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THE GRAPHICAL REPRESENTATION OF RHYTHM

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Introduction

Rhythm is a concept familiar to most people; for the majority it is probably something associated mainly with music. Many people are obviously also aware of the relevance of rhythm for speech, and of the role that it plays in the poetry of many languages. These meanings of 'rhythm' relate it to temporal phenomena that can be observed primarily through the senses of hearing and vision, but also proprioceptively by the performer.

In a more figurative sense the concept of rhythm is also applied to fields relating to other areas; e.g. spatial phenomena that can primarily be observed through the sense of vision, for instance in the description of a painter's technique or the undulating hills on the horizon.

Although since antiquity people have had an understanding of the importance of rhythm both for music and for poetry (and for the polished composition and rendition of prose), research into the nature of rhythm has progressed surprisingly slowly.

In linguistic research, great advances have been made in the present century in the study of fundamental frequency (F_0) phenomena such as intonation and tone. Both the phonetic details and the functional properties of these phenomena are already relatively well understood, even if many outstanding problems remain. If one attempts to gain a picture, on the other hand, of what one now knows about the phonetic nature of rhythm and how it functions in different languages, the conclusion must be that surprisingly little has become known about this in spite of a very considerable amount of effort.

The concept of isochrony

In trying to understand this striking discrepancy between effort and concrete results, some interesting facts emerge. Most fundamentally, there is no general agreement about what rhythm really **is**. As a result of this, to some extent researchers grope around blindly. Early on, the concept of isochrony became a centre of attention (Classe 1939; Pike 1946), and much of the following work has been done on the assumption that **regularity** is the essence of rhythm, and has concentrated on finding the answer to the question: regularity of **what**? This discussion has taken the form of a debate about the correctness of the assumption spelled out most clearly by Abercrombie (1964: 17, 1967:97) that natural languages fall into one or other of two categories, stress-timed and syllable-timed languages. The hypothesis is that the governing principle is in both cases that of **isochrony**, or equal timing or duration, of the stressed syllables of successive 'feet' or of successive syllables, respectively. Some investigators accept this premiss without question, either in its strict form or with some modification, whereas others are at pains to show the falsity of this dichotomy. All this has led to undue emphasis being placed on this particular aspect of rhythm to the detriment of other, perhaps more important ones. Despite this emphasis, even those who advocate isochrony (for example Uldall 1971) have been unable to show experimentally anything that can reasonably be described as showing a very regular rhythm (see for instance Dauer 1983).

Reasons for the lack of headway in rhythm research

The obsession with isochrony has prevented scholars from adopting approaches which might be more productive in revealing the nature of rhythm at both the phonetic and linguistic (i.e. functional) levels. Significantly, there has been no evolution of an accepted protocol for the graphical representation of rhythm - unlike the situation with pitch variation. Investigators have tended to use simplifying and misleading measures in attempting to quantify rhythmic phenomena. For example, in measuring the duration of feet, they have measured the distance between each primary stress, irrespective of whether there are intervening secondary stresses that may be relevant timing units. They may in this way have had reasonably clear criteria to work from, but the results have not been very revealing of the phenomena they were studying.

The absence of suitable means to show graphically the units that are relevant for rhythm, and the effects of varying those units, has been a severe hindrance to effective research. In some respects, rhythm is a very abstract phenomenon, and without a suitable method for picturing it on paper it is even more difficult to represent it mentally. It may seem that such an aim is by definition impossible in the absence of a clear definition of rhythm. However, I shall argue below that a logical basis for such a representation can readily be found, and show that the ensuing result holds out great promise as a means to furthering our understanding of rhythm. The key to the approach lies in learning from the success story of F_0 research.

The graphical display of F_0 phenomena

The rising and falling of the pitch of a spoken utterance is something many people are able to visualize instinctively, and graphical representations of F_0 were used long before technical aids like spectrographs and pitch meters provided accurate measurements to support and provide correction of the mental representations. One common device has been to use musical notation or a schematic quasi-musical one (see e.g. Jones 1956: 324). What an F_0 trace does is to display one physical parameter as a function of another, in a two-dimensional display. Figure 1 gives a schematic representation of the pitch pattern in a hypothetical tone language. On the basis of systematic investigations based on such traces one may be able to establish that the language in question has three levels of tone, H(igh), M(id), L(ow), and that the exact physical location of these along the F_0 scale depends on factors such as absolute position within the intonational phrase (due to the effect of downdrift) and the functional values of neighbouring tones (effects such as tone

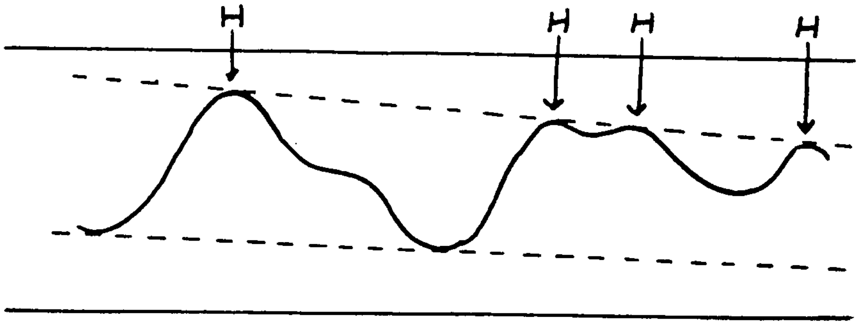

Figure 1: Pitch in a tone language

sandhi and downstep). It has been possible to establish and study systematically phenomena such as downdrift and downstep precisely because one has had the opportunity of being guided by the graphical representations. Because one is able to see that a sloping line connects the points marked H in figure 1, it is possible to say that these points are **equal** in some sense: although they are physically produced on different pitches they can be identified on the **functional** level as being syllables with High tone. Although much sophisticated speech processing equipment has contributed to these advances in our understanding of F_0 phenomena, the single most important conceptual device has been a simple plot of the fundamental frequency as a function of time. A glance at the literature pertaining to speech rhythm reveals that such an effective means of showing rhythm phenomena has been lacking. But what are the relevant parameters of rhythm, and is it **possible** to display them graphically in an illuminating way if they can be identified? It seems that this simple and basic question has not been asked and addressed by most of those who have spent large parts of their lives in search of an answer to the riddles of rhythm.

The parameters of rhythm

There are several candidates for the position as 'main parameters' of rhythm. Linguistic elements that can be easily related to rhythmical phenomena are: the durations and timing of segments, syllables, and pauses, the intensity of the syllabic centres (making allowance for differences in intrinsic intensity), stress (primary, secondary ...), and tempo. In a wider context, it is of course essential to investigate the relationship between the rhythm itself and other prosodic phenomena (mainly tone and intonation), although such a study falls beyond the scope of the present paper.

If our aim is to find the two most important parameters for use in a two-dimensional display, then it is obvious that a representation of time in one form or another must be one of those parameters, at least in the case of the rhythm of speech and music, which to a large extent may be regarded as the pattern of occurrence in time of certain events. Given this, what are we going to choose as the other? Since the question has not been properly addressed previously, researchers have not provided a suitable answer to this question. My answer is, paradoxically, that the second parameter should **also** be based on time.

Traditional displays of rhythm

The way data on speech rhythm have been displayed can be summarized as follows: time enters into the displays in that what is measured is the durations of some elements, such as segments, syllables, groups of syllables, or utterances. Some other parameter, such as stress, may enter into the display implicitly, for instance as a determinant of feet boundaries. The measured durations can be displayed in one of the following ways:

1. as a listing of numbers (e.g. Uldall 1971, 1978);

2. as X-Y plots showing duration of elements (e.g. syllables) along the y-axis; the x-axis may merely represent the relative order of the measured units (e.g. Strangert 1985: 45-48);

3. a horizontal line divided into portions proportional to the durations of the different elements that they represent (e.g. Strangert 1985: 145).

Each of these methods has serious drawbacks, both as a descriptive tool, and as candidate models of the way the human speech apparatus might represent the rhythmic patterns of the respective utterances. The numerical method is vitiated by the lack of any iconic correspondence to the temporal events represented. The X-Y plot method is able to give us an understanding of the relative durations of the units in question, which is important, but the reference to real time is missing. The third method gives a real-time representation of the events but the relative durations of those events have to be worked out cumbersomely by the observer referring to the horizontal scale.

