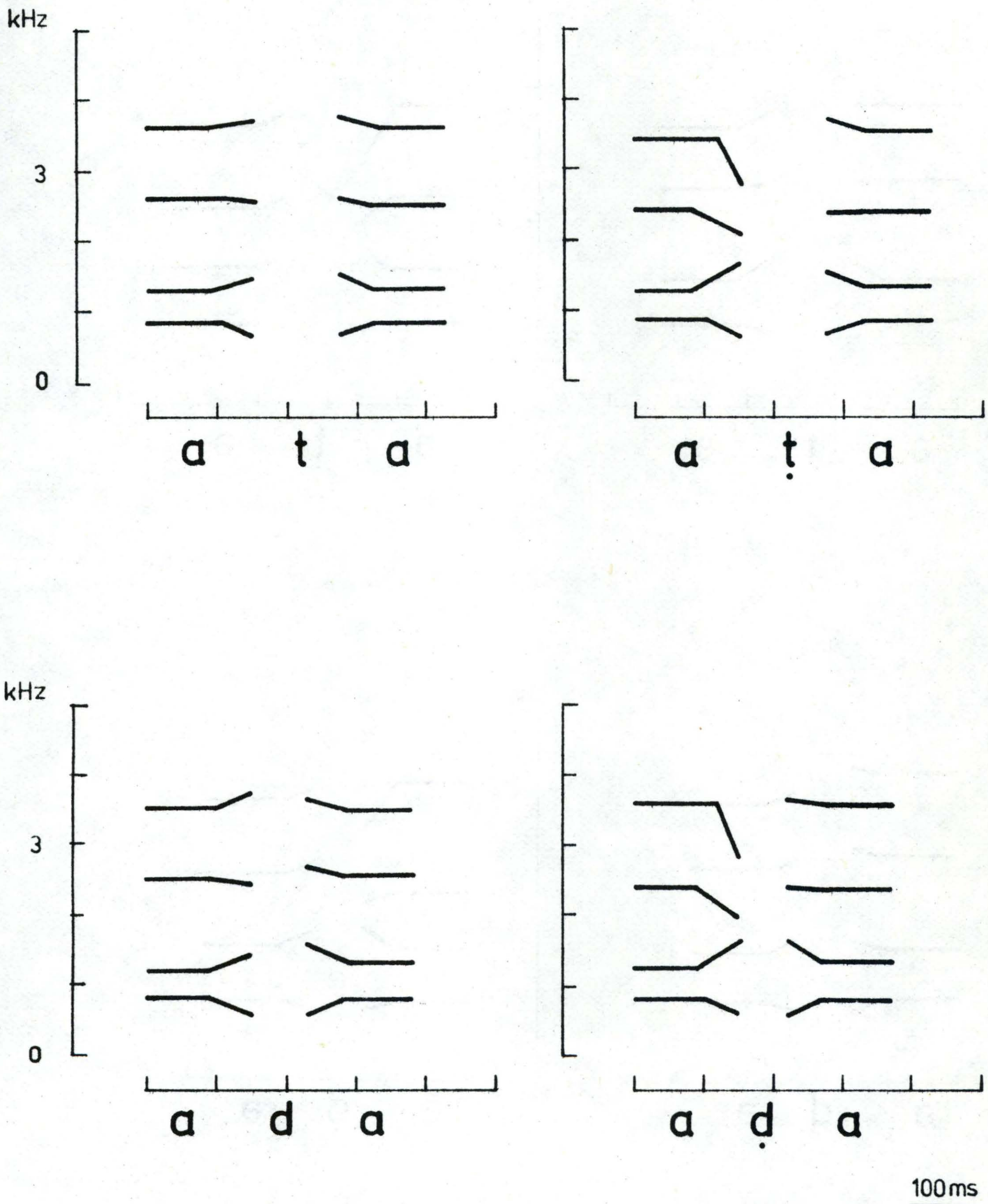


Figure 85

Schematized spectrograms. Speaker RD.

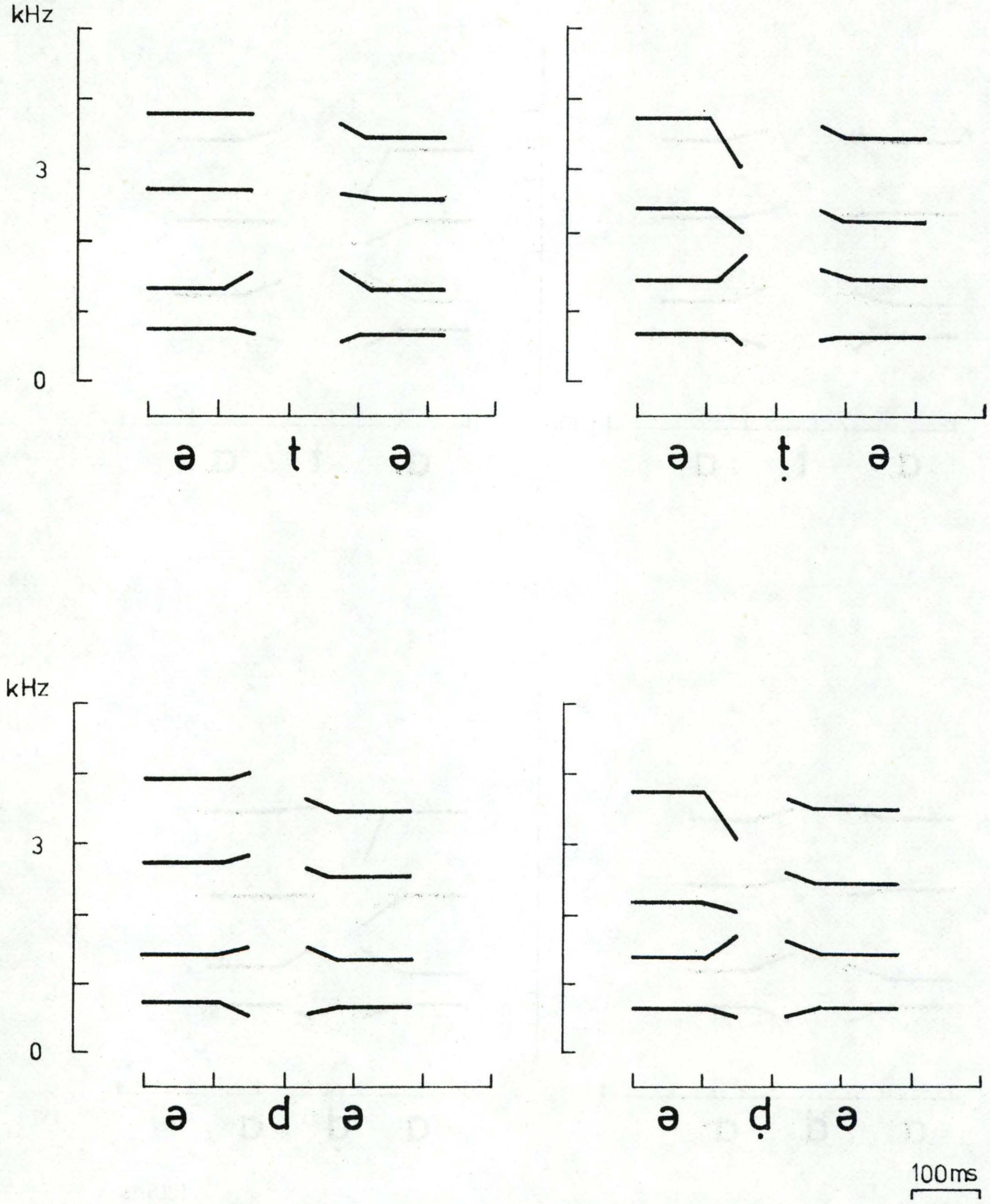


Figure 86

Schematized spectrograms. Speaker RD.

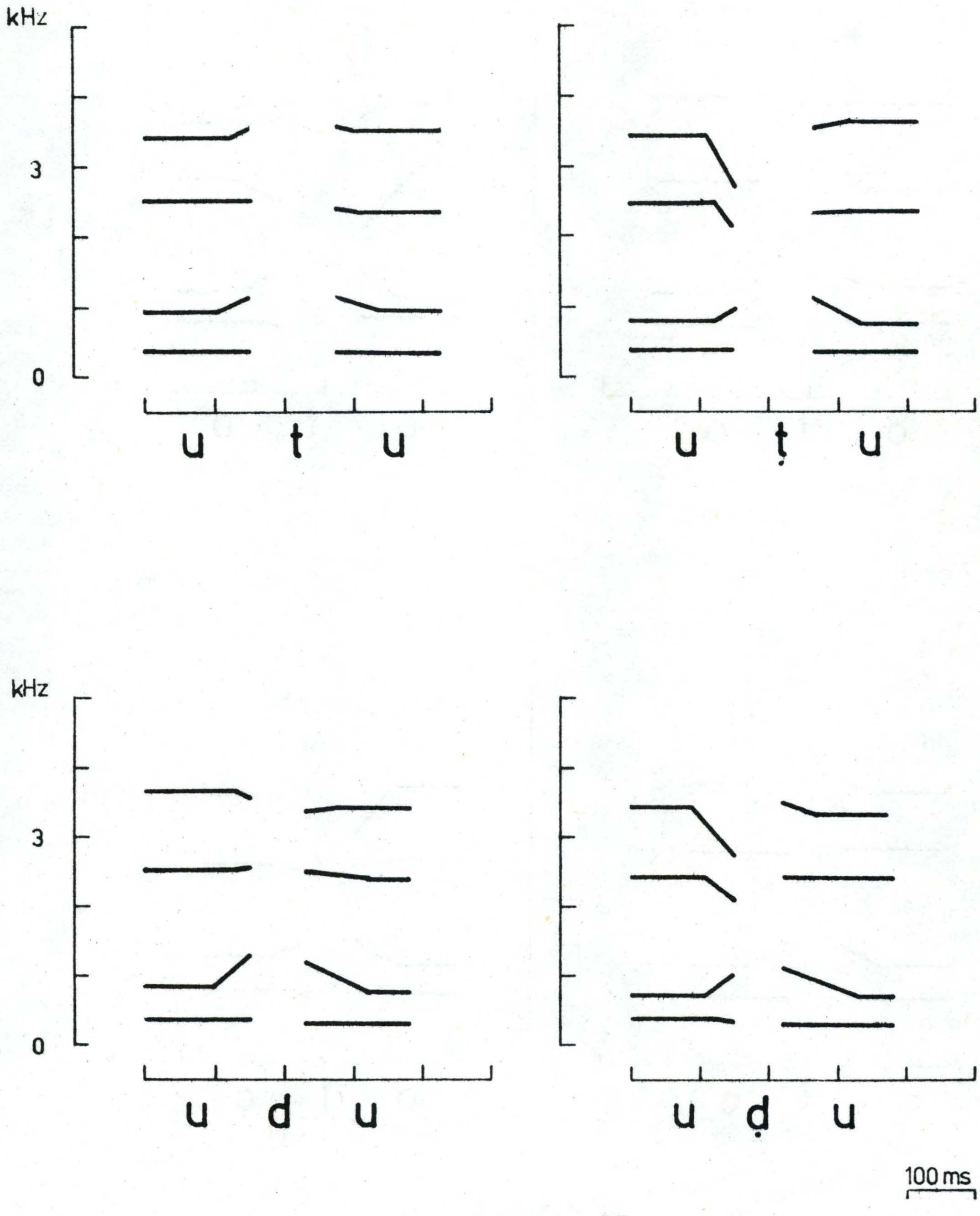


Figure 87

Schematized spectrograms. Speaker RD.

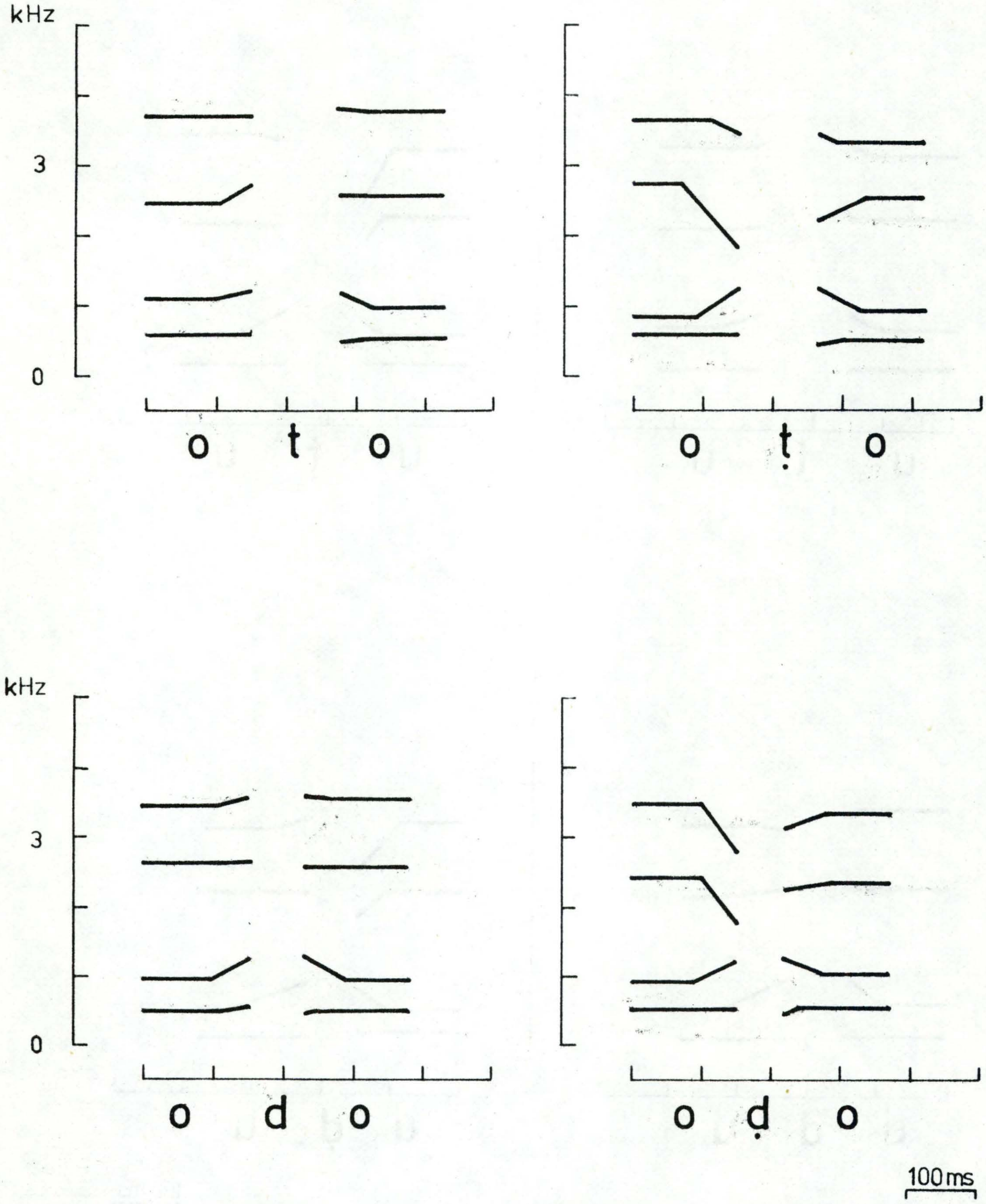


Figure 88

Schematized spectrograms. Speaker RD.

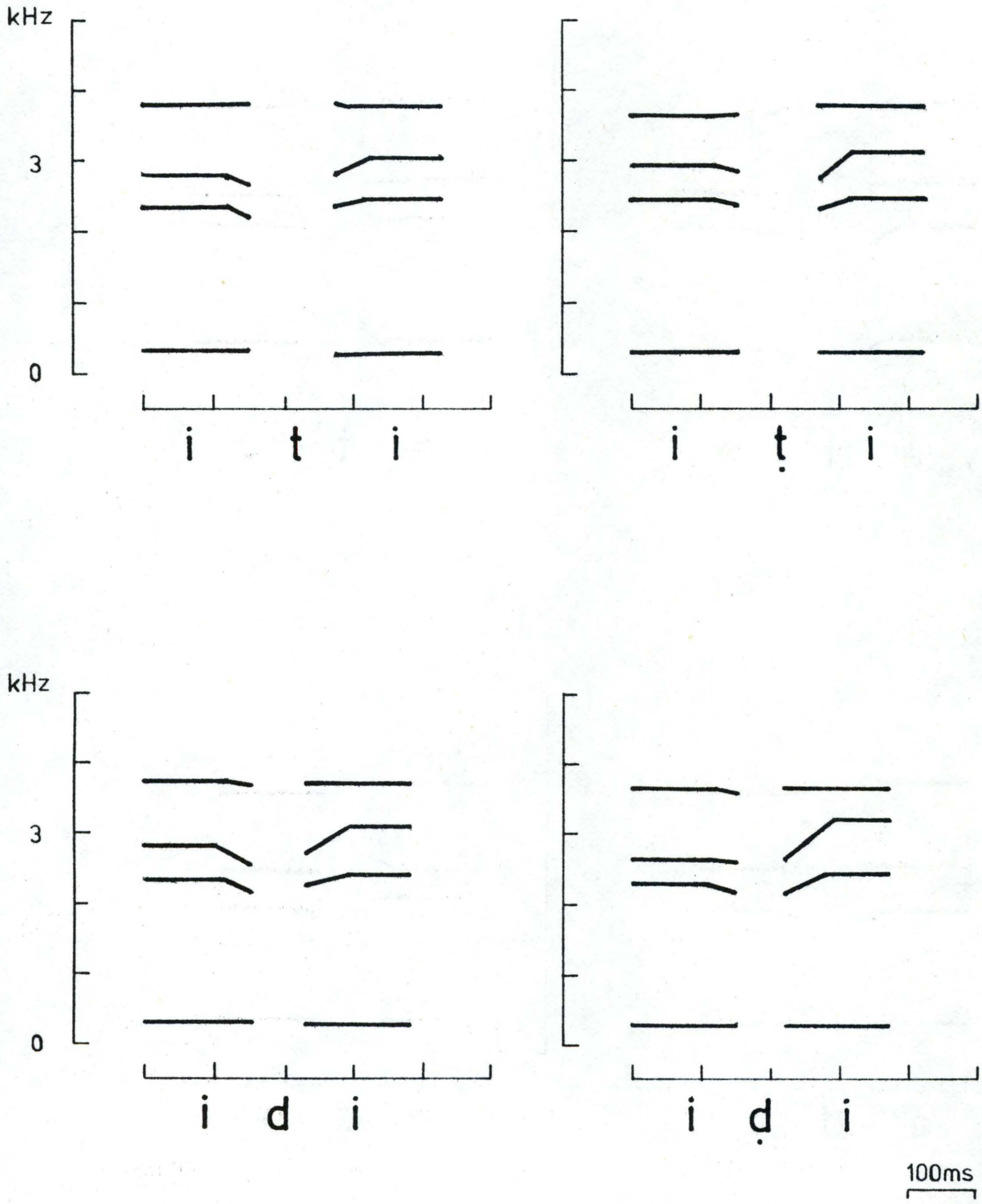


Figure 89

Schematized spectrograms. Speaker RD.

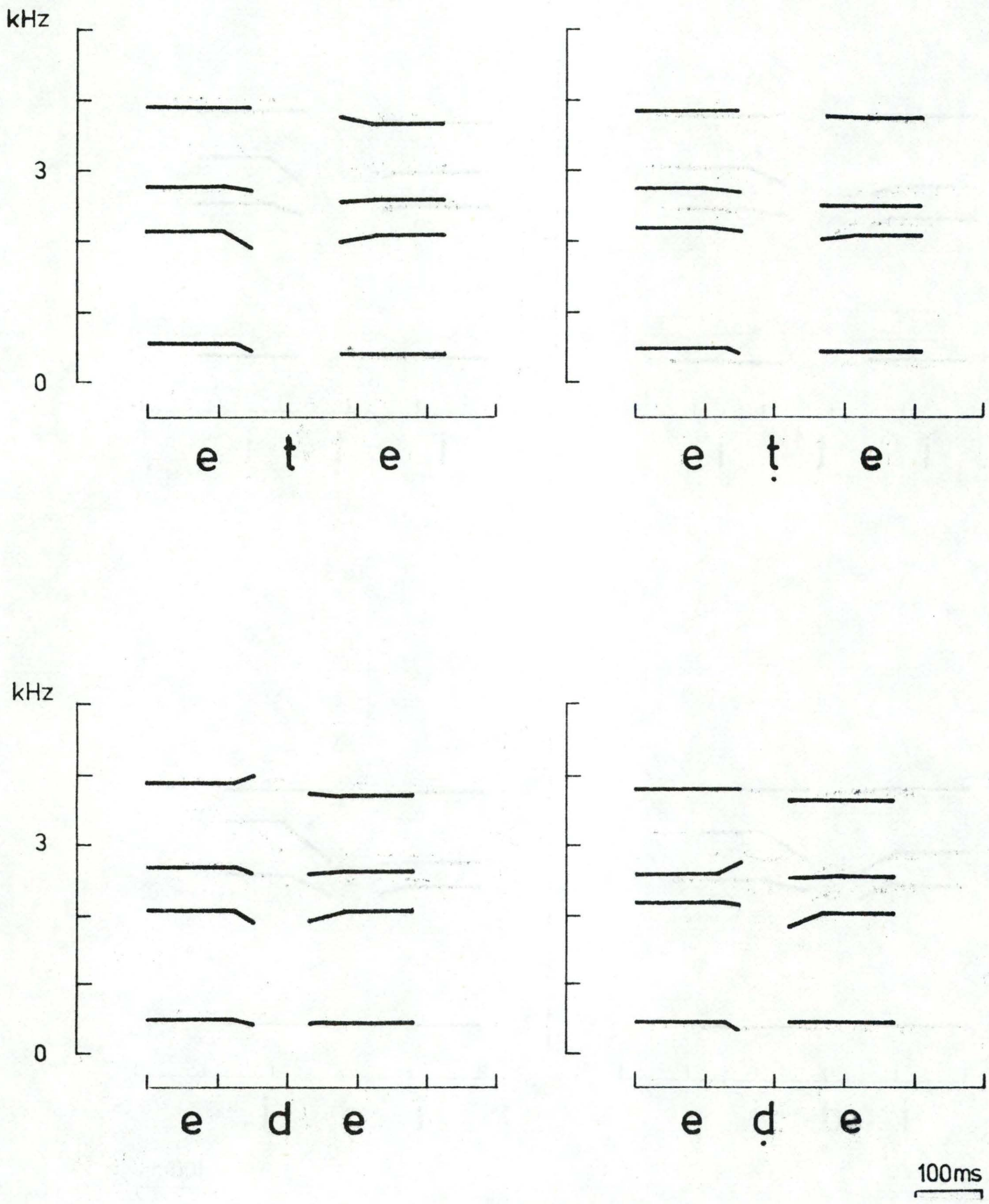


Figure 90

Schematized spectrograms. Speaker RD.

