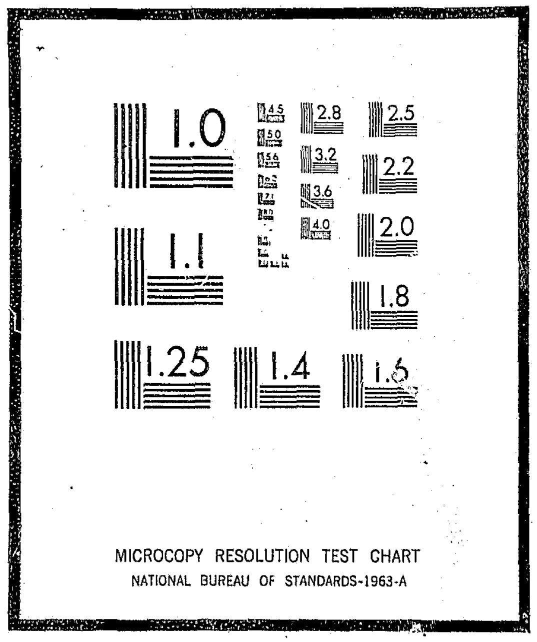

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SEMI-AUTOMATIC SPEAKER IDENTIFICATION SYSTEM (SASIS)

ANALYTICAL STUDIES FINAL REPORT

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FOREWORD

In recent years, speaker identification through the use of voiceprints has been an important and much publicized source of evidence in investigative activities and in criminal court proceedings. Speaker identification techniques currently in use are hampered by time consuming, manual methods. The unscientific subjective nature of those methods has also led to controversy over their admissibility in courts of law.

In an effort to overcome these drawbacks, the National Institute of Law Enforcement and Criminal Justice has supported efforts to evaluate the effectiveness of speaker identification techniques and to develop improved methods and equipment. One such effort, conducted by the Electronics Resarch Division (ERD) of Rockwell International, was a project to develop techniques for quantitative, reliable, computer-aided speaker identification. This effort consisted of an algorithm development, or analytical studies phase, and a prototype system development phase, conducted concurrently.

The analytical studies utilized both mathematical and experimental methods. In particular, the specialized speech research laboratory facilities of ERD's Information Sciences Group were used to acquire and process a data base of over 6,000 specially designed sentences, recorded over a telephone channel from 254 speakers, yielding over 35,000 usable phonetic segments.

The speaker comparison system which resulted from these analytical studies operates in the following sequence of steps:

1. Input of the analog speech recording into digital computer memory.
2. Display of the speech by the computer on a video screen.
3. Operator examination of the speech display, and use of an electronic pointer to specify to the computer those elementary sounds, or phonemes, in the speech recording to use for comparison. This step is called phoneme labeling. Thirteen (13) phoneme types, out of the 40 or so which comprise English speech, are used.
4. Computation by the computer of thirty measurements, called "features," on each phoneme labeled by the operator.
5. Repeat of steps 1 to 4 on the other speech sample to be compared.
6. Computer computation of numerical "distances" between corresponding phonemes of the two speech samples, consisting of weighted combinations of the features from step 4.
7. Computer averaging of distances by phoneme type, and merging of the thirteen types down to ten.
8. Computer combination of the merged average distances into a single number called the "similarity measure."
9. Translation of the similarity measure into a probability that the speakers are the same or different. The relationship between the computed similarity measure and the likelihood of a speaker match or mismatch was obtained by performing steps 1 through 8 on a large fraction of the speech recordings mentioned above, and tabulating the results.

The problems which had to be solved, and the tasks which had to be carried out in the SASIS Analytical Studies included:

1. Design of phonetically and statistically valid speech data bases and recording procedures.
2. Recruitment, screening, scheduling, and recording of over 250 speakers.
3. Processing of the data bases to examine, analyze, label, extract, and catalog over 35,000 phonetic tokens.
4. Research on the effects of coarticulation on speaker comparison.
5. Development of a large set (162) of candidate feature measurements and refining of that set down to the thirty best features for each phonetic type.
6. Research on the effects on speaker comparison of the channel over which the speech is transmitted and the acoustic surroundings at the speaker location.
7. Development of optimum techniques for combining features into distance measures, and distance measures into similarity measures.
8. Development of statistically valid system performance testing techniques.

Moreover, the research and development activities listed above had to be carried out in such a manner that the techniques which were developed could be easily transferred from ERD's large research computer to an inexpensive minicomputer system without losing anything in the process.

The report which follows describes how the analytical studies tasks were developed, including some approaches which were not successful and some recommendations for further work. That the results were, on the whole, highly successful is due not only to the intelligence and perserverence of the SASIS team, consisting of Dr. James Paul, Dr. Arthur Rabinowitz, Dr. John Riganati, Dr. John Richardson, Ms. Marilyn Kimura, Ms. Marilyn Griffith, and Mr. Gerald Kephart, but also to the continued support and encouragement of the Aerospace Corporation staff who acted in the capacity of the program managers for LEAA, and to the management of the Electronics Research Division of Rockwell International.

R. J. Rennick

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The research and development work described in this report represents the efforts of several individuals other than the authors.

Mr. Robert J. Rennick, Program Manager, provided coordination between prototype development and analytical studies and was responsible for the overall scheduling and financial aspects of the program. Dr. V. A. Vitols, Manager, Information Sciences in the Electronics Research Division, provided guidance to all phases of the project and personally conducted the channel equalization study.

Ms. Marilyn M. Kimura programmed algorithms and tests. Ms. Marilyn Griffith programmed the interactive graphics system.

Gratitude is also due to the technical staff of the Aerospace Corporation. Mr. George Papcun and Dr. C. Henderson contributed to sentence design and coarticulation evaluation, and they along with Dr. B. Sklar provided independent review and confirmation of portions of the Analytical Studies Results.

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I. INTRODUCTION

1.1 OBJECTIVES

The objective of the Semi-Automatic Speaker Identification System (SASIS) development program was to design, fabricate, and deliver a prototype computer-aided speaker identification system. The system is designed to analyze, parameterize and compare selected samples of criminal and suspect utterances. From this comparison, a similarity measure between these utterances may be derived and probability measures may be produced indicating whether the utterances were made by the same or different speakers.

This report describes the technical studies which were carried out to develop the techniques used in the SASIS prototype system. The objective of this research and development effort, hereafter referred to as the SASIS "analytical studies," was to develop speaker identification techniques which would be accurate, reliable, repeatable, efficient, and objective. Moreover, these techniques must also be cost-effective, in the sense of being capable of implementation in an inexpensive set of equipment, such as a minicomputer system. Furthermore, the techniques must be simple, in the sense of being capable of operation by a forensic technician who, although skilled in the use of the system as he is in the use of other modern forensic equipment, is not an expert or an academician in the fields of linguistics or phonetic acoustics, nor in the fields of electronics or computer science.

1.2 BACKGROUND

Research leading to the conception of the SASIS can be divided into two broad categories, one treating manual spectrographic comparison (voiceprint) techniques and the other treating automatic or semi-automatic computer-assisted speaker identification techniques.