Figure 2 shows some real speech data (from Danish) displayed according to these three methods; instead of X-Y plots I use histograms, which give an equivalent representation.

An optimal representation would make explicit simultaneously the absolute durations of units of different sizes - feet, syllables, etc., and their durations relative to one another. With the third method one can show simultaneously the durations of (for instance) groups of syllables and the elements (syllables) which they consist of, but the relationship between them does not become much more apparent than does the durational relationship between elements that are located at different points along the line. With the second method one can show the durational relations between groups of syllables if one so wishes, but there is no convenient way of showing simultaneously the relations between elements that belong to different levels: segments, syllables, groups of syllables and so on.

A new method

The second and third methods, then, each have advantages that are not shared by the other one; a display method that could combine the advantages of methods 2 and 3 would therefore be preferable. The simple answer to this desideratum is to combine the two methods. This has been done in figure 3, using the same data as in figure 2. It can be seen that by plotting the durations of

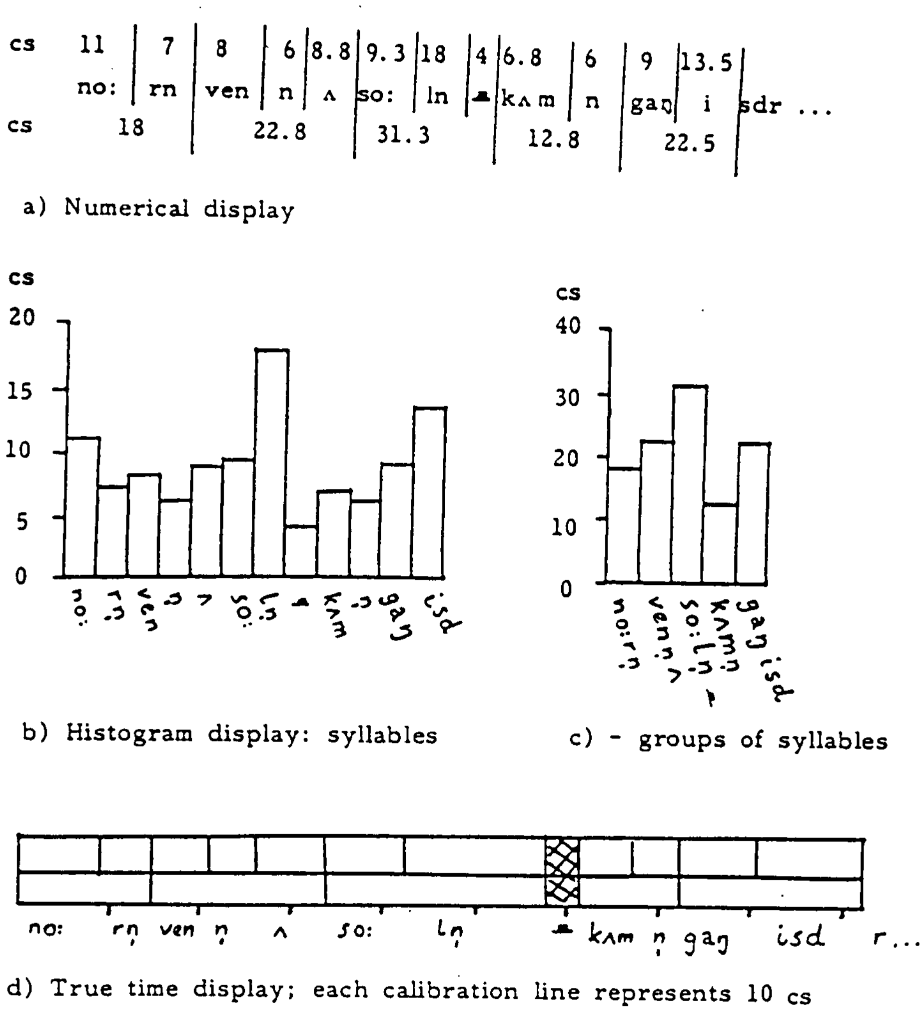

Figure 2: Three ways of showing temporal relations (from Gustafson 1987; the symbol ▲ here and elsewhere in transcriptions indicates a pause; data from Danish)

syllables **both** along the horizontal **and** the vertical axis one gets an impression of the real-time relationship between the elements that are displayed, and at the same time an idea of the durational relations between the different elements, both those that are next to each other and those that are separated by others. In fact, one gets an impression of how the durations of the syllables constantly change with time; one **sees** the rhythm of the utterance.

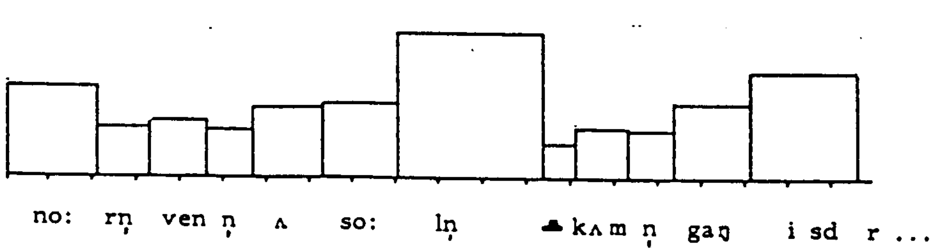

Figure 3: Durations displayed as squares

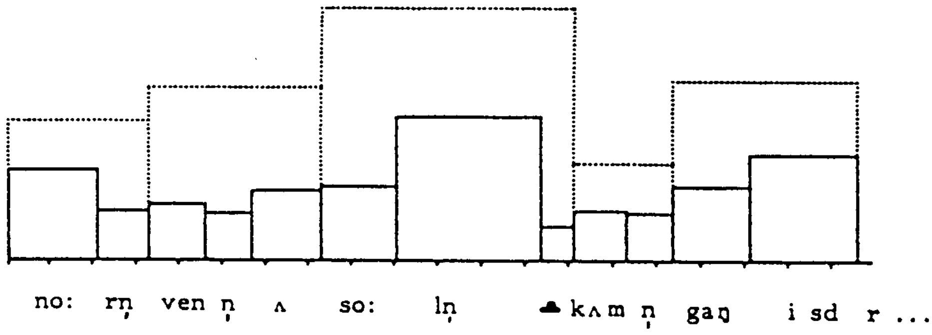

Figure 4: Durations on different levels displayed simultaneously (from Gustafson 1987)

Figure 4 shows how (in this case with the use of different kinds of lines) the durations of elements of different levels can be displayed simultaneously and in such a way that the relationship between them becomes apparent. Similarly the relationship between syllables and the segments that constitute them can be displayed, as in figure 5.

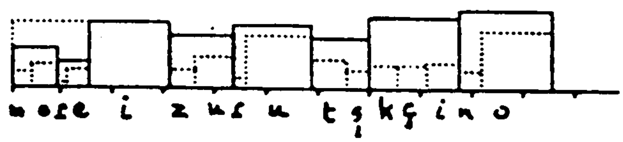

Figure 5: Simultaneous display of segments and syllables - Japanese

I have called this kind of display TEDAS (Temporal Elements Displayed As Squares). Displaying the same quantities along both axes may initially seem counter-intuitive, but in fact rhythmic patterns are precisely determined by variations through time (x-axis in my display) in the amount of time taken by events (y-axis). The type of display proposed does capture the importance of both of these durational aspects of the timing of different events, in that it displays duration as a function of time. It also facilitates comparison of the duration of any one element relative to that of any other element in the utterance (or even in a different utterance).

Some interesting possibilities emerge from this way of displaying the temporal aspects of speech events. One is able to display the durations and timing of elements of different orders (e.g. segments, syllables, feet, groups of feet) at the same time, and to show how they all **vary** with time. This opens up the possibility of studying, simply through inspection, the durational **relationship** between different kinds of elements or between elements occurring in different positions relative to some regulating factor (e.g. emphatic stress). One most striking and immediate observation and one which I believe to have great importance, is the fact that the boxes vary in height almost all **the time**.