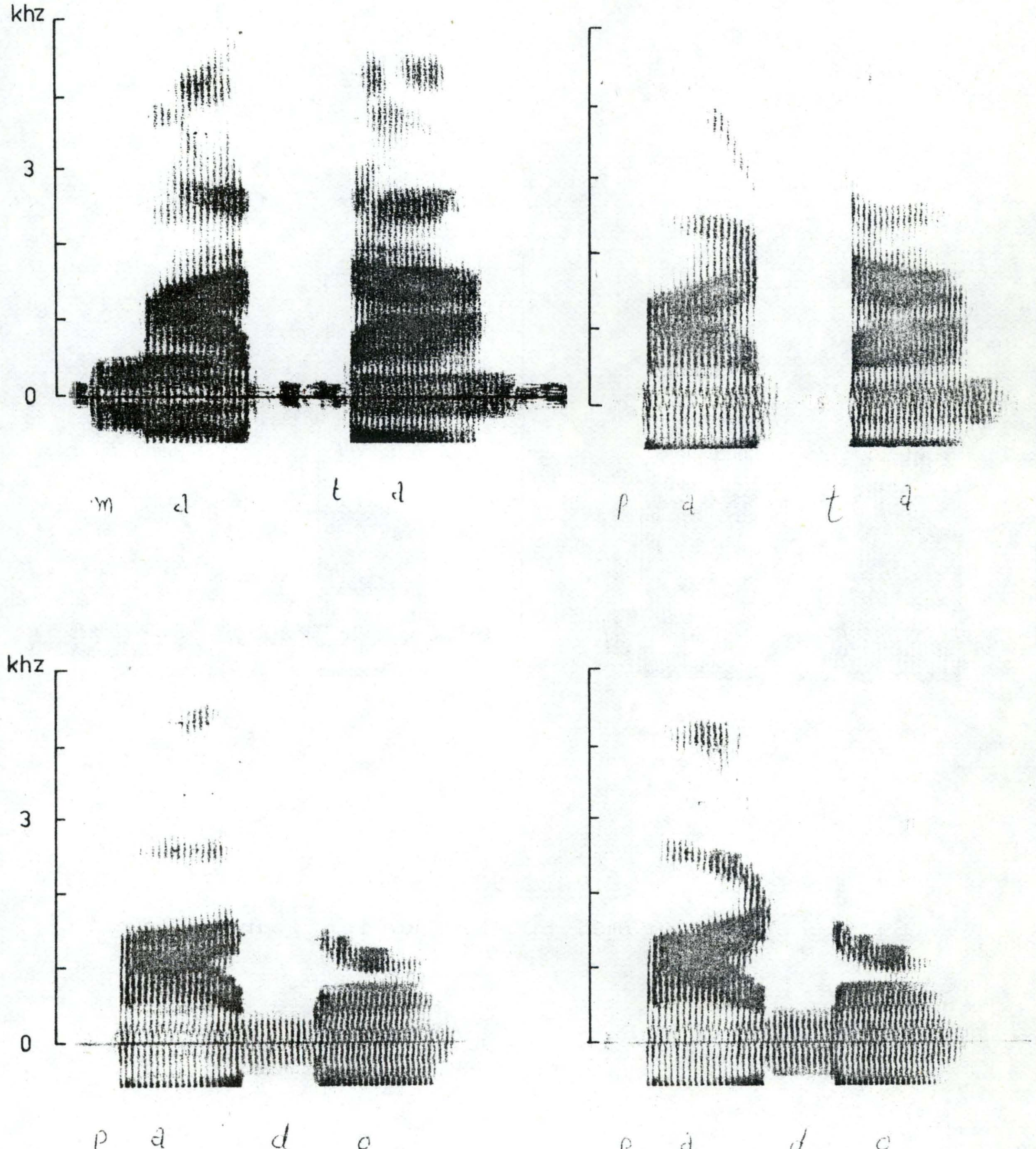


Figure 91

Sample spectrograms. Speaker RD.

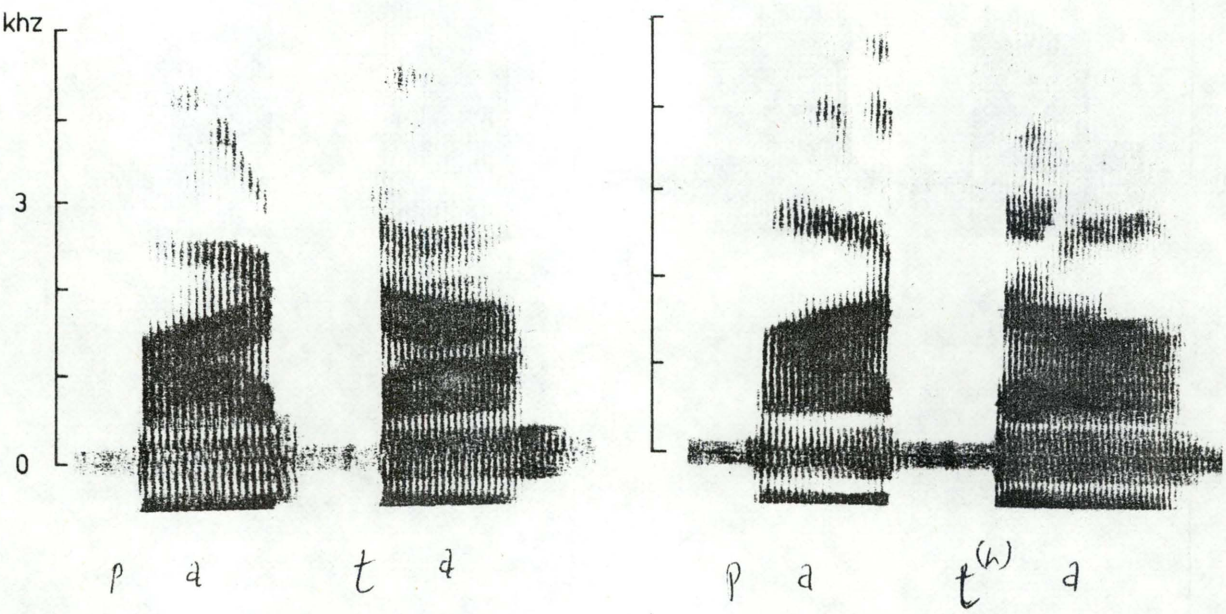


Figure 92

Sample spectrograms. Speaker RD left, and RT right.

In Figs. 93-95 the average transitions of the formants of preceding vowels have been set up in a graph showing how the formants of different vowels converge.

For F2 it is possible to set up a locus with tolerable precision. It is evidently higher before retroflex consonants than before dental consonants. If we take the average between the two end points of the falling and rising transitions which are closest together, those of *e* and *ə*, the result is 1672 and 1737 Hz for the dentals *t* and *d*, respectively, and 1950 and 1958 for the retroflex stops *ṭ* and *ḍ*, respectively. If we extrapolate from the direction of the close transitions of *e* and *ə* they will meet at approximately 50 ms distance, as they should according to the Haskins experiments (but the other vowels won't, and they should not be expected to, either, in real speech). This method gives 1700 for dentals, and 2000 and 2200 for *ṭ* and *ḍ*, respectively. Thus it can be said that there is a locus around 1700 Hz for dentals, and around 2100 Hz for retroflex stops.

As for F3 and F4, the transitions are not as regular, and it can only be said that an F3 locus for dental *t* and *d* must be somewhat below 3000 Hz, approximately at 2700 Hz, which is in good agreement with what has been found earlier. As for F4, it could be somewhat above 3500 Hz, but this is rather guesswork.

F3 and F4 in retroflex consonants, on the other hand, do not point to a definite frequency, but simply go steeply downward, except for *e* and *i* which show very little influence at all (*e* before *ḍ* goes upwards which is due to coarticulation with a following *i*, as mentioned above). The lowest point reached by the F3 transitions is 1800 Hz, and that reached by the F4 transitions is 2750 Hz.

RT's spectrograms show quite similar transitions of F3 in retroflex consonants, but he rarely has any transition of F4 (see Fig. 92).

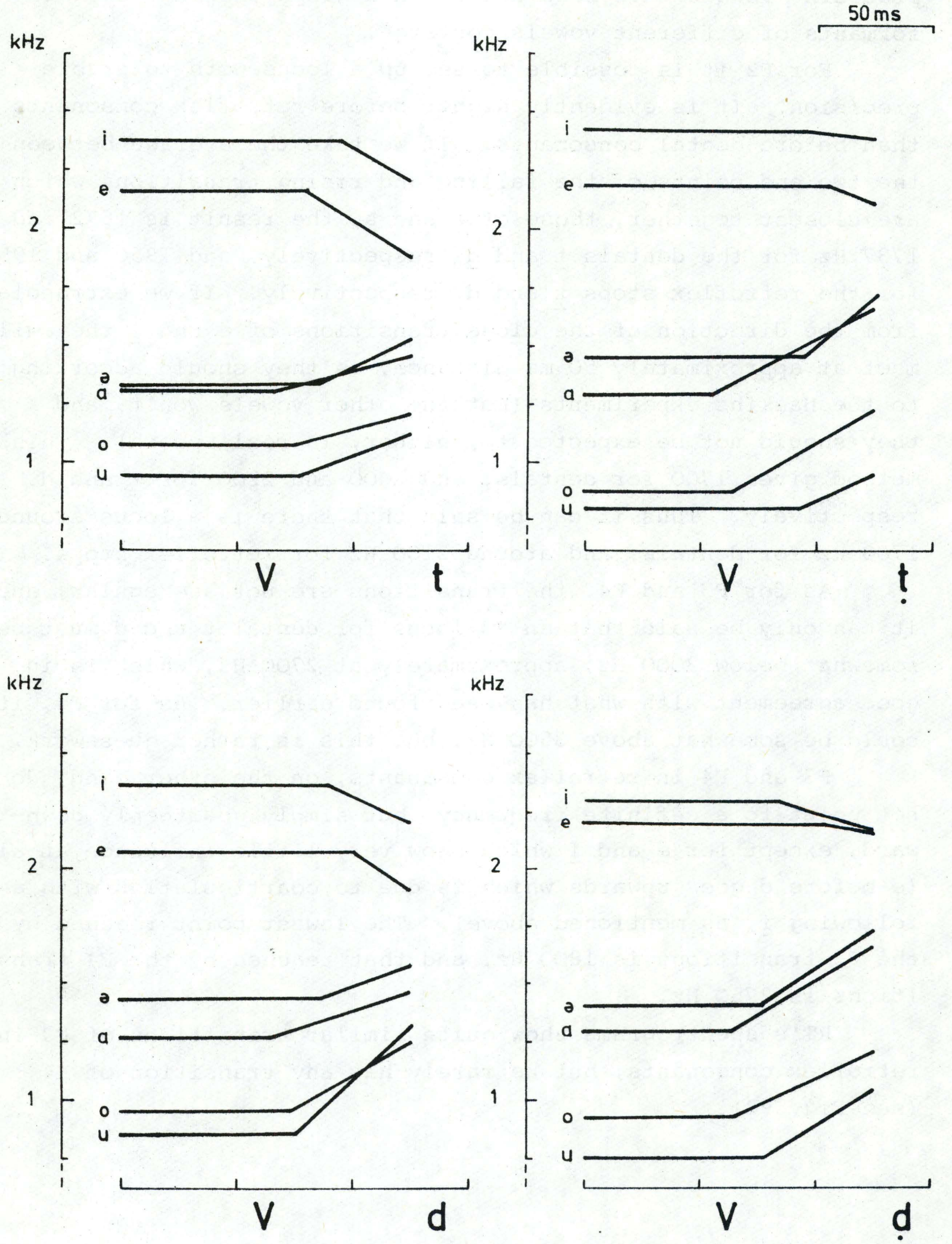


Figure 93

Schematized F_2 movements. Speaker RD.

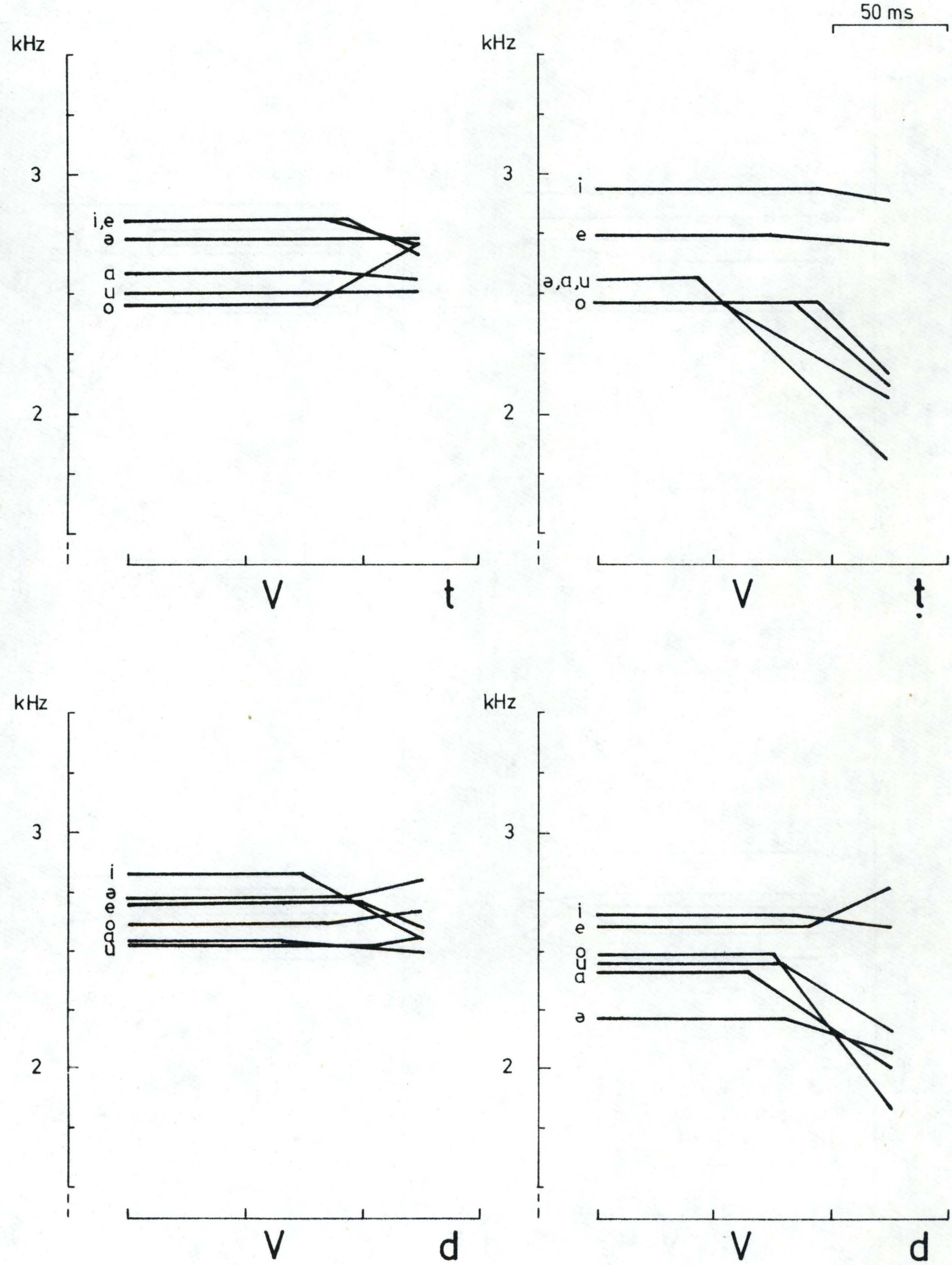


Figure 94

Schematized F_3 movements. Speaker RD.

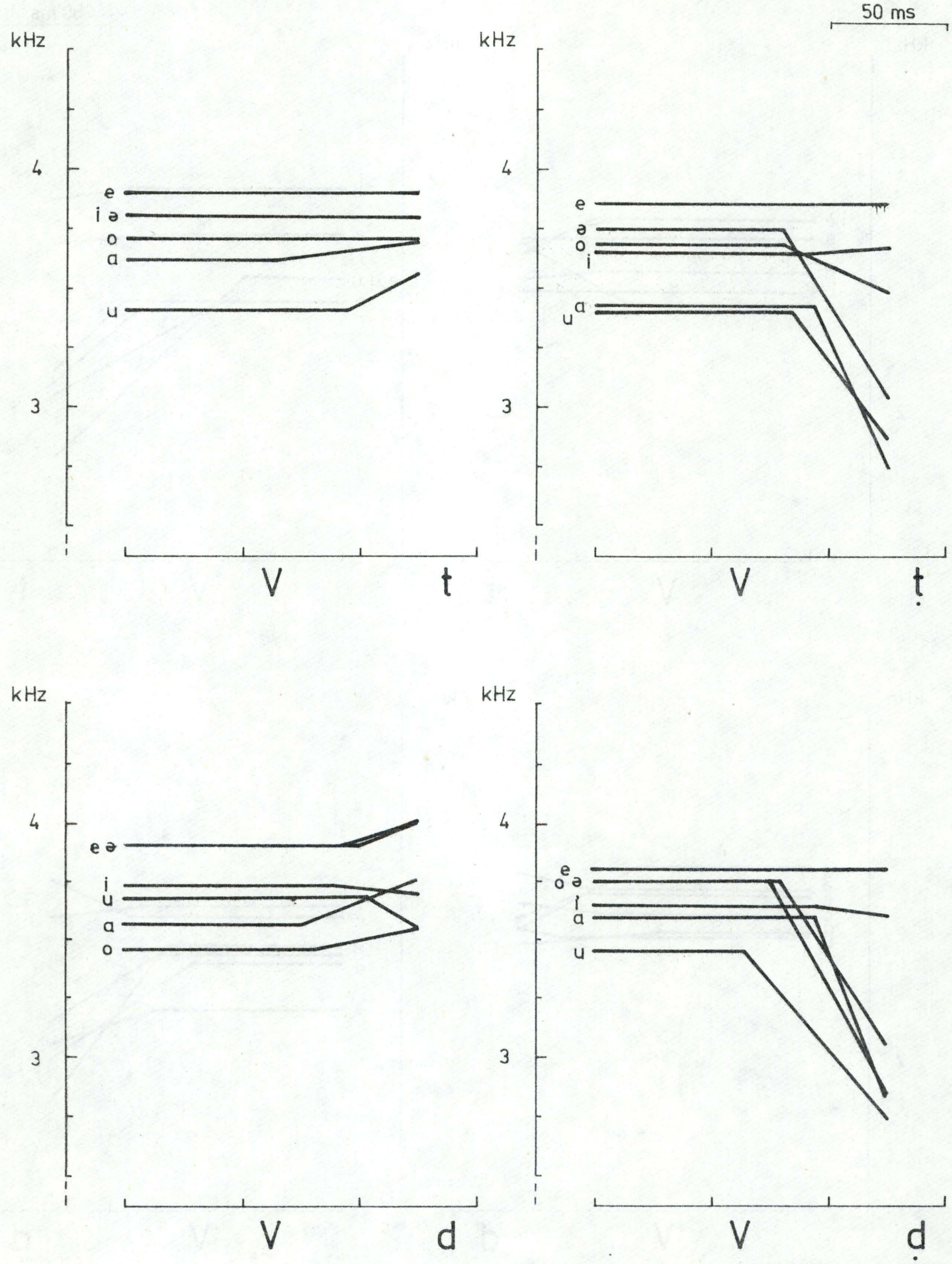


Figure 95

Schematized F_4 movements. Speaker RD.