It is generally acknowledged that voice spectrograms contain significant information about speaker identity. The spectrographic comparison method has been used extensively in forensic applications (People vs. Law, 1974) but has been recently under increasing criticism from the linguistic community (Papcun, et al, 1973; Poza, 1974). The primary deficiencies in the voiceprint technique are subjectivity on the part of the voiceprint examiner, and lack of continuous training of the examiner's discriminant ability.

The voiceprint research has contributed to the conception of the SASIS in establishing a definite need for the system's objectivity and introducing the concept of voice identification to the investigative and forensic application areas. The methodology of voiceprint comparison is poorly documented in the published literature, but basically attempts to match relevant areas of corresponding spectrograms for an identification decision. This method differs significantly from the SASIS in that it relies primarily upon the dynamic properties of the spectrum, whereas the SASIS approach analyzes steady-state segments of phonetic events.

The computer-assisted approach to speaker identification has also been investigated, and a number of systems have been proposed (Hecker, 1971, Holmgren, 1966). Most techniques developed prior to SASIS have attempted to be completely automatic, based on digital spectrographic comparison of samples of speech from groups of speakers. Typically, such systems require the speakers to say a sequence of specified words, which are automatically segmented and compared using Fourier, LPC, or analog filter measurements. Such automatic segmentation techniques are not yet advanced to the state where these systems can deal with the kind of unconstrained speech found in criminal utterances. Therefore, the emphasis by the law enforcement community has been on techniques such as SASIS which uses the best and most dependable capabilities of both the human operator and the computer.

Two prior studies were sponsored by the Law Enforcement Assistance Administration (LEAA) under Title I, Omnibus Crime Control and Safe Streets Act of 1963, and relate directly to applications of computer-assisted speaker recognition to law enforcement. These studies were carried out by Stanford Research Institute (SRI) and Texas Instruments (TI).

The SRI semi-automatic speaker recognition study (Becker et al, 1972) was the pilot study on which the SASIS architecture is primarily based. Vowel events were labeled on an interactive graphics terminal displaying the time-squared series of the time-domain speech signal. These events were specified using this time-energy information along with audio playback, and an expanded time series was displayed from which four pitch periods of the steady-state portion of the vowel were manually segmented.

Three data bases were collected, one with six talkers for development, the second with five talkers for further algorithm development, and the third with 100 talkers for system evaluation. The sentence material was designed around the six vowels /i/, /u/, /ɔ/, /I/, /ɑ/, and /æ/. These vowels were constrained to be surrounded by unvoiced stops to reduce co-articulation and labeling complexity.

The labeled vowel segments were parameterized using LPC spectral analysis, and individual spectral vectors for the six phonetic events from each speaker were concatenated to form an overall feature vector for that speaker. All spectral measurements were assumed independent.

The first experiment attempted to compare a formant-oriented computer-assisted identification approach with the voiceprint approach, but problems with labeling dynamic events and truncation for time-normalization rendered the results of this experiment of little value in comparing the two approaches.

Two other experiments served to evaluate four distance measures, the uniformly-weighted Euclidean, the $1/\sigma_{intraclass}$ weighted Euclidean, F-Ratio weighted Euclidean and a maximum likelihood (based on a gamma model) classifier.

The first of these two experiments used the 25 utterances from five speakers of the second data base. Perfect separation was achieved using the maximum likelihood and F-ratio procedures; however, the statistics for these were derived from the testing data. The $1/\sigma$ classifier followed with the uniform-weighted measure having lowest performance. When exposed to a

supplementary data base of 14 speakers, disjoint from the five speakers, the performance of the likelihood and F-ratio procedures dropped below the other two distance functions, indicating a lack of validity of the statistics and/or a lack of suitability of these measures to the data.

The final experiment involved the third, 100-speaker data base. The six vowels, each parameterized into a 64 spectral estimates from a 64-coefficient LPC, were cancatenated into 384-dimensional feature vectors. The first 50 speakers, Group A, were used for training (computing weights), and the second 50, Group B, were used for testing. Classification performance for each distance measure was evaluated and ranked; the likelihood measure ranked first and uniform weighting next.

The semi-automatic approach advocated by SRI appeared to have much merit. Based on Group B, if a decision was not made in 30 percent of the cases, an error rate of less than 1 percent could be achieved; if a P_{II} error of 20 percent could be tolerated, a P_I error of 2 percent could be achieved.

The SRI study was well-founded and many of the results and recommendations have guided the development of the current SASIS system.

A second speaker identification study under the LEAA Grant was carried out at Texas Instruments (Hair and Rekieta, 1972). This study, while supplementary to the SASIS development, does not directly relate to the architecture of the subsequent system.

This study made use of a data base previously acquired from over 200 male and female speakers. The spoken data consist of six isolated words recorded once a week for nine consecutive weeks. Phonetic events were automatically segmented and spectrally analyzed over 32- and 64-milliseconds "steady-state" regions of the phonetic events.

The major deficiency of this study occurs at the onset and, unfortunately, propagates through the corpus of experiments that ensue. The problem is that, of the five phonetic events used in the majority of experiments, two were diphthongs /ou/ and /eI/ and have poorly defined steady-state regions, especially as might be estimated automatically. Furthermore, the 64 msec spectral windows spanned dynamic regions in a majority of these diphthong cases.

The remaining events are /n/, /i/, and /a/. A sixth event, /I/, was added to later experiments and showed substantial improvement, as might be predicted, due to the outstanding discriminating ability of /I/ (see Section 4.0 of this report) and the reduced weighting of less valuable events.

A number of experiments were carried out. Pattern vectors were formed by cancatenating the individual feature vectors of the five or six phonetic events. Decision functions were based on the unweighted Euclidean distance nearest-neighbor procedure. A distance threshold was introduced

later to explore effects of open and closed sampling cases. It was shown that female and male speakers had about the same intra- and inter-class distance distributions, and that when decisions were forced, performance was very similar.

It was also shown that significant improvement could be achieved when the speaker referent was selected as an average of several utterances rather than as a single utterance.

It was predicted that continual increase in the number of phonetic events would continue to improve performance; however, this conclusion may not be completely valid, since it is based only on the results of adding /I/ to the set. SASIS experiments of this nature carried out in a more controlled fashion are discussed in Section 8.0.

1.3 APPROACH

The SASIS analytical studies project was divided into 20 tasks, each treating a particular aspect of algorithm development.

The organization and sequential order of the individual task developments is shown in Figure 1-1.

1.3.1 Description of Tasks

For clarity and ease of presentation, the analytical tasks are not presented in this report in the chronological order of Figure 1.1, but are presented in topic form in Sections 2.0 through 9.0.