If a series of elements is represented by boxes of the same height then the duration of the elements depicted is the same for all of them. Perfect isochrony as it has commonly been envisaged should look like that, where boxes of equal height would represent feet in a stress-timed language and syllables in a syllable-timed language: see figure 6.

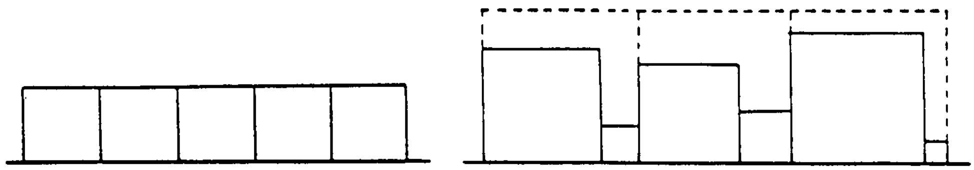

Figure 6: "Perfect" isochrony

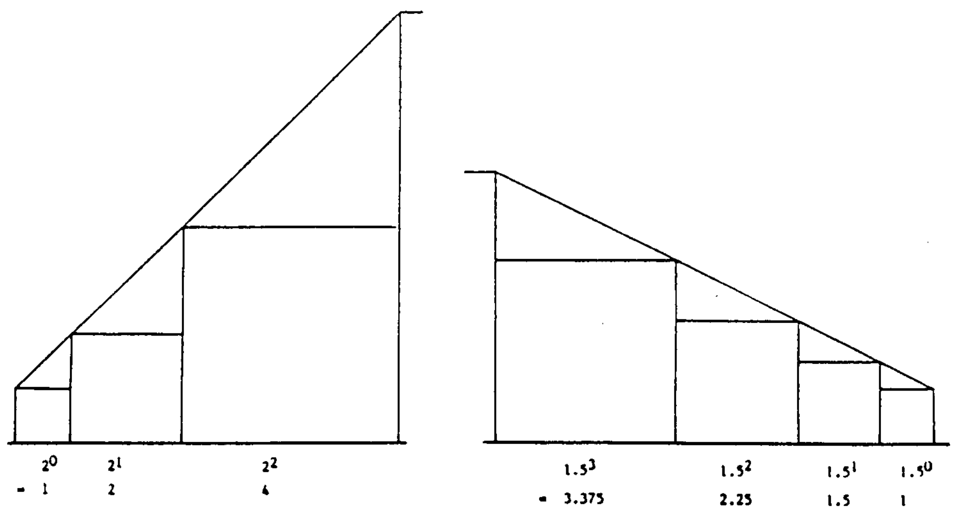

Figure 7: Tempo changing uniformly

If, on the other hand, each box gets successively greater (or successively smaller), then the elements they represent get successively longer (or shorter). In other words, the **tempo** slows down (speeds up): and if the slowing down (or speeding up) is as is shown in figure 7, then the change in tempo is achieved **at a constant rate** (the durations represented by successive boxes in these cases are related as geometric progressions). But that means that if we were to observe such a regular slowing down or speeding up it would be possible to regard the represented elements as being **functionally equal**, subject to the changing tempo. In my material I have many examples that lend themselves to such an analysis or to an analysis with a tempo that is changing in a more complex way, but a much larger quantitative analysis has to be made before generalizations can be made. What is immediately clear is that if the height of the boxes representing functionally equal

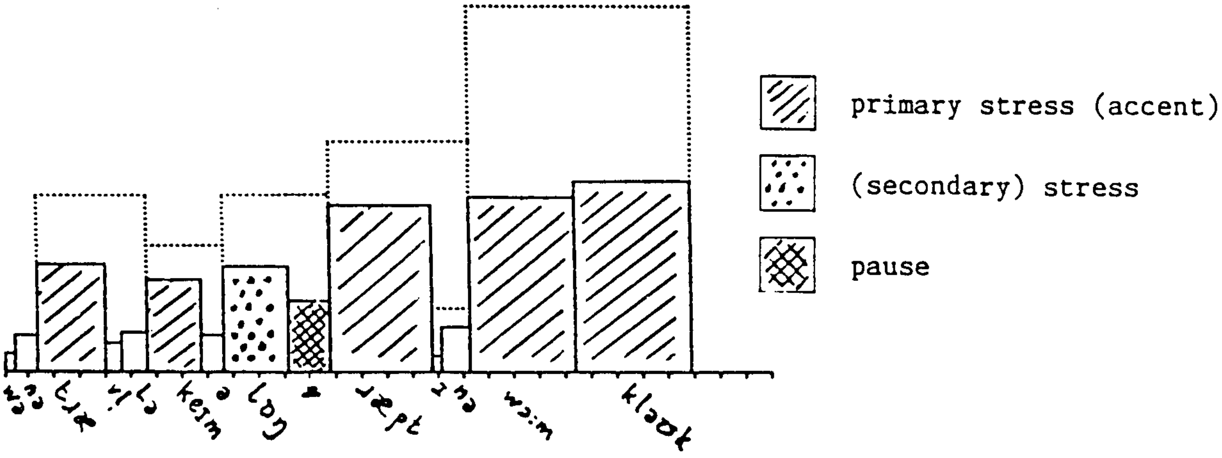

Figure 8: Rhythm and tempo - English

elements (as a working hypothesis one might for instance choose, for English, groups of syllables from one stressed syllable up to the next, and, for French, individual syllables) is taken to be to a large extent a measure of the tempo of the utterances, then one gets a picture of tempo as something that is continually changing. This becomes analogous with the picture of a constantly changing topline and baseline that has become familiar from works on F_0; the exact durations of individual syllables or of groups of syllables can then be viewed against a background consisting of the tempo of the utterance. One can judge this for oneself by considering figures 8 and 9 [1]. (In the French example I have also tentatively joined some syllables into groups on an auditory basis. Could it be that these groups are as important in French as they are in English?)

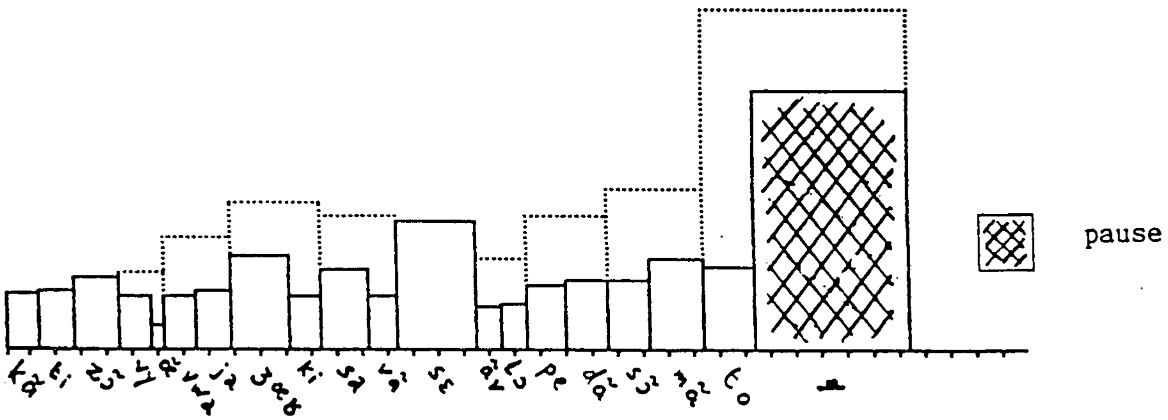

Figure 9: Rhythm and tempo - French

From the discussion so far we can draw the following conclusions:

- with TEDAS it is possible to establish the durational relationship between elements of the same level in different parts of an utterance (e.g. two syllables);
- it is possible to establish the relationship between elements belonging to different levels (e.g. a syllable and the segments which make it up);
- one gets a view, and potentially an objective measure, of tempo and tempo changes, and the relationship between tempo and other aspects of rhythm can be studied;
- the degree of isochrony in an utterance can be studied directly, both if this term is taken at face value and if allowance is made for the effect of tempo.