D. Comparison with formant transitions adjacent to other stop consonants

List IX, spoken by RD only, also contains examples of labial, palatal, and velar stops before the six vowels (in connection with a there are also examples after the vowel). Measurements of vowel transitions after these consonants were made for the purpose of comparing them with the transitions after dental and retroflex consonants. This comparison was interesting, particularly because Stevens and Blumstein (1975) have shown that retroflex and velar consonants before a can be synthesized with the same transitions (but with different bursts).

The material is rather restricted. There are examples of all vowels following labial, velar, and palatal stops, but normally only one example of each, so that the results should be taken with some reservations. As for preceding vowels, the material comprises a + p b k g, ə+g, and i+k. The tables containing the frequencies of transitions with these consonants have been left out here (they are found in the thesis), but schematic diagrams of the transitions are given in Figs. 96-101. The curves are arranged so that they can be compared with Figs. 85-90 containing dental and retroflex stops.

A comparison between Fig. 85 and Fig. 96 shows that there is a high degree of similarity between the transitions of the vowel a following a velar consonant and a following dental or retroflex consonant. As for a preceding a, the transitions of F2 and F3 are very much alike for velars and for retroflex stops, but F4 has a clearly different transition. There is also similarity between the formant transitions of ə before retroflex and velar consonants, but in the case of a preceding ə there is a clear difference not only in F4, but also in F2 and F3. As for the other vowels, the material comprised only CV syllables with velars (except ik). In these cases there is a difference in F2, which has a positive transition in u and o after retroflex stops but a level transition after a velar stop, whereas i and e have negative F2-transition after a retroflex stop, but rising or level transition after a velar stop. Thus the similarity in

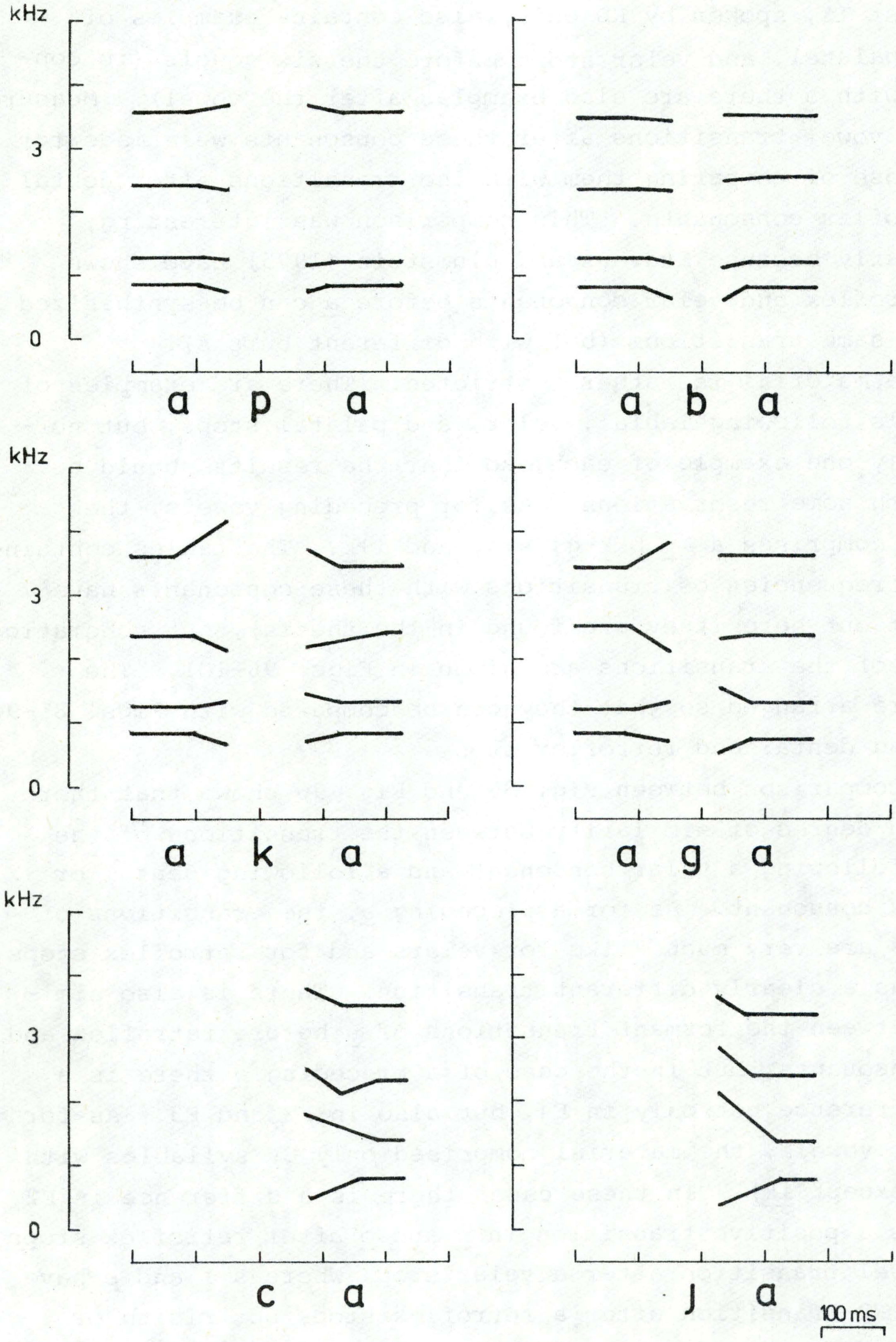


Figure 96

Schematized spectrograms. Speaker RD.

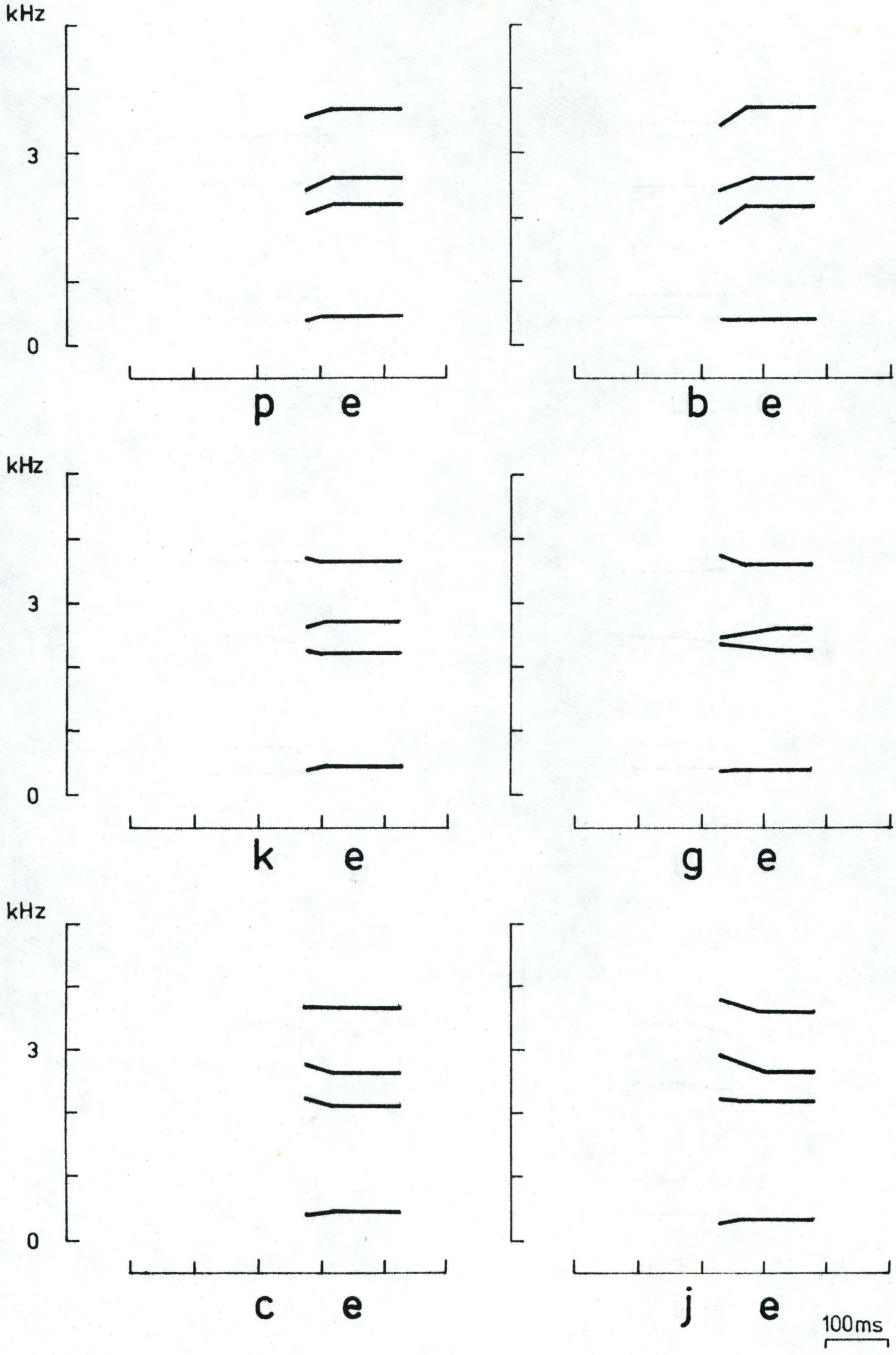


Figure 97

Schematized spectrograms. Speaker RD.

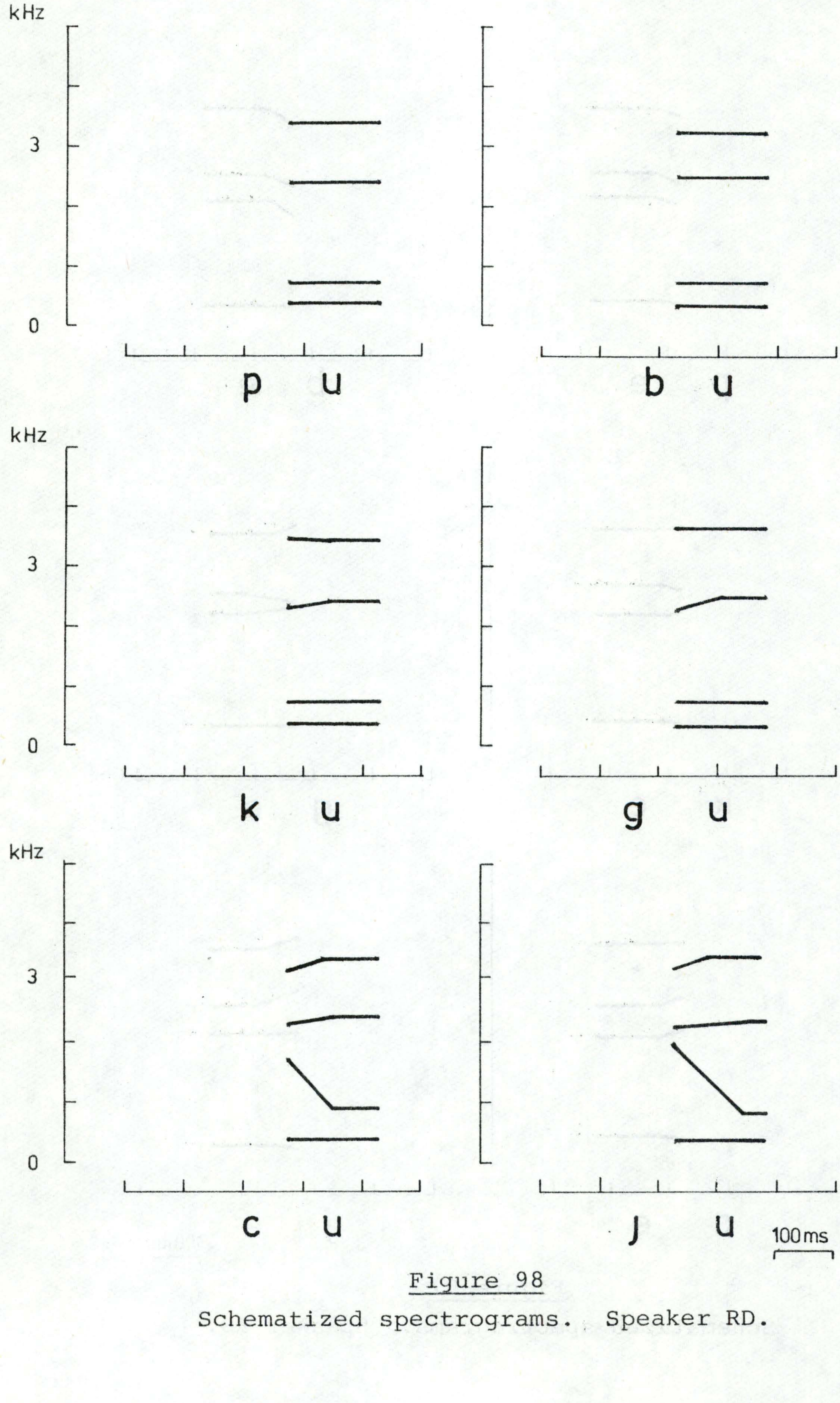


Figure 98

Schematized spectrograms. Speaker RD.

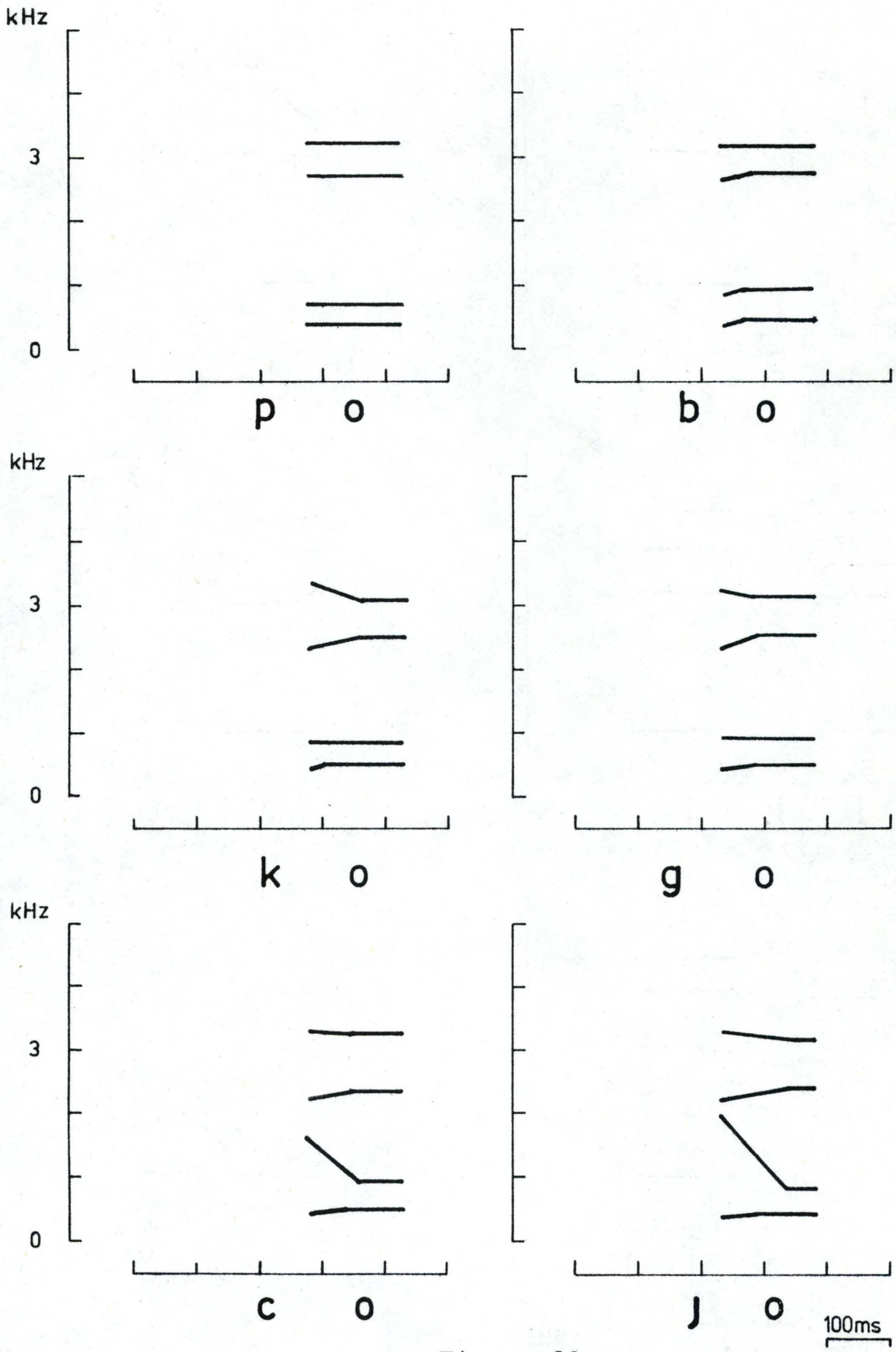


Figure 99

Schematized spectrograms. Speaker RD.

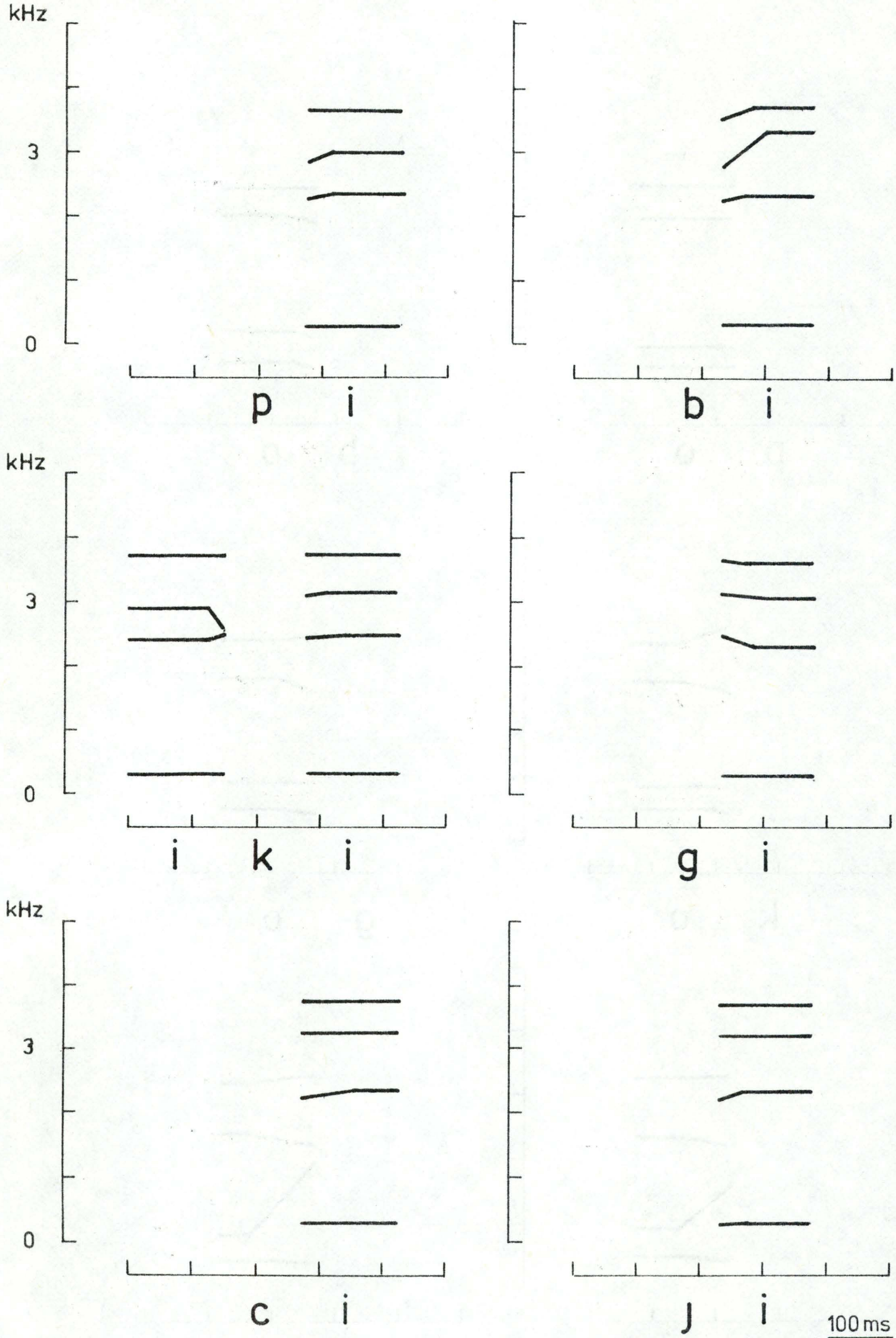
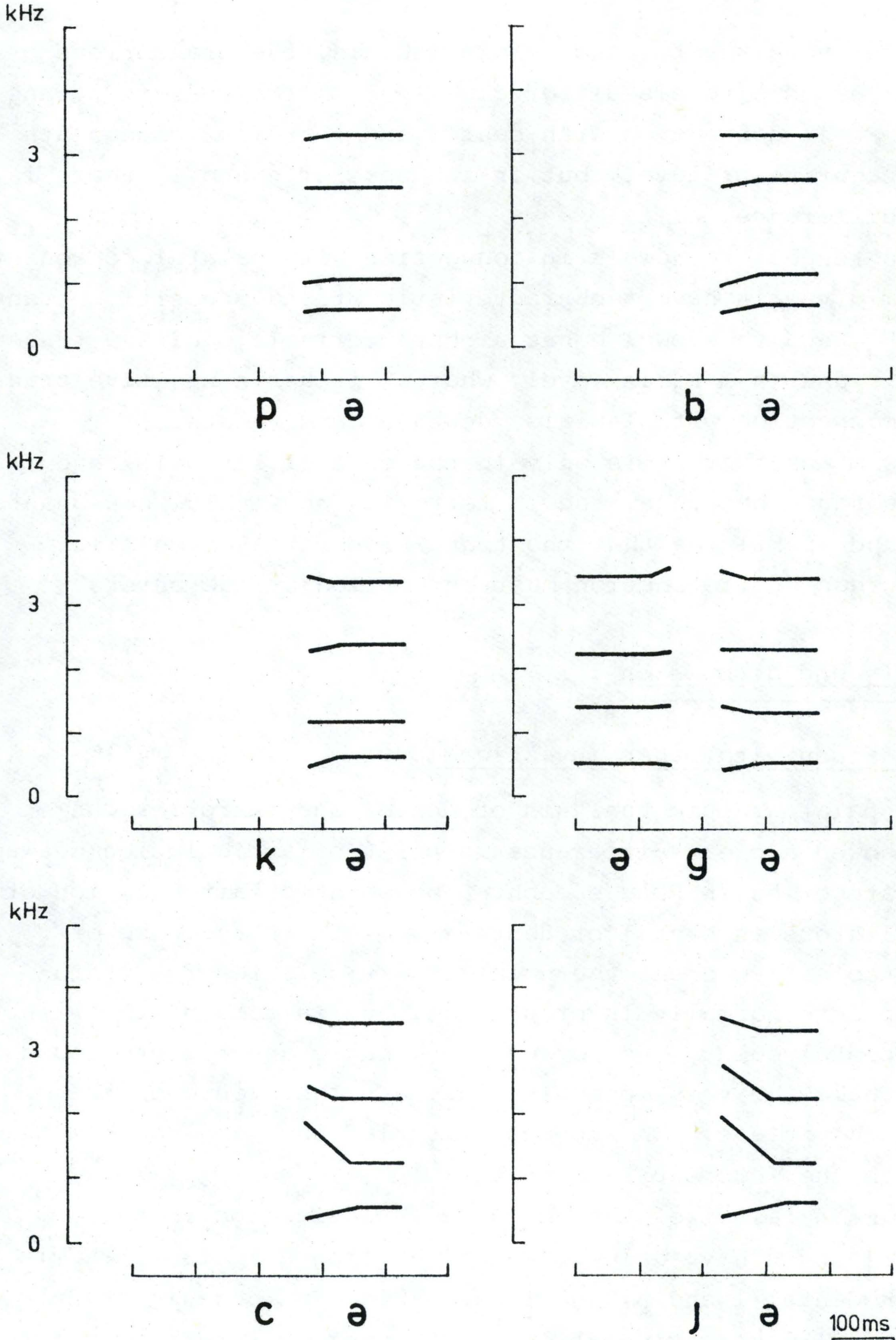