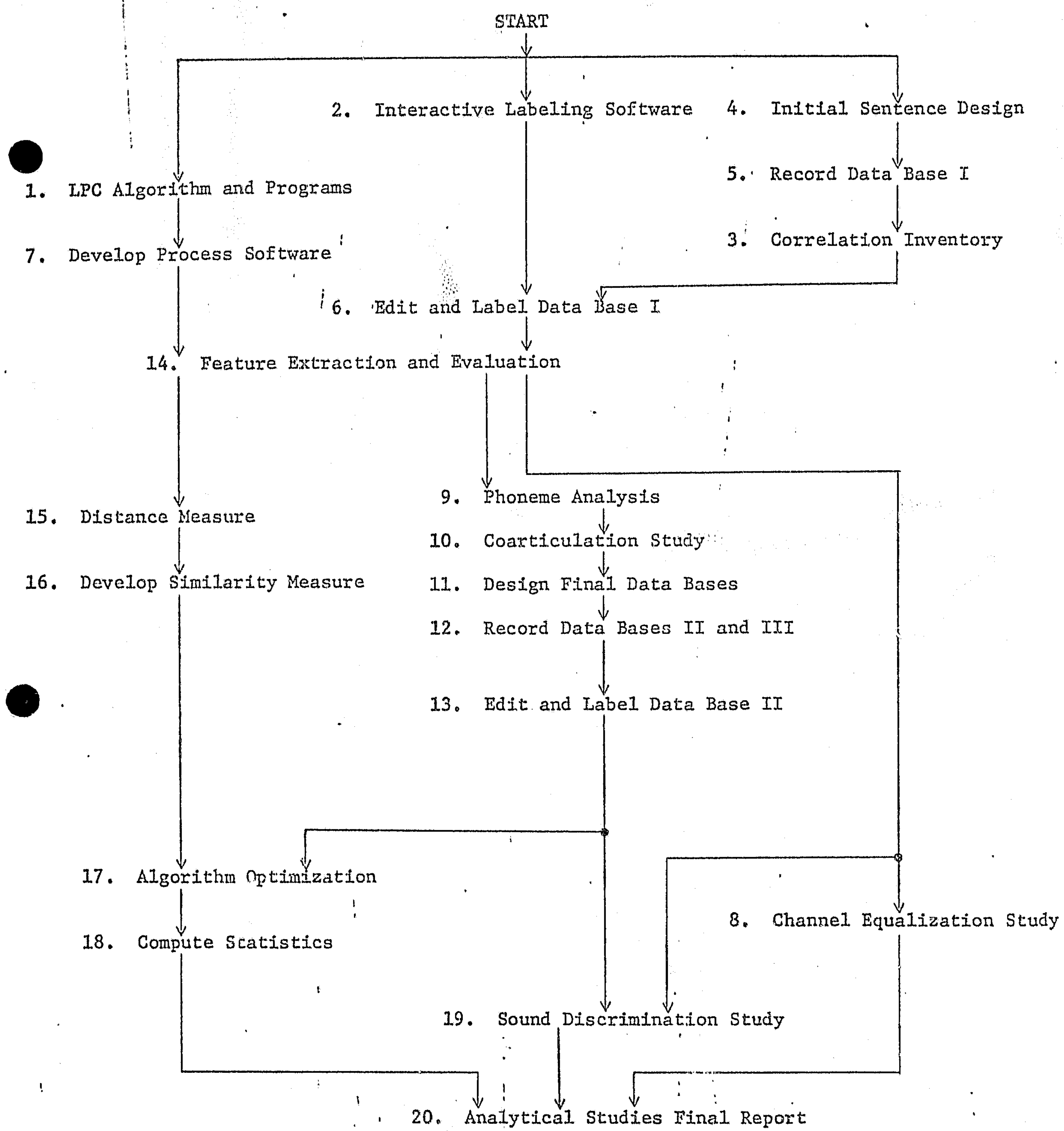


FIGURE 1-1. TASK ORGANIZATION OF ANALYTICAL STUDIES

Section 2.0 is concerned with designing and acquiring three data bases. Data Base I is the developmental data base and consists of 25 male speakers speaking 20 sentences on two occasions. Data Base II is used for system optimization and evaluation and consists of 232 male speakers speaking 10 sentences on two occasions. Data Base III is used for system testing and is composed of 50 male speakers speaking 10 sentences over a telephone network. The tasks covered in this section include

- initial sentence design,
- record Data Base I,
- phoneme analysis,
- design final data bases, and
- record data bases II and III.

The interactive digitizing and editing of the audio data bases along with interactive phonetic event labeling and segmentation are discussed in Section 3.0. This section outlines the software and procedures used in converting the audio data bases into digital form, and extracting from them a set of nearly 35,000 labeled and segmented phonetic events. Included in the discussion are topics relating to generating the phonetic correlation reference inventory, labeling error correction procedures, and a tabulation of the resultant phonetic data bases. The topics covered in Section 3.0 are

- interactive labeling software,
- correlation inventory,
- edit and label Data Base I,
- edit and label Data Base II, and
- sound discrimination study.

Section 4.0 is concerned with phoneme and coarticulation analysis. The results of this study are based on analyzing Data Base I and were used in designing Data Base II and III. Based on these studies, 14 phonetic events (later reduced to 13) were selected for comparison in the SASIS, and a set of second-formant (hubs) contexts were specified to span the range of contextual effects.

Feature extraction involving defining, evaluating, and selecting a set of features for each phonetic event independently. Features included are LPC-based, Fourier-based, time-domain-based, and a special set of functions. The process of specifying the features was carried out in two phases. The first phase defined the procedure and a set of features based on Data Base I, and the second phase were one of optimization. Optimization was carried out on Data Base II, and a final set of 30 features for each phonetic event was defined. These tasks are discussed in Section 5.0

In order to reduce system complexity, it became necessary to decrease the number of inputs to the similarity measure. Section 6.0 discusses the process of reducing the number of allowable phonetic types from 14 to 13 and then grouping (merging) the 13 phonetic types into ten categories. The criteria for selecting merge candidates includes phonological as well as statistical considerations.

The distance and similarity measure design and optimization are treated in Section 7.0. A distance measure using the weighted Euclidean

distance is computed for each phonetic event group. The similarity measure procedure forms a desensitized Fischer discriminant based on the individual phonetic distances as input variables. The similarity measure, S, is the value of the discriminant function. A total of 1023 different combinations of the 10 merged phonetic events are possible, and a unique set of Fischer coefficients were computed for each combination.

The evaluation of the SASIS performance, including the production of 1023 inter-speaker and intra-speaker probability tables from which to interpret the similarity measure, S, is treated in Section 8.0.

Section 9.0 discusses the results of the channel equalization study and summarizes the effects on the SASIS of using audio from switched telephone circuits with operational acoustic environments.

1.3.2 SASIS Research Facilities

The SASIS analysis was carried out in the Speech Laboratory of ERD's Information Sciences Group. This laboratory has a full complement of audio filters, amplifiers, recorders, and a sound booth.

The computational tool of the laboratory is a Systems Engineering Laboratory 8600 computer configuration as depicted in Figure 1-2. The CPU is oriented around 32K - 32 bit word 600 nsec memory with a direct memory I/O subsystem. Three 150 ips 9-track magnetic tape drives along with a 24-m bit disk are configured along with 4800 LPM electrostatic line printer/ graphics output device.