One can also inspect the effect of another parameter, such as stress, on the duration of syllables. Figure 10 shows the effect of different stress placement on the durational pattern of English utterances; the utterances are: (a) Why's the wording in*crease* CHANGing? (b) Why's the WORDing in*crease* changing? (c) Why's the wording *in*crease CHANGing? (d) Why's the WORDing *in*crease changing? (capitals indicate accented syllables, italics indicate stressed but unaccented syllables, in the sense of O'Connor and Arnold 1973).

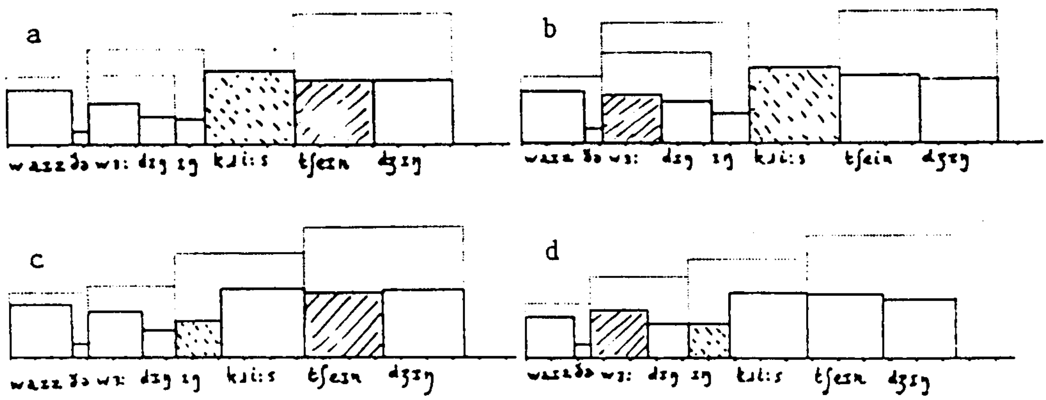

Figure 10: The effect of stress on durational patterns

As I pointed out earlier, very much of the previous work that has been done on rhythm has proceeded from an assumption that the essence of rhythmicality is regularity of some kind; previous work has been hampered by the inability of the researchers to provide experimental evidence for the regularity that they have often felt to be there. The use of TEDAS shows that a main reason for this discrepancy between the intuition of the investigators and the results shown by their measurements is the lack of a means to display the measurements in such a way that the effect of varying tempo is taken into account. When this is done, as it is with TEDAS, the regularity of the speech rhythm of, say, English can be observed to be far greater than it has been possible to see before.

However, this procedure does not eliminate all irregularity; indeed it makes clear that there are many cases of durational

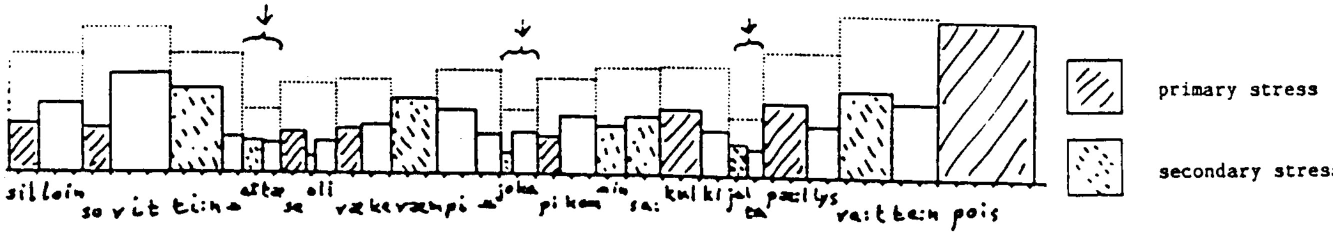

Figure 11: Rhythmic Irregularity

irregularity in speech. This is quite clear to the careful listener. When I listen to the recording of the utterance represented in figure 11, for instance, I can hear the rhythmic effect created by the lack of regularity at the points marked with arrows. Listening to speech with the corresponding TEDAS displays in front of me has led me to conclude that lack of regularity is just as much a constituent of rhythm as regularity - both have their functions, both make up the **rhythm** of the utterance.

Fields of study that can benefit from TEDAS

The rhythm of an utterance can be looked at from a phonetic point of view; one can describe the different aspects of that one performance. But it is obviously also possible to regard an utterance as a token of a class of utterances and study with the aid of TEDAS the differences between the different members of such classes of utterances.

In this way one can study for instance:

- the differences between different readings of the same passage by the same person, possibly displaying stylistic variation;
- the differences between readings of the same passage by different readers of the same dialect;
- the differences between dialects of the same language;
- the differences between languages, both closely related and unrelated.

In the short presentation of TEDAS in Gustafson (1987) I give illustrations of the beginning of 10 different readings of "The North Wind and the Sun", 2 by different speakers of Danish, 1 by a Swedish speaker, 2 by different speakers of Icelandic, and 5 Norwegian examples: 2 by different speakers and 3 by a third speaker showing deliberately different speaking styles. These last three are reproduced here as figure 12.

A further illustration, figure 13, shows a reading of Finnish. One notes a fair amount of near-isochrony even in the traditional sense, and also the fact that the groups of syllables that enter into this regular pattern begin sometimes with syllables with main stress (word-initial syllables) and sometimes with syllables that carry secondary stress.

Figures 14 and 15 show (part of) the two readings by David Abercrombie that are the subject of Uldall (1971) and (1978), a

