R E P O R T R E S U M E S

ED 014 044 AL 000 077

STUDIES ON THE SPEECH OF THE DEAF.
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PUB DATE JAN 66

EDRS PRICE MF-$0.25 HC-$1.04 24P.

DESCRIPTORS- *SPECTROGRAMS, *PHONEMES, SPEECH, *ARTICULATION (SPEECH), *DEAF RESEARCH, *ACOUSTIC PHONETICS, SPEECH HANDICAPS, ROYAL INSTITUTE, SONAGRAMS

A COMPARISON OF SEGMENT FEATURES IN THE SPEECH CHAIN OF THREE DEAF-BORN BOYS WITH THOSE OF THREE NORMAL-HEARING BOYS REVEALS THAT THE DEAF-BORN HAVE SPEECH PROBLEMS ASSOCIATED WITH A LACK OF SYNCHRONY BETWEEN ARTICULATION AND PHONATION. IN ORDER TO DETERMINE THE DIFFERENCES BETWEEN THE TWO GROUPS (BOTH REPEATING THE SAME SWEDISH SENTENCES), A SPECTROGRAM SEGMENTATION METHOD WAS USED, ANALYZING THE MANNER OF PRODUCTION AND CORRESPONDING ACOUSTIC CORRELATES OF THE SOURCE FEATURES AND RESONATOR FEATURES. SPECTROGRAMS REVEALED THAT THE DEAF BOYS' SPEECH DEVIATED FROM NORMAL PATTERNS IN VARIOUS WAYS, PARTICULARLY IN AN ERRATIC TRANSITION IN SOME PARTS OF THE VOWEL. IN ADDITION, THE ARTICULATION WAS NOT ALWAYS UNDER CONTROL, AND THE DEAF BOYS HAD DIFFICULTY WITH FRICATIVE ASPIRATION. THE SECOND PART OF THIS TWO-PART STUDY DESCRIBES A SPECTROGRAM SEGMENTATION TECHNIQUE IN WHICH SEGMENT BOUNDARIES COINCIDE WITH A CHANGE IN THE FEATURE COMPOSITION. AN EARLIER MODEL WAS LIMITED BY THE FACT THAT SLIGHT SHIFTS IN THE TIMING OF FEATURES CAUSED NEW SEGMENTS TO ARISE. ALSO, TIME DURATION OF SEGMENTS WAS NOT INDICATED. THE REPRESENTATION OF FEATURES AS A FUNCTION OF TIME WAS CONSIDERED MORE ADVANTAGEOUS, AND THEREFORE, A COMPARISON OF THE DURATION OF PHONEMES BETWEEN NORMAL HEARING AND DEAF SUBJECTS WAS CARRIED OUT. THE RESULTS SHOW A MUCH LOWER RATE OF SPEAKING FOR DEAF SUBJECTS. THIS DOCUMENT WAS PUBLISHED IN QUARTERLY PROGRESS AND STATUS REPORTS, OCTOBER 1965 AND JANUARY 1966, BY THE SPEECH TRANSMISSION LABORATORY, ROYAL INSTITUTE OF TECHNOLOGY, STOCKHOLM. (FB)

IN QUARTERLY PROGRESS AND STATUS REPORT Oct. '65 AND JAN '66, SPEECH TRANSMISSION LABORATORY, ROYAL INSTITUTE OF TECHNOLOGY, STOCKHOLM

C. STUDIES ON THE SPEECH OF THE DEAF

J. Mártony

Introduction

The speech of deaf-born people differs in many ways from the speech of normal-hearing subjects. The following study is an attempt to specify this deviation on an objective level. For the description of the speech material a spectrogram segmentation method has been used, and the segment features in the utterance of deaf and hearing subjects have been compared. The study is of introductory nature only.

The acoustic chain of speech contains successive minimal speech units (segments) with different characteristics (features). By definition the segment boundaries coincide with a change in the feature composition. The features describe the relevant qualities of the acoustic signal which can be correlated with the speech production as well as with the speech perception. This method of segmentation has been worked out by Fant and Lindblom (1).

There are two types of features used for description of the segments:

1. Segment type features which describe segments by their manner of production, respectively the corresponding acoustic correlates.
2. Segment pattern features related to the place of articulation, and specified by their acoustic correlates.

This study is concerned with the first category only, i.e. segment type features. The description of the segments in a speech chain in terms of these features contains no information about the prosodic features, such as stress, intonation, and rhythm.

The segment type features are the following:

Source features:
1. voice
2. noise
3. transient

Resonator features:
4. occlusive
5. fricative
6. lateral
7. nasal
8. vowel-like
9. transitional

The material used in this study is the second sentence of the text: "Det är vackert väder idag. Solen skiner, men det är kallt".

This text has been recorded, spoken by three boys with normal hearing (H1, H2, H3) and by three deaf boys (D1, D2, D3), all in the ages between 13 and 15 years and after their period of voice breaking (audiograms of the deaf boys, see Fig. I-C-1).

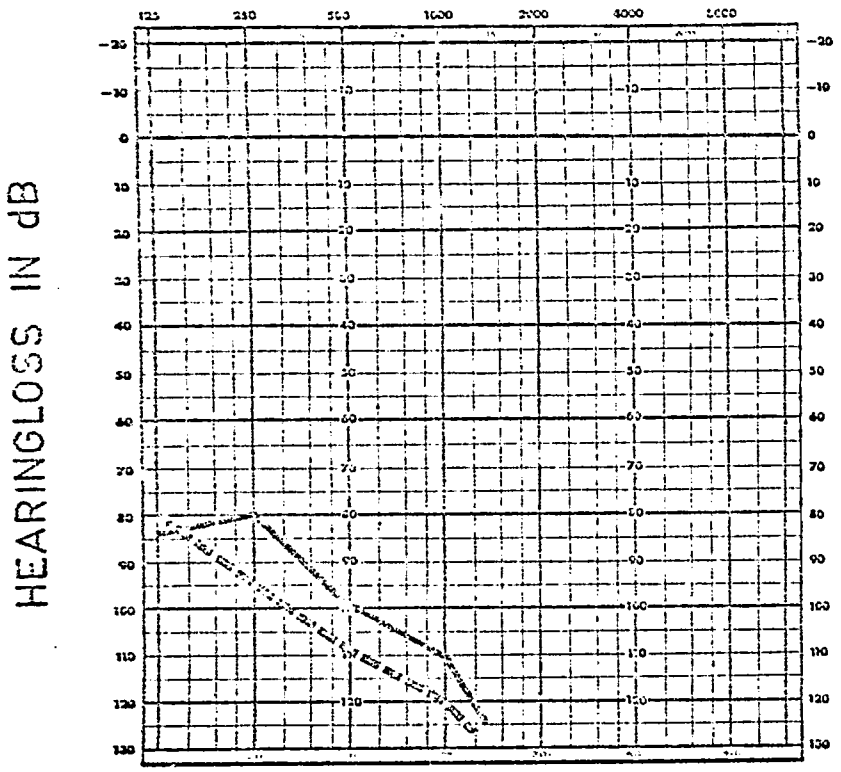
The sentence used in this analysis can be transcribed in broad transcription as: /su:lɛn ʃi:nɛr mɛn de:kalt/.

Fig. I-C-2 shows sonagrams with segmentation of this sentence spoken by the three normal-hearing boys (H1, H2, H3). In these sonagrams one can see that the five words are spoken continuously without pause, except for H3, where there is a pause between "skiner" and "men". "Det är" is spoken in a colloquial manner as /de:æ/ or only /de:/. Speaker H2 has a rather reduced articulation, he speaks a Stockholm dialect used by teen-agers. H3 speaks very well; well articulated and clear, but in a colloquial style. A segmentation of the utterances of these normal subjects is carried out in Fig. I-C-3. In this symbolic representation the time lengths of the segments are not shown. A mean pattern for those three subjects here referred to as a normal pattern has been constructed and is shown in Fig. I-C-4. A distinction is made between segments and features of primary importance and those of secondary importance. The individual pattern of speaker H3 comes closest to the normal pattern. Fig. I-C-4 shows the segment type feature pattern for the normal version.

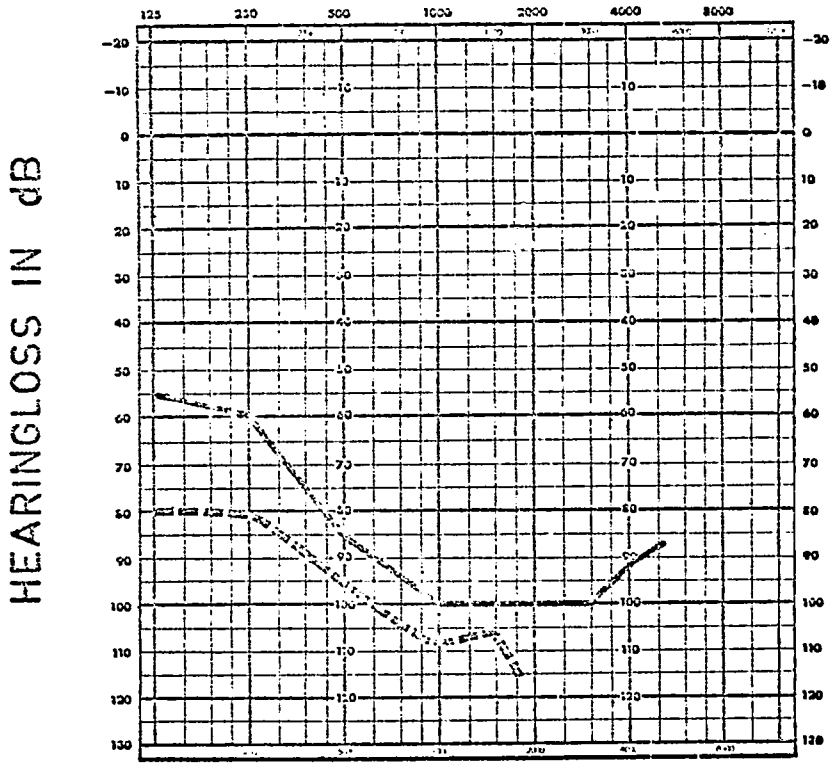
Description of the segments of the normal pattern

Segment 1 pertains to /s/. Its source feature is noise and the resonator feature is fricative.