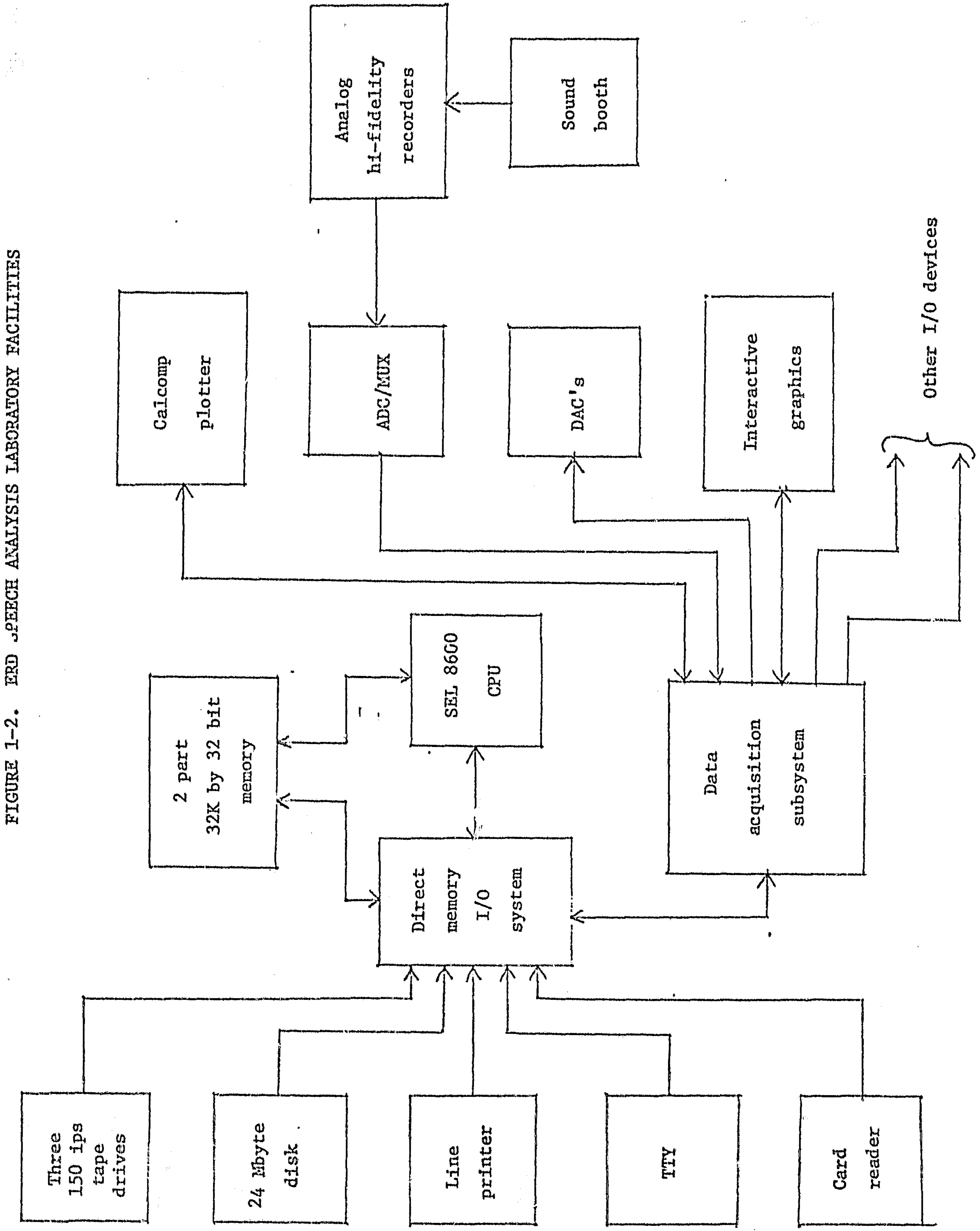


FIGURE 1-2. ERD SPEECH ANALYSIS LABORATORY FACILITIES

Special purpose I/O is accomplished via a 4-port data acquisition system. Interfaced to this system are the analog conversion devices and an interactive graphics terminal. The terminal consists of a storage CRT, keyboard and interactive graphic cursor control and provides the facility for carrying out phonetic labeling.

This computer system operates under a real time monitor with full multi-programming capabilities.

1.4 TERMS AND CONVENTIONS

In carrying out the SASIS research and documenting the results of this research, a set of conventions and definitions have been established.

<u>Context</u> - Context refers to the phonetic environment in which the phonetic event being observed is centered. In the SASIS only the effects of the two adjacent events are considered.

<u>Context free</u> - Two phonetic events are compared in a context free sense when no consideration is given to the influence context. Example: Shed and Pep.

<u>Context dependent</u> - Two phonetic events are compared in a context dependent sense when the hub positions of the preceding phonetic events matches and the hub positions succeeding phonetic event match. Example: Pet and Bed.

<u>Text-dependent</u> - Two phonetic events are compared in a text dependent sense when not only the phonetic events in context

are identical, but also the effects of stress and intonation are similar. This is the most restrictive comparison condition and is employed in the SASIS process. To satisfy text dependency, the two events being compared are extracted from identical positions in identical sentences.

Hub - Hub refers to the position of the second formant and is quantified as high, middle, or low. The hub position is the primary source of contextual influence considered in the SASIS (Potler, et al, 1947).

Triad - Phonetic events are labeled in the SASIS as a triad of three phonetic events, indicating the preceding, central, and succeeding event, though only the central event is segmented and analyzed, the surrounding events are identified to measure contextual effects.

Basis and query processes - The basis process refers to the initial, unknown voice sample, and the query process refers to the known voice sample being compared with the basis process. In a investigative environment, the basis is the criminal utterance and the query is the suspect utterance.

P_I and P_{II} - These refer to error probabilities of the first and second types and are specified for a particular decision threshold. P_I is the probability of two utterances from the

same speaker being identified as not in the same class (false exoneration). P_{II} is the probability of two utterances from different speakers being identified as in the same class (false incrimination).

Phoneme Labels - Table 1.1 defines the set of 34 phonetic events used in the SASIS. Given in the SASIS event number, the International Phonetic Association (IPA) alphabetic symbol, the SASIS alphaphonetic symbol, the class of event, hub position, excitation, and an example of the phoneme. SASIS classification is based on events 20 through 32. The remaining events are used in context positions.

SOC - The SASIS Operating Characteristic (SOC) curve is a unified curve which plots P_I on the abscissa and P_{II} on the ordinate.

TABLE 1.1 PHONETIC EVENT LABELS

SASIS No.	IPA Symbol	Alphaphonetic Symbol	Class	Hub Position	Voiced/ Unvoiced	Example
1	p	PX	Stop	Low	U	peep
2	b	BX	"	Low	V	beep
3	t	TX	"	high	U	tot
4	d	DX	"	high	V	dot
5	k	KX	"	variable	U	kog
6	g	GX	"	variable	V	good
7	N/A	XX	silence	N/A	U	N/A
8	f	FX	fricative	low	U	five
9	v	VX	"	low	V	very
10	θ	TH	"	middle	U	thin
11	ð	DH	"	"	V	then
12	s	SX	"	"	U	six
13	z	ZX	"	"	V	zoo
14	ʃ	SH	"	high	U	shop
15	ʒ	ZH	"	high	V	azure
16	w	WX	glide	variable	V	work
17	j	YX	"	"	V	yes
18	l	LX	"	"	V	let
19	r	RX	"	"	V	run
20	m	MX	nasal	low	V	moon
21	n	NX	"	middle	V	no
22	ŋ	NG	"	variable	V	sing
23	i	EE	vowel	high	V	eve
24	I	IX	"	"	V	it
25	ɛ	EH	"	"	V	met
26*	a	AH	"	middle	V	ask
27*	ɑ	AA	"	"	V	father
28	ɔ	AW	"	low	V	all
29	U	UX	"	"	V	put
30	u	UU	"	"	V	boot
31	ʌ	UH	"	middle	V	up
32	ɝ	ER	"	"	V	bird
33	ə	SW	"	"	V	the
34	h	HX	aspirate	variable	U	hat

* In Data Base I the numbering for AH and AA was reversed.