Figure 100

Schematized spectrograms. Speaker RD.



<u>Figure 101</u>

Schematized spectrograms. Speaker RD.

formant transitions between retroflex and velar consonants is only valid for a and ə after (but not for a and ə before) the consonant.

As for vowels after and before labials, the transitions of F_2 in back and mid vowels differ clearly from the positive transitions of F_2 in connection with dental and retroflex consonants in being negative or level, but in the case of e and i, there is not much difference.

With respect to vowels in connection with palatal consonants, back and mid vowels have a characteristic strongly positive transition of F_2, and the vowel e has a characteristic positive transition of F_3, and in i F_3 is level, whereas it has a negative transition in connection with labials, dentals, and velars.

This means that it is only in the case of retroflex and velar consonants before a, and in retroflex and labial consonants before i and (partly) e that the transitions are very similar and the burden of distinction must be carried by the bursts.

4. Summary and discussion

4.1 Comparison with other investigations

The palatographic analysis of dental and retroflex consonants showed a clear difference in point of articulation between the two categories in RD's speech. The point of articulation of the dental stops is dental or denti-alveolar (in the case of r mostly alveolar), whereas the point of articulation for retroflex consonants normally is prepalatal, but in combination with i rather postalveolar. Retroflex ḷ, ṇ, and ṛ are flapped sounds, and ḷ and ṇ may be very open with only a slight touch in the middle of the palate. The tongue is curled back and touches the palate with the lower surface of the tip.

The main result of the acoustic investigation is that retroflex ḷ and ṇ have a lower F3 and F4 (for ṇ F4 is often missing) than dental l and n, and ḷ has a high F1 (because of its open and vowel-like articulation). Moreover, all retroflex consonants have a lowering effect on the transitions of F3 and F4

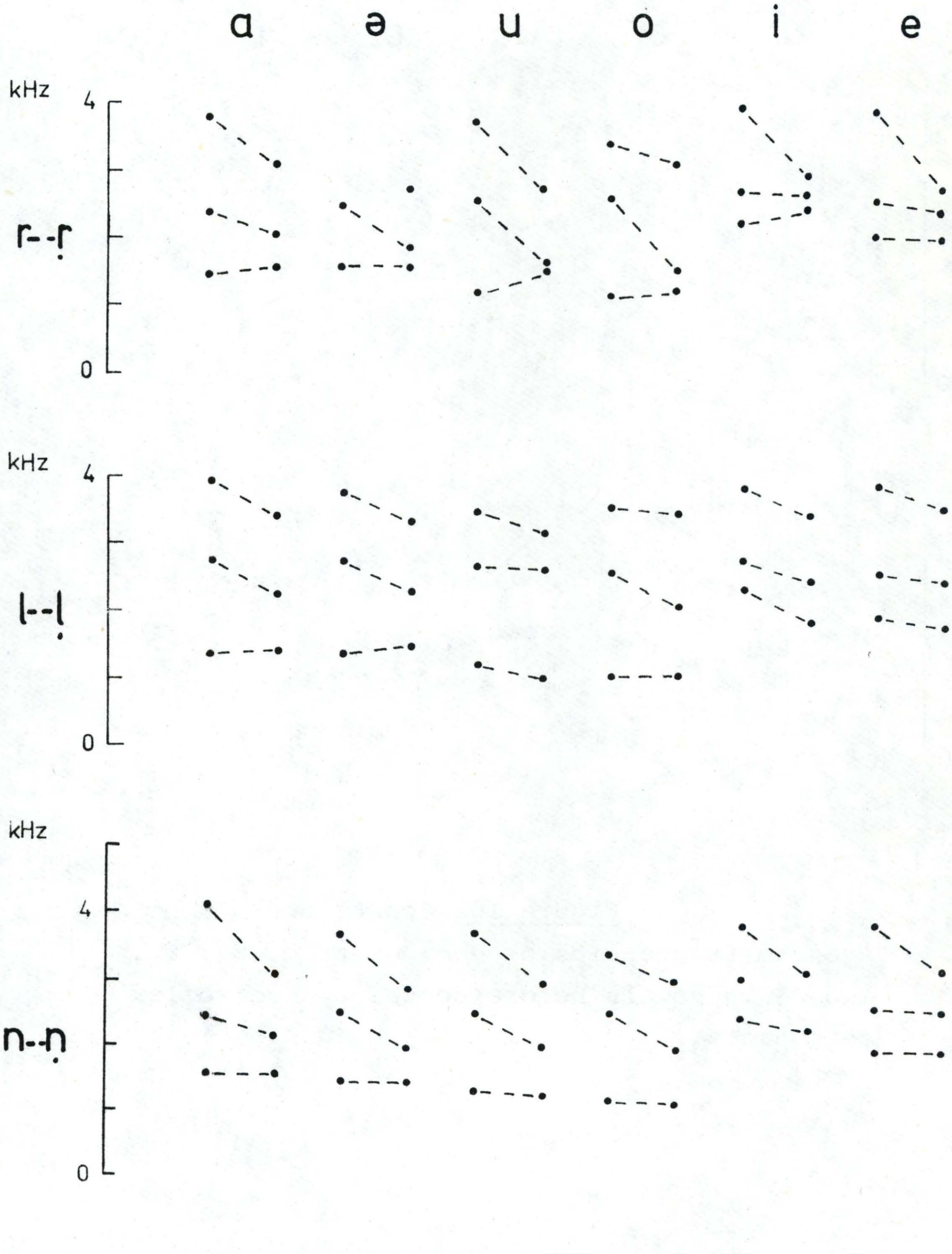
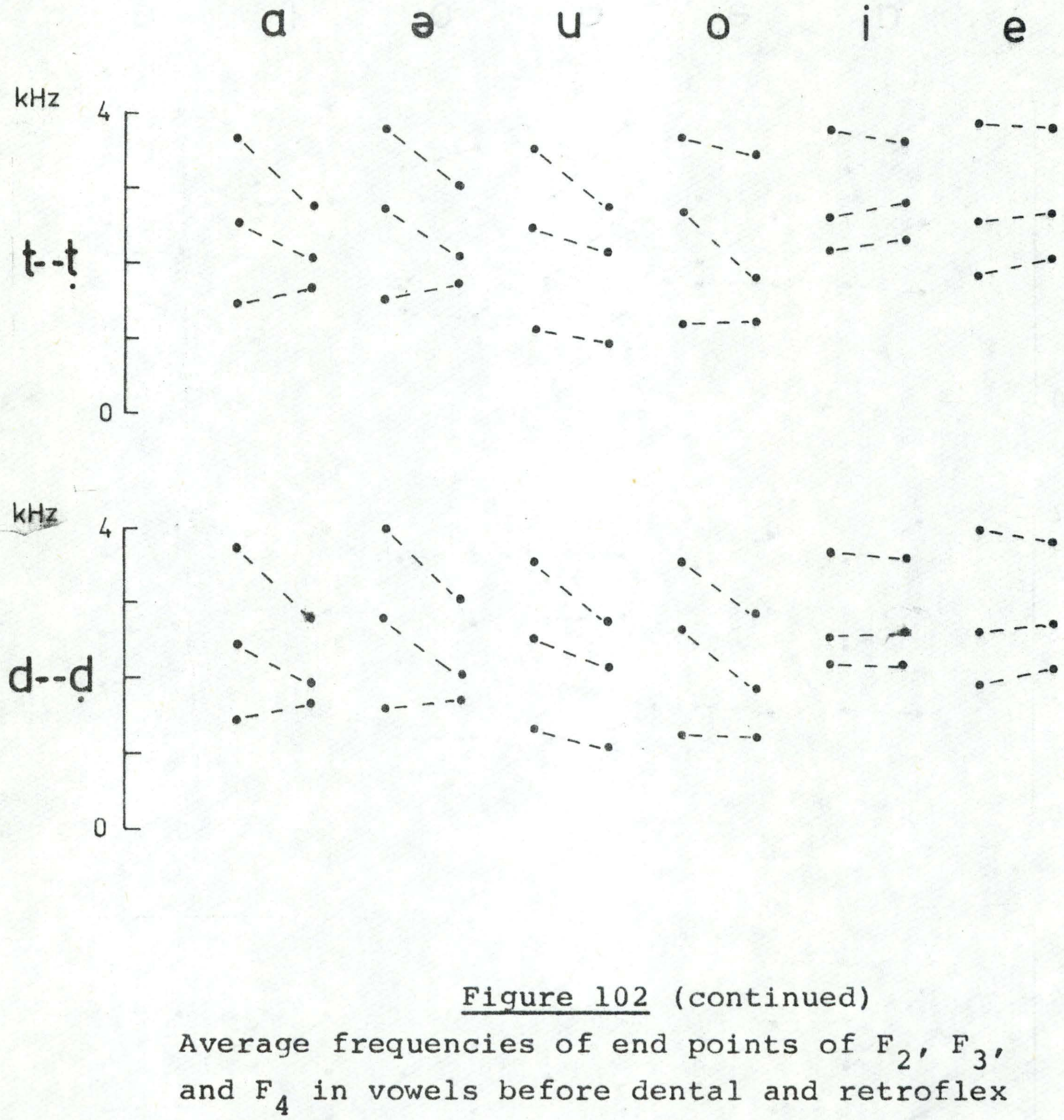


Figure 102

Average frequencies of end points of F_2, F_3, and F_4 in vowels before dental and retroflex consonants.(Continued next page).



<u>Figure 102</u> (continued)
Average frequencies of end points of F_2, F_3, and F_4 in vowels before dental and retroflex consonants.

of the preceding vowel (compared to dental consonants). The effect of stop consonants on the transitions of i and e is, however, small. But the frequencies of the steady state part of F3 and F4 of these vowels tend to be lower. And this tendency is also found in other vowels before retroflex stops and (for F4) in vowels before nasals and liquids. The effect of retroflex consonants on the following vowel is much more irregular but still clear for the vowel a. It may, therefore, not be accidental that retroflex nasals and liquids are not found initially in Gujarati nor that retroflex consonants are on the whole less common before front vowels (Bhat 1974).

The burst has more energy at lower frequencies in retroflex stops than in dental stops, and for RT there is a peak around 3000 Hz (somewhat higher for i and lower for o).

Compared to the results of Ramasubramanian and Thosar's (1971) investigation of Tamil retroflex stops there is agreement on the main point, i.e. that F3 is lowered in vowels adjacent to retroflex stops as compared to dental stops. There is also agreement in the finding that retroflex ḷ had a lower F3 than dental l. For retroflex ṇ they indicate a higher F3, which is somewhat surprising and not in agreement with the findings of the present investigation. Moreover, they indicate a higher F2 both in retroflex ṇ and ḷ; this is difficult to compare with the present measurements, since they only give an average value, and F2 differs according to the surrounding vowels. They have not measured F4.

On the basis of their experiments with synthesis they set up a number of loci, different for front, central, and back vowels (which is not in agreement with the locus concept of the Haskins group), and also terminal frequencies found to be efficient for the synthesis of retroflex stops. For F3 they have lower loci and lower terminal frequencies of the vowels in retroflex than in dental consonants, but their locus for dental stops (2000 Hz) seems extraordinarily low. For F2 they assume a higher terminal frequency in a in combination with dental stops than with retroflex stops (1590 vs. 1450 Hz), which is not in agreement with the present measurements. In the table on p. 78 the end points of F1 of the vowels are indicated as 350 Hz in combination with dentals, and 300 Hz in combination with velars both for i, u, and a, although the locus of all consonants is indicated to be 200 Hz, and i and u have F1 at 280. This must be a misprint, which also appears from the schematic drawings of their synthetic stimuli on p. 83-84.

Still more confusing is what they say about bursts. On p. 78 the poles are indicated to be 3500, 6000, and 4500 Hz for t, 2600, 3900, and 2000 for ṭ, and 3500, 6000, and 4500 Hz for k; but on p. 82 it is said that the poles for retroflex stops are 3500 and 6000 Hz (which were the frequencies indicated for dental and velar stops on p. 78), and that there is a zero at 4500 Hz (mentioned as a pole on p. 78). In the drawings of their synthetic stimuli they only indicate the lower pole, which is in agreement with the indication on p. 78, thus 3500 for dentals and velars, and 2600 for retroflex stops. It is surprising that they use the same burst frequencies in front of a, u, and i. A ka and a ku with a burst at 3500 Hz are completely unrealistic, and one wonders how these syllables sound. Nothing is said about the perceptual tests which must have been used in their experiments with synthesis.

Much more interesting is the article by Stevens and Blumstein (1975). They have taken some spectrograms of t and ṭ in intervocalic position spoken by 3 Hindi speakers. The spectrograms of aṭa reproduced on p. 220 show strongly negative transitions for F3 and F4 of the preceding vowel for two of the informants. (The spectrogram of the third informant does not show the higher formants.) The formants of the following vowels differ, one informant having no rise in F3 or F4. This difference between preceding and following vowels with less evident transitions in the following vowel is in agreement with the findings of the present investigation, and so is the negative transition of F3 and F4 and the transition of F2 in the first a. The differences between the bursts which are said to be lower in the retroflex consonant (around 2700-3000 Hz) are not very evident in the published spectrograms.

The results of their perceptual tests with synthetic stops in CV syllables with the vowel a are clear. Stimuli with a positive transition of F3 in combination with a burst between F3 and F4 are heard as ta, a straight or negative transition of F3 combined with a somewhat lower burst (between F3 and F4) gives ṭa, and a lowering of the burst to the level of F3 has the effect that the listener hears ka.

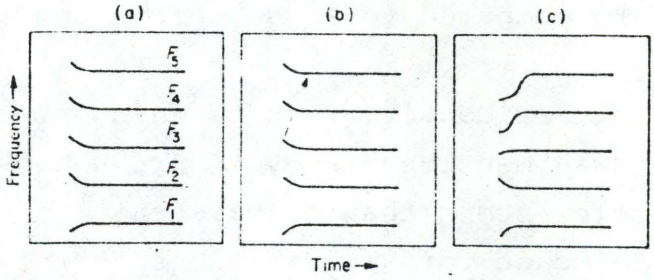
There are, however, some differences in the reactions of the 8 listeners. Some hear ṭa even when F3 has a slight positive transition. Since the position of the burst and the transition of F3 are not varied independently, it is not possible to say what has been more important for the listeners. But it is shown that the addition of a rising F4 increases the number of retroflex-responses. The main characteristic of retroflex consonants is said to be a clustering of F2, F3, and F4 in a relatively narrow frequency region. In order to illustrate this point, the end points of F2, F3, and F4 in vowels before dental and retroflex consonants of the present investigation are compared graphically in Fig. 102. The tendency is evident, although F2 does not always contribute to the result. In this picture the dashed lines do not depict formant transitions; they simply combine the end points of formants before dental and before retroflex consonants to make the difference more clear.

4.2 The relation between articulation and acoustic result

Stevens and Blumstein also try to explain the acoustic differences between the formant transitions before dental and retroflex consonants on the basis of their production. F2 in consonants with an apical place of articulation is said to depend on the cavity behind the closure. This may explain why the vowels a and ə were found to have a higher end point of F2 before retroflex consonants than before dental consonants in this investigation (with ən as the only exception). When the tongue tip is curled back, the cavity behind the place of articulation gets shorter and must have a higher resonance (the consonantal section of ḷ also has a higher F2 after a and ə). For the other vowels this difference is not consistent. For e and i it is found before stops but not before ḷ, ṛ, ṇ. The manner of articulation of the consonant also seems to play a role. Before ṛ the end point of F2 is higher (except in eṛ), before ṇ it is only higher in aṇ (and this is only due to the word paṇi which should not have been included in the average).

F3 and F4 are - according to Stevens and Blumstein - usually associated with the cavity behind the constriction in dental consonants, and they are generally higher than F3 and F4 of the adjacent vowels so that these get positive transitions. In the present material most fourth formants of the vowels have positive or straight transitions before dentals (see Figs. 93-95). But F3 has negative transitions in i, e, and partly a. i and e seem to have a higher F3 than the locus for the dental F3 (this was also found for Danish, see Eli Fischer-Jørgensen 1954).

The cavity in front of the constriction is so small in dentals that it has a very high natural frequency which is of no importance. But in retroflex consonants, where the tongue is curled back, the front cavity is larger and, according to Stevens and Blumstein, its resonance comes into the vicinity of F3 and F4. When the tongue moves down from the consonant to the vowel, the size of the cavity decreases rapidly, and the resonance increases rapidly. This is depicted in Fig. 103 (Fig. 2 in Stevens and Blumstein 1975). They explain in the text that two formants cannot intersect physically. When they come close together they are displaced upwards and downwards.



Schematic representation of formant movements at release of consonants produced by raising tongue blade. Part (a) shows falling trajectories of all formants above F_1 for a dental place of articulation; the same trajectories are shown in part (b), together with a dashed line indicating the movement of the front-cavity resonance for a retroflex consonant; the resulting trajectories of the formants at the release of a retroflex consonant are given in (c).

<u>Figure 103</u>

(after Stevens and Blumstein 1975)

We thus get a picture with a lowered F3 and a rising F4 and F5 in CV syllables. In Stevens 1973 it is shown on the basis of calculations of the resonances of the vocal tract that if the place of articulation is about 12.8 cm from the glottis (that is, slightly behind the denti-alveolar place of articulation), F4 is lowered and comes close to F3, and the graph shows that still further back F3 is lowered and comes close to F2. This is quite in agreement with Fant, who says that retroflex consonants with a postalveolar articulation have F4 close to F3, and retroflex consonants with palatal articulation have F3 close to F2 (1968, p. 239).

In the palatographic investigation RD's retroflex consonants were found to have a palatal place of articulation, except for the consonants in the environment of i, which had a post-alveolar place of articulation. We might, therefore, expect to find a more exclusive lowering of F4 rather than of F3 in the environment of i, and perhaps e. This is, on the whole, confirmed in the present investigation when the end points before retroflex consonants are compared to those before dental consonants (Fig. 102).