D1



D2



D3

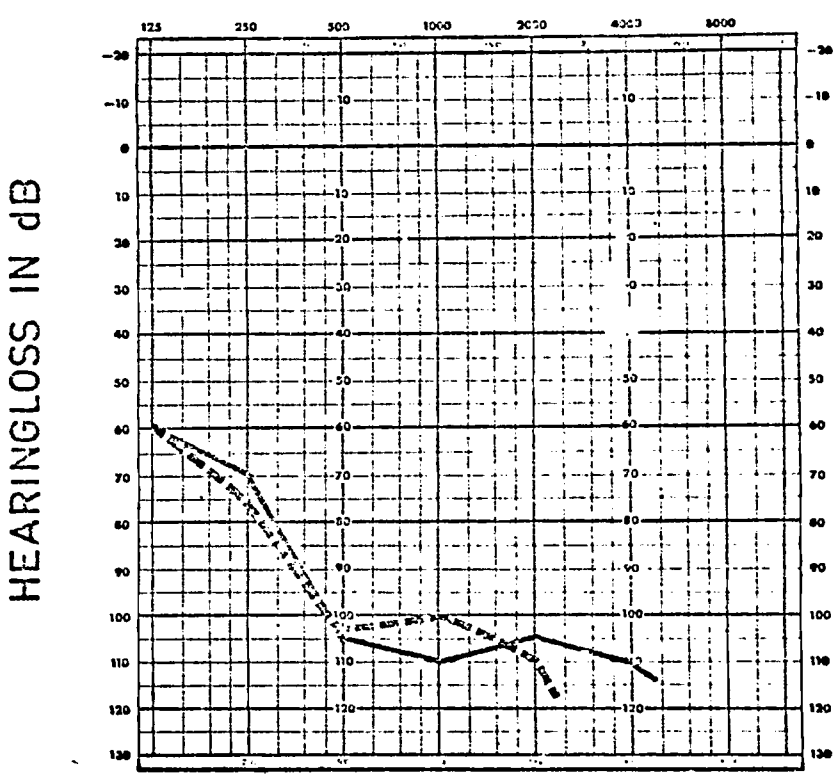
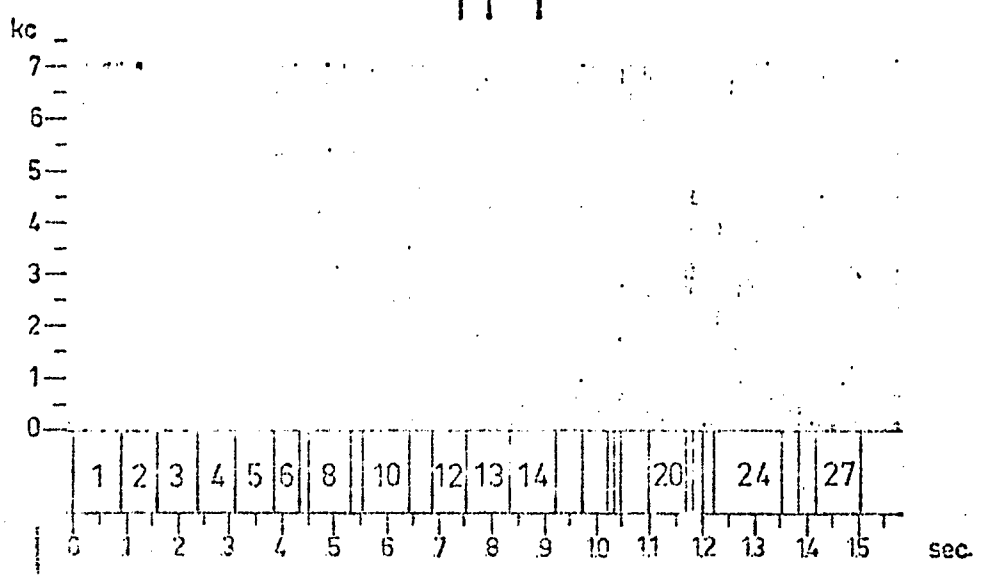
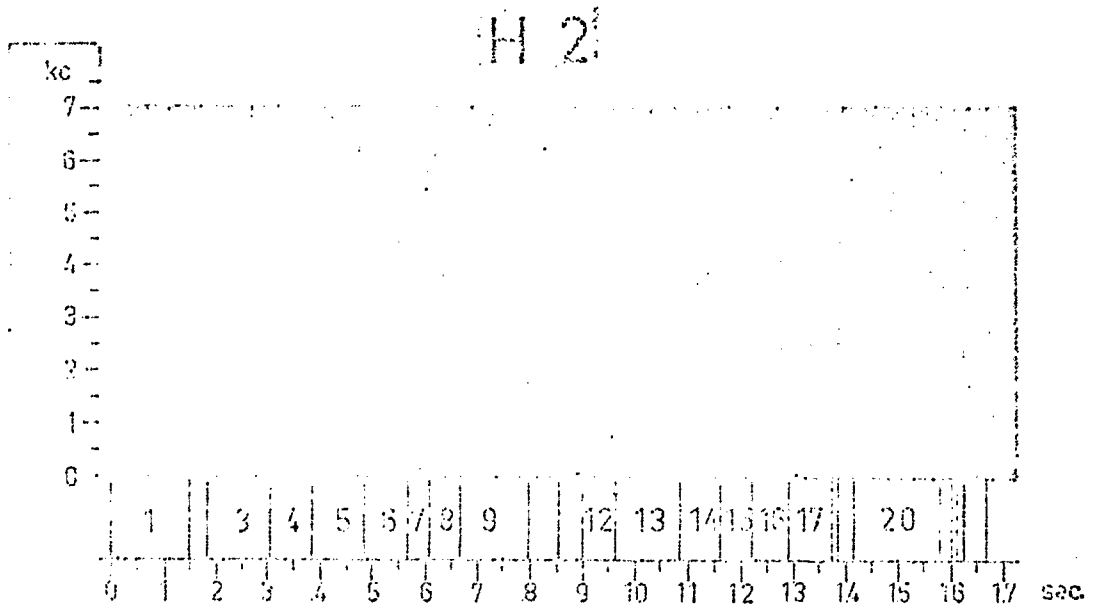


Fig. I-C-1. Audiograms of D1, D2, and D3. Air conduction.
Right ear = solid line, left ear = dotted line.





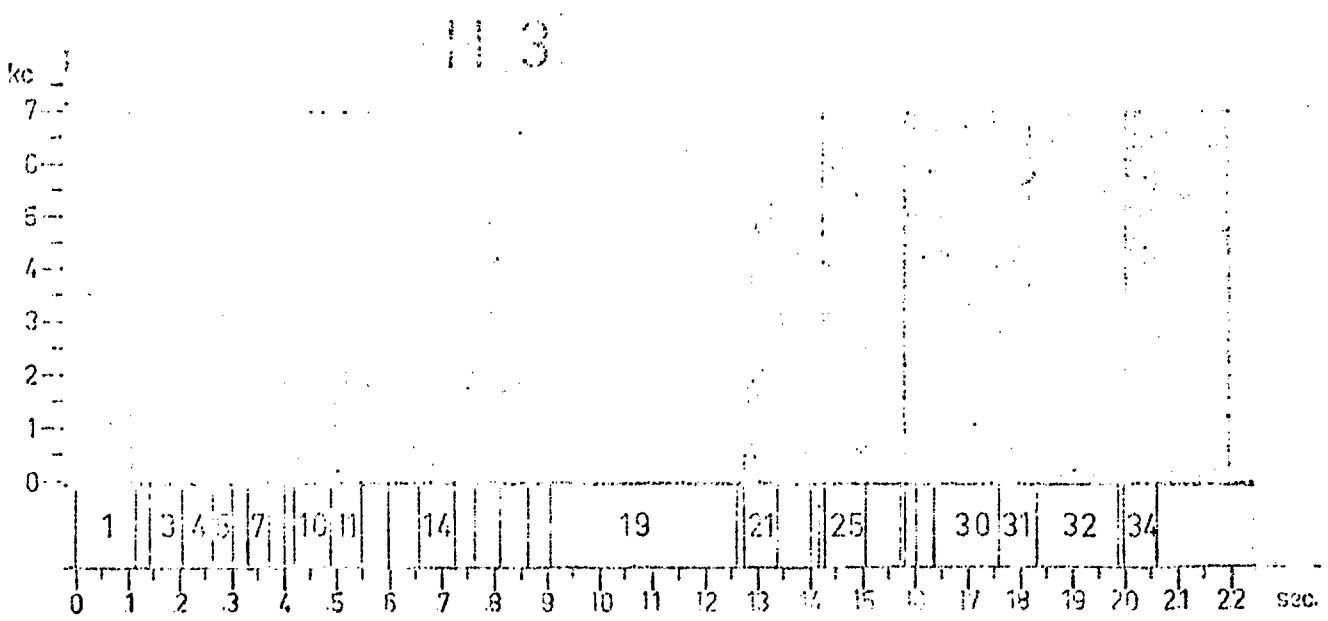


Fig. I-C-2. Sonagrams of the test sentence spoken by the three normal hearing subjects, H1, H2, and H3.

H1

Segments:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Voice			x	x	x	x	x			x	x	x	x	x	x	x	x	x	x					x	x		
Noise	x	x						x	x													x	x				x
Transient																		x			x						
Occlusive							x					x		x		x	x			x						x	
Fricative	x	x						x														x					x
Lateral				x																					x		
Nasal						x	x				x	x	x	x	x	x											
Vowellike		x	x		x	x			x	x	x		x		x				x			x	x	x			x
Transitional			x		x	x				x	x		x		x				x				x	x			x
	s		u:	l	ɛ	n	ʃ		i:	n	ɛ	m	ɛ	n	d	e:		k		a	l		t				

H2

Segments:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Voice			x	x	x			x	x	x	x	x	x	x	x	x				x	x			
Noise	x	x				x	x												x					x
Transient																		x					x	
Occlusive										x			x		x		x					x		
Fricative	x	x				x	x												x					x
Lateral				x																	x			
Nasal			(x)	(x)	x				x	x	x	x	x	x	x									
Vowellike		x	x		x	x	x	x	x		x	x		x		x			x	x				
Transitional			x		x		x	x	x			x		x		x				x				
	s		u:	l	ɛ		ɦ		i:	n	ɛ	m	ɛ	n	e:		k		a	l		t		

H3

Segments:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Voice			x	x	x	x	x	x				x	x	x	x	x	x			x	x	x	x	x	x					x	x			
Noise	x	x							x	x	x							x										x	x					x
Transient																								x		x						x		
Occlusive				x			↘							x					x	x		x	x			x						x		
Fricative	x								x	x																		x						x
Lateral					x																									x			
Nasal								x					x	x	x					x	x	x												
Vowellike		x	x			x	x	x		x	x	x	x		x	x	x	x			x				x			x	x	x				
Transitional			x			x						x			x		x				x				x				x	x				
	s		u:		l		ɛ			ʃ		i:	n		ɛ		r	#	m	ɛ	n		d		e:		k			a	l		t		

Fig. I-C-3. Segment feature pattern of the test sentence for the three normal hearing subjects H1, H2, and H3.