1.5 CONCLUSIONS AND RECOMMENDATIONS

The SASIS analytical studies work has resulted in techniques for performing statistically valid speaker comparisons for certain types of speech over certain types of channels, and these techniques have been installed in a prototype system capable of being used by crime laboratory personnel. Performance evaluation of these techniques on a large test group gave very good results -- correct identification in 94 percent of the comparisons for the case of nine available phonetic event types, and as high as 84 percent correct identification when only two phonetic event types were available. These results were obtained on General American English speech spoken into a telephone handset and recorded over a telephone channel simulator. Some study was made of other dialects and other channels, resulting in a recommendation that more work be done to refine the techniques to deal effectively with these variations, particularly channel variations.

Topics which were not completely resolved, or were not even addressed, within the scope of the SASIS analytical studies include:

1. Channel equalization
2. Dialects other than General American English
3. Female speech
4. Emotional stress effects in speech
5. Disguise
6. Operator variability

Other technical areas considered to have great potential for improvement of SASIS performance and range of applicability include:

1. The use of nasal and glide environments.
2. Refinement of the amplitude normalization techniques.
3. Modifications to the distance and similarity measure techniques.
4. More extensive consideration of coarticulation effects.

Channel equalization heads the list of unresolved problem areas. During the recording of data bases I and II, only stationary effects of telephone microphone distortion and telephone line phase and bandlimiting were introduced. Moreover, the sound booth in which the recordings were made is a relatively "sanitary" environment compared to real-world acoustic environments for bomb threats, extortion calls, and so forth. Based on the small study made during the SASIS analytical studies, it was indicated that inter-channel spectral variance on the same speaker can far exceed intra-channel spectral variance for several different speakers. In addition to the obvious direct effects, it is also a problem to know how to interpret speaker comparisons made in different channel conditions than those on which the system performance statistics are based.

The recommended approach to resolving the channel equalization problem consists of making a large number of measurements over different channels, in different acoustic environments, developing a model of the channel process which would include both environmental noise and transmission channel distortion effects, designing and testing a neutralization procedure, and finally performing a re-evaluation of system performance statistics.

Another problem area which warrants some discussion here is the question of operator variability. It is not known in a quantitative way what variation in system performance is introduced by variations in the way an operator, or different operators, label and isolate the phonetic events. In particular, very little is known of the effect on SASIS operation of varying the position of the cursor in isolating the phonetic event. In a sustained vowel, greater than 10 pitch periods are available from which the operator selects three subjectively, and differences can occur in segmentation between two operators. We suspect that these differences will not affect performance significantly, but as yet, no means of quantifying these have been developed.

In order to measure the effects of cursor variation, it is recommended that an experiment be conducted with a set of phonetic event tokens which vary in duration from four to ten-plus pitch periods. Each event will be labeled and isolated more than once, each time selecting a different, but not necessarily disjoint, set of pitch periods. An intra-speaker versus interspeaker comparison can thus be made measuring the degree of variation directly attributable to modification in cursor position (event boundaries).

Extension of the SASIS techniques to include nasal and glide environments heads the list of suggested improvements. There are indications that in real-world criminal conversations over telephone channels, as much as

40 percent of candidate classification events possess a nasal or glide in their immediate context. Since telephone threats, bomb calls, etc., are usually short in duration and are often accompanied with extraneous noises, it appears desirable to attempt to accommodate this type of data.

A procedure for determining the effects of these nonstandard environments on SASIS operation is to select data recorded from 25 or more speakers from either Data Base I or II, or a combination of the two. These data inherently have a large sample of glide/nasal environments. After quantifying these environments, selected events from this already digitized data base size could be as small as 1000 events, if well planned. The system statistics could then be recomputed based on nonstandard environments and compared with the standard-environment statistics. Should statistics differ significantly, one of these approaches could be selected.

(a) remove from consideration nonstandard environments,

(b) develop a second set of statistics to be used with these environments, or

(c) develop a normalization procedure at either the feature level or the distance measure level to normalize the effect of these environments to that of standard phonetic environments.

The following are suggestions for future work in the area of phoneme analysis and the effects of coarticulation. This list is not meant to be all-inclusive, and it is expected that other points will require treatment in any further analysis.

(1) Experimental work should be undertaken to ascertain which contexts enable the highest degree of speaker discrimination. The usefulness of vowels in glide environments and the zero-introducing effect of nasals requires quantification. These results, from the context viewpoint, will establish a more optimal basis for phoneme selection by the operator.

(2) It is probable that individuals with a rapid rate of speech will be less separable due to greater formant undershoot and a higher level of intraspeaker variance. An examination of the relationship between speech rate and spectral variation on an intraspeaker basis would be appropriate.

(3) The usefulness of relatively unstressed events and the consequences of various syntactic structure requires consideration.

(4) The value of diphthongs in a discrimination situation should be determined and rules developed for the consistent labeling of such events.

(5) The extendability of the conclusions developed in this study to Mexican-American and Black dialects deserves further attention.

Amplitude normalization is another area for SASIS improvement, particularly when confronted by noisy speech data. In the current SASIS procedures, audio data is amplitude normalized at the sentence level in the time domain, using a combination peak and average magnitude normalization procedure. This procedure works well with laboratory data by closely matching the amplitude levels of two sentences and preserving the intrasentence stress levels.

In an operational environment, audio data is not structured on a uniform sentence basis, and stress levels are not always identical with the same speaker. This is due to different acoustic environments, emotional stress, etc. Moreover, random segments may be edited from either the basis or query utterance due to noise or other undesirable extraneous audio. It, therefore, seems plausible to employ an alternate amplitude normalization procedure on the isolated phonetic event.

The procedure proposed is to take a time-domain three-pitch-period segment and to normalize the energy in this signal to a reference value. Two unknowns immediately ensue. First, the effect on feature values is unknown, since the normalization process neutralizes acoustic stress information. Second, system performance statistics (SOC curves) are probably modified, since the input data has been modified.

The task proposed is to introduce event-level amplitude normalization and to determine both the effect on feature selection and overall system performance statistics. Given that the system is available with both normalization procedures, a comparison can be effectively derived on a limited data base of operational data.

The distance measure being used in SASIS is an 'unedited' weighted Gaussian form. A number of modifications are know which improve upon the performance of this measure when the SOC curves are used as the criterion of optimality. These were not pursued at this time for a variety of reasons. Chief among these are the unavailability of the data at the time the experiments were performed and the suspicion, supported by engineering judgment, that an editing procedure would introduce conditions which are unrealistic in the operational situation. For the second reason, the edited forms discussed in 7.2.1.3.1 were discarded; for the first reason, the forms discussed in 7.2.1.3.2 were not pursued. Both of these deserve additional attention.