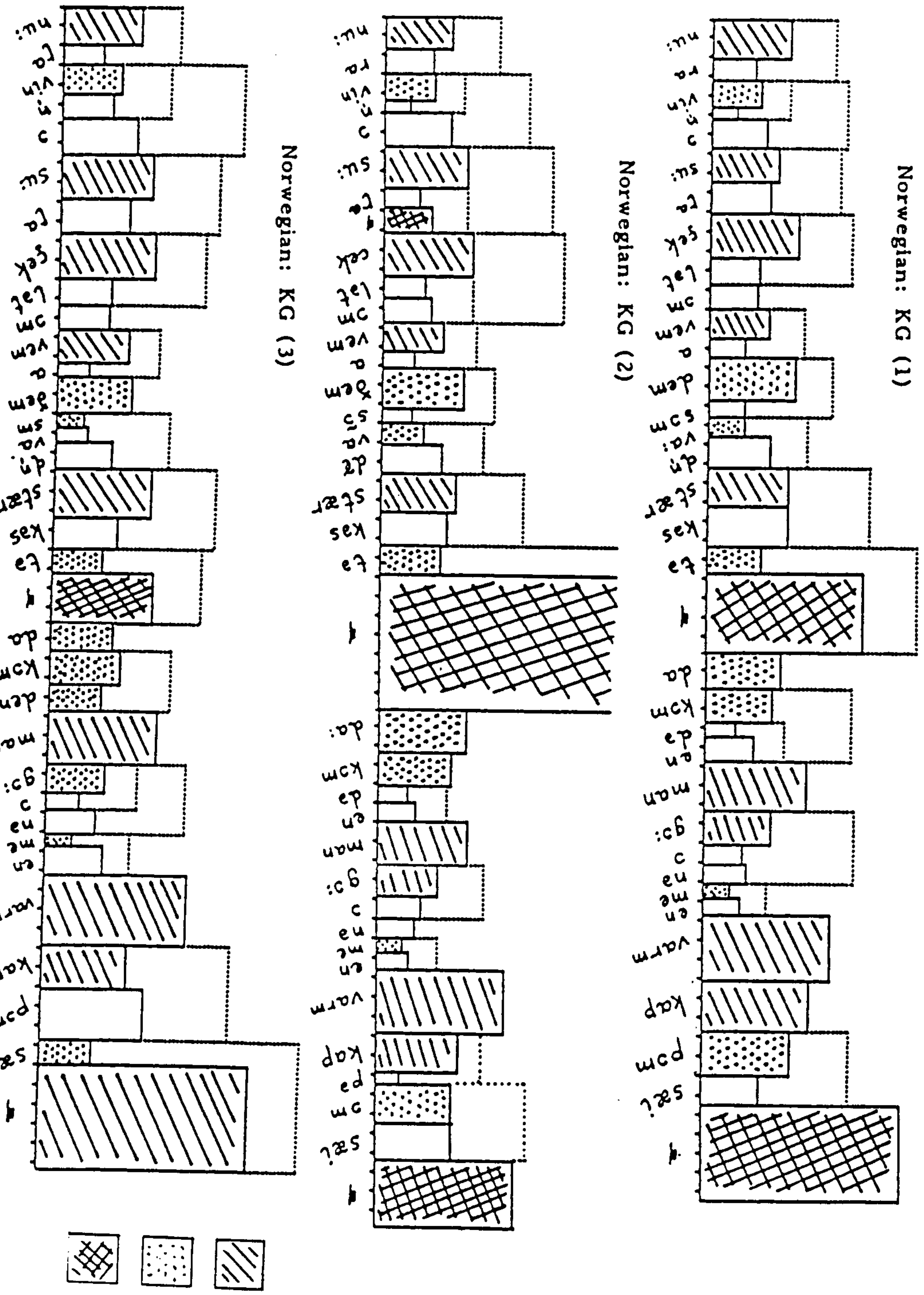

Figure 12: Three readings of Norwegian in different reading styles

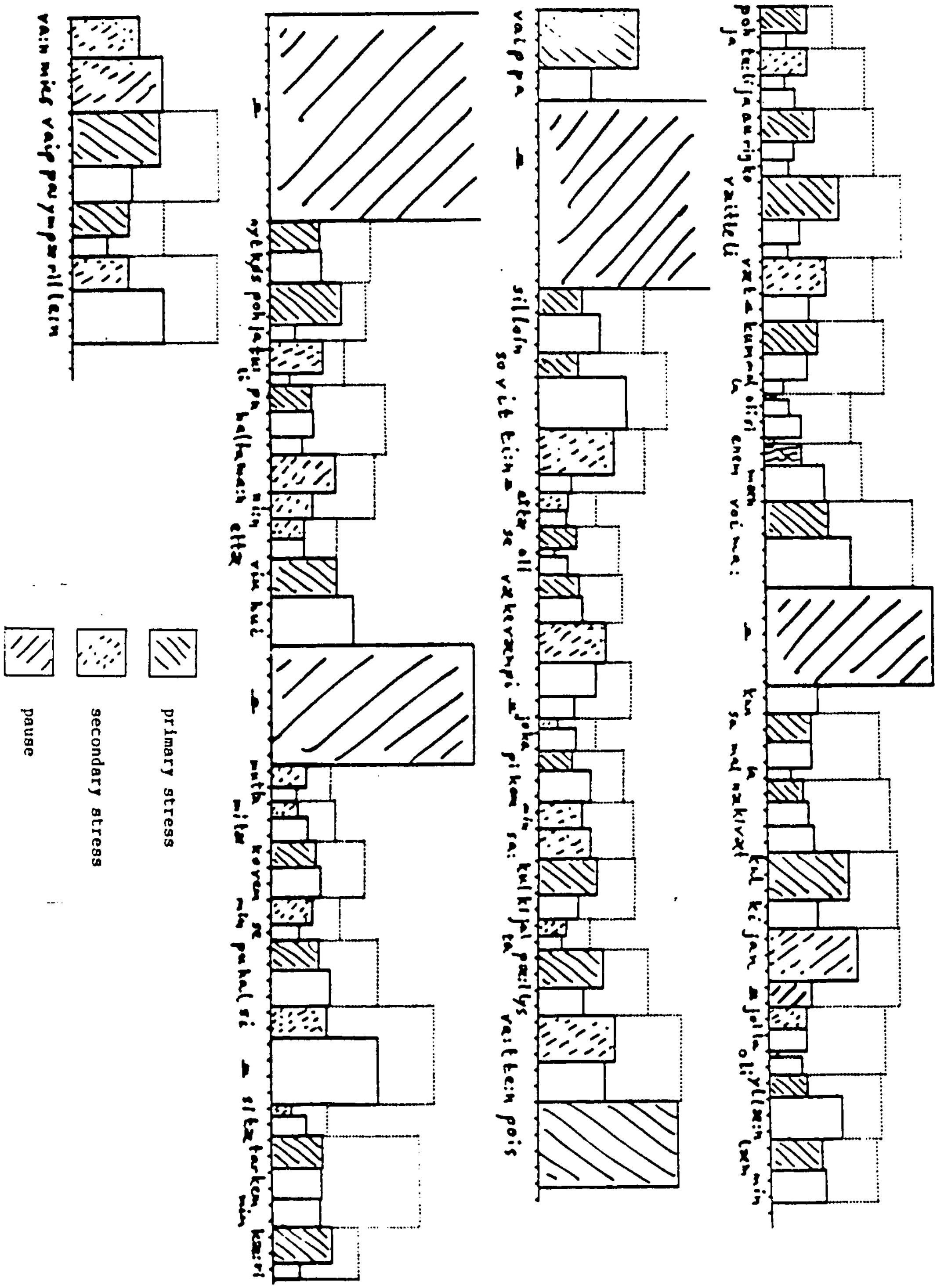

Figure 13: A reading of Finnish

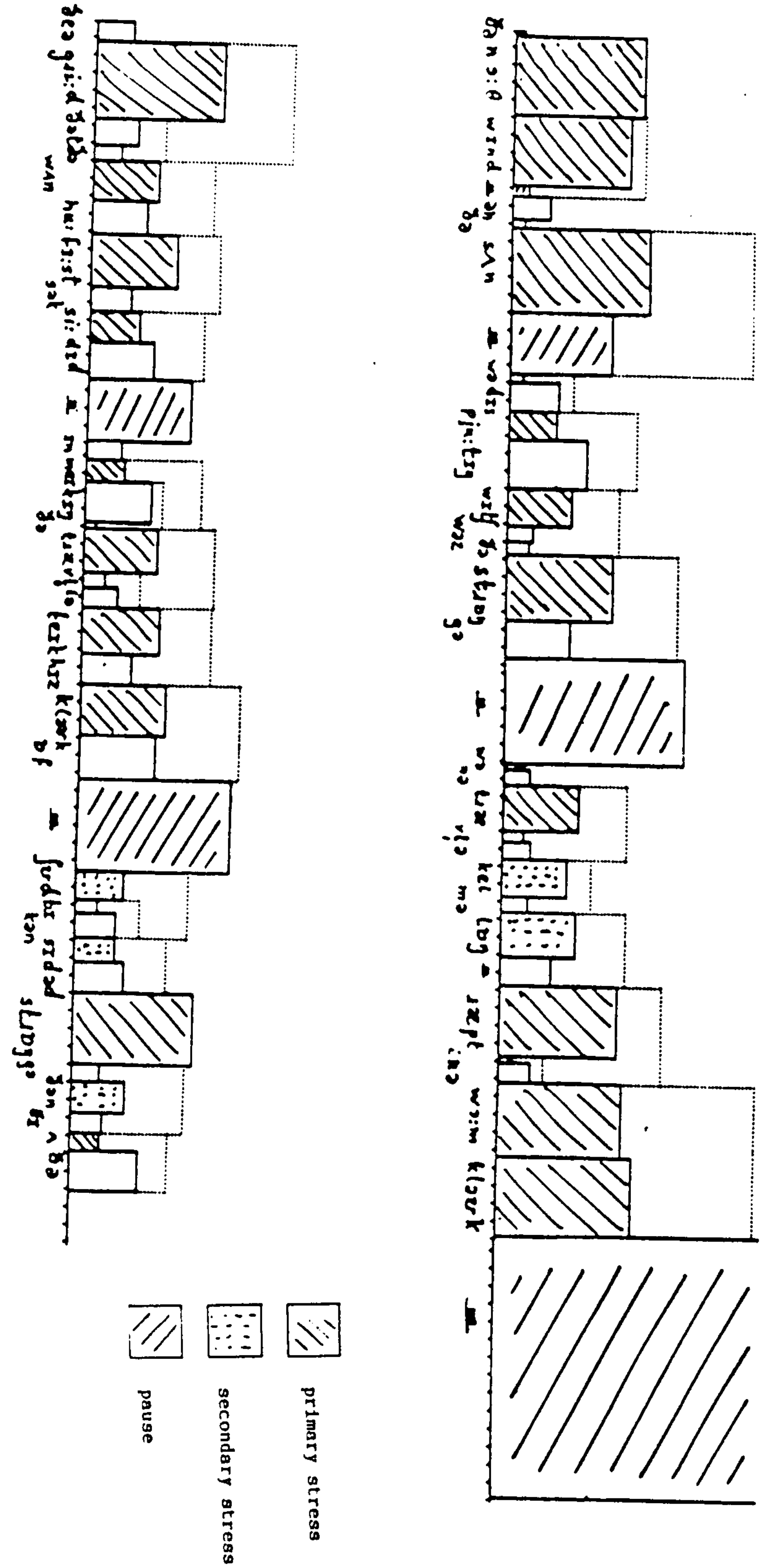

Figure 14: Fairly slow reading of English

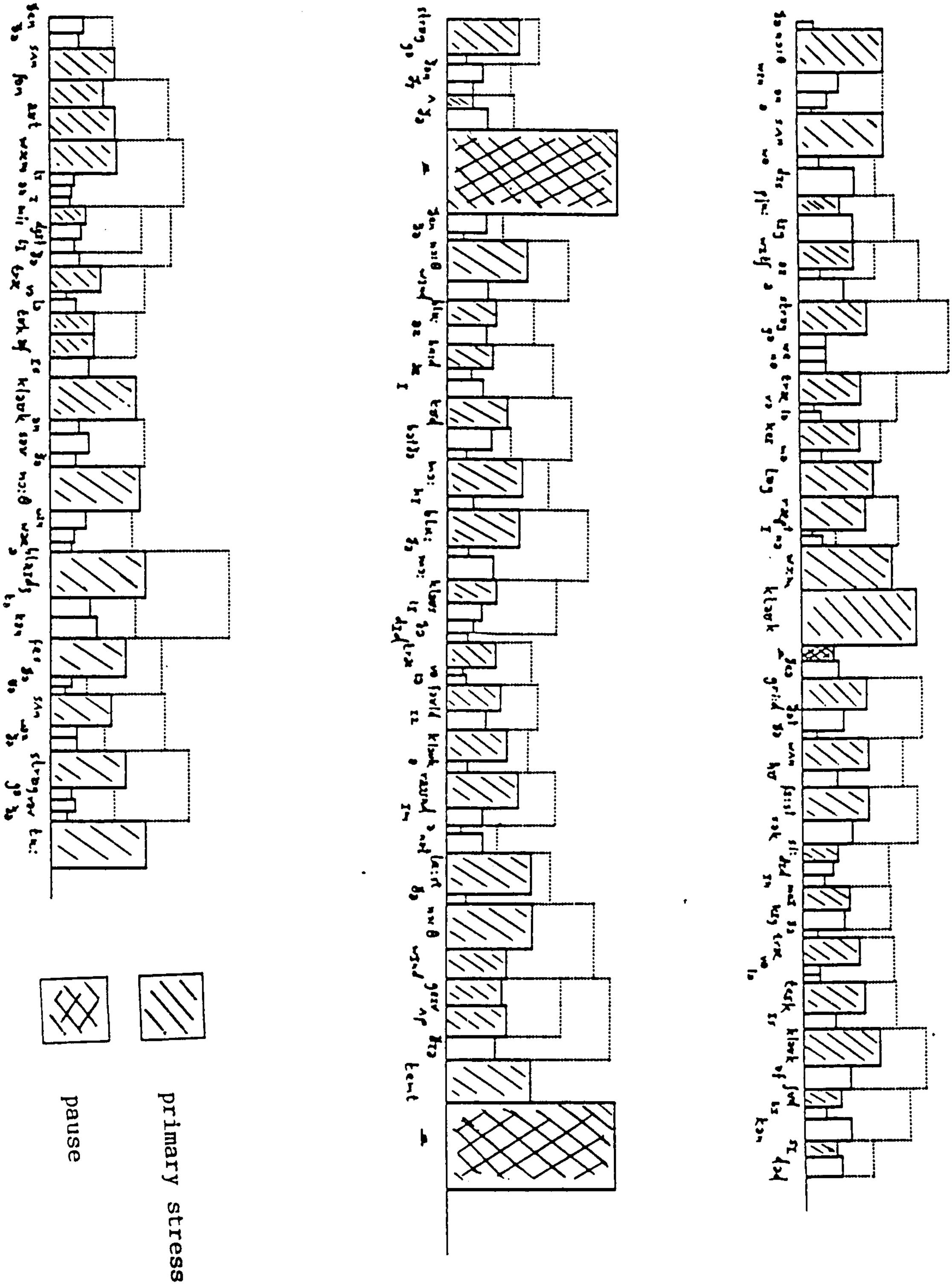

Figure 15: Very rapid reading of English

fairly slow and a very rapid one (the time scale in figure 15 is the same as that in figure 14).

At present working with TEDAS is very time-consuming if one has to provide one's own data as the result of acoustic measurements. All my measurements are the result of painstaking segmentation of spectrograms. No doubt the situation will one day be such that segmentation can be done automatically, perhaps in real time. No doubt many people have data of their own that lend themselves to TEDAS displays. The programming required to make such displays is fairly elementary, and given the basic idea the exact form of the program and of the displays can of course vary to suit the individual. No doubt new ideas can spring from this to make advances in our understanding of prosodic phenomena. A desirable enhancement, for example, might be to show simultaneously the rhythm and the F_0 pattern of an utterance (this is a trivial task, although I have not done it yet) - such a display ought to lead to new insights into the complex interactions of the different prosodic parameters.

Further possibilities