Segments:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Voice			X	X	X	X	O			X	X	X	X	O	O		X	X	X	O	X	X				X	X			
Noise	X	X						X	X						O										X					X
Transient																					X			X				X	
Occlusive							O					X				O	X		X	O			X					X		
Fricative	X	X						X	X						O										O				X	
Lateral				X																							X			
Nasal						X	O				X	X	X				X	X	X											
Vowellike		X	X		X	X			X	X	X		X	O	O			X				X			X	X				O
Transitional			X		X	X				X	X		X	O				X				X			O	X				
	s		u:	l		ɛ	n		ʃ		i:	n		ɛ	ˈ	#	m	ɛ	n	d		e:		k		a	l		t	

Fig. I-C-4. Normalized segment feature pattern of the test sentence.

Segment 2 pertains mainly to /s/ but it is influenced by the fol- ·ng /u:/. Its source feature is noise and the resonator features are vowel-like and frictive. The vowel-like feature is common at the boundaries between fricatives and closed vowels and is realized by the appearance of F2. The friction is reduced and at the last 10-15 msec it totally disappears.

Segment 3 pertains mainly to /u:/. It has the features voice, vowel-like, and transitional. The transitions at the beginning of the /u:/ are influenced by the /s/ and at the end by the following /l/.

Segment 4 pertains to /l/ and has the features voice and lateral.

Segments 5 and 6 pertain mainly to /ɛ/. They are voiced and vowel-like. Segment 5 is transitional and 6 is both transitional and nasal. One might prefer to include a stationary part in the middle of the vowel, but this did not seem motivated here. The nasalization can start earlier. In that case segment 5 falls away (see H2).

Segment 7 pertains to /n/. It has the features voice, occlusive, and nasal. This segment is not important for the perception of /n/. A strong nasalization of the preceding vowel is a sufficient cue. This segment is missing with H3 and is very short for H1 and H2.

Segments 8 and 9 pertain to /ʃ/. The /ʃ/ starts directly with a segment (8) with the features noise, fricative, and finishes with a segment (9) with the features noise, vowel-like and frictive. In case the allophone [ʂ] is used as with subject H2 the feature vowel-like coexists in both segments and at the end there enters the additional feature transitional. For speakers H1 and H3 there is an interval without friction before the vowel of about 20 msec length. Usually there exists such a segment in the boundary between /ʃ/ and /i:/ but much shorter and of no importance.

Segments 10 and 11 pertain to /i:/. The features are voice and vowel-like. As segment 10 is influenced even by the preceding /ʃ/ there is the important additional feature transitional. Segment 11 is influenced by the following /n/ and has therefore the additional features nasal and transitional.

Segment 12 pertains to /n/ and has the features voice, occlusive, and nasal.

Segments 13 and 14 pertain to /ɛ/ in "skiner". The first segment (13) has the features voice, vowel-like, nasal, and transitional because of the preceding /n/. Segment 14 is not nasalized but it is transitional. For speakers H1 and H3 the phoneme /r/ in /ʃi:nɐr/ is highly reduced. It is indicated mainly as a special formant transition in the preceding vowel. In case segment 15 (/r/) and segment 16 (pause) are missing, in accordance with their secondary importance, the nasalization goes through the whole of the vowel /ɛ/ which is so reduced to one segment, see speaker H1 (Fig. I-C-3). Therefore segment 14 of the normal pattern is of secondary importance only.

Segment 15 pertains to /r/ which in this combination is a voiced fricative variant. It has the features voice, noise, fricative, and vowel-like. This segment is not of primary importance.

Segment 16 with the only feature occlusive stays for pauses. It is not an important segment.

Segment 17 pertains to /m/ in "men" and has the features voice, occlusive, and nasal. For speaker H3 this segment is of the order of 10 msec length. This is unnaturally short and only by the strong nasalization can a normal perceptual effect be achieved.

Segment 18 pertains to /ɛ/. It has the features voice, vowel-like, nasal, and transitional. In the second part of the segment the formant transitions are quite slow. The segment is nearly stationary and it could perhaps be subdivided into two parts, the second one lacking the transitional feature.

Segment 19 pertains to /n/. It has the features voice, occlusive, and nasal.

Segments 20 and 21 pertain to /d/. Segment 20 is the occlusive part with the segment features voice and occlusive. This segment is related to the interval of velar closure before the opening of the oral passage. In spite of its short length this segment is important for a correct /d/, since it allows for the over-pressure preceding the explosion of the stop sound. However, it can be difficult to identify and is attributed a secondary importance here. Segment 20 was found with the speakers H1 and

H3 but not with H2. In case of H2 even the following segment, i.e. the explosion is missing. Segment 21 is the explosion of the stop sound with the features voice and transient. This segment is quite weak or missing, if the occlusive part (segment 20) is too short or missing, as was the case with H2.

Segment 22 pertains to /eæ/ or /eː/ depending on the verification of "det är". The segment has the features voice, vowel-like, and transitional. The transition at the beginning of the segment depends on the preceding /d/ and on the end of the following /k/.

Segments 23, 24, and 25 pertain to /k/. Segment 23 with only one feature (occlusive) is the occlusive part. Segment 24 is the explosion with the feature transient. Segment 25 is the aspirative part with the segment features noise, fricative, vowel-like, and transitional. The /k/ is here in word initial although phonetically intervocalic position. Intervocalic, voiceless explosives have usually a short aspirative (vowel-like, noise) part lacking the features frictive and transitional. The /k/ is in the present case in word initial position and the aspirative segment is longer. The features frictive and transitional exist but appear to be of secondary importance.

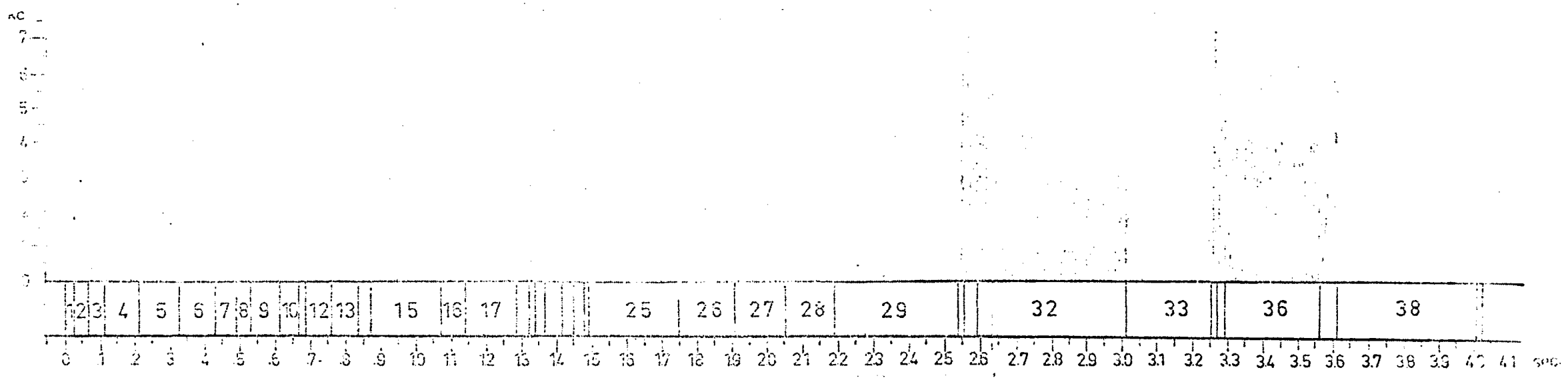
Segment 26 pertains to /a/ and has the features voice, vowel-like, and transitional. In the middle part of the segment the formant pattern is nearly stationary.

Segment 27 pertains to /l/ and has the features voice and lateral.

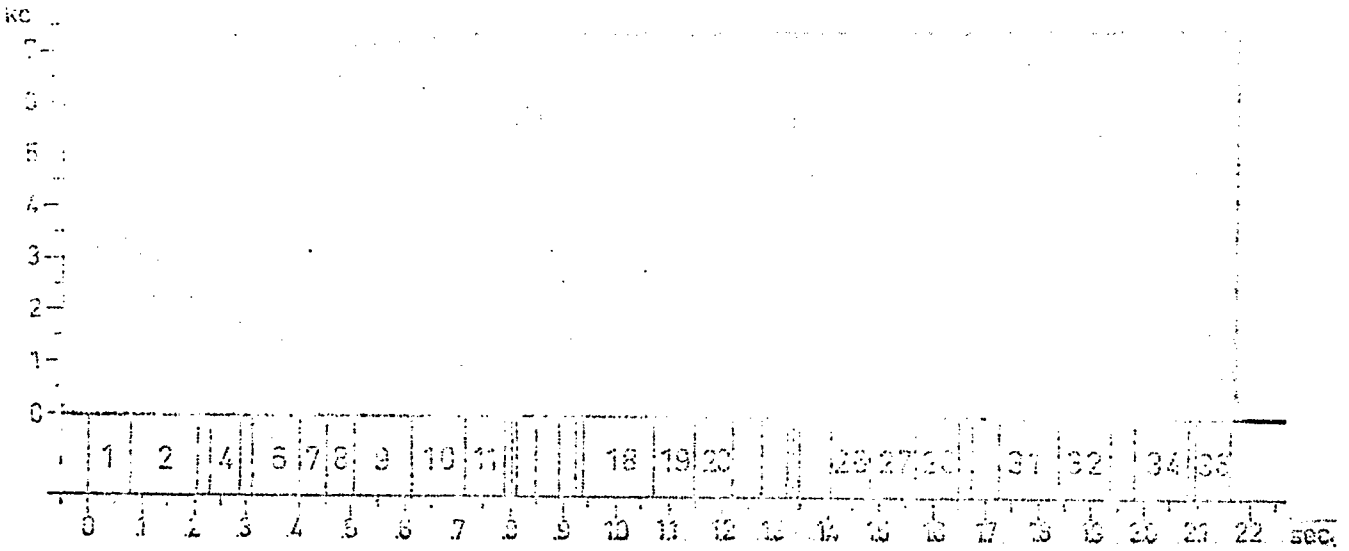
Segments 28, 29, and 30 pertain to /t/. Segment 28 is the occlusive part with the feature occlusive. Segment 29 is the explosion with the feature transient. Segment 30 is the aspirative segment with the features noise, fricative, and vowel-like. These are the common segment features in a postvocalic, final /t/. Because the /t/ here follows a lateral the aspirative segment has a very low intensity and is barely visible. It has therefore been considered as of secondary importance.