We might also look for confirmation of this expectation in a different way: It was mentioned above that RD had a shorter VOT value of his retroflex stops than of his dental stops, whereas this was not the case for RT. Now RD's retroflex stops are generally spoken with the tip of the tongue curled back, and according to Stevens (1973) consonants made with the tip of the tongue have a shorter VOT value than those made with the blade because the tip moves more quickly. It might therefore be assumed that RT's retroflex stops were not completely retroflex, but that the blade took part in the constriction. This is in agreement with the fact that his retroflex stops sound more similar to the dental stops than those of RD. Moreover, the spectrograms of his dental and retroflex consonants were also more similar. However, it seems that there is some conflict between the assumption of a more advanced articulation and the acoustical theory referred to above, for RT's consonants were more similar because he very rarely has any transition of F4 (see Figs. 67 and 92), and if his place of articulation is not as far back, he should rather have been expected to have more lowering of F4 than of F3.

Finally, it is supposed by Stevens and Blumstein that when the tongue goes down and the front cavity decreases in size and thus increases its resonance, F4 should not be influenced until a certain decrease has taken place, about 20 ms after the release. Conversely, it might be expected that when the tongue tip moves up to the retroflex position, we should first see a fall in F4 and then in F3 as it comes close to the palatal place of articulation. But this is not the case. The steep rise of F4 generally starts immediately after the release, and the fall of F4 in the preceding vowel generally starts later than the fall in F3. In a single case (RD's pi<u>ḷi</u>, Fig. 104) there is first a downward transition of F3 in the first i, and then a downward transition of F2 (and conversely in the second i). This really looks as if there is a cavity which increases gradually in size, first influencing F3 and then F2. But similar pictures are never found for F4 and F3.

We have thus had some difficulties in applying the very plausible explanations given in Stevens and Blumstein to our material. But that may be due to the fact that the relations between cavities and formants are extremely complicated, and F3 and F4 may be influenced by both the back and the front cavities. Generally, a quickly descending F4-transition before a retroflex stop is clearly seen in the spectrograms, whereas the preceding steady state part of F4 is very weak or almost missing, and in these cases F5 is stronger (see, e.g., paṭa in Fig. 91).

Stevens and Blumstein do not mention the asymmetry in the spectrograms of retroflex stops, i.e. the fact that the lowering of F3 and F4 is much more pronounced in the preceding than in the following vowel. Asymmetries can also be found in connection with other consonants, but they are much more evident in connection with retroflex stops. A glance at the figures 57-59, 61-62, 64-65, and 85-95 will show that the transitions of preceding and following vowels are much more symmetric in combination with dentals than in combination with retroflex consonants. This may be explained by the following two points: (1) the movement up to the place of articulation is probably slower than the movement down; (2) when the closure is made with the lower surface of the tip, the contact is probably moved somewhat forward before the tip goes down. In the flapped consonants it is evident that the tip slides forward along the palate. This means

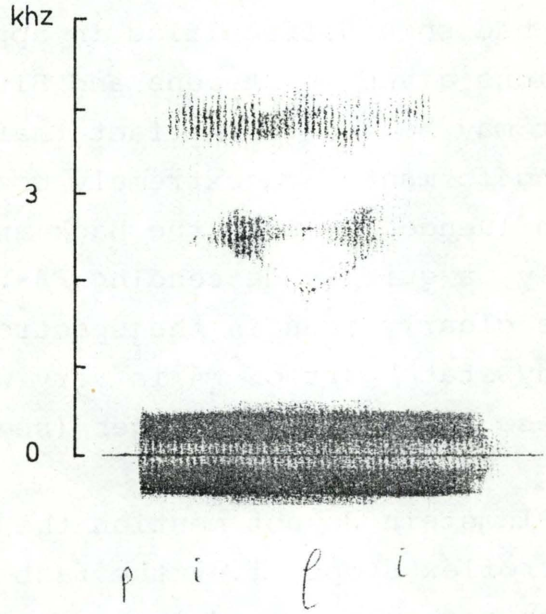


Figure 104

Spectrogram of [piḷi]. Speaker RD.

that at the release the place of articulation is less retracted, the size of the front cavity has already decreased, and the transitions will not be so clearly different from those of the dentals. This is also the explanation given by Bhat (1974). Bhat also mentions that in a tap consonant like alveolar r the tip may move inward so that it ends in a more retroflex position. This is confirmed in the spectrograms of r in the present investigation, which may sometimes show a rising F4 in the following vowel, whereas the retroflex ṛ has a falling F4 in the preceding vowel (see Fig. 57, ərə and əṛə).

4.3 The distinctive feature of retroflex consonants

According to Roman Jakobson retroflexion belongs together with rounding and pharyngealization as different manifestations of the feature "flat" (see Jakobson, Fant, Halle 1952, p. 34 and 49). Acoustically flat phonemes are characterized by a downward shift and/or weakening of some of their upper frequency components. This description is in full agreement with the lowering of F4 and F3 found in the present investigation, as well as by Ramasubramanian and Thosar, and by Stevens and Blumstein. Articulatorily they are said to be produced by a decreased back or front orifice of the mouth resonator and a concomitant velarization which expands the mouth resonator (Jakobson, Halle 1968, p. 431-32). In Jakobson, Fant, Halle 1952, an elongation of the mouth resonator is mentioned as the most important characteristic. This description still requires verification. It is not improbable that the hollowing of the tongue body behind the tip in the retroflex articulation entails a certain velarization; even an alveolar r is considered to entail a certain velarization; but to confirm this assumption it would be necessary to make X-ray photos of retroflex consonants. The picture given in Stevens and Blumstein 1975 of Polish retroflex ḍ does not show any velarization, nor any elongation of the mouth cavity. And the physiological explanation of the lowered F3 and F4 given by Stevens and Blumstein is not based on the cavity behind the constriction but on the cavity in front of the constriction. This point requires further investigation.

APPENDIX

Table 1

Formant transitions of vowels adjacent to <u>r</u> and <u>ṛ</u>. (Number of examples in parentheses)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(7) a + r				(2) r + a		
F_4	3563	3746	+183	3375	3800	+525
F_3	2593	2362		2275	2175	+100
F_2	1345	1440	+95	1425	1400	+25
F_1	870	605		588	775	-187
(6) a + ṛ				(3) ṛ + a		
F_4	3767	3075		3700	3700	0
F_3	2488	2033		2050	2325	-275
F_2	1292	1550	+258	1475	1500	-25
F_1	817	604	-213	641	783	-142
(1) ə + r				(1) r + ə		
F_4				2725	3775	-1050
F_3	2450	2450	0	2225	2425	-200
F_2	1425	1550	+125	1575	1550	+25
F_1	650	550	-100	550	725	-175
(1) ə + ṛ				(1) ṛ + ə		
F_4	3700	2700	-1000	2775		
F_3	2375	1825	-550	2400	2400	0
F_2	1325	1575	+250	1550	1500	+50
F_1	725	425	-300	525	625	-100

Table 1 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1) u + r				(1) r + u		
F_4	3700	3700	0		3700	
F_3		2550		2500		
F_2	950	1175	+225	1075	875	+200
F_1	375	375	0	350	350	0
(1) u + ṛ						
F_4	3225	2750	-475			
F_3	2225	1650	-575			
F_2	975	1500	+525			
F_1	375	375	0			
(1) o + r				(2) r + o		
F_4	3650	3400	-250	3125	3600	-475
F_3		2575		1750	2100	-350
F_2	925	1150	+225	1200	1000	+200
F_1	525	525	0	575	575	0
(1) o + ṛ				(2) ṛ + o		
F_4	3600	3100	-500	3200	3650	-450
F_3	2275	1550	-725	1750	2500	-750
F_2	850	1250	+400	1250	1088	+162
F_1	500	400	-100	525	575	-50

Table 1 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	i + r			(2)	r + i	
F_4	3950	3950	0	3938	3950	-12
F_3	3013	2675	-338	2663	2988	-325
F_2	2463	2250	-213	2363	2563	-200
F_1	300	300	0	300	300	0
(2)	i + ṛ			(2)	ṛ + i	
F_4	3700	2900	-800	3950	3950	0
F_3	3200	2650	-550	2825	3300	-475
F_2	2388	2450	+62	2375	2463	-88
F_1	288	288	0	300	300	0
(1)	e + r			(1)	r + e	
F_4	3950	3900	-50	3925	3925	0
F_3	2800	2550	-250	2525	2700	-175
F_2	2300	2020	-280	2050	2225	-175
F_1	450	450	0	475	475	0
(1)	e + ṛ			(1)	ṛ + e	
F_4	3750	2750	-1000	3950	3950	0
F_3	2800	2400	-400	2550	2600	-50
F_2	2200	2000	-200	2000	2200	-200
F_1	500	300	-200	400	475	-75

Table 2

Formant transitions of vowels adjacent to l and ḷ.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(6) a + l				(4) l + a		
F_4	3891	4016	+125	4088	4038	+50
F_3	2579	2716	+138	2599	2494	+75
F_2	1263	1341	+78	1369	1313	+56
F_1	854	650	-204	688	819	-131
(6) a + ḷ				(2) ḷ + a		
F_4	3754	3379	-375	3638	3800	-162
F_3	2546	2221	-325	2375	2438	-63
F_2	1283	1388	+105	1375	1400	-25
F_1	796	713	-84	725	763	-38
(1) ə + l				(1) l + ə		
F_4	3750	3750	0	3600	3200	+400
F_3	2650	2700	+50	2350	2225	+125
F_2	1325	1350	+25	1300	1450	-150
F_1	750	500	-250	750	750	0
(1) ə + ḷ				(1) ḷ + ə		
F_4	3600	3300	-300	3600	3750	-150
F_3	2350	2225	-125	2550	2700	-150
F_2	1300	1450	+150	1475	1450	-50
F_1	750	750	0	700	700	0

Table 2 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(l) u + l				(l) l + u		
F_4	3500	3450	-50	3650	3650	0
F_3		2650		2550		
F_2	950	1200	+250	1300	975	+325
F_1	400	375	-25	425	425	0
(l) u + ḷ				(l) ḷ + u		
F_4	3300	3150	-150	3400	3400	0
F_3	2700	2600	-100			
F_2	800	950	+150	1100	1025	+75
F_1	375	375	0	400	400	0
(l) o + l				(l) l + o		
F_4	3650	3500	-150	3600	3550	+50
F_3		2550		2650	2650	0
F_2	950	1025	+75	1100	1050	+50
F_1	500	500	0	550	550	0
(l) o + ḷ				(l) ḷ + o		
F_4	3600	3400	-200	3600	3600	0
F_3	2475	2050	-425	2150		
F_2	850	1050	+200	1050	975	+75
F_1	525	550	+25	600	600	0

Table 2 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	i + l			(2)	l + i	
F_4	3825	3800	-25	3850	3888	-38
F_3	2903	2763	-150	2713	2875	-162
F_2	2425	2363	-62	2325	2463	-138
F_1	313	313	0	313	313	0
(2)	i + ḷ			(2)	ḷ + i	
F_4	3675	3375	-300	3725	3725	0
F_3	3038	2438	-600	2600	3050	-350
F_2	2350	1850	-500	2050	2325	-275
F_1	300	300	0	350	350	0
(1)	e + l			(1)	l + e	
F_4	3850	3850	0	3850	3850	0
F_3	2650	2550	-100	2550	2625	-75
F_2	2250	1900	-350	2000	2100	-100
F_1	525	525	0	500	500	0
(1)	e + ḷ			(1)	ḷ + e	
F_4	3725	3500	-225	3750	3850	-100
F_3	2525	2450	-125	2500	2600	-100
F_2	2200	1750	-450	2000	2100	-100
F_1	525	525	0	500	500	0

Table 3

Formant transitions of vowels adjacent to n and ṇ.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(6) a + n				(4) n + a		
F_4	4008	4088	+80	4088	4050	+38
F_3	2367	2413	+46	2475	2362	113
F_2	1342	1533	+191	1575	1418	157
F_1	933	863	-70	782	850	68
(6) a + ṇ				(2) ṇ + a		
F_4	3841	3042	-799	3813	3850	-37
F_3	2250	2150	-100	2237	2300	-63
F_2	1325	1538	+213	1462	1450	+12
F_1	913	946	+33	900	900	0
(1) ə + n				(1) n + ə		
F_4	3700	3700	0	3750	3750	0
F_3	2400	2525	+125	2500	2375	-125
F_2	1450	1450	0	1400	1525	+125
F_1	700	750	+50	700	700	0
(1) ə + ṇ				(1) ṇ + ə		
F_4	3450	2850	-600	3700	3700	0
F_3	2325	1950	-375	2400	2475	-75
F_2	1400	1450	+50	1450	1450	0
F_1	775	775	0	800	800	0

Table 3 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(l) u + n				(l) n + u		
F_4	3725	3725	0	3700	3700	0
F_3	2500	2500	0	2600	2600	0
F_2	1200	1325	+125	1100	850	+250
F_1	400	400	0	325	325	0
(l) u + n̩						
F_4	3650	2975	-675			
F_3	2600	2000	-600			
F_2	650	1250	+600			
F_1	300	300	0			
(l) o + n				(l) n + o		
F_4	3625	3400	-225	3400	3600	-200
F_3	2500	2500	0	2500	2500	0
F_2	1000	1175	+175	1175	1125	+50
F_1	550	675	+125	700	675	-25
(l) o + n̩				(l) n̩ + o		
F_4	3525	3000	-525	3650	3650	0
F_3	2500	1975	-525	2100	2475	-375
F_2	950	1125	+175	1050	1050	0
F_1	550	700	+150	750	725	+25

Table 3 (continued)

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	i + n			(3) n + i		
F_4	3850	3850	0	3925	3925	0
F_3	3262	3075	187	2950	3208	-258
F_2	2563	2413	-150	2433	2633	-200
F_1	325	325	0	308	308	0
(2)	i + ṇ			(3) ṇ + i		
F_4	3763	3150	-613	3975	3975	0
F_3				2817	3333	-516
F_2	2425	2288	-137	2267	2638	-371
F_1	313	313	0	338	338	0
(1)	e + n			(1) n + e		
F_4	3850	3850	0	3825	3825	0
F_3	2650	2600	-50	2700	2800	-100
F_2	2200	1950	-250	2100	2225	-125
F_1	400	400	0	500	500	0
(1)	e + ṇ			(1) ṇ + e		
F_4	3750	3150	-600	3975	3975	0
F_3	2750	2525	-225	2800	2750	+50
F_2	2250	1925	-325	2000	2125	-125
F_1	400	400	0	550	550	0

Table 4

Formant transitions of the vowel a adjacent to dental and retroflex stops.

(4) a + t	Steady state	Trans. end	diff.	(7) t + a	Trans. start	Steady state	diff.
F_4	3613	3688	+75		3750	3607	+143
F_3	2588	2550	-38		2604	2504	+100
F_2	1300	1444	+144		1489	1310	+179
F_1	838	644	-194		661	829	-168
(5) a + d				(8) d + a			
F_4	3565	3750	+185		3675	3516	159
F_3	2530	2485	-45		2700	2575	+125
F_2	1255	1460	+205		1597	1344	253
F_1	845	610	-235		588	825	-237
(4) a + ṭ				(7) ṭ + a			
F_4	3425	2763	-662		3700	3564	+136
F_3	2444	2044	-400		2346	2368	-22
F_2	1281	1638	+357		1543	1332	+211
F_1	875	613	-262		668	846	-178
(6) a + ḍ				(8) ḍ + a			
F_4	3596	2833	-763		3644	3595	+50
F_3	2410	1995	-415		2406	2388	+19
F_2	1283	1654	+371		1662	1369	+294
F_1	842	613	-229		600	813	-213

Table 5

Formant transitions of the vowel ə adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1) ə + t				(2) t + ə		
F_4	3800	3800	0	3650	3475	+175
F_3	2725	2725	0	2638	2588	+50
F_2	1325	1525	+200	1513	1288	+225
F_1	750	675	-75	563	638	-75
(1) ə + d				(2) d + ə		
F_4	3900	4000	+100	3625	3463	+162
F_3	2725	2800	+75	2688	2588	+100
F_2	1425	1575	+150	1525	1363	+163
F_1	725	550	-175	575	625	-50
(1) ə + ṭ				(2) ṭ + ə		
F_4	3750	3050	-700	3600	3425	+175
F_3	2450	2100	-350	2425	2275	+150
F_2	1450	1725	+275	1600	1425	+175
F_1	675	525	-150	588	625	-38
(1) ə + ḍ				(3) ḍ + ə		
F_4	3750	3050	-700	3625	3517	+108
F_3	2200	2050	-150	2600	2467	+133
F_2	1400	1725	+325	1683	1492	+192
F_1	650	525	-125	517	642	-125

Table 6

Formant transitions of the vowel u
adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2) u + t				(7) t + u		
F_4	3400	3550	+150	3540	3515	+25
F_3	2500	2500	0	2394	2369	+25
F_2	938	1125	+188	1121	939	+182
F_1	375	375	0	371	371	0
(2) u + d				(3) d + u		
F_4	3675	3550	-125	3325	3400	-75
F_3	2525	2550	+25	2500	2413	+88
F_2	850	1300	+450	1200	794	+406
F_1	400	400	0	358	358	0
(2) u + ṭ				(4) ṭ + u		
F_4	3400	2750	-650	3550	3625	-75
F_3	2450	2150	-300	2325	2350	-25
F_2	800	950	+150	1119	750	+369
F_1	400	400	0	375	375	0
(3) u + ḍ				(3) ḍ + u		
F_4	3450	2733	-717	3500	3350	+150
F_3	2433	2133	-300	2475	2475	0
F_2	750	1033	+283	1167	742	+425
F_1	375	375	0	375	375	0

Table 7

Formant transitions of the vowel o adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1) o + t				(3) t + o		
F_4	3700	3700	0	3775	3750	25
F_3	2450	2700	+250	2541	2533	+8
F_2	1075	1200	+125	1175	925	+250
F_1	600	600	0	475	500	-25
(2) o + d				(4) d + o		
F_4	3450	3550	+100	3600	3556	+44
F_3	2613	2638	+25	2606	2600	-6
F_2	950	1243	+293	1294	963	+331
F_1	500	538	+38	450	475	-25
(2) o + ṭ				(3) ṭ + o		
F_4	3688	3488	-200	3433	3367	67
F_3	2550	1825	-725	2242	2533	-292
F_2	875	1225	+350	1267	950	+317
F_1	588	588	0	475	508	-33
(2) o + ḍ				(5) ḍ + o		
F_4	3500	2850	-650	3192	3367	-175
F_3	2475	1825	-650	2290	2380	-90
F_2	925	1200	+275	1280	1020	+260
F_1	550	550	0	480	530	-50

Table 8

Formant transitions of the vowel i adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.		Trans. start	Steady state	diff.
(2)	i + t			(5)	t + i		
F_4	3800	3800	0		3785	3765	+20
F_3	2800	2650	-150		2820	3060	-240
F_2	2375	2200	-175		2335	2455	-120
F_1	313	313	0		290	290	0
(3)	i + d			(5)	d + i		
F_4	3725	3692	-33		3705	3715	-10
F_3	2825	2550	-275		2710	3110	-400
F_2	2367	2192	-175		2250	2410	-160
F_1	308	308	0		295	295	0
(2)	i + ṭ			(5)	ṭ + i		
F_4	3650	3675	+25		3755	3750	+5
F_3	2925	2875	-50		2745	3100	-355
F_2	2425	2388	-38		2290	2445	-155
F_1	313	313	0		300	300	0
(2)	i + ḍ			(4)	ḍ + i		
F_4	3650	3600	-50		3688	3688	0
F_3	2650	2600	-50		2638	3200	-563
F_2	2300	2175	-125		2206	2444	-238
F_1	313	313	0		300	300	0

Table 9

Formant transitions of the vowel e adjacent to dental and retroflex stops.

	Steady state	Trans. end	diff.		Trans. start	Steady state	diff.
(1) e + t				(3) t + e			
F_4	3900	3900	0	F_4	3767	3683	+83
F_3	2800	2700	-100	F_3	2567	2600	-33
F_2	2175	1900	-275	F_2	2000	2100	-100
F_1	550	450	-100	F_1	417	417	0
(1) e + d				(3) d + e			
F_4	3900	4000	+100		3750	3725	+25
F_3	2700	2600	-100		2592	2633	-42
F_2	2075	1900	-175		1935	2092	-157
F_1	475	400	-75		408	425	-17
(1) e + ṭ				(4) ṭ + e			
F_4	3850	3850	0	F_4	3744	3719	25
F_3	2750	2700	-50	F_3	2531	2538	-6
F_2	2200	2125	-75	F_2	2050	2100	-50
F_1	475	400	-75	F_1	475	475	0
(1) e + ḍ				(3) ḍ + e			
F_4	3800	3800	0		3650	3650	0
F_3	2600	2750	+150		2533	2550	-17
F_2	2200	2150	-50		1867	2033	-166
F_1	450	350	-100		458	458	0

Table 10

Formant transitions of the vowel a adjacent to labial, velar, and palatal stops.