The two-step procedure described in Section 7.1 omits any information from the distance measure block concerned with the amount of data upon which any particular distance measure was based. Hence, it is not known by the similarity measure if a specific phonetic event class distance is based upon a single triad-pair comparison or multiple triad-pair comparisons. Certainly, this is statistical information which may be considered to refine the validity of the two-step process. Whether this can be done within reasonable complexity constraints (and evaluated with the data available) is doubtful and this route has not been pursued. However, its effect should be investigated.

Finally, the question of a direct or indirect approach to either a distance or similarity measure has been considered above within the constraints of the current effort, to be resolved in favor of the indirect approach. Under more general considerations and with the a priori existence of the data, the direct approach, particularly in a parametric form, has much to recommend it. This would be particularly appropriate after the collection of realistic operational data.

The similarity measure used in SASIS is a linear form where the coefficients are calculated using a desensitized discriminant function which is optimal under a set of realistic conditions. A brief investigation of nonlinear forms was made. Although the examples given there were found to be superior to the linear forms, as judged by the SOC criterion, the nonlinear structure could not be completed in the time remaining on the current effort. Hence, a complete optimized linear form was chosen as the current implementation rather than a rather incomplete but promising nonlinear form. Clearly, the evidence presented merits reconsideration and extension of these nonlinear forms. This would naturally result from a reconsideration of the data now available, in conjunction with a re-examination of the direct/indirect tradeoff outlined above.

Full exploration of the results of the current system was curtailed because of funding limitations. A number of very informative conclusions merely await a few experiments. Among these are:

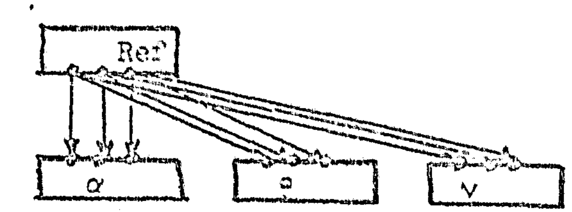
1. The intrinsic dimensionality represented by the 1023 cases described above. This is alluded to in Section 8.4, but needs to be made more quantitative.

2. The existing approach computes curves for each of the 1023 pseudo comparison sessions by averaging over triad-pair triplets:
   (a) the variation within classes of operational interest should be computed,
   (b) the procedure should be repeated for
      (i) triad-pair singlets
      (ii) triad-pair "all-the-available-data"ets
3. An additional tabulation; based on the Λ values themselves would give an additional perspective on how the statistics change with the data.

Additional operational scenarios may be investigated with the data available if it is restructured. Consider a

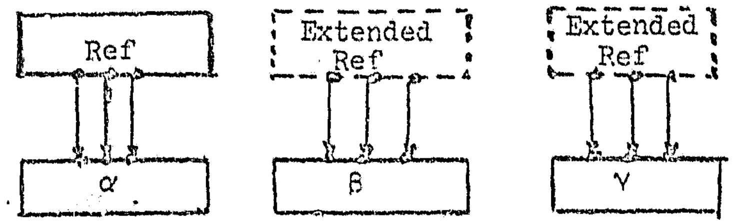
Scenario: base speaker: speaks 3 phonetic events
suspect 1 : α speaks 3 phonetic events
β repeats 3 " "
γ " " " "

Formulation A:



i.e., run the entire SASIS system 3 times

Formulation B:



Run the SASIS system <u>once</u> by extending the reference data by repetition.

Using the current data, we may compute inter-speaker numbers using, e.g., speaker i, session 1 with speaker j, session 1 (this data has not been used to date).

Specifically, compute

1) all the statistics again, and measure the sensitivities,
2) compute (a) Λ_1 using speaker i, session 1 and speaker j, session 2
   (b) Λ_2 using speaker i, session 1 and speaker j, session 1

across a number of scenarios and find the average

$$\frac{|\Lambda_1 - \Lambda_2|}{|\Lambda_1 + \Lambda_2|}$$

Either procedure would shed light on whether there should be any operational preference for formulation A or for formulation B.

2.0 AUDIO DATA ACQUISTION

Three audio data bases have been recorded during the course of the analysis investigation. These data bases are defined as follows:

Data Base I - The pilot data base on which initial system design is based. This base consists of 25 General American English (GAE) dialect speakers saying 20 phonetically balanced sentences on two separate occasions, separated by approximately two weeks.

Data Base II - The system optimization and evaluation data base. This base consists of 193 GAE, 21 Chicano, and 18 Black Urban dialect speakers saying 10 phonetically balanced sentences on two separate occasions, separated by one to two weeks.

Data Base III - The system and prototype testing data base. This base consists of 50 GAE speakers (from Data Base II) saying the same 10 sentences. Unlike the other two data bases in which recording was carried out in a soundbooth, recording these data was carried out in various laboratory and office environments over the telephone network.

2.1 DATA BASE I ACQUISITION

2.1.1 Procedure and Purpose

The first data base has as its purpose to provide a basis in which coarticulation, channel equalization, feature extraction, distance measure and similarity measure studies can be carried out. In addition to these tasks, the design of the more extensive Data Base II and Data Base III is based on analysis of this data base.

Data Base I is the result of a sequence of tasks. The first task involves designing a sentence set sufficient to span the phonetic situations of interest with sufficient representation to maintain statistical validity. Next, a procedure for extracting voice samples was designed and the recording equipment configured to satisfy the specified requirement. Finally, the speaker base was specified, speakers interviewed, selected, and recorded.

2.1.2 Sentence Design

The sentence design task was carried out in three phases: initial event selection, vocabulary design, and sentence construction.

2.1.2.1 Selection of candidate phonetic event set.

A basic 14-phonetic-event set was selected on which to base analysis. These initial events were candidates from which the final event set was selected. Considerations on which this candidate event set was based are listed below:

- Vowels selected for labelling are stressed, non-nasalized, and preferably internal to a syllable. An exception is the schwa, which is also being analyzed.
- Fricatives will not be selected for eventual evaluation because it is probable they show less inter-speaker variability due to a lack of definite formant structure.

- Some vowels on the vowel chart are not to be considered for analysis due to their extreme proximity to other vowels and the expected difficulty of an operator in distinguishing the members of a pair. Two vowels in this category are æ (at) and ɔ (not).
- Diphthongs will not be considered for speaker comparison due to their formant variation resulting from two target regions.

The 14 selected phonetic events for Data Base I are given in Table 2.1.

2.1.2.2 Selection of Phonetic Contexts

In order to consider the effects of coarticulation on the candidate phonetic events, a set of contexts were specified. Context is defined here in a first-order sense, i.e., the effects of the phonetic event immediately preceding and immediately succeeding the central candidate phonetic event. This triplet of phonetic events is defined as a triad, event though only the central, candidate, event is isolated for analysis. Notations of the two adjacent context events is carried in the labeling, however.