Comparisons of the deaf subjects' speech with the normal pattern

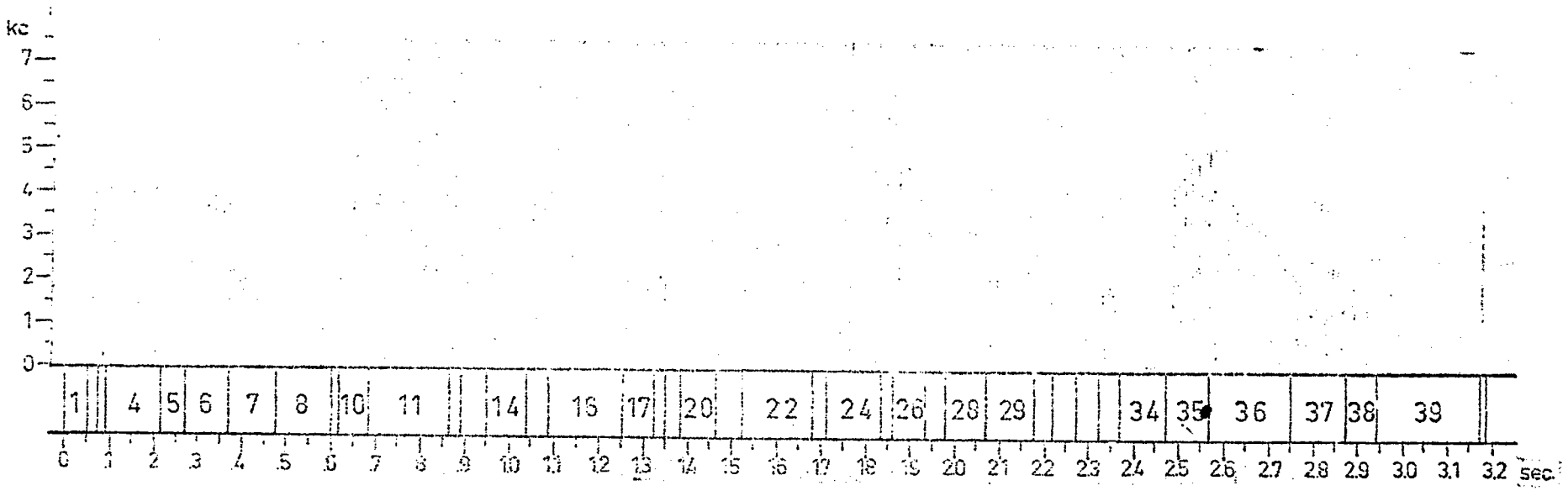
Sonagrams with segmentation of the sentence spoken by the three deaf subjects (D1, D2, D3) are shown in Fig. I-C-5. Fig. I-C-6 shows the segment type features of each segment.



D1



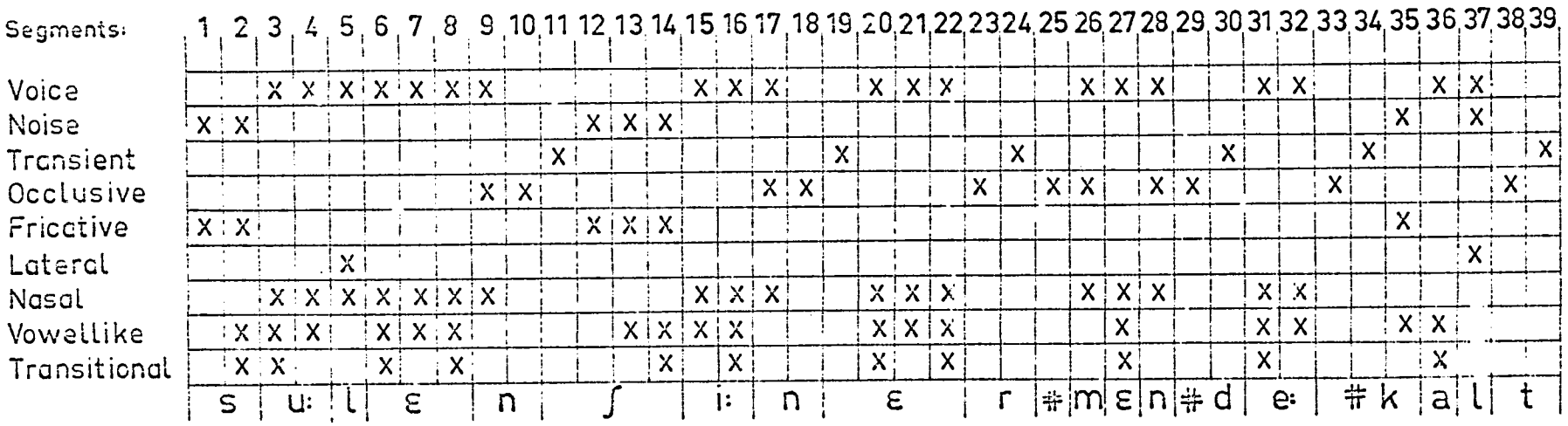
D2



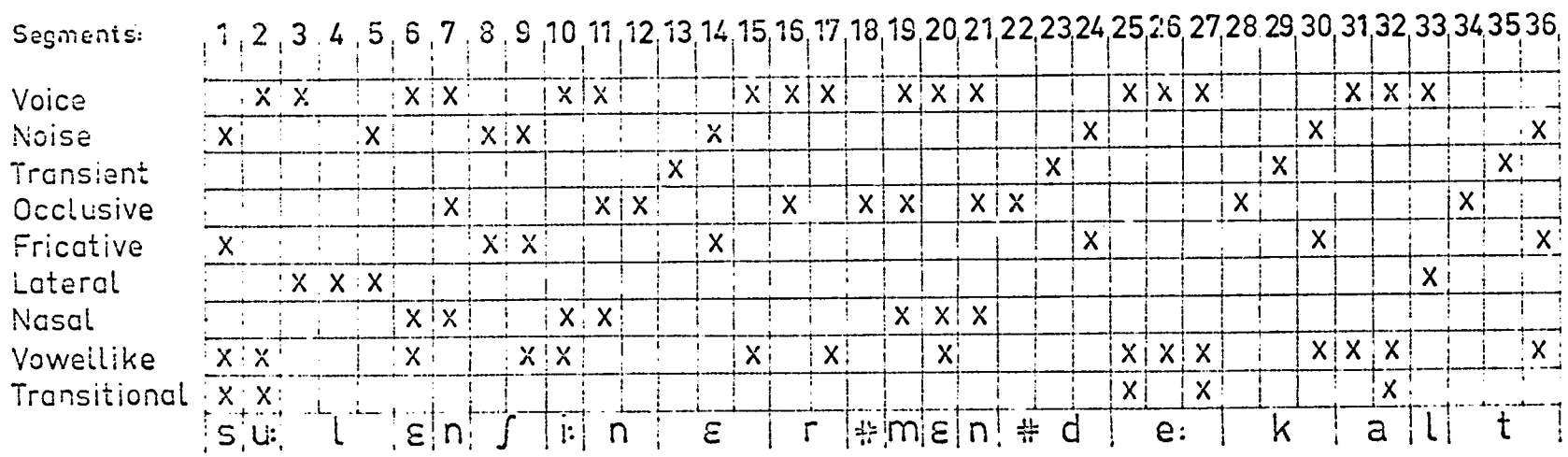
D3

Fig. I-C-5. Sonagram of the test sentence spoken by the three deaf subjects D1, D2, and D3.

D 1



D 2



D 3

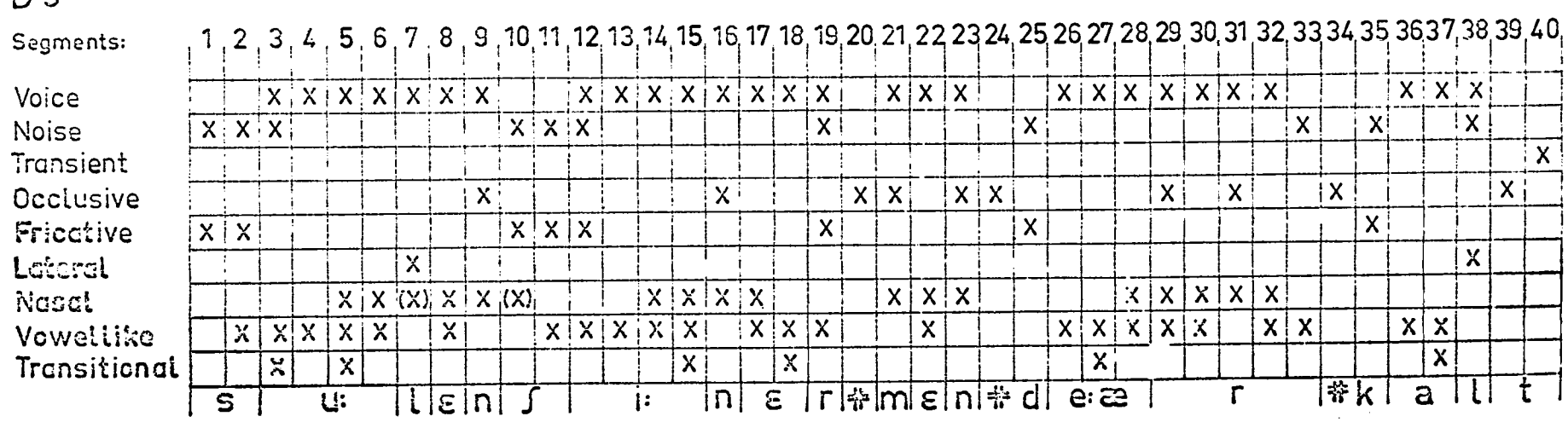


Fig. I-C-6. Segment feature pattern of the test sentence for the three deaf subjects D1, D2, and D3.