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	a + p			(7)	p + a	
F_4	3575	3675	+100	3643	3579	+64
F_3	2400	2350	-50	2450	2443	+7
F_2	1288	1263	-25	1175	1236	-61
F_1	838	725	-113	743	857	-114
(2)	a + b			(4)	b + a	
F_4	3500	3450	-50	3519	3538	-19
F_3	2388	2350	-38	2506	2563	-57
F_2	1275	1200	-75	1138	1213	-75
F_1	825	675	-150	631	831	-200
(2)	a + k			(3)	k + a	
F_4	3625	4175	+550	3692	3475	+217
F_3	2375	2113	-262	2183	2400	-217
F_2	1250	1325	+75	1425	1316	+109
F_1	850	650	-200	700	825	-125
(1)	a + g			(3)	g + a	
F_4	3400	3800	+400	3633	3617	16
F_3	2500	2100	-400	2325	2383	58
F_2	1200	1300	+100	1508	1308	+200
F_1	825	700	-125	517	775	-258

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	c + a			(1)	ɟ + a	
F_4	3750	3500	+150	3700	3400	+300
F_3	2500	2300	-200	2800	2400	+400
F_2	1800	1400	+400	2100	1375	+725
F_1	500	800	-300	400	775	-375

Table 11

Formant transitions of the vowel ə adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	p + ə			(1) b + ə		
F_4	3250	3300	-50	3300	3300	0
F_3	2475	2475	0	2500	2600	-100
F_2	1000	1050	-50	925	1175	-250
F_1	575	600	-25	550	650	-100
(1)	k + ə					
F_4	3450	3325	+125			
F_3	2300	2375	-75			
F_2	1175	1175	0			
F_1	500	625	-125			
(1)	c + ə			(1) ɟ + ə		
F_4	3525	3425	+100	3550	3350	+200
F_3	2475	2275	+200	2775	2225	+550
F_2	1900	1250	+650	2000	1250	+750
F_1	400	600	-200	400	625	-225

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(2)	ə + g			(3) g + ə		
F_4	3425	3550	+125	3533	3400	+133
F_3	2200	2213	+13	2308	2300	+8
F_2	1413	1450	+37	1425	1333	+92
F_1	550	500	-50	475	567	-92

Table 12

Formant transitions of the vowel u adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1)	p + u			(1)	b + u	
F_4	3400	3400	0	3250	3250	0
F_3	2400	2400	0	2500	2500	0
F_2	725	725	0	725	725	0
F_1	400	400	0	375	375	0
(4)	k + u			(2)	g + u	
F_4	3483	3433	+50	3650	3650	0
F_3	2350	2400	-50	2250	2500	-250
F_2	731	731	0	737	737	0
F_1	381	381	0	350	350	0
(1)	c + u			(1)	ɟ + u	
F_4	3200	3400	-200	3200	3400	-200
F_3	2275	2425	-150	2250	2350	-100
F_2	1725	900	+825	2000	850	+1150
F_1	400	400	0	375	375	0

Table 13

Formant transitions of the vowel o adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1) p + o				(1) b + o		
F_4	3200	3200	0	3150	3150	0
F_3	2725	2700	+25	2650	2750	-100
F_2	700	700	0	800	850	-50
F_1	400	400	0	350	425	-75
(1) k + o				(1) g + o		
F_4	3350	3100	+250	3250	3150	+100
F_3	2300	2500	-200	2300	2550	-250
F_2	850	850	0	875	875	0
F_1	475	500	-25	450	500	-50
(1) c + o				(1) ɟ + o		
F_4	3300	3250	+50	3300	3200	+100
F_3	2200	2350	-150	2200	2400	-200
F_2	1625	950	+675	2000	875	+1125
F_1	425	500	-75	400	450	-50

Table 14

Formant transitions of the vowel i adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(3)	p + i			(2)	b + i	
F_4	3675	3675	0	3563	3725	-162
F_3	2875	3000	-125	2750	3350	-600
F_2	2283	2350	-67	2268	2350	-82
F_1	292	300	-8	313	313	0
				(3)	g + i	
				3650	3633	-17
				3167	3100	+67
				2483	2350	+133
				283	308	25
(1)	c + i			(1)	ɟ + i	
F_4	3750	3750	0	3700	3700	0
F_3	3250	3250	0	3200	3200	0
F_2	2350	2400	-50	2200	2325	-125
F_1	300	300	0	275	300	-25

	Steady state	Trans. end	diff.	Trans. start	Steady state	diff.
(1)	i + k			(4)	k + i	
F_4	3725	3725	0	3731	3731	0
F_3	2900	2550	-350	3100	3138	-38
F_2	2400	2500	-100	2433	2450	-17
F_1	300	300	0	306	306	0

Table 15

Formant transitions of the vowel e adjacent to labial, velar, and palatal stops.

	Trans. start	Steady state	diff.	Trans. start	Steady state	diff.
(1) p + e				(1) b + e		
F_4	3575	3675	-100	3400	3700	-300
F_3	2475	2600	-125	2400	2600	-200
F_2	2050	2200	-150	1875	2175	-300
F_1	400	450	-50	400	400	0
(1) k + e				(1) g + e		
F_4	3700	3650	+50	3750	3600	+150
F_3	2600	2700	-100	2450	2600	-150
F_2	2250	2200	+50	2350	2250	+100
F_1	400	425	-25	375	400	-25
(1) c + e				(1) ɟ + e		
F_4	3650	3650	0	3775	3600	+175
F_3	2750	2600	+150	2950	2675	+275
F_2	2200	2100	+100	2225	2200	+25
F_1	400	425	-25	275	375	-100

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CAN PHONOLOGICAL DESCRIPTIONS BE MADE MORE REALISTIC?[1]

Jørgen Rischel

Abstract: This is an informal presentation of some reflections on current phonological theory, with special reference to notions such as "psychological reality", "productivity", and "naturalness".

The study of sound patterns in language largely reflects the theoretical bias in linguistics in general. For the last fifteen years transformational grammar has been by far the most influential trend. Before this epoch the international scholarly debate was a reasonably proportioned mixture of contributions from different structuralist schools, but with the advent of the transformational-generative paradigm the situation changed in the course of a few years. Transformational-generative theory, as it was developed by Morris Halle and Noam Chomsky, came to enjoy an unparalleled world-wide popularity, and soon dominated the thinking of a generation of young linguists inside and outside the U.S.A, the ideas emitted from the scholarly center at M.I.T. being adopted with something akin to orthodoxy in many parts of the world. Outside the U.S.A. this kind of linguistics caught on first and foremost in countries which had not

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1) This paper was presented in part as an introduction to a discussion of phonological theory at the 4th Scandinavian Meeting of Linguists, Hindsgavl (Denmark), January 6-8, 1978. It must be emphasized that the paper does not attempt anything like a survey of the relevant literature, cf. that the references are limited to a couple of items which happen to be mentioned in the text.

had a strong and influential structuralist tradition. In old structuralist quarters the conversion rate was considerably slower, and there remained a great many sceptics or straightforward opponents to the whole trend. Even in the U.S.A. there were contemporaneous groups representing independent approaches such as tagmemics and stratificational grammar, the latter furnishing the most elaborate alternative in terms of phonological theory.

Now, why is orthodox transformational-generative phonology (henceforth OTG-phonology) increasingly under attack these years? It is obvious that the prestige of OTG-phonology is declining, and it is interesting to study who the leading figures are in this recent development. - One might assume that after a period of defeat the recognized structuralists have finally gathered strength enough to strike a fatal blow. But in fact this is not what is happening. Rather, the ground for a revolte has been prepared by an increasing flow of radical revisions of OTG-phonology, marked by eager disputes on the most deep-rooted ideas as well as a general shift of bias, cf. the increasing scepticism toward abstract morpheme representations and toward ad hoc rule ordering, and the increasing interest in surface structure. Phonological feature theory, in particular, is as far as ever from providing a basis for the unification of our science.

This revision has been and is being undertaken by linguists who for the most part share some of the notions of generative phonology (in a very general sense). That is, it is to a considerable extent an inside job. Formerly devoted adherents to OTG-phonology have to take a stand to these issues, and after the forceful attacks of recent years it may seem necessary to find out whether there is anything left that is of use to linguists.

The present writer belongs to those who - though rooted in a structuralist tradition - felt that transformational-generative phonology, at the time it appeared, had distinct advantages over other descriptive paradigms, not just because it provided such elegant solutions, but rather because it formalized the relationships among levels of representations more precisely than structuralist approaches (including glossematics) had done. Seen from this angle, and perhaps especially from a European viewpoint, transformational-generative phonology was not as totally different from classic structuralism as its proponents wished it to be: it seemed to be rather a matter of developing the formal apparatus needed to account for the somewhat neglected morphophonemic component of grammar. As for the insistence on the linguistic relevance of underlying representations, and the rejection of surface phonemics, such a viewpoint was not at all far from that of glossematics. To the present writer, the great attraction and challenge in transformational-generative phonology lay, and still lies, in the fact that this approach invites research serving to fill the gap between syntax and phonetics, and even seems to provide some means for approaching the difficult field of prosody in its interrelations with syntax. (Deplorably, the advance in research on that very point has not been nearly as glorious as one might have hoped.) I feel that the generative approach as such IS fruitful despite all well-founded attacks on current versions of the American OTG-phonology; it is fruitful precisely because it lays emphasis on aspects of linguistic structure which were in part neglected within previous descriptive paradigms.

As this decision is formulated here, it has to do only with a strictly limited goal, viz. that of stating the patterning observable in language. That in itself is certainly no simple task, although the scientific challenge of it is often ignored in lofty discussions of abstract interpretations and restatements of data furnished by other linguists. (I think there is a considerable danger in the widespread inclination to make theoretical constructs on the basis of data the intricacy of which is only properly understood by a linguist who has been doing field-work extensively himself.)

The present reaction against OTG-phonology has to do with a much higher - and admittedly more fascinating - goal than that of mere description of sound patterns. The all-pervading question is: how do we arrive at statements that reflect REAL properties of languages, and not just refer to a more or less adequate (but in principle arbitrary) model of language? There have been rather successful attempts to demonstrate that some - especially some of the intuitively far-fetched generative solutions are psychologically implausible or even at variance with empirical evidence. This is an important objection because it has been implicit or explicit in the OTG-phonological literature that this paradigm represents a serious hypothesis about <u>internalized</u> phonologies. Such a claim has seemed to many of us quite unwarranted and only indirectly useful, and it is a relief that it has now become a commonplace to realize this.

Unfortunately, however, there may have been an exaggerated enthusiasm over recent attempts to change the paradigm in the direction of a psychologically real phonology. I do not see that our science has advanced very far on this issue except for the very general observation that phonology is probably less abstract than some phonologists have liked to assume.

Much excellent work is being done by people studying verbal behaviour, speech defects, etc., and from phonetics we begin to learn quite a bit about peripheral processes. But this whole field of cumbersome observation and experimentation does not at present endorse the advancement of ambitious claims about the fine structure of internalized phonologies. The descriptive phonologist must content himself with much more modest claims.

One of the most immediately useful questions a linguist may ask if he discovers a regularity in his data, is: do speakers of the language master this regularity? If not, the regularity in question may perhaps still be worth stating, since it may throw light on earlier stages of the language, or it may possibly be relevant to practical applications of the linguistic description. But one might reasonably define it as a major goal for linguists to find out what pieces of structure and what generalizations across these pieces of structure the speakers of the language have somehow internalized. If this could not even be recognized as a goal which may in theory be accomplished, synchronic linguistics would indeed be mere taxonomy, and synchronic patterns would be explicable solely in terms of diachrony.

However, recognizing a goal is not tantamount to reaching it. There is a danger in just stating that from now on we should do psychologically real phonology and ridicule linguists who do not do this. It is not that simple. I certainly share the view that OTG-phonology may have hampered empirical research in this field by axiomatizing away the issue, but the sad state of affairs is that we are still waiting for substantial results from research on internalized phonologies of adults. One may attempt to derive a criterion of PLAUSIBILITY from the scattered pieces of research available so far, and one may strongly emphasize the tentative character of phonological descriptions as long as there is no workable criterion such as psychological reality. But it is absolutely essential not to content oneself with a vague belief in concrete phonology as being "psychologically real" by virtue of its concreteness, since this easily results in axiomatizing away the issue once more.

One basic difficulty is that it is not clear a priori what kind of "psychological reality" we are after. Whom is the allegedly psychologically real pattern to be attributed to? We do not seriously entertain the idea that all speakers arrange their linguistic knowledge in exactly the same way. What then? Are we referring to some kind of inter-subjective common core, or are we constructing a linguistic superman like Chomsky and Halle's ideal speaker-hearer? Is a psychologically real phonology a closed system, or should we rather attempt to design our linguistic description in such a way that it explicitly takes care of the range of the alternative ways in which different speakers of the language may arrange the ingredients? I personally should greatly prefer the latter alternative, although at present I see no practical solution to this.

Secondly, we must state what is representationally implied by the notion "psychologically real". Nobody thinks of the current rule format as being piece by piece represented in the brains of people. (Incidentally, stratificationalists have made stronger claims as to representionality than has ever been done in OTG-phonology, as far as I know.) We rather think of the contents of rules as having possibly a psychological reality, which may be tested by studying whether the predictions of the rules are borne out under conditions provoking their application. Thanks to the work and argumentation of John Ohala, Bruce Derwing, Per Linell, and others it can be safely concluded today (if it was ever doubted) that there is something psychologically unrealistic about OTG-phonological descriptions. However, testing a single rule is a difficult matter since rules typically form close-knit wholes one part of which may be crucially dependent on how the other is stated. It may not be difficult to demonstrate that this or that rule in some OTG-phonological description fails to be represented as such in the brains of speakers of the language in question, but the conclusions to be drawn from such a proof are sometimes of limited interest exactly because of the trading relationship between different parts of a phonology. It may be more realistic to take the whole phonology as a black box with an input end and an output end and investigate whether it functionally matches the competence of speakers of the language. Thus, what may be tested off hand, is whether the phonological description covers the kinds of information about the language that is available to the user of it. This is, indeed, an interesting issue, and I think that if the result of such a test comes out positive one may reasonably claim that the phonological description does in a certain, very restricted sense satisfy the demand for psychological reality, even though there may be little isomorphy between the descriptive statements and internalized representations. The emphasis is shifted here from the question about the reality of rules to the reality of phonological information, that is, it is no longer specifically transformational-generative phonology that is at issue but descriptive phonology as such. I think that is a useful change of viewpoint. The "psychological reality"-issue is in fact independent of the transformational-generative versus the structural viewpoint. It is used today to criticize OTG-phonology, and that is perfectly legitimate since this type of phonology has been associated with claims about internalized representation, but one might at the same time give OTG-phonology credit for having provoked the current interest in this highly important topic.

Testing whole phonologies tells us something, if it can be accomplished. However, we are still badly in need of information about details of internalized phonologies. In many cases it is perfectly possible to take regularities (in the sense of equivalences or alternations recurring over sets of forms) and ask quite generally whether they are mastered by speakers of the language. Taking a trivial case like the alternation between non-final [d] and final [t] in German, for example, the problem at issue may be detached from the generative solution according to which underlying /d/ is rewritten as [t] in final position, and stated instead as a question about the alternation: do speakers make use of the fact that there is an alternation between [d] and [t] recurring in several forms, or would it not make any difference if the alternations in individual sets of forms were quite idiosyncratic? - Is a certain regularity used productively? This is an extremely important question, but not the only important question. Couldn't it be the case that a given, restricted regularity is accessible to users of the language even if it is not used productively? How can we test whether that is the case?

There are questions enough to be answered before we even approach the formalizations of specific phonological descriptions. And even in the simplest possible conceptual framework we run into difficulties when we wish to state exactly what is

E R R O R

p. 164, l. 15 from bottom;

for: by foreign (or nonsense) items ...

read: by foreign (or nonsense) items combined with an already existing item, where the latter exhibits alternation in accordance with the phonological make-up of the various foreign (or nonsense) items ...

at issue. Taking the notion of PRODUCTIVITY, which is a central concept in the current debate (Skousen 1975) we immediately realize that regularities meet this criterion in an absolute sense if they will be extended to new combinations of lexical items meeting the structural conditions, specifically so that existing lexical items come to exhibit an alternation not otherwise found with them, or so that foreign (or nonsense) words turn out to exhibit alternation. We expect this especially with alternations which are "necessary" to prevent violation of some output constraint (unless some quite different strategy rescues the form in question). - But there may also be alternations shared by a closed set of lexical items where each item has an alternant which is strictly phonologically conditioned and occurs if and only if the appropriate feature (complex) is present in the context of the lexical item in question. This situation is not irrelevant to the issue: the context may be new and still turn out to trigger the alternation if and only if it is phonologically appropriate. One such type of data is represented by unfamiliar compounds or derivatives consisting solely of existing lexical items; another type is represented by foreign (or nonsense) items with which it is combined (example: vowel harmony in suffixes, cf. Rischel (1975)). What may be tested in these cases is not whether an alternation is productive in the sense that it can be extended to apply in new lexical items, but whether it is productive in the sense that items already exhibiting this alternation turn out to distribute their alternants in new contexts in accordance with the phonological properties of these new contexts. - It does not make much sense to use the term "productivity" without distinguishing carefully between these different phenomena, of course. But all of them are crucial for phonological theory, since the very existence of strictly phonologically conditioned alternations will prove that speakers perform some kind of phonological analysis (i.e., that not every wordform is just stored as a gestalt differing as a whole from those of other wordforms). No matter what a "real" phonology looks like, the very possibility of proving the existence of phonology is a rescue for all of us who hope that in our strictly descriptive work we are nevertheless contributing tiny bits of information which can be used in the construction of hypotheses about speakers' and listeners' linguistic competence. If this is so, phonologists and phoneticians can feel reassured that their accomplishments will eventually converge, no matter how far we are at present from making educated guesses about the ways in which speakers' command of their language is organized.

So much for the productivity issue. At the bottom of all assumptions about regularities, possible uses of rules (or analogy, whatever that precisely means), etc., lies the notion of RELATEDNESS among lexical items. And this is really where the basic research needs to be done.

Structuralist phonology as well as "generative" statements about morpheme structure or surface constraints, all of this is about structure: items, hierarchies, and rules of combination or of dependency. The essence of transformational-generative phonology, on the other hand, is about projection of one representation of a chunk of language onto another, more abstract or less abstract, representation of the very same chunk. "Abstraction" here implies that lexical items in more or less invariant shapes enter the representation. Now, in fact all descriptivists deal with relatedness among sentences (or utterances). Structural phonemics concentrates on partial similarities in terms of segments and suprasegmentals, with more or less disregard of the way in which the strings are composed of lexical items. Transformational-generative phonology, on the other hand, emphasizes the partial similarities in terms of lexical material and accounts for these by positing abstract representations in which lexical items occur, in more or less invariant shapes, as constituents. (Glossematics attempts to unite both of these viewpoints.) - If one chooses the latter approach it is crucial how we identify parts of wordforms, i.e.

morphemes, in different contexts. One prerequisite to this procedure is to decide whether a set of wordforms are synchronically related at all. These very problems were shared by classic morphophonemics and Morphonologie as well as glossematic analytical practice, and it is indeed remarkable that phonological theory has developed for half a century without more progress being made on this point over the years. As I see it, much of the current dispute about alternative formats of description is of marginal interest compared to the very question: how do we decide whether two forms are related for the purpose of synchronic description? A satisfactory solution to this problem is a prerequisite to the identification of relevant regularities and hence it should ideally be solved before one turns to the next important issue: how do we decide what is a linguistically significant generalization?

What can we do about all these questions in actual field-work? It is no difficulty to recognize the existence of these issues, but apparently, linguists have also found it easy enough to continue doing descriptive work without having any satisfactory solution to them. Now this is coming into the focus of interest, and it must be generally recognized as a strict obligation of contemporary linguistics to cope with it. (Notice that the question of relatedness faces any descriptivist, no matter whether he looks for psychological or immanent structure.)

Now, taking it for granted that there are crucially related forms and significant, phonologically statable regularities pertaining to them, the next question is: do these regularities operate according to the OTG-phonological paradigm, i.e. in terms of abstract invariant morpheme representations and rules mapping these onto actual phonetic representations, or is the mutual relatedness among surface forms rather to be stated in terms of inferences (Eliasson 1977) or interpretive rules (Leben and Robinson 1977)? It seems attractive that the relationship between abstractness and allomorphy falls nicely into place with the latter analysis: the less alternation, the less complex the statement of relatedness. Even if a particular alternation, say, vowel shift in English, can be stated in rule form, it is simpler if occurrences of a form can be identified without use of the rule. With this view of phonology recent ideas about recoverability, transparency, and paradigmatic cohesion seem to fall naturally into place. I think it is probable, however, that the truth lies somewhere in between the generative and interpretive views. It seems to me wildly improbable that all wordforms should be stored lexically; at any rate, this does not make much sense for polysynthetic languages (cf. Rischel 1975).