Context is based on the hub (Potter, et al, 1947) position, i.e., the position of the second formant. For the vowel events, three types of context were chosen and are high-vowel-high, middle-vowel-middle, and low-vowel-low hub positions of surrounding non-nasal consonants. The context consonant classes include stops and fricatives. The nasals exhibit little formant variation across adjacent events; therefore, they are not embedded in triads and were not used in coarticulation analysis as were the vowels.

The selected consonant hub positions are given in Table 2.2.

2.1.2.3 Derivation of Vocabulary

Designing the vocabulary for Data Base I was carried out by first specifying all possible triads for each candidate phonetic event and then selecting vocabulary members which have these triads in normally stressed positions.

Table 2.1

Candidate Phoneme Event Set for SASIS

Event	Example
i	eve
ɪ	it
ɛ	met
a	ask
ɑ	father
ʌ	up
ɝ	bird
ɔ	all
ʊ	put
u	boot
m	me
n	no
ŋ	sing
ə	the (schwa)

Table 2.2

Consonant Events Used in Vowel Context

Hub Position	Stops		Fricatives	
High	t	to	ʃ	she
	d	day	ʒ	azure
middle	k	key	θ	thin
	g	go	ð	then
			s	see
			z	zoo
low	p	pay	f	for
	b	be	v	very

A triad chart was constructed for each vowel. An example for the vowel /i/ is given in Figure 2.1. The vocabulary derived from this chart is given in Table 2.3. The vocabulary for the remaining phonetic events is given in Appendix 2A.

Additional considerations employed in designing the vocabulary are given below.

- Although it is preferable to employ words that would be expected in a criminal situation; e.g., bomb, gun, insurance, police, money, the use of such entries would only be at the expense of desired vocalic tokens, given a fixed number of sentences.
- Words selected were relatively common and easily readable by poorly educated individuals.
- Analysis on the schwa was concentrated on the vocalic event in "the."
- Words containing /m/, /n/, and /ŋ/ nasals were introduced at sentence design time, to link vowel vocabulary members, since context was not imposed in this class of phonetic events.

2.1.2.4 Design of Sentence Set

The sentence set (Table 2.4) was constructed from the vocabulary. The first sentence is a dummy used to sense the speaker's audio level and absorb speaker start-up effects. The remaining 20 sentences are the accepted data.

During the design of the sentence set, the following three considerations were observed:

- It is desirable to use syllabic frequencies strongly compatible with those of GAE; however, this would be at the expense of desired vocalic tokens.

Table 2.3

Word List from Vowel /i/

Teach Teed (golf) Deed Cheat	Detach Detail Detain Detect Deteriorate Determine Detest Detract	Sheet Petite	High-Vowel-High
Cease Ceaseless Seize Seizure These Thesis	Keith Keys Donkeys Monkeys Geese Seek	Seesaw Cecil	Middle-Vowel-Middle
Peep Beep People Beef	Feeble		Low-Vowel-Low