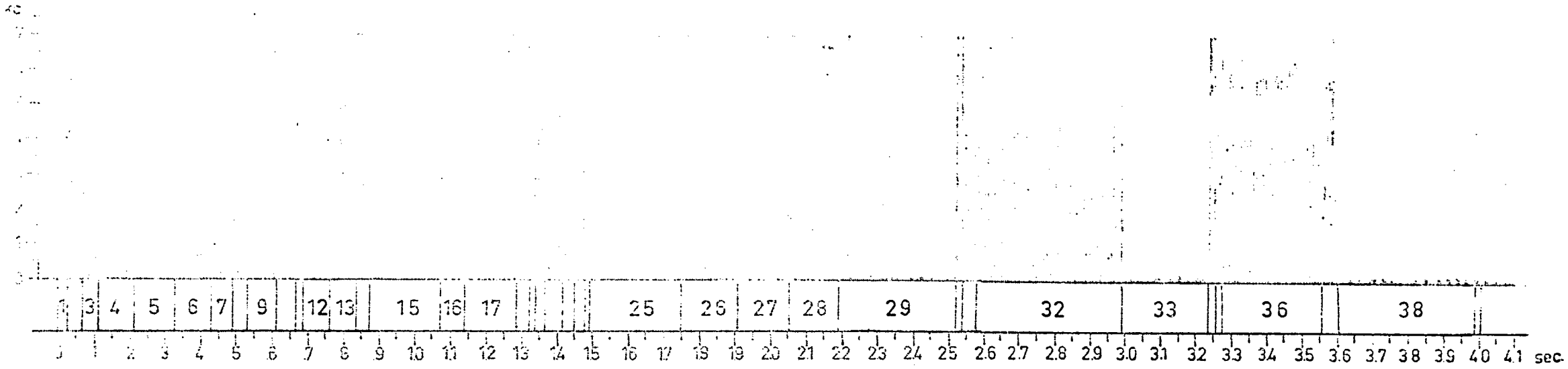
Speaker D1

Fig. I-C-7 contains the sonagram and diagram of evaluated segment type features of subject D1. The correct features present are marked with x. Features in the normal pattern denoted as primary and of secondary importance are included as correct. The present but not necessary features are marked with ⊠. The present but erroneous features are marked with ⊟. Missing features of secondary importance are marked with o. Missing features of primary importance are marked with ⊙.

Segment 4 of D1 pertaining to [u:] departs from the normal pattern by being stationary and nasalized. The misplaced nasalization extends throughout segments 3-7 and the major part of the sentence. The nasalization is a real problem for this speaker. The junction of [n] and [ʃ] (segments 10 and 11) shows irregularities. Segment 10 is a misplaced interval of devoicing due to abnormal rhythm but is not a serious error. [ʃ] starts with a transient segment which is erroneous. The voice onset in [i:] is delayed, resulting in an additional segment (14) with the features, noise, vowel-like, transitional, but also fricative. Without friction this segment could be the starting transitional part of the corresponding segment (11) in the normal pattern. However, because of the friction, it is related to the [ʃ]. In segment 15 the transitional feature, which is considered necessary, is missing. The junction [n]-[ɛ] in "skiner" is erroneous too. There is an occlusive segment (18) and an explosive (19). The control of the vocal cords and of the velum is not correct here. This results in some kind of [d] between [n] and [ɛ]. In segments 22, 31, and 32 there is an erroneous nasalization. Segment 21 is an unimportant stationary vowel segment. The /d/ in segments 29-30 is voiceless and [l] in "kallt" has both voice and noise as source features. The aspirative part of [t] is missing but this failure is not of main importance.

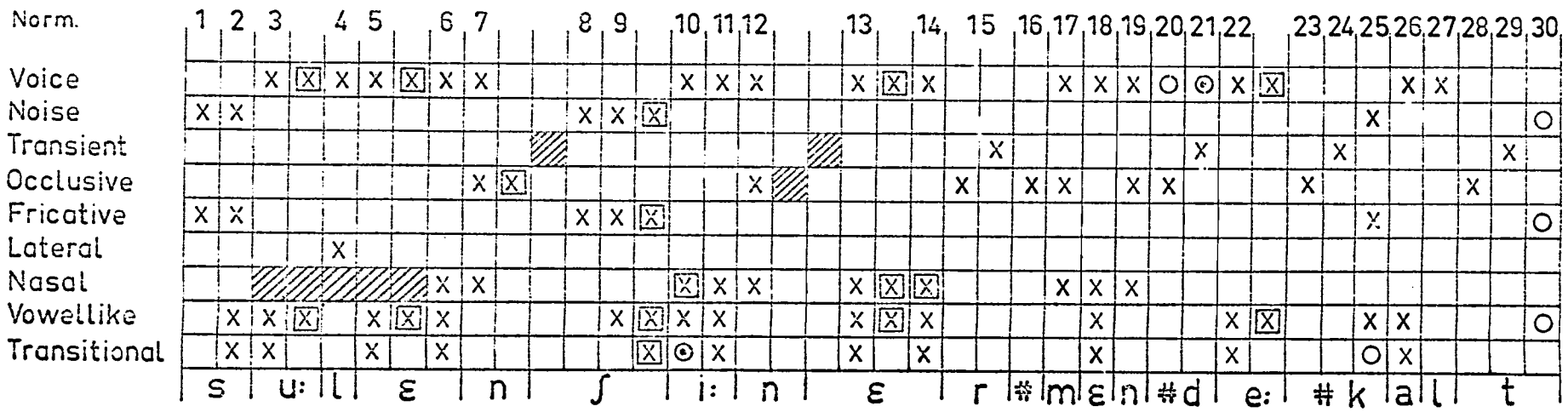
There is no missing segment feature transitional (except in segment 15), but the transitional segments are quite short compared with the stationary vowel segments. So, for example, in segment 36 we have the feature transitional, but the transitions in some parts of the vowel are quite erratic and show that the articulation is not really under control.

D 1



Segments nr.

D 1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39



Legend

- Present incorrected segment featur
- Present, not necessary for identification
- X Present
- O Absent
- ◎ Absent, necessary

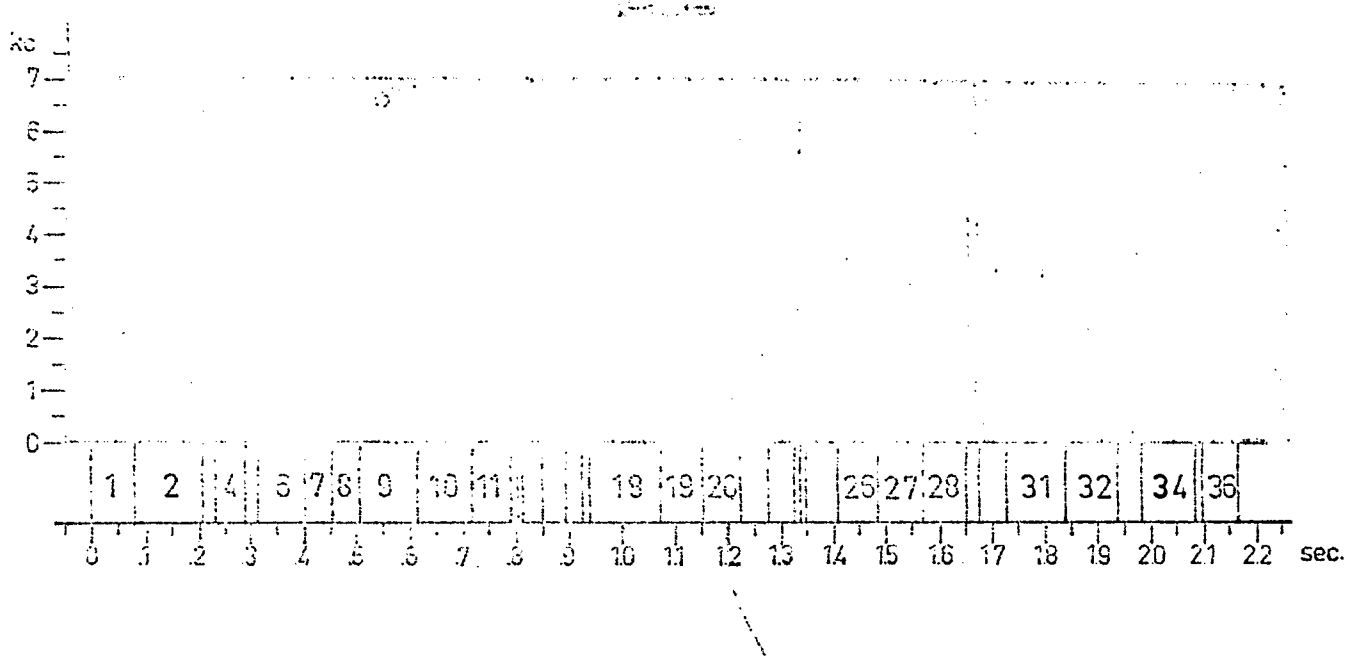
Fig. I-C-7. Sonagram and evaluated segment feature pattern of the test sentence spoken by D1.

The nasalization is, as mentioned above, a problem for the speaker. Voice source quality and pitch range are quite good.