Many readers will by now have raised the following questions. How can we know how to delimit the units that we measure? For instance, if we display the duration of syllables, what are the relevant points that determine the beginning and end of the syllables? Psychologically we do not know how clearly defined the edges of events are, but we need an accepted procedure for analytic purposes. A large body of evidence attests to the psychologically real role of syllables in speech production (Fromkin 1971); we therefore need a way to determine their beginnings and ends. As I see it, TEDAS enables us to **experiment** in an attempt to determine the nature of the timing mechanisms active during speech production. With TEDAS one can see the effect of using different criteria to determine the relevant boundaries. Quantitative studies of this sort ought to shed light on which criteria are the most relevant. Figures 16 and 17 show the effect of analysing the same data in two different ways. Figure 16 shows some sequences of nonsense syllables deliberately pronounced in such a manner as to have a **regular** rhythm; the left half of the diagram is the result of measuring syllables from the beginning of each syllable-initial consonant to the next, the right-hand side shows syllables measured from the beginning of each vowel to the next. It can be seen that the second method gives a picture more consistent with the concept of a regular rhythm.

In figure 17 a Japanese poem (a *tanka*), read by a native speaker, is analysed in two different ways; on the left-hand side the measured durations are those from one syllable-initial sound (vowel or consonant) to the next, on the right the durations are those between the intensity peaks of each syllable. It can be argued that the right-hand diagrams better indicate a regular timing than the left-hand ones.