Assuming that there is some generative mechanism producing complex wordforms does not, however, entail that we must assume the existence of morphemes behaving according to current analytical practice. I do not feel that it is particularly plausible that naive speaker-hearers process their language in terms of morphemes with exactly the boundaries which phonologists like to set up in order to account for alternation with a minimum of suppletion in underlying representations. There may be quite different strategies which override this specific notion of descriptive simplicity.

Another question is the relation between levels of distinctness, fast speech as reduction of slow speech-forms, etc. Off-hand, this sub-component of phonology seems to invite a generative treatment (in accordance with Linell's suggestion concerning "concrete phonology" (1974)).[1] - One must exploit the possibility of matching observations of phonological variation with studies of speech production mechanisms. Fast speech data obviously provides an aid to the latter field of research, and vice versa.

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1) It may be appropriate to keep syllabated speech (as in over-distinct dictation) outside this generative sub-component, cf. Rudes (1976).

A good deal of the recent work in phonology is referred to under the cover term "natural phonology". Without attempting any kind of definition of this term, I assume that natural phonology is characterized, inter alia, by emphasis on generalizations statable over surface forms (i.e., "concreteness") and by the role of performance motivated processes in the metatheory. Probably every phonologist would agree that it is desirable to have a metatheory providing a universal repertory of possible processes, just as phonetic theory provides a framework for the specification of possible types of sound segments. But it is a difficulty that feature theory is still so controversial. Moreover, it must be emphasized that the principles of hierarchical organization of speech are understood only to a very small extent. There is an enormous lot of research to be done in this field. Finally, it goes without saying that the specification of "natural" processes must depend not only on language typology but also on advances in the phonetic analysis of motor processes and perceptual processes. I do not think that one should distinguish rigidly between "competence" and "performance" in this context.

As I see it, what one can accomplish at present is to put constraints on phonological descriptions which make these somewhat more PLAUSIBLE hypotheses about internalized phonologies, and at the same time provide a better framework for statements concerning a variety of dynamic phenomena such as language acquisition, fast speech and speech errors, and language change, which in turn may provide crucial evidence for the theoretical constructs. Also from the point of view of strictly descriptive work (with no ambitions concerning psychological reality) a theory that is maximally constrained by substantive universals may offer a better chance of describing the phonologies of different languages in an analogous fashion so as to make the descriptions comparable for typological applications.

Naturalness should not be equated with the psychological reality issue, although there is an affinity, of course. It seems immensely plausible that natural, universal tendencies play a major part in language acquisition, language change, etc. But we hardly arrive at psychologically real, static descriptions of adult persons' internalized phonologies just by referring to naturalness. It may be possible, for example, to set up some strict learnability criterion, but how do we know that every internalized phonology behaves in accordance with this criterion? Maybe internalized information may be rearranged in strange "unnatural" ways. And it need not make sense to ask whether a certain regularity is represented explicitly or whether it is simply implicit in the internalized lexicon. Maybe it is both, in many instances. We may guess that there are all kinds of redundancies in internalized representations, and all kinds of short-cuts in language processing. If we wish to make claims about internalized phonologies on the basis of a theory of natural phonology without having access to the mental processes of the speakers whose language is being described, there is probably nothing more to do than to state the simplest and at the same time most complete account of the observed data which is consistent with the theory. It seems reasonable to attempt to delimit phonological descriptions in such a way that they contain all and only the phonological generalizations which may possibly be utilized, under normal conditions of language use,[1] by speakers and listeners employing the language in question. Doing just that requires a working definition of LINGUISTICALLY SIGNIFICANT GENERALIZATION which supplies us with a real criterion. Maybe that is the highest goal one can reasonably set for linguistic theory in the present phase of the strive toward realism.

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1) That is, including "creative" use of language but excluding introspection for the purpose of stating generalizations and the like.

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(ARIPUC 11, 1977)

THOUGHTS ON ANALOGY AND SOME PROBLEMS IN INTERPRETING PHONOLOGICAL EXPERIMENTS[1]

Paul Over

Abstract: An inconclusive pilot study in Danish phonology gives rise to questions about testible differences between explanation by analogical algorithm versus rules. The literature on analogy shows its resistance to valid limitations on its operation in terms of markedness, similarity, or on the basis of purely conceptual or grammatical considerations. It is argued that being the less constrained mechanism, it is inferior as a working hypothesis to rules. It is suggested that the convincing instances of synchronic analogy are special cases where a speaker resorts to a more basic cognitive strategy as ill-defined and hence powerful as our ability to recognize similar aspects of nonidentical complexes.

1. Introduction

These remarks begin with the description of a pilot study undertaken to test the status of consonant gradation regularities in native speakers' grammar of modern Danish. Out of this very restricted experiment rose a number of questions about the possibilities of interpreting such data in terms of analogy as opposed to generative rules. The focal point of this paper lies in the discussion of these questions. If I devote some space to the discussion of the pilot study, which for a number of reasons to be mentioned later cannot be said to contribute substantially to our understanding of consonant gradation in Danish, it is because I believe the confrontation with such an experiment can increase our awareness of some of the problems involved in research on the "psychological reality" of phonological alternations.

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1) This paper was made ready for ARIPUC in the summer of 1976 during the author's stay at the Institute. [Editors' note.]

No attempt has been made to cover all the relevant literature on analogy, but the positions discussed do, I think, represent the crucial viewpoints in the history of this long and involved debate. In any case, the remarkable lack of progress on this topic since the Neogrammarians suggests to me that the problem may lie in the formulation of the question itself. It is hoped that the synoptic view presented in the following pages, while not new in the particulars, will nevertheless be of help to those who run across similar problems in the design and interpretation of grammatical experiments.

The term consonant gradation as applied to Danish (Rischel 1970) comprises several morphophonemic alternations, which as Hans Basbøll (Basbøll 1974) has pointed out, all have in common the weakening of a consonant in syllable-final position. "According to this principle the phonemes /p,t,k,d,g,r/ are manifested as [pʰ,tˢ,kʰ,d,g,ʁ][1] in syllable initial position and as [b,d,g, ð,ɣ,ɒ] in syllable final position ..." (Basbøll 1974a, p. 43). This pilot study was specifically concerned with the alternation between [ɣ/g] and [ð/d], as for example in Danish <u>røde</u> - <u>rødt</u> 'red' [ʁœːðə - ʁœd] or <u>søge</u> - <u>søgt</u> 'to seek - sought' [søːɣə - søgd]. Considering only surface forms it is clear that these alternations are not automatic, since there are surface [d]'s and [g]'s that do not alternate even though the phonetic environment is present. In the relatively well leveled morphology and phonology of modern Danish these alternations are in fact restricted in native vocabulary to a few morphological positions. They do not generally occur in adjectives in [-ɣ], but do show up in weak verbs with infinitives of the form [-ɣə], e.g. <u>søge</u>, <u>smage</u>, <u>bage</u>, <u>koge</u>, <u>bruge</u>, when a [d] (participial ending) is added. (With stems in [-ð] it is not possible to interpret the forms unambiguously because the [ð] disappears before [d] as for example in the verb [møːðə – mød].)

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1) In the text the letters [b,d,g] represent [b̥,d̥,g̊]. The neuter singular adjective ending and the participle ending -t are written [d], i.e. [d̥], even though [tʰ] occurs.

The pros and cons of several variant generative descriptions of gradation have been discussed in the literature (Rischel 1970, Austin 1971, Basbøll 1974a,b). The form of the rule is not at issue here but rather the status of the regularities described in the grammar of native speakers. Formulating the question in terms of "psychological reality" hardly offers any advantage in specificity and hence testibility. This concept or bundle of concepts is not sufficiently well defined at the moment. I would like rather to begin with a more specific question: will Danes extend these given regularities to words which they believe are Danish, but which they have never encountered before, i.e. nonsense words which fill accidental gaps in the vocabulary of modern standard Danish (Rigsmål)? If under these conditions consonant gradation appears, we can conclude that speakers have not merely memorized independent forms showing the change, but have at some level learned the regularity as such, and that the latter is productive in the sense of the experiment. The question of what model best describes the mechanism involved will remain open.

2. The pilot study

2,1 Method

Using work on Danish syllable structure (Spang-Hanssen 1959, Vestergård 1967, Basbøll 1973, 1974a) it was possible to construct a list of nonsense monosyllables with one of the four vowels i,ø,u,a as the syllable peak flanked by one two or three consonants. Adjustments were made for the distribution of vowel allophones, length restrictions ($^{*}V{:}\eta, ^{*}V{:}\begin{Bmatrix} b \\ d \\ g \end{Bmatrix}$ [1]), and to assure that adding the ending [d] would not produce a malformed cluster.

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1) The sequences V:g and V:d do not generally occur in adjective and verb stems. Stems of the form V:b do occur but are frequently subject to diphthongization and in consultation with Jørgen Rischel it was decided to exclude the entire class $V{:}\begin{Bmatrix} b \\ d \\ g \end{Bmatrix}$

The monosyllables were then screened with Politikens Rimordbog ('Rhyming Dictionary') to eliminate already existing forms. The nonsense words were also checked by a native Dane and trained linguist, Jørgen Rischel, who is of course not responsible for any errors in the list. An attempt was made to weed out those forms which might cause problems in audibility, seemed marked as childish, vaguely obscene sounding, or onomatopoetic - even if the criteria for these judgements will not be made explicit. Stød was assigned wherever the phonetic basis was fulfilled (Basbøll 1972) and it was compatible with the morphological patterns of Danish.

The entire material was recorded on tape by Jørgen Rischel. The subjects saw nothing but the scales to be marked in the fifth section of the test (see below). The first section began with a statement that the goal of the study was a description of Danish sentence patterns and their intonation.[1] The subjects were warned that many of the adjectives and verbs they would hear might sound a little strange because they were not a part of everyday Danish vocabulary and because the subjects would hear a number of them during the course of the experiment. It was suggested that the words could be found in older Danish literature, handicraft and agricultural language, and modern nonsense poetry. The subjects were instructed to give the answer that sounded best regardless of whether they were familiar with the word in question.

The first section consisted of 26 short sentences with nonsense verbs in the present tense. The participants were asked, after having heard each sentence twice (5-6 sec.), to record the sentence changing it to present perfect. For example: "De [tʁalgɒ] gennem junglen" 'They (nonsense verb) through the jungle' → "De har [tʁalgd] gennem junglen". Two examples were

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1) The linguists were well aware of the real point of the study, while the non-linguists had no prior knowledge of its purpose. This was considered acceptable in a pilot study and is taken into account in the discussion of the results.

given using nonsense verbs two and three syllables long and incapable of a change in the stem consonant. This section had a dual purpose: first to see which weak ending (d/ə$\begin{Bmatrix}\eth \\ d\end{Bmatrix}$) the subjects would use and whether this was predictable from the structure of the stem. The forms represented most of the possible stem types according to final consonantism. Among them were two stems in [ð] and three in [ɣ][1] to see if subjects would harden these before the weak participial [d]. Hardening would not be expected before the other weak participial ending [ə$\begin{Bmatrix}d \\ \eth\end{Bmatrix}$]. The timing was identical in sections 1-4. In each of the sections the crucial forms, i.e. those stems capable of showing the alternation [ɣ/g] or [ð/d], were mixed with other stems in order to conceal the focus of the study and reduce any learning effect within each section. The ratio of crucial to dummy forms was 1:3.

Directions for the third section were identical to those for section one, except that 16 sentences with nonsense verbs in the present perfect tense were to be changed to present tense: "Hun har [kvi:ʼld] tøjet i en stor gryde" 'She has (nonsense verb) the clothes in a big pot' → "Hun [kvi:ʼlɒ] tøjet ...". Among the participles were four in [gd] and two in [d] to see if Danes would soften the [g] or reintroduce the [ð]. The same example sentences were used as in the first section just going in the opposite direction - present perfect to present.

In the second section the subjects were given sixteen sentences with a neuter predicate adjective, i.e. one with a [d] ending. The cue sentences had the form: "Det her (<u>neuter noun</u>) er (neuter adj.)", 'This ______ is ______.'. Subjects were asked to change each sentence so that it had the form: "De fleste (<u>noun's plural form</u>) er (<u>adjective + plural [ə]</u>)", 'Most ______ are ______.'. Among the nonsense adjectives were four stems in [gd] which could be interpreted as alternating with [gə] or [ɣə]. For example: "Han har [vøgd] ..", 'He has (nons. vb.)..' could become in the present tense "Han [vøgɒ].." or "Han [vø:ɣɒ]..". There were also two stems in [d].

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1) This paper distinguishes categorially between stop "[g]" and continuant "[ɣ]", the latter symbol being used irrespective of weakening to semivowel or zero in actual forms.

Section number four required subjects to change a sentence of the form: "Mange (plural noun) er (adjective + plural [ə])." 'Many ____ are ____.' to one of the form: "Men det her (singular noun) er utrolig (adj. + neuter [d])." 'But this ____ is unbelievably ____.'. Examples were the same as in part two just going in the opposite direction - plural predicate adj. to neuter singular. The crucial forms, those which could show an alternation in the final stem consonant, were identical except for the initial consonant(s) within sections I/IV and sections II/III. The difference between corresponding crucial forms was thus for all practical purposes limited to morphological and semantic information.

The fifth section had a different character from the preceding four. The subjects were told that, as they perhaps had guessed, not all of the new adjectives they had heard existed in Danish, but that these might appear some day in a nonsense poem or as a brand name. They were asked to listen to a list of these words and rate their relative "Danishness" on the basis of their first impression. A scale from 1 (normal Danish) to 10 (not at all Danish sounding) was printed on a piece of paper so that they could record their impression of each item.[1] It was suggested that the ratings need not be equally distributed over the whole scale. The words read were simply the crucial forms in each section. Subjects were informed of the morphological category from which each of the forms came, whether present tense verb, neuter adjective, etc. Half the participants heard the list in the same order they had heard the crucial items during the course of section I - IV; the other half heard the same order of sections but with each list read from bottom to top. Each form was read twice (2-3 sec.) and the subject had 4-5 sec. to mark an answer.

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1) The scale was patterned after an 11 point scale used by Greenberg and Jenkins (1964) in a very similar rating test in English. Several of the linguist-participants in the present study felt the scale was approximately twice as broad as advisable.

There were 9 subjects in the pilot study, all native Danes and Rigsmål speakers. Five were linguists connected to the Institute of Phonetics, while four had little or no training in linguistics. The cue sentences were played back to each subject over headphones and responses were recorded by means of a desk microphone and a second tape recorder. Each subject was alone during the test.

2.2 Results

The following paragraphs contain a synopsis of the results for the crucial forms according to final stem consonant and morphological category.

2.2.1 Verbs -ɣɒ → -$\begin{Bmatrix}\text{ɣ}\\ \text{g}\end{Bmatrix}$d

Of the 234 responses only 5 first responses showed the weak participial ending [d]; all others ended in ə$\begin{Bmatrix}\text{ð}\\ \text{d}\end{Bmatrix}$ regardless of the structure of the stem. Three of the five variant responses were given by subject number 2 in sentences 1 and 2, who then revised her answer to sentence 2 using the [əð] ending and continued to use this ending (with one exception) throughout the rest of the section. Because of this strong preference for the [əð] ending none of the final [d] or [g] stem consonants came into a position where we would expect hardening. Thus only the potential changes gd → $\begin{Bmatrix}\text{ɣɒ}\\ \text{gɒ}\end{Bmatrix}$ will be of interest in the verbs (see table 1, cues 43, 48, 49, 55). As mentioned before, the change in [ð] is not subject to clear interpretation because of possible assimilation or deletion before [d]. The two [ð] stems in the first section were included for the sake of balance and curiosity.

2.2.2 Adjectives -ðə → -$\begin{Bmatrix}\text{ð}\\ \text{d}\end{Bmatrix}$d

The surface [ð] to [d] change between plural and neuter respectively occurred in 7 of the 10 responses by linguists but only in 1 of 5 by non-linguists (some of the non-linguists' re-

Table 1

Presence or absence of alternation in the crucial forms

O No alternation ɣ/g or ð/d
X Alternation present
[ ] Response not usable (P Interpretation of cue as Past Participle)

Verbs (Subject: Linguists 1–5, Non-Linguists 6–9)

Cue	Response	1	2	3	4	5	6	7	8	9
3 kri:ðɒ	krid	O	O	O	O	X	O	O	O	O
15 vu:ðɒ	vud	O	O	O	O	X	O	O	O	O
43 sløgd	slø(:)ɣɒ	X	O	O	O	X	O	O	O	O
48 kvagd	kva(:)ɣɒ	X	O	X	X	O	O	O	O	O
49 migd	mi(:)ɣɒ	X	O	X	X	X	X	O	X	O
55 vøgd	vø(:)ɣɒ	X	O	O/X	X	X	X	O	X	O

Adjectives (Subject: Linguists 1–5, Non-Linguists 6–9)

Cue	Response	1	2	3	4	5	6	7	8	9
68 blu:ðə	blud	O	X	X	X	X	O	O		X
70 fi:ðə	fid	O	X	X	X	O	O	O		
61 fli:ɣə	fligd	X	X	O	O	O	X	O		O
65 to:ɣə	togd	X	O	O	X	O	O	O		O
67 pa:ɣə	pagd	O	O	O	O	O	O	O		X
27 vrigd	vri(:)ɣə	X	P	X	O					P
30 fnagd	fna(:)ɣə	X	P	O	X		P			P
39 pøgd	pø(:)ɣə	X	P	O	X			P	P	P
32 kvad	kva(:)ðə	X	O	X	X	X	O	O	O	O
42 kred	kre(:)ðə	O	O	O	O	O	O	O	O/X	O

sponses could not be used because one merely repeated the plural form and another used a different stem altogether; see table 1, cues 68, 70). The remaining responses showed [ðd], confirming Basbøll's contention that this is the productive strategy (Basbøll 1974b, p. 64).

2.2.3 Adjectives -ɣə → $-\left\{\begin{matrix}\text{ɣ}\\ \text{g}\end{matrix}\right\}$d

Here 4 out of 15 linguist responses showed [gd]. Only 2 of 9 non-linguist responses evidence the alternation. (See table 1, cues 61, 65, 67.) These data are difficult to explain as adjectives do not normally participate in this change.

2.2.4 Verbs -gd → $-\left\{\begin{matrix}\text{ɣ}\\ \text{g}\end{matrix}\right\}$d

12 out of 20 linguist responses interpreted the final stem consonant as a [ɣ] and this with some consistency. The non-linguists behaved differently. For the first two crucial examples (43, 48) none of the subjects 6, 7, 8, or 9 softened the [g]. Then on items 49 and 55 (of which 55 has the same vowel as 43) two of the non-linguist subjects softened the [g] to [ɣ]. (See table 1, cues 43, 48, 49, 55.)

2.2.5 Adjectives -gd → $-\left\{\begin{matrix}\text{ɣ}\\ \text{g}\end{matrix}\right\}$ə

Considering the same change in adjectives the picture is even more complex. Among the linguists' 15 responses, 6 had the alternation. One subject consistently interpreted the [gd] form as a past participle and merely added [ə] in the plural. This strategy makes it impossible to get any evidence for or against the existence of the alternation in these cases. None of the non-linguists' responses showed the softening. The change d → $\left\{\begin{matrix}\text{ð}\\ \text{d}\end{matrix}\right\}$ə in adjectives was found in 4 out of 10 responses by linguists and once (quickly revised) among the 8 answers from non-linguists.

The fairly consistent difference between the linguists' and the non-linguists' responses in sections I - IV also appears in part V. The item averages for the former ranged from 1 to 2.4 while the latter's item averages ranged from 4 to 7.8. Conversations with non-linguists after the test indicate clearly that they were not aware that they were working with nonsense forms during the course of the first four sections. Several reported that they were upset that so few (in fact none) of these words, which they felt they ought to know, were familiar to them.

2.3 Problems of interpretation

In order to be able to generalize any conclusions to Danish about the subjects' treatment of nonsense syllables we must be reasonably certain that they treated the constructed verbs and adjectives as though they were Danish. The data support this conclusion. The low ratings given by the linguists in part V attest to the well-formedness of the nonsense stems. While the higher ratings given by the non-linguists could be used as an argument against this conclusion, I believe that these subjects' informal comments to the effect that they felt the words were genuine Danish should be taken into consideration. The higher ratings may be due to the fact that they did not have such ready access to information on well-formedness as linguists, who had no doubt dealt with the problems of accidental versus systematic gaps. But as Per Linell (1974) points out, we always run the risk that the linguistic knowledge we want to test "is being modified and manipulated in various ways through the very process of investigation (the testing or introspective analysis). It may happen that test subjects organize or make conscious their linguistic knowledge in an artificial manner during the test. In addition, various linguistically irrelevant factors may influence the output of the test or analysis." (p. 139). The fact that both groups may have been reacting to the semantic features which the carrier sentences suggested for the nonsense forms, if they could in fact remember them, rather than to the structure of the items themselves, should not have skewed one group's responses in relation to the other.

The overwhelming majority of responses, especially among non-linguists, can be described in terms of invariant stems and the addition or subtraction of invariant endings in a given morpho-syntactic environment. However, the fact that the alternations were extended by non-linguists suggests that the subjects have not merely memorized the independent forms which show the alternation, but have at some level grasped the relationship between the alternating forms. The extension common to both groups occurred in adjectives [ɣə - gd] and verbs [gd - ɣɒ]. Only linguists softened the [g] in adjectives.