Speaker D2

Fig. I-C-8 shows the sonagram and the diagram of evaluated segment features. The initial fricative is of inferior quality. It is aspirated the whole time and not only at the end. (The fricative spectrum is not correct either.) In [l] the vocal cord vibration stops. There is a silent segment (4) which is followed by a segment with noise as source feature. Both the segments (4 and 5) are incorrect. In the following vowel [ɛ] in segment 6 the important transitional feature is missing. The whole vowel is nasalized. According to the normal pattern it should not be so, but this is of secondary importance. A lack of transition can be observed in segment 10, i.e. in [i:] too. The junction [n]-[ɛ] causes some difficulties even for this speaker as is the case with speaker D1. There can be seen a voiceless occlusive segment related to the velum closing and the vocal cords set to rest before the oral cavity opens. The release is a kind of explosion with a following aspiration. A [t] can be heard because of these irregularities. In the [ɛ] in "skiner" the features transitional and nasal are missing which both are of main importance. The transitional feature in the [ɛ] in "men" is an important, missing feature. The /d/ in "de" (segments 22, 23,24) is voiceless, not only the explosion is voiceless but there is also a short aspirative segment. The result is that /d/ sounds like a [t]. In [e] and [a] of "de" and "kallt" there are stationary segments of no importance.

The main difficulty for subject D2 is the improper control of the vocal cord functions (see segments 4-5, 12-13-14, 22-23-24). The vocal cord vibration seems to be too weak. This is the reason for the numerous fall out. A second difficulty exists in the failing transitional features. The speaker has a nearly normal speech tempo and rhythm, but the right speed does not always result in a correct transition from one phoneme to another.



Segments nr.

D 2 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Norm.	1	2	3	4			5	6	7	8	9	10	11	12			13		15		16	17	18	19	20	21		22			23	24	25		26	27	28	29	30
Voice			X	X			O	X	X			O	X	X	▨			X	X	X		X	X	X	O	⊙		X	[X]	[X]				[X]	X	X			
Noise	O	X				▨				X	X					▨										▨						X						X
Transient															▨										X						X					X		
Occlusive									X					X	▨			X		X	X		X	X						X						X		
Fricative	O	X								X	X															▨						X						X
Lateral				X	▨	▨																													X			
Nasal								X	X				X	X			⊙					X	X	X														
Vowellike		X	X				O	X			X	O	X				X		X				X					X	[X]	[X]			X	[X]	X			X
Transitional		X	X				O	⊙				O	⊙				⊙						⊙					X		[X]			O		Y			
	s		u:		l		ɛ	n	ʃ		i:		n		ɛ		r	#	m	ɛ	n		d			e:			k		a		l		t		

Legend

- ▨ Present incorrected segment feature
- [X] Present, not necessary for identification
- X Present
- O Absent
- ⊙ Absent, necessary

Fig, I-C-8. Sonagram and evaluated segment feature pattern of the test sentence spoken by D2.

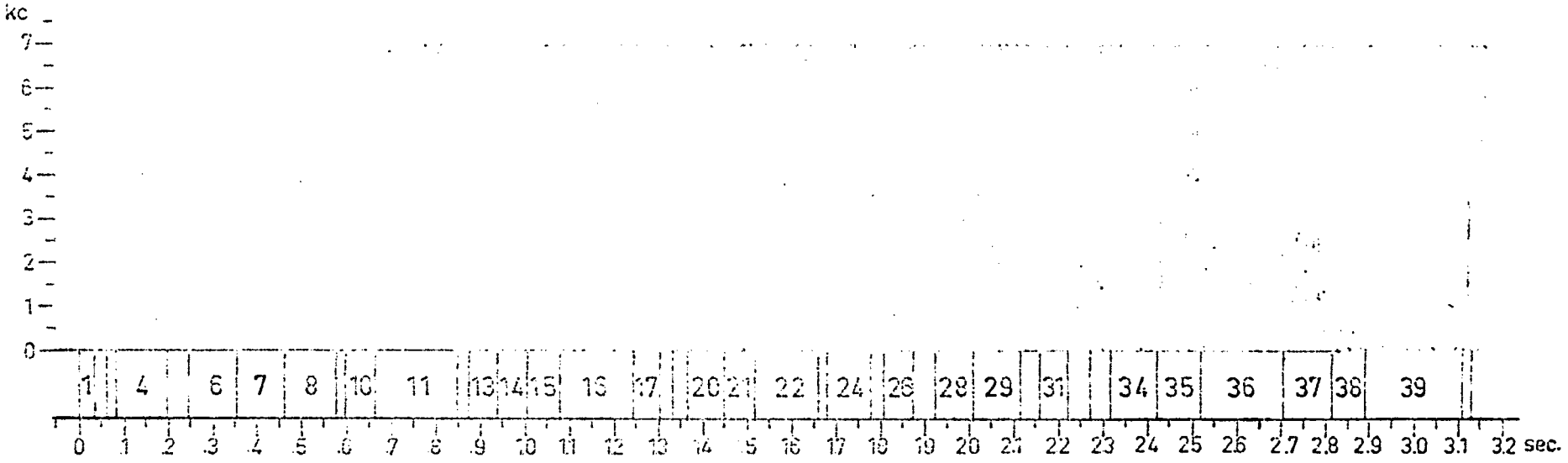
Speaker D3

Fig. I-C-9 shows the sonagram and the diagram of evaluated segment features. The diagram shows that this speaker has the greatest number of errors. The voicing after a very weak [s] starts only slowly. Consequently there are both voice and noise as source features at the beginning of [u:] in segment 3. The noise feature is incorrect. The other segments of [u:] are transitional and stationary alternatively with erroneous transitions. The nasalization starts too early already in the middle of [u:] in segment 5. Probably the [l] (segment 7) is nasalized too.

The nasalization continues in the following vowel [ɛ] which is not incorrect. The important transitional feature is missing there. D3 has difficulties with the correct timing of the onset of the vocal cord vibration at the junction between [ʃ] and [i:] as well as at the junction between [s] and [u:] (segment 3) and accordingly segment 12 appears as a voiced fricative. The whole segment is incorrect. In [i:] there are some minor errors owing to missing or too short transitions. The formant transitions are in the following vowels missing in the two segments 17 and 22.

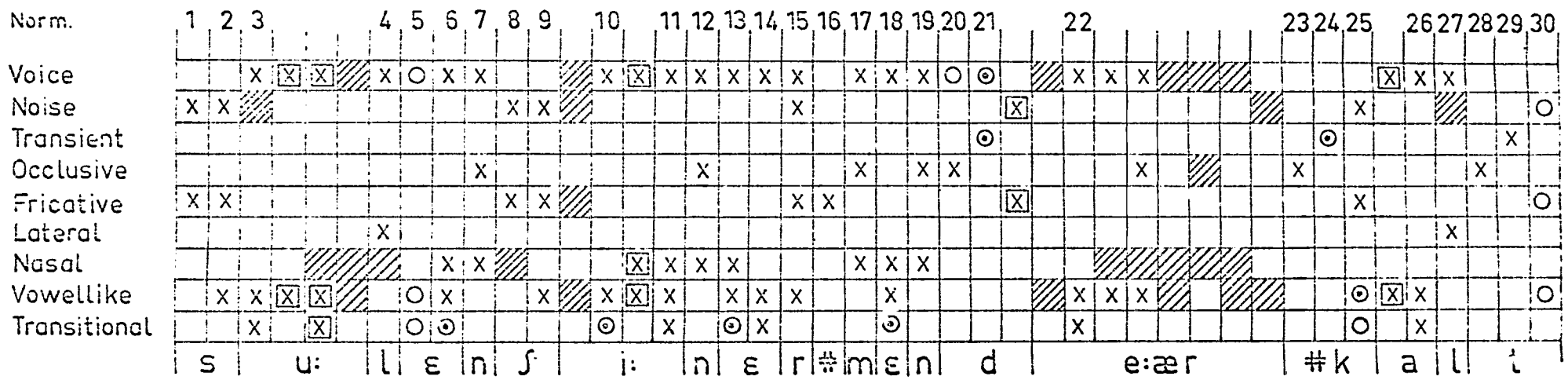
The burst segment of /d/ of "det" is a short voiceless fricative instead of a voice explosive. D3 is the only speaker in both the hearing control group as well as in the deaf group who says "är" /ær/ instead of the normal reduced form [e] or [ɛ]. There is a nasalization in the segments 28 to 33. The [r] is rolled with very fast occlusions (maybe uvulas). After [r] there follows four unwanted segments. The whole utterance "det är" is realized as [dɛɲrɛnə], spoken very fast at the end. /k/ contains a back fricative [x] and the explosion is missing. In segment 38, i.e. [l], the source is incorrect, there are both voice and noise as source features.

The pitch of speaker D3 is very high and he has difficulties in joining voiced with voiceless sounds. The articulation is often incorrect too. There are long stationary vowel segments with only quite short transitional segments. All the stops of D3 are incorrect.



Segments nr.

D 3 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40



Legend

- Present incorrected segment feature
- [X] Present, not necessary for identification
- X Present
- O Absent
- ⊙ Absent, necessary

Fig. I-C-9. Sonagram and evaluated segment feature pattern of the test sentence spoken by D3.

Summary and discussion

The comparison made between the speech of deaf and normal-hearing children reveals the main difficulty in phonation and specially the lack of synchrony between articulation and phonation, e.g. at the junction between a fricative or a nasal consonant and a following vowel. Prominent errors in velar functions have been observed in the form of abnormal and misplaced nasalization of vowels but also a too early denasalization of nasal consonants.

A third characteristic apparent from the study is the superstationary form of vowels. Transitions are often missing or if present they are too short indicating too abrupt articulatory movements. Errors in speech rhythm were not evaluated in this study since additional measures would be needed.

A critical evaluation of the segmentation techniques employed in the present work reveals certain ambiguities in the labeling of segments and the determination of their boundaries. However, variations in the detailed segmentational transcription of the material would not have effected the conclusions of the study.

A further development of the techniques for articulatory interpretation of spectrograms and perceptual evaluation of pattern abnormalities by means of synthesis experiments is planned. A study of feature distribution in non-normalized time is planned for a coming report.

Reference:

(1) Fant, G. and Lindblom, B.: "Studies of minimal speech sound units", STL-QPSR 2/1961, pp. 1-11.

B. STUDIES ON THE SPEECH OF THE DEAF. II

J. Mártony

In the first part of this study (published in STL-QPSR 3/1965) a spectrogram segmentation technique has been described. On the basis of the segment feature pattern we have an objective tool for the description of an utterance and of its possible abnormities.

Anyhow, the method has some lacks. By definition the segment boundaries coincide with a change in the feature composition. An exact determination of segment boundaries is very difficult in some instances and by slight shifts of the timing of features new segments can arise which are of short duration and usually unimportant. The other disadvantage of our earlier approach was that the time duration of the segments was not indicated.