Measuring the duration of syllables from the beginning of the syllable-initial sound (vowel or consonant), as was done for among others the English and Finnish examples, is unsatisfactory both from a theoretical point of view (it is unlikely to correspond

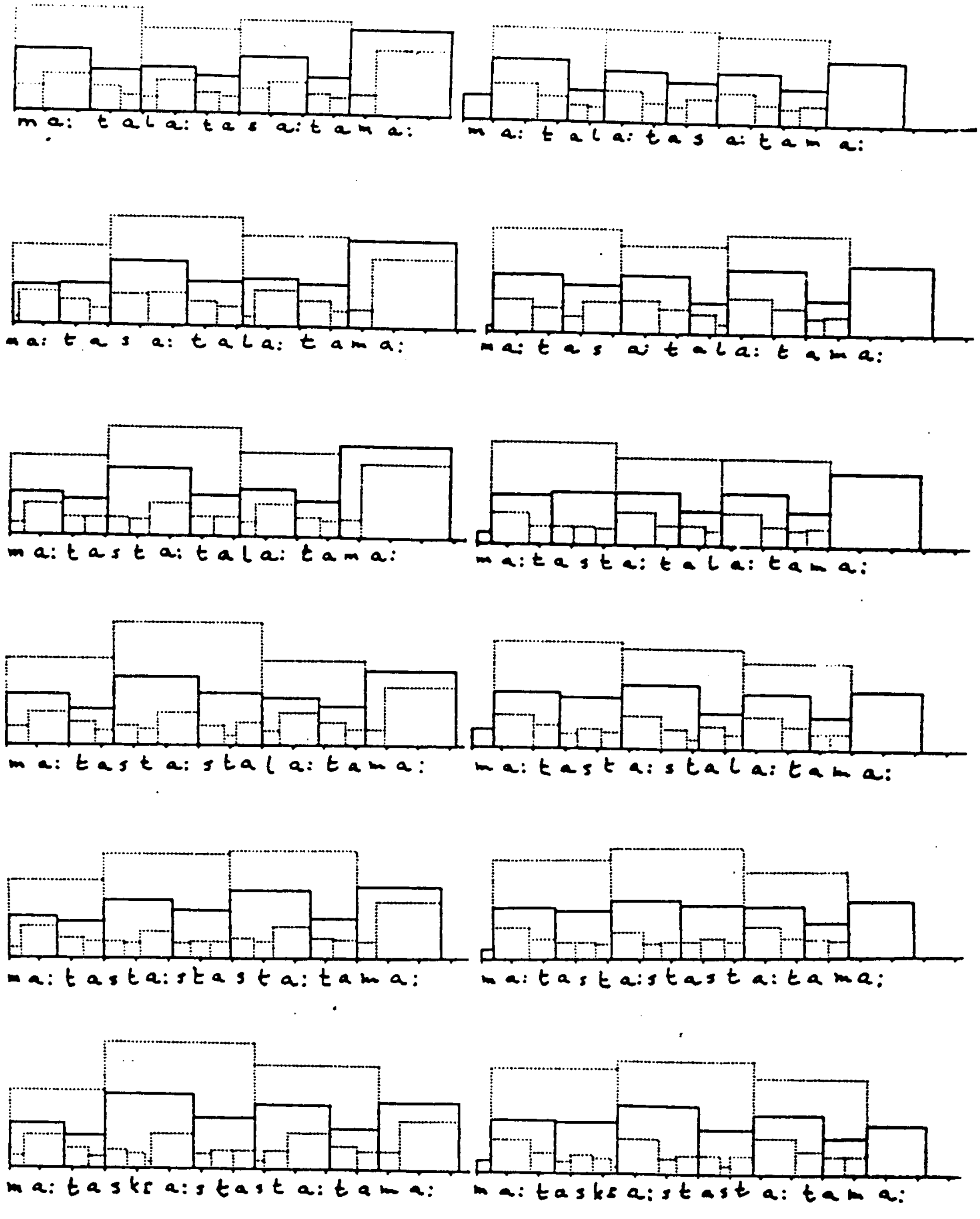

Figure 16: Two analyses of nonsense syllables

closely to the timing points of speech production or perception) and from a practical one (e.g. because of the impossibility of determining from acoustic data the point from which to measure an utterance-initial voiceless stop). In my Nordic examples I used a point at the beginning of the syllable nuclei - this point was determined by hand, a procedure which future research will no doubt be able to improve on, but I think precisely through the use of TEDAS.

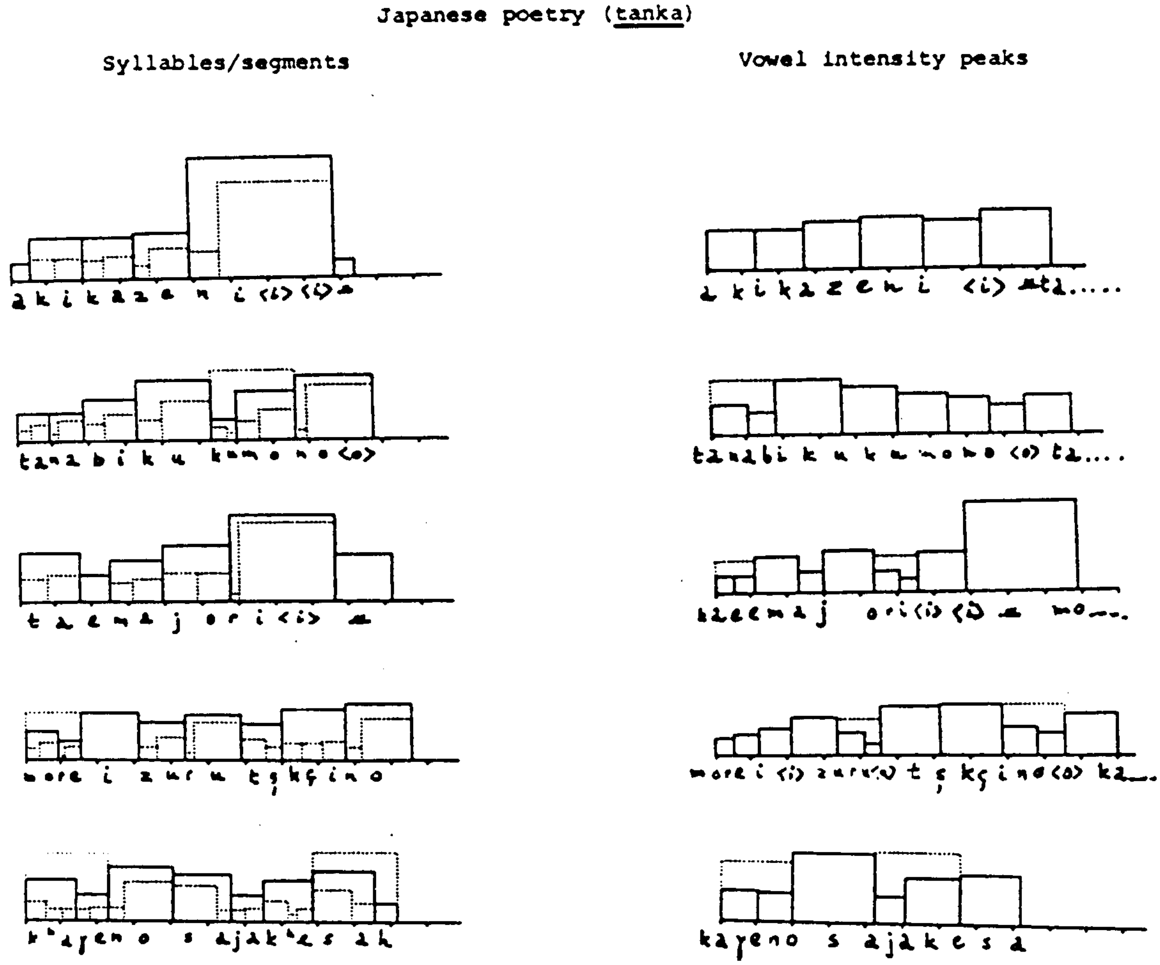

Figure 17: Two analyses of a Japanese poem

With the aid of programs more sophisticated than those I have at present it is conceivable that a measure of the best fit, for instance, could indicate where to place the syllable boundaries so that a straight line might join the top left-hand corner of boxes representing syllables that are slowing down at a regular rate (and top right-hand corners if the tempo is increasing in a regular way). In this way, in the future one may be able to gain better insight into the nature of the timing mechanisms of speech production. And if P-centres (Morton *et al.* 1976) are a reality in the production and perception of speech, then it may be that a more precise definition of their location can be gained through this kind of procedure.

Figure 17 also illustrates a further possible use of TEDAS - the investigation of the rhythm of poetic readings. The metre of the *tanka* consists of 5 lines with the following pattern of morae: 5 - 7 - 5 - 7 - 7 (in this reading there are strictly speaking 8 morae in the fourth line); it is interesting to note how the total duration of each of the five lines is much more equal than the difference in the number of syllables (morae) might indicate, and how the reader achieves this equality by lengthening the vowel of the last syllable of each of the shorter lines, indicated by the use of angled brackets, introducing extra intensity peaks in the process.