We can proceed a little further and ask on what data the extension is based. It cannot in any case be in analogy to or induction based on the other cue forms in the list, since none of these allows a change in the final stem consonant. If there is any rule to be induced from the majority of items on the list, it is to use invariant stems and endings. Could the extensions be based on analogy to forms of similar phonological, semantic, and morpho-syntactic make-up already existing in the speaker's lexicon? This cannot be the case with the adjective stems in [ɣə] which showed hardening in two responses from non-linguists, unless subjects ignored morphological categories suggested by the data. Adjectives in [ɣ] do not show the alternation; a few verbs do. It may be objected that the two responses were flukes of the test situation and statistically insignificant. The pilot study is clearly to be viewed with a critical eye as far as the generalization of the conclusions is concerned. But flukes or not, the two items under discussion are nevertheless responses, and the only pattern available is in the verbs.

Here the fairly consistent surface pattern is [ɣɒ ~ gd], and subjects might have been expected to produce new forms which fit this pattern. However, not surprisingly, only a few non-linguist responses (4 of 16) showed the alternation and these occur in items 49 and 55, not in 43 and 48 which differ from the former only in the initial consonants. Again small numbers make interpretation precarious, but if subjects were using model verbs which rhymed (à la Ohala 1973), then 49 should have been less likely to evoke the alternation since there are virtually no verbs in [iɣ] which have hardening in the participle. And why soften in 55 [vøgd] if not in 43 [sløgd]? This difference can hardly be based on phonological cues.[1]

3. The appeal to analogy

3.1 Ohala and Hsieh

This is as far as this particular pilot study can bring us in the issues discussed so far. The really interesting question of whether a classical independent phonological rule or an analogical rule mechanism is the best explanation for these data cannot be resolved here. But the difficulty in deciding this question may not lie so much in the experimental design as in the form of the question and its tacit assumptions about the relationship between analogical and independent rules, as for example Ohala (1973) has outlined them. What are the testible differences between these two types of rules and what are the ramifications of adding an analogical algorithm to the theory? While in attempting to answer such questions one risks repeating part of a long, well-known debate. I believe there is ample justification to do so. First of all, the assumption that the debate is a part of every linguist's basic education may not be

1) Jørgen Rischel has suggested that there may be pressure against responding to [sløgd] with [sløgɒ] because apparently only a few verbs which take the [d] weak ending have stems ending in [d,g]. This fact is confirmed by my own visual search of Gyldendals Dansk-Engelsk Ordbog (Danish-English Dictionary). Speakers would then have to choose between two unusual things, - a stem showing the alternation and a new stem type in the [d] class of weak verbs. (There is precedent for such a type in the form of such verbs with stems in [b].)

true for the upcoming generation of linguists. Second, and more importantly, an increasing number of scholars (Hsieh 1970, Ohala 1973, Vennemann 1972) are rejecting significant parts of the transformational model and invoking "analogy" as the best explanation for certain synchronic and diachronic data. Rare is the case in which more than passing mention is made of the impressive difficulties involved in defining what we mean by "analogy", even operationally, or of the implications for theory testing of adding such an unrestrained, powerful mechanism to a model of language. The work of John Ohala and Hsin-I Hsieh in synchronic linguistics is particularly interesting in this connection.

John Ohala in an unpublished paper "On the design of phonological experiments" and in "Experimental Historical Phonology" (1973) argues against the existence of vowel shift in English as an independent phonological rule and for the explanation of the behaviour of the subjects in question by an analogical phonological rule. According to Ohala, analogical phonological rules are ones "which for their application require not only information about the given phonological item but also information culled from the lexicon as a whole." (Ohala 1974, p. 25). Linguistically naive speakers of English were asked in one part of the experiment to fabricate new derived forms. They were primed with a form which really existed. Hearing the pair detain - detention as an example and cued with obtain, 18 out of 26 (all those who changed the stem at all) responded with [ʌb t^{h}ɛnʃən]. Given explain - explanatory as an example and the same cue, most of the subjects left the stem unchanged, but 10 changed it to [ʌb t^{h}ænətɔri]. 9 of these 10 were among the 18 who gave [ʌb t^{h}ɛnʃən].

Ohala (1973) concludes as follows: "This shows among other things that the assumption by generative phonologists of unique underlying forms is not supported, because they would apparently posit a different underlying form for those words showing the [ej-ɛ] alternation versus those showing the [ej-æ] alternation (Chomsky and Halle 1968). But here we have the same word showing both alternations in the speech of some subjects. So these derivations cannot be based on a single underlying form or perhaps, ... as I will suggest below, on any abstract underlying form. It also shows that the particular form of the derivations, contrary to the assumption of generative phonology, does depend on other words or pairs of words in the lexicon of the speaker. Having found, or in the present case, having been provided with suitable existing models, the speaker can pattern new derivations after them, that is, he can analogize."

The conclusion is carefully stated; the use of unique underlying forms and an independent phonological rule is _not supported_. But neither is their existence called into question except in this one special instance discussed by Ohala. He has shown that given an example, speakers, using something akin to the ability to recognize and reproduce rhyme, can solve an analogical proportion a:b::a':x and x = b'. Having specified three of the quantities, the predictability of x is hardly surprising. The interesting question in instances of analogy is, given a' and some information about x, what a and b will the speaker choose? Given _bring_ and the fact that x must be the past tense form of the same verb, what factors affect the choice of which, if any, models to produce _bringed_, _brang_, or _brought_?

As for the distinction between analogical and independent rules with regard to their dependence on information from the lexicon, it has perhaps been made misleadingly clear. Generative phonological rules are in fact based on other forms in the lexicon, only in a much more explicit way than Ohala's analogical algorithm. An independent phonological rule could be described as a more or less permanent (from speech act to speech act) analogical rule stripped of all but the structural similarities of the set of alternating morphemes specified as relevant for triggering the rule. In most versions of the formalism and evaluation metric such an independent rule is constrained by the goal of encompassing maximally natural classes of forms. The analogical rule is based on a subset of those data that underlie the independent rule, - a subset with one or a pair of members. The analogical rule refers to a specific form while the independent one represents an abstraction from this piece of data and others. The relatively unconstrained nature of an analogical rule makes it impossible to find an individual output for which an independent rule can be shown to be necessary and sufficient. It appears that an analogical rule can produce any individual output an independent rule can, but as Ohala's experiment shows, the reverse is not true. In fact, any distinction must lie in the predictions the two types of mechanisms make about the relatedness of various outputs. As Kiparsky (1972a, p. 280) points out, propositional analogical equations are not systematically related as independent rules may be (stress mine). The former cannot represent overall aspects of morphological organization but rather only relations between individual morphemes. The exact nature of the relation is left open.

Hsieh's experiments provide a broader argument for invoking an analogical mechanism than Ohala's, but the nature of the mechanism is equally vague. In brief, Hsieh (1975) tested five tone shift rules in Taiwanese by confronting native speakers with new forms (partially nonsense syllables), which were eligible to undergo tone sandhi, an exceptionless process among native morphemes in the correct environment. He presents a good deal of evidence that at least in the test situation speakers use a lexicon with surface form and handle new material by associating it with familiar forms and proceeding as though the new material followed the pattern of the familiar model.

Hsieh concludes (p. 132) "The experimental results, some of which have puzzled us earlier, can now be satisfactorily explained in terms of the power of association". Consistently more frequent application of two of the rules is "explained" by the larger number of forms in these tone categories. Differences in the applicability of a given rule depending on whether it is used forward (base to sandhi form) or backward can be attributed to different "powers of association" for words in their base forms as opposed to their sandhi forms. Variation among different test items governed by the same rule stems supposedly from a different "degree of associability" based on phonetic, syntactic, and semantic factors (p. 130-132).

This sort of explanation does not solve the problems involved but rather restates them in terms of a more general cognitive process, one which is unfortunately not at all well understood despite decades of study. Like Ohala, Hsieh brings experimental evidence for the existence of some sort of analogical strategy, but both leave us hanging as far as the details of how analogy works and its relation to present linguistic models.

3.2 Traditional analogy

Unfortunately the background literature on this problem, as extensive as it is, offers a bewildering mass of data but no gain in specific explanation. Hermann Paul (1920, p. 109) for example agrees with Ohala and Hsieh on the importance of analogy in synchronic linguistic behaviour. He writes: "Man wird diesem Faktor des Sprachlebens (analogy) nicht gerecht, wenn man ihn erst da zu beachten anfängt, wo er eine Veränderung im Sprachusus hervorruft". While Paul allows for relatively unrestricted association of forms on the basis of partial identity in semantic, phonetic, and morpho-syntactic traits, he restricts the operation of the analogical equation as follows (p. 117): "Es muss ein jeder (Glied) mit dem andern irgendwie vergleichbar sein, d.h. in diesem Falle, es muss mit dem einen im stofflichen, mit dem andern im formalen Elemente eine Übereinstimmung zeigen. So lässt sich z.B. im Lat. eine Gleichung ansetzen animus:animi = senatus:x, aber nicht animus:animi=mensa:x". (A stofflich group would be all the case forms of one noun; a formal group - all datives, all causatives, etc.)

Paul provides no real arguments for requiring so much overlap. In the case of the example, animus:animi = senatus:x = mensa:x, it is apparently not enough that animus and mensa are both nouns, singular, and nominative. They must be of the same declension. This requirement seems to contradict other proportions mentioned by Paul such as gebe:gab = kann:konnte = bin:war = lebe:lebte or processes like elision in French or the [c - x] alternation in German, which he believes are undoubtedly analogical. As a result he is forced to admit a large class of exceptions which look like instances of analogical extension but according to Paul lack the required degree of partial identity. These examples include the extension of an inflectional ending or set of inflectional endings from one subclass of forms to other subclasses, e.g. the extension of the -s noun plural in English or the -s genitive in Danish from one subclass of nouns to almost the whole class. In each of these instances the terms have some common traits, as is almost trivially true of any two forms in the lexicon. Hermann Paul believes in the central role of analogy but is no good source of principled restrictions on its operation.

The only other limitations placed on analogy by Paul or later by Eduard Hermann (1931) are statements to the effect that the association of forms or proportions is facilitated by maximal overlap in sound and meaning, by the strength of the form in the memory, and syntagmatic associational links. These are very fragmentary and speculative observations. Deese's (1966) investigations into the interaction of grammatical class and associations in English demonstrate that the situation is much more complex than occasional casual references to associativity as the basis for analogy would indicate. He found that both common and rare nouns tend to elicit paradigmatic associates. Associates to common adjectives are more likely to be paradigmatic than those to uncommon ones. Unlike other classes, syntagmatic responses to nouns define paradigms of meaning and do not necessarily reflect the context in which the stimulus word appears. Most paradigmatic associates to adjectives are polar opposites or synonyms. For common adjectives they are overwhelmingly antonyms. The correlation of frequency of usage (Thorndike-Lorge) with the appearance of an antonym is .889 (p. 110). Facts like these must be taken into account in discussions of the structure of the lexicon, which must in turn be considered in determining how a speaker would search his lexicon for an analogical model.

Another attempt at limiting analogy so that it allows the historically attested examples which linguists want to call analogy but does not predict implausible or even absurd formations, has been made by Kuryłowicz (1945-49) and Manczak (1958). These restrictions come under the heading of marking. Nigel Vincent (1974, p. 430) summarizes their principal hypotheses in three groups as follows:

(i) morphological markedness - i.e. certain syntactic categories are unmarked - e.g. indicative mood, masculine gender, etc., and these are of relevance in establishing the direction of change.

(ii) length/strength of exponents - i.e. there is a tendency to form regular exponents of morphophonemic categories with elimination of zeros and retention of longer rather than shorter morphological endings.

(iii) elimination of redundancy and reduction of allomorphic variation, i.e. as in the previous case, changes operate to establish more regular correspondences between categories and exponents - this time by elimination of redundant variation.

The views of analogy presented so far are representative of the best thinking on this subject by traditional and modern grammarians, and yet the picture of analogy one gets is a very blurred one. Markedness studies deal in tendencies which allow many exceptions. They tell us mostly about the generalizations which apply to historical analogical realignment and only very indirectly about the process itself. Association studies have not yet been exploited as a source of information about the lexicon.

We are left with an intuitively grounded requirement of similarity between the terms of a proportional equation but no principled measure of the degree of overlap.

3.3 Generative criticism

Generative grammarians have had little to say about analogy beyond a rejection of it in both synchronic and diachronic models. In Cartesian Linguistics Chomsky (1966, p. 109) writes:

"To attribute the creative aspect of language use to "analogy" or "grammatical pattern" is to use these terms in a completely metaphorical way with no clear sense and with no relation to the technical usage of linguistic theory. A description in these terms is incorrect if the terms have anything like their technical meanings and highly misleading otherwise, in so far as it suggests that the capacities in question can somehow be accounted for as just a "more complicated case" of something reasonably well understood."

Regrettably, Chomsky does not reveal "their technical meanings" so it is difficult to judge the truth of his assertions. It is debatable too why we cannot consider as creative "the decision to exclude some concrete actually occurring factors as irrelevant while retaining others as central to a perceptual unity" - the essence of analogy according to Dinneen (1968, p. 102).

In diachronic studies analogy has been rejected as "often terminologically empty", a catchall "for irregularities in the operation of regular sound laws" (King 1969, p. 127). Analogy was reinterpreted as grammar change. The generative criticism of traditional analogy is summarized in King (1969) and Kiparsky (1974). It is threefold. If one requires only that there be some similarity between the items of the proportion then the mechanism is asserted to be not only too strong but also too weak. Because almost every lexical item has some trait(s) in common with every other, proportions can be set up and presumably solved producing results which are unattested historically and seem intuitively highly unlikely to occur in the future. Ear:hear = eye:x x= heye. John knows Mary: Mary who John knows = John knows Bill and Mary:x x = Mary who John knows Bill and. Kiparsky suggests the proportion must correspond to an actual or potential rule of the language and not violate other constraints. Thus there is no rule in the case of ear:hear and the rule in the second example violates the coordinate structure constraint (Kiparsky 1974, p. 259). It is a fact, however, that such formations occur especially in the speech of children and in folk etymology, cf. four airplanes:formation = three airplanes:"threemation" (Anttila 1972, p. 274).

King (1969) and Kiparsky (1974) argue analogy is too weak by pointing out some cases which they claim cannot fit a proportional equation. Kiparsky cites double plurals such as <u>mices</u>, <u>feets</u>, <u>mens</u>, and changes in isolated non-derived forms as for example the assimilation of loan words to native vocabulary in stress and other characteristics.

But the irregular plurals <u>mice</u>, <u>feet</u>, <u>men</u> must be memorized anyway. Why not explain the double plurals by saying that the speaker chose the correct irregular plural stem but for some reason (habit?) went ahead and formed the productive plural, by analogy if one will, just as in the case of a normal stem. As for examples like <u>garáge</u> > <u>gárage</u> I can see no way to make them fit a four membered proportion. (However, Dinneen (1968) mentions other forms of analogy such as a:b=b:c or the basic similarity relation a:b.)

Finally King (1969, p. 132) writes: "To show that Old English <u>caru</u> 'care' gave up its plural <u>cara</u> for <u>cares</u> by proportional analogy, one must produce an a-stem noun agreeing with <u>caru</u> in some way. And we must do the same for <u>dæd</u> 'deed', <u>tunge</u> 'tongue', and a host of other nouns that did not originally take a plural in -s. This simply cannot be done since, for one thing, a-stem nouns ended only in consonants in Old English".

This is one of the many examples which even Paul recognized as not fitting the requirement of Übereinstimmung. But this depends on how much and what kind of overlap one requires. If you do not require that nouns belong to the same declension, then there are proportions available. a (noun sing.): a+s (noun pl.) = cara (noun sing.): x (noun pl.) x = cara+s. It seems to me one can complain in these cases that the mechanism is much too strong and that the direction of change is not predictable from the proportional model, but not that the mechanism is too weak.

The third and final objection to the traditional proportion model is undoubtedly the most serious. Because analogy applies to a form at a time, changes by analogy, it is argued, should proceed item by item. "But in reality it is only morphological analogy which is typically sporadic; in the case of syntactic phenomena on the one hand and purely phonological phenomena on the other, analogical change proceeds typically (though not always) across the board" (Kiparsky 1974, p. 260). Traditional analogy is then seen as one manifestation of "a universal process of simplification that ultimately goes back to the child's acquisition of grammar" (King 1969, p. 130). Then the asymmetry of across the board versus item by item spread could be a reflection of the generalization of morphological rules, which apply to designated individual lexical items, versus syntactic and phonological rules, which are more general (Kiparsky 1974, p. 262).

However, rule simplification will not explain it all, as King himself points out. (See also Vincent 1974, Skousen 1974). Kiparsky (1971, p. 590-4, 1974, p. 265) and Ohala (1974) give evidence that speakers do not necessarily learn the generalizations linguists deem simplest and hence optimal. Kiparsky (1974, p. 261) concludes as follows: "Therefore, the class of possible analogical changes that a language can undergo cannot be characterized on the basis of grammar alone, any more than it can be characterized on the basis of surface structure alone. The failure of the first two approaches brings us by default to the third, in which reference is made to both grammar and surface structure". This third approach is generally called functional.

3.4 Functional explanations

Although there is some debate as to the status of functional explanations within the theory, there is considerable agreement on the tentative functional guidelines arrived at by various scholars. Kiparsky (1972, p. 222) cited three substantive targets imposed by performance on language change and hence analogy. The first is maximal distinctiveness of categories, which he relates to perceptual needs. The second is maximal paradigm coherence, which he presumes to be mostly a matter of ease of acquisition. The third is optimalization of phonotactic structure to avoid overly complex articulations. For this last one one might want to substitute preferred structures as the target. In 1974 Kiparsky reiterates the importance of "learnability", "perceptibility", and "producibility".

Already in 1969 Karl Heinz Wagner went beyond the generative equation of analogical change with grammar change by suggesting, a little too strongly perhaps, the automatic elimination of a rule with low functional yield, reordering of rules if the order has a low functional yield, and change in the abstract phonological status of morphemes in the case of phonological ambiguity.

Vennemann (1972) like Wagner interprets analogy in terms of grammar change, but he distinguishes two types of analogy on the basis of motivation for each type. On the one hand, phonetic analogy, or grammar simplification (when the formalism has been adjusted to mirror various sorts of simplification), has as its goal preferred phonological structure, but may lead to diversity in the output, the linguistic sign, by introducing paradigmatic variation. Conceptual analogy works toward uniformity of the linguistic sign but may result in marked phonological structures. Vennemann has dubbed this "innate principle of linguistic change". Humboldt's Universal: "Suppletion is undesirable, uniformity of linguistic symbolization is desirable: Both roots and grammatical markers should be unique and constant" (Vennemann 1972, p. 184). This corresponds quite well with Kiparsky's formulation (minus the phonotactic constraints).

Nigel Vincent (1974) has pointed out the similarity of these principles to those of Kuryłowicz (1945-49) and Manczak (1958) and has tried to relate them for further explanatory adequacy to Bever and Langendoen's (1972) work with perceptual strategies. Strong unique, invariant grammatical markers would facilitate the perceptual strategies' first guess as to the morphemic structure. The tendency to maximize ease of perception would be countered by a tendency to maximize ease of prediction (ease of learning). "The postulation of such a pair of forces in mutual opposition will help us explain the continual interplay along the time dimension of phonetic change and analogical reformation, in a way that King's unidirectional principle of grammar simplification cannot hope to do" (Vincent 1974, p. 435). These functional proposals provide more explanation than merely attributing the change to grammar simplification without showing why simplification takes place, i.e. in what sense the system becomes simpler. But there is a good deal less specificity as to how the analogical adjustment takes place and no suggestions for getting at this question empirically.

4. Conclusion

On the one hand we have been confronted with data which seem to require an analogical mechanism of the proportional type. On the other we have seen that across-the-board leveling phenomena, and one could add synchronic notions such as "unmarked ending" or "productive process", can hardly be accounted for by the pairwise relations on which analogy is based. Because it has up to now been impossible to pin down the factors which determine the choice of an analogical model, rules, as one way of formalizing an empirical regularity as powerful as they are often lamented to be, remain the more constrained hypothesis and are thus the initial alternative which must be demonstrated to be implausible before one turns to analogy as an explanation. This is only sensible methodology. The instances for which analogy seems most plausible as an explanation are in fact special and have something in common. I refer to examples of analogy documented in language acquisition and to the behaviour of subjects more or less forced to cope with unfamiliar linguistic material. In the first case, the speaker has a smaller set of model forms and less experience with the statistically dominant regularities of the language. In the second, the speaker also apparently lacks an appropriate generalization and so must, if he does not merely balk at the task, use a more basic cognitive strategy. This ability to recognize individual elements in a larger complex and to factor out common similarities or differences goes by the name of analogy - perhaps in its elementary form not a predominantly linguistic ability at all. The data from association studies cited indicate that while linguistic usage accounts for some associative cohesion among our linguistic symbols, psychologists and with them linguists have only just begun to understand the extra-linguistic moment. This is, I think, important to consider if analogy looks like the bandwagon of the future.

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