A representation of features as a function of time is perhaps more advantageous. In Figs. III-B-1 to III-B-4 such feature patterns are shown. The utterance and the speakers are the same as in the first part of the study.

Fig. III-B-1 shows sonagram and feature pattern of the test sentence spoken by the hearing subject H3. Test utterances can almost be considered as a normalized feature pattern except for the pause between the two parts of the test sentence. Figs. III-B-2 to III-B-4 show sonagrams and feature patterns of the test sentence spoken by the deaf subjects D1, D2, and D3. These sentences were discussed in the previous part.

A comparison of the length of the segments or the features for the different speakers is not easy because of deviations in the number of segments and features. An alternative method is to study phoneme durations as shown in Fig. III-B-5. Of course a determination of phoneme boundaries is not unambiguous and to avoid large errors in some instances adjacent phonemes have been taken together in groups. Generally as in Fig. III-B-5 it is apparent how much lower the rate of speaking of the deaf subjects is compared with that of the hearing subjects.

H3

s u: l ɛn ʃ i: n ɛ r # mɛnde k a l t

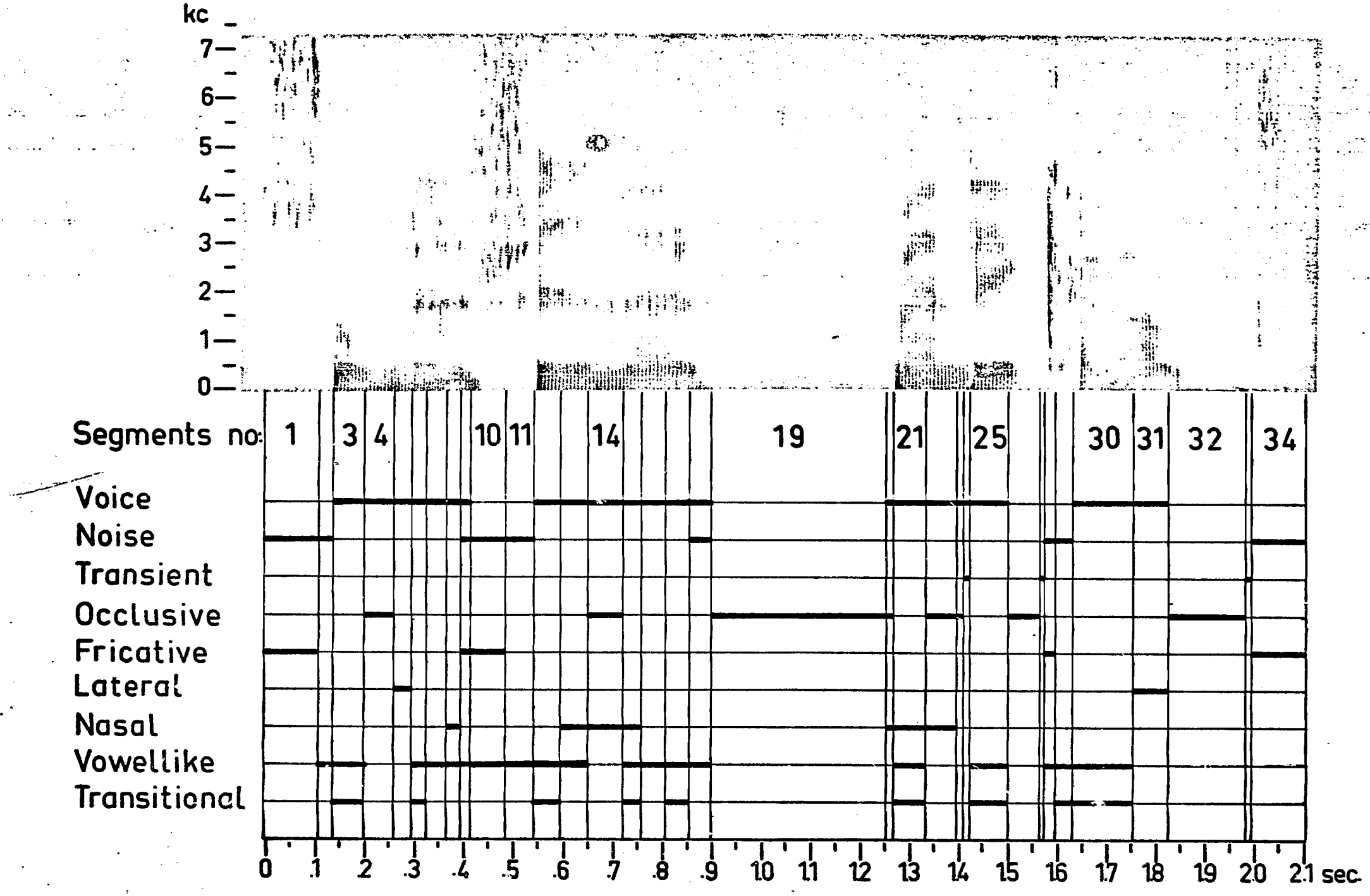


Fig. III-B-1. Sonagram and feature pattern of the test sentence "solen skiner men det är kallt" spoken by the hearing subject H3.

D1

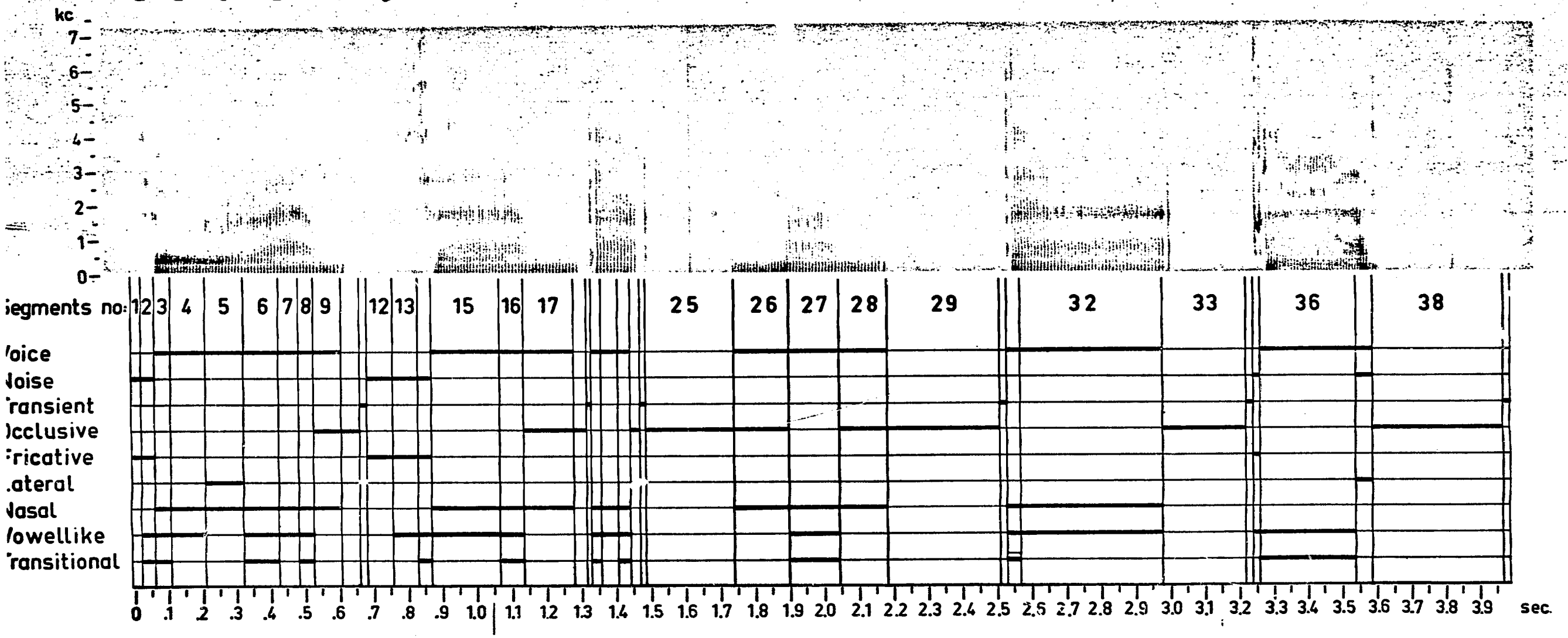


Fig. III-B-2. Sonagram and feature pattern of the test sentence "solen skiner men det är kallt" spoken by the deaf subject D1.