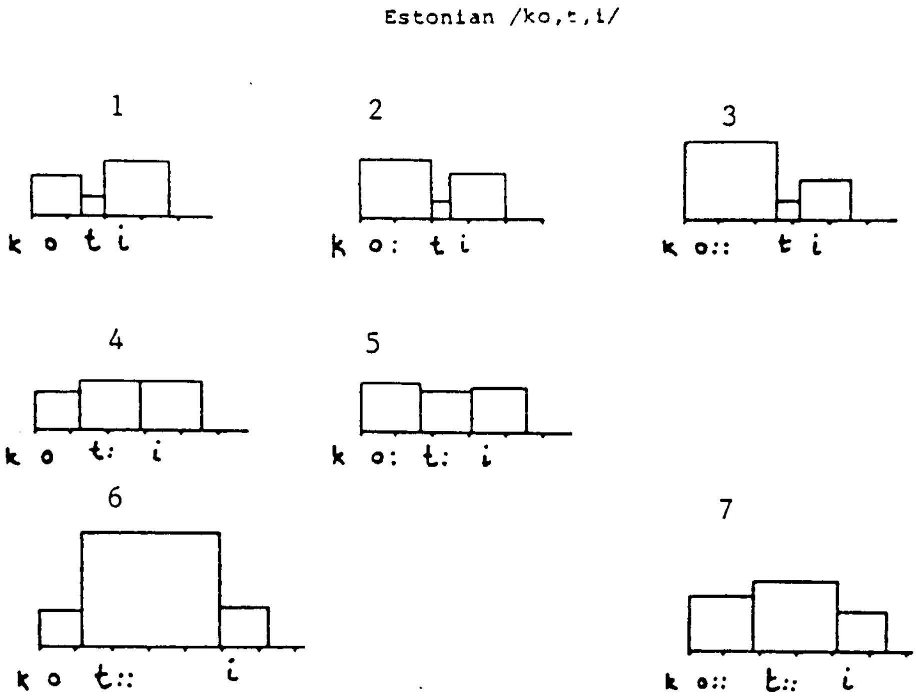

Figure 18: Quantity in Estonian

Figures 18 and 19 show further potential applications of TEDAS. Figure 18 illustrates data from Lehiste (1977) pertaining to the durational differences involved in different syllable types of a quantity language, Estonian. Long segments are indicated by one length mark, overlong segments by two length marks; quantity is distinctive only in the first syllable in each example. The

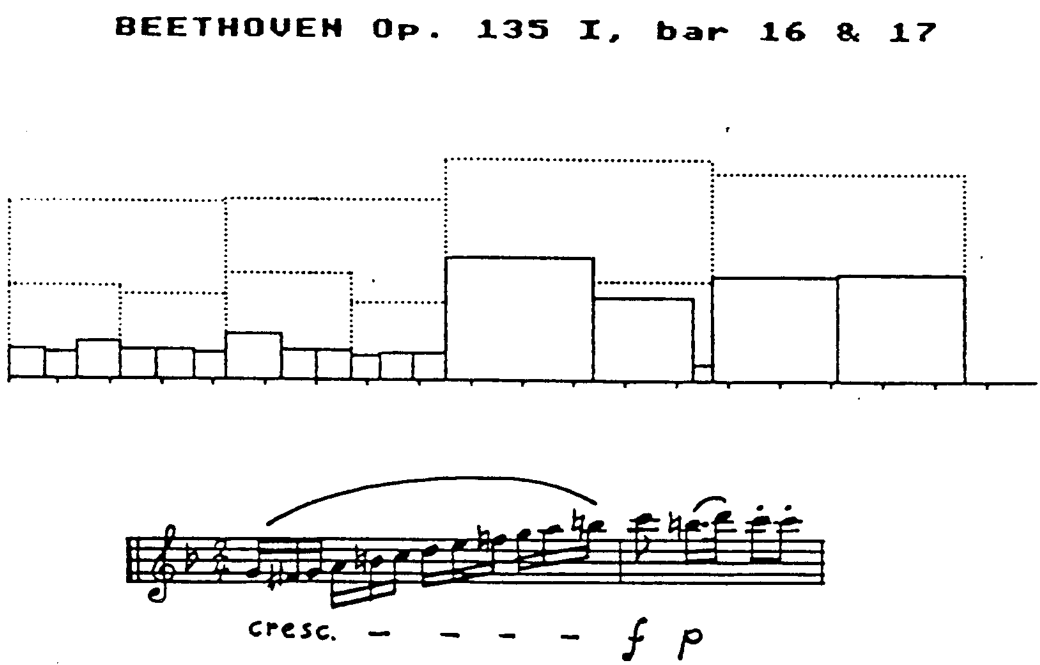

Figure 19: Musical rhythm

quantity of the **syllable** is determined by the quantity of the vowel of the first syllable and/or the inter-syllabic consonant: if either or both are long the first syllable is long (nos. 2, 4, 5), if either or both are overlong the first syllable is overlong (nos. 3, 6, 7), otherwise (no. 1) the first syllable is short. Finally, figure 19 shows the application of TEDAS to the investigation of musical rhythm. The reader should be able to draw some interesting conclusions for himself; the measurements (in this case of the first violin in a recording by the Budapest Quartet) were again made from spectrograms.

Into the future

I believe the use of TEDAS can teach us a lot about rhythm (and perhaps about other, very different, phenomena). The method is slow to use at the moment, but I hope it will be used by researchers in the field of rhythm and that they will develop more efficient procedures for its use. I can supply a copy of a printout of my own program for anyone who wishes to make use of it. It is my hope that some time in the future, when segmentation of utterances into segments and syllables can be done automatically, TEDAS displays with F_0 traces can be displayed in real time. This kind of operation would be of great value both for theoretical investigations into the nature of prosody and as a practical aid in the teaching of spoken languages.

In the displays in this article I have marked as stressed the syllables that I **judged** to be stressed, on an auditory basis. In many cases this judgement is based on what I would claim to be professional or other (for instance native speaker) competence; in one case I was able to test my judgement against that of a competent native speaker (Kristján Árnason in the case of the Icelandic samples shown in Gustafson 1987). Our judgements were coincident except for one very minor point. But the important point here is that it should be possible with the help of TEDAS to determine which groups of syllables are the relevant ones for timing purposes in a particular language. Ultimately this should bring us nearer to an understanding of the nature of linguistic stress as well.

One hypothesis I would like to advance here is that any syllable which is initial in a timing group is in some sense stressed. This is a strong claim, and one worth testing. My basic guideline throughout has been as follows. When joining syllables together into groups, first position in, and therefore the beginning of, a group or subgroup was generally assigned to a syllable which I perceived as being stressed (primarily or secondarily). If my judgement here is sound, and if the resulting syllable groupings can be shown, by the use of TEDAS, to reveal significant patterns in the timing of speech, then this seems to offer strong evidence of the close link between the durational patterns created by the timing mechanisms active during speech production and the perception of primary and secondary stresses.

I hope researchers in prosodic phenomena will use this method; I am quite certain that they will find that their efforts are rewarded. Certainly my own understanding of rhythm has been greatly enhanced by the use of TEDAS.

NOTES

[1] The diagrams used in this paper originate from different times. The original idea was to use the same scale along both axes; in the original program a perfect square on the screen was printed slightly flat, and this was corrected later. It was later also found that by compressing the x-axis by a factor of 2 one got a display that corresponded, possibly, even better to our mental representation of the rhythm at the same time as it was possible to display twice as much per line. The calibration marks found below the lowest horizontal line in most of the diagrams are separated by 0.1 seconds. The groupings of syllables represent my **suggestions** in each case and are of course open to testing; I have indicated primarily stressed and secondarily stressed syllables and pauses by the use of different fillings. The exact details of these vary somewhat from illustration to illustration - there is a key to the correct interpretation in each case. I have had to use my old illustrations since at the time of writing I did not have access to the necessary equipment to produce new diagrams. I offer my apologies for the obviously deficient quality of some of the illustrations!

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