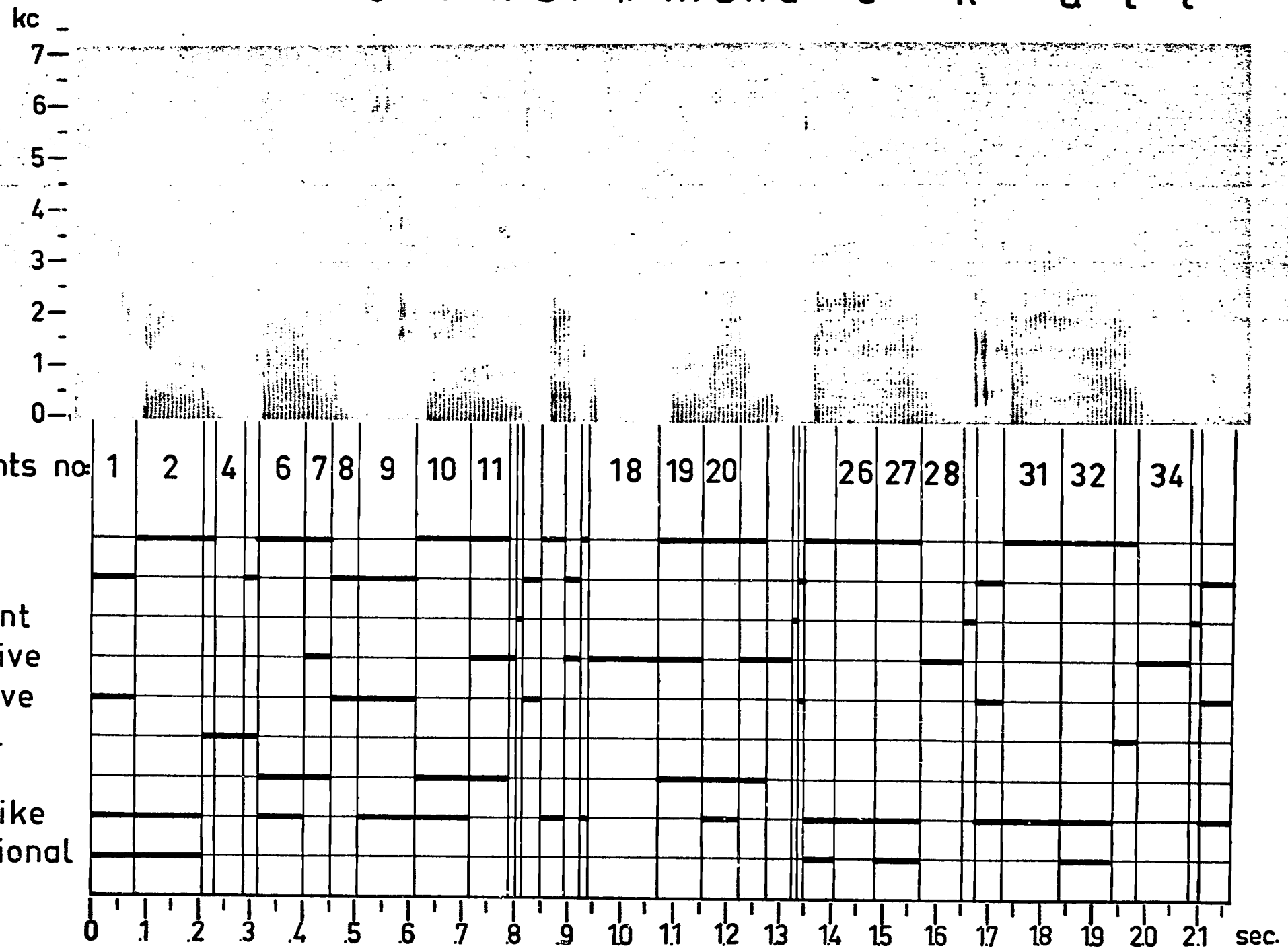


Fig. III-B-3. Sonagram and feature pattern of the test sentence "solen skiner men det är kallt" spoken by the deaf subject D2.

D3

s u: l ɛ n ʃ i: n ɛr#m ɛ n d e:ær #k a l t

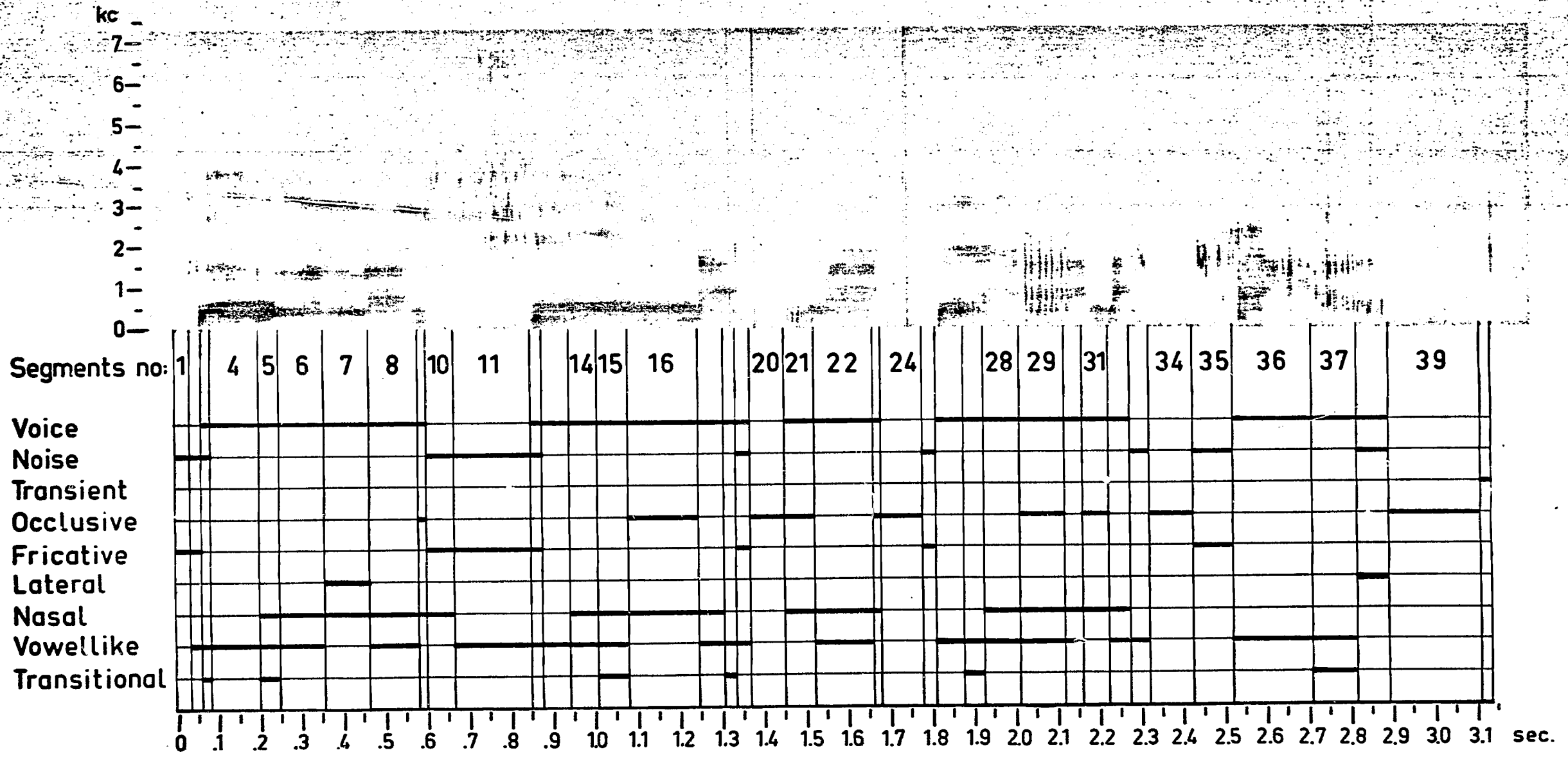


Fig. III-B-4. Sonagram and feature pattern of the test sentence "solen skiner men det är kallt" spoken by the deaf subject D3.

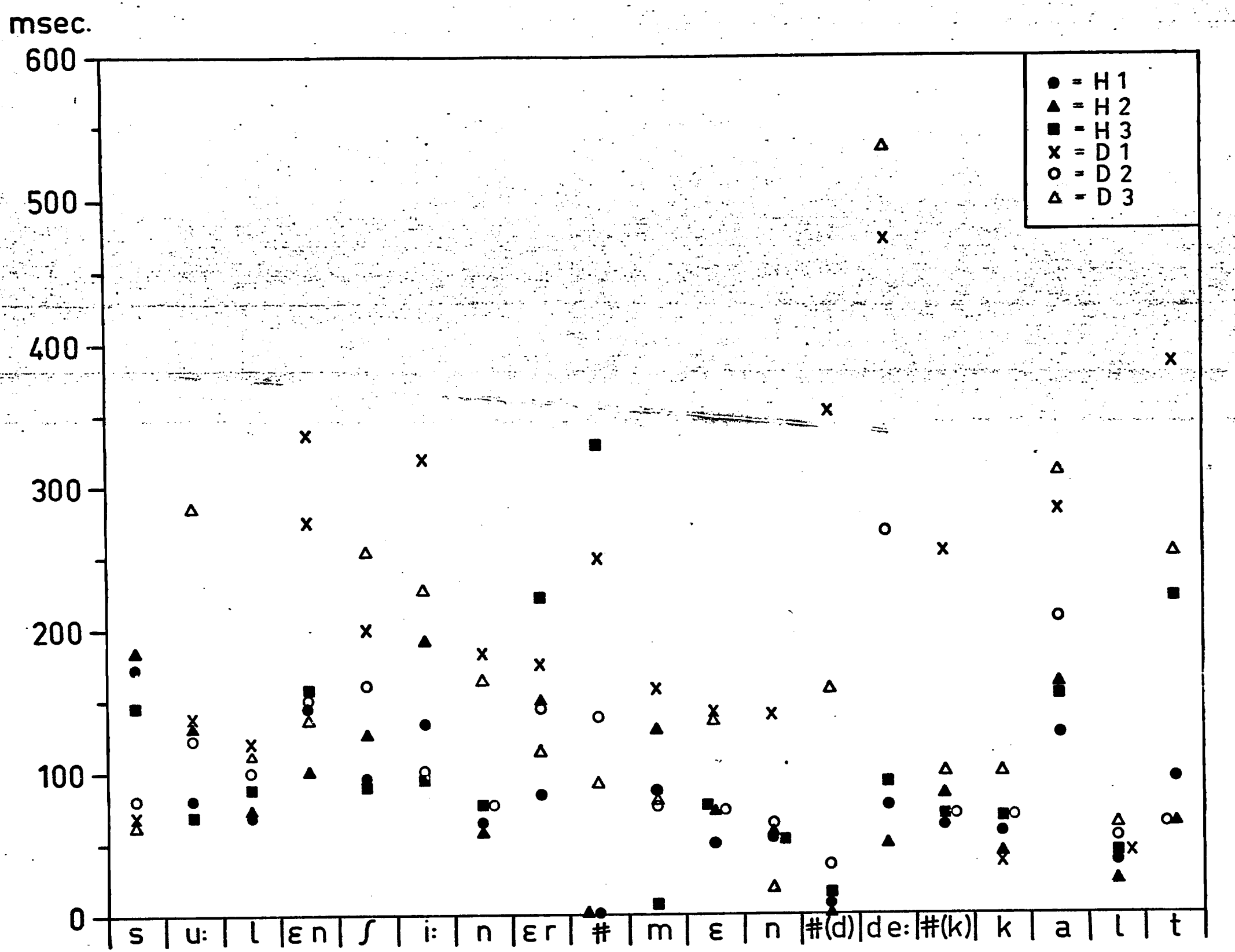


Fig. III-B-5. Phoneme durations in the test sentence "solen skiner men det är kallt" measured at the three hearing subjects H1, H2, H3, and at the three deaf subjects D1, D2, and D3.