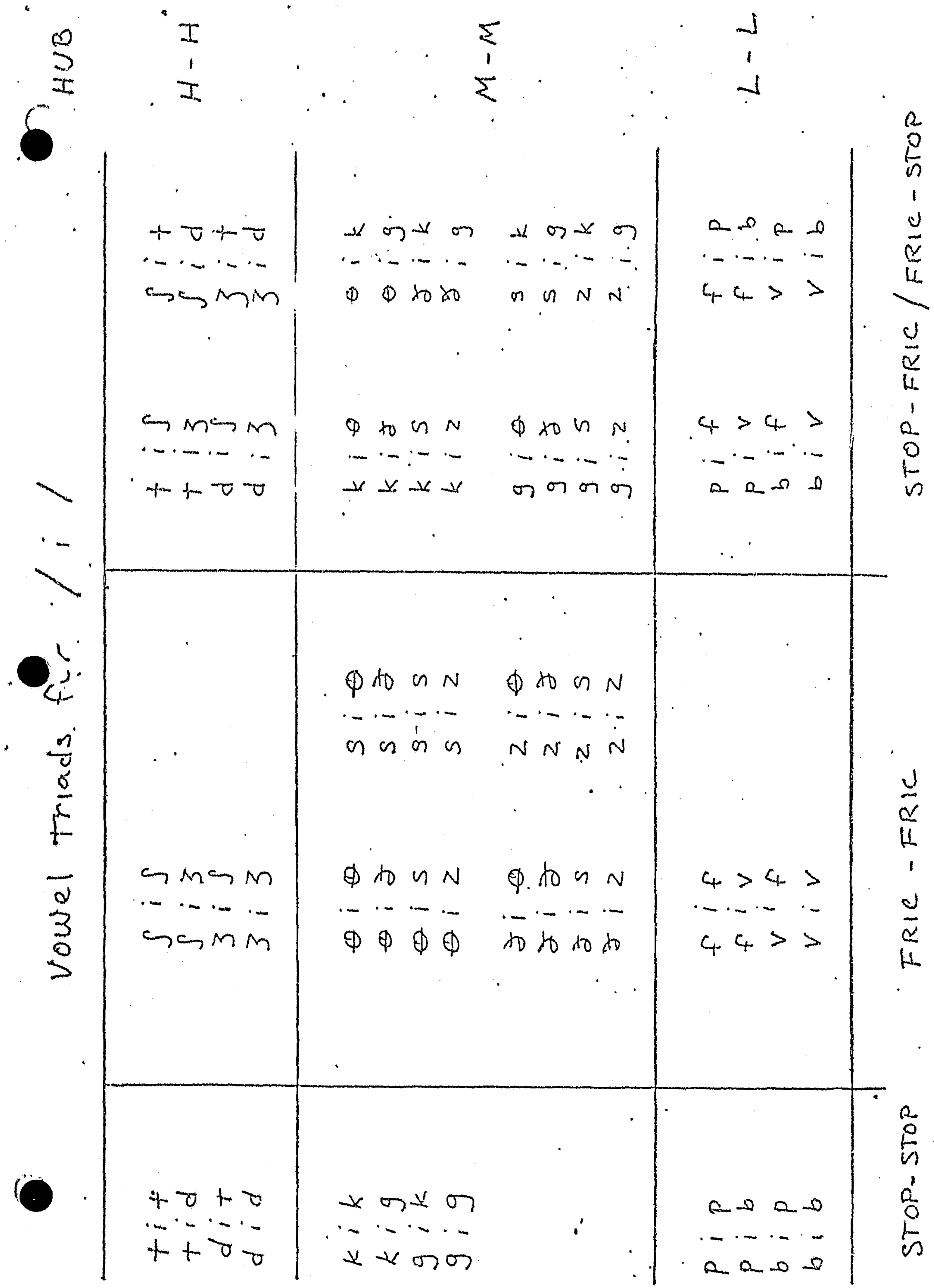


Figure 2.1
ENVIRONMENTS

TABLE 2-4

Sentence Set 1

1. It should be pointed out that linear prediction has had extensive application in other fields.
2. Keith Dudley taught his daughter Susan to cook a fabulous pudding dish.
3. The thug ransacked the shed with ceaseless determination to do damage.
4. Above all, the judge was baffled by the dirty revolver which shot the guest.
5. Thus, the excessively shoddy book caused the tutor's enthusiasm to deteriorate.
6. Did Bev's giggling sister kick the sassy dude?
7. Few people guessed that Vivian's daughter performed this involved process.
8. Dad dashed from the shed to kick the puppy chewing his new shirt.
9. These people shuddered in disgust when Cagney made a caustic and uncouth rebuff.
10. The teacher should have popped the beef dish into the sizzling oven.
11. Is it the duty of the packers to perform each detail?
12. Ted's shirt, together with his socks, were ruined by the booby trap.
13. Fifty talkers babbled casually as the cooks jittered dirty dishes on the buffet.
14. Bob determined that people in Dunkirk caught puppies in sacks as a gag.
15. Susan's enthusiasm should not cause backers of Ted to persist in their attitude.
16. Because the cost involves steadily performing the process, Tod should not dash into debt.
17. Beverly was baffled by the pauper who fibbed about his populous family.
18. Tod's feet should be hurting because he has a pebble in his sock.
19. The singing officers asked for a third song.
20. Did Dutch's daughter chat with the goggle-eyed circus clown?
21. The third sauce stimulated their peptic ulcers and caused them to burp.

Table 2.5

Context Distribution for SASIS Data Base I Sentence Set

Hub Context	i	ɪ	ɛ	ə	ɑ	ʌ	ɝ	ɔ	ʊ	u	m	n	ŋ
H	5	6	5	4	4	4	5	4	4	4	-	-	-
M	6	6	7	7	4	4	8	8	2	2	-	-	-
L	4	3	4	5	4	5	4	5	0	0	-	-	-
Mix	3	11	1	6	0	7	5	2	5	5	17	18	6

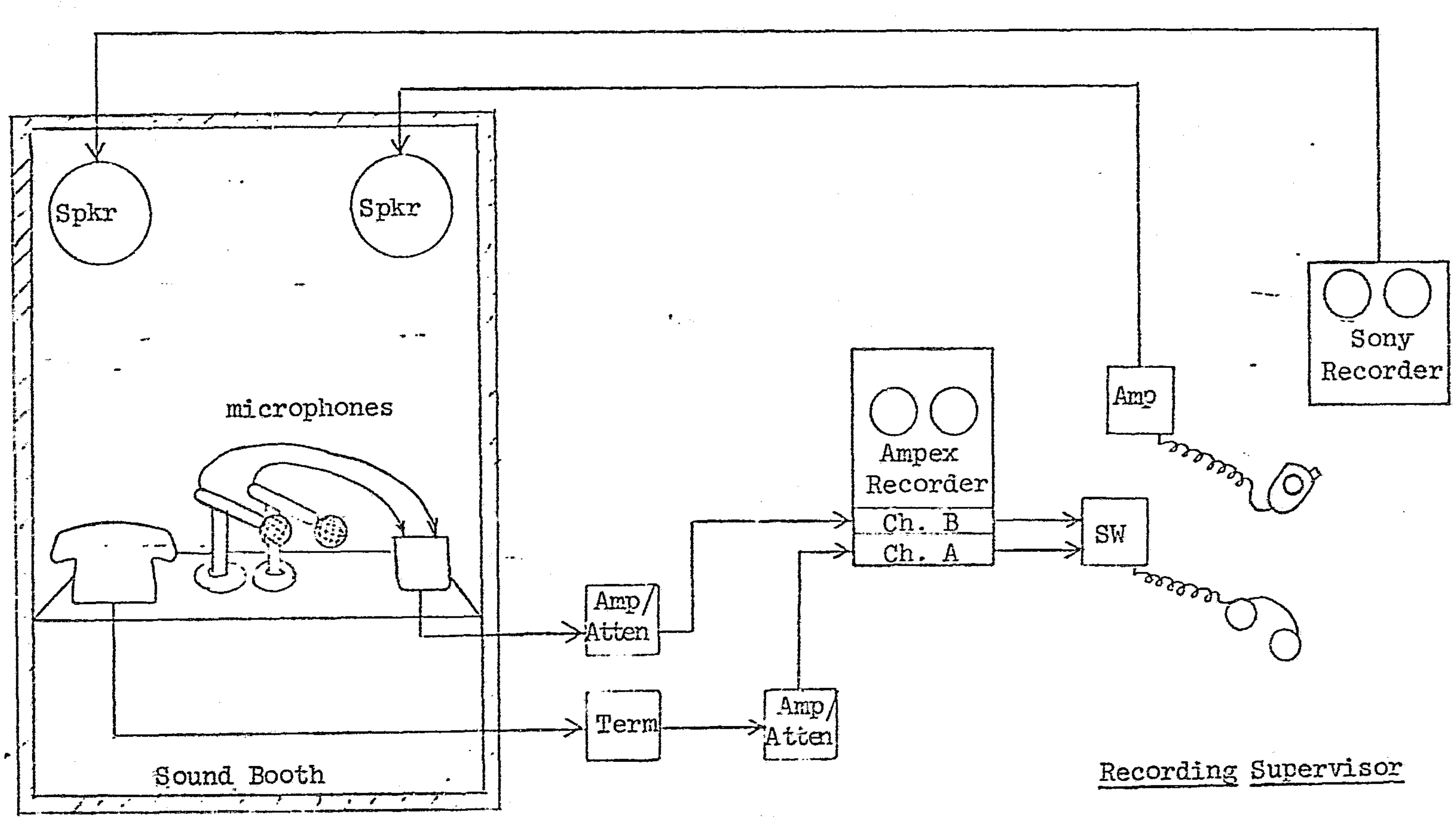


Figure 2.2 Configuration of Recording Equipment to carry out SASIS Audio Data Collection

- Long sentences are preferable in order to provide enough tokens for each context and to minimize end effects.
- No constratins are to be made on the types of sentences used (e.g., declarative, interrogative, imperative).

During sentence construction a major effort was directed at distributing the triads evenly throughout the data. As is illustrated in Table 2.5, a good distribution was achieved in all but a few cases, where the number representative vocabulary members was very limited.

2.1.3 Data Base I Recording

2.1.3.1 Purpose

Data Base I had as its function to provide a basis on which initial system algorithm development could be carried out. This data base consists of 25 GAE speakers saying the 21 sentences of Section 2.1.2 on two separate occasions. Each recording occasion is referred to as a recording session.

Speech was simultaneously recorded from a dynamic microphone arrangement and a conventional desk style telephone. All recording was carried out under the direct control and the monitoring of the recording supervisor, the senior laboratory technician.

2.1.3.2 Recording Setup

A diagram of the recording set up is given in Figure 2.2.

2.1.3.2.1 Soundbooth Configuration

Sentence recording from the speakers was carried out in a semi-anechoic chamber situated in a sound treated laboratory room. The chamber was manufactured by General Acoustics Corporation and measures 56" x 48" x 105." The estimated attenuation of this soundbooth is given in Table 2.6.

Included in the soundbooth are a console with full remote control for two tape recorders, two microphones, a telephone instrument, a mixer,

Table 2.6 Estimated Attenuation of Sound Booth

Frequency (Hz)	63	123	230	500	1000	2000	4000	8000
Attenuation (dB)	28	46	56	63	75	82	89	80

two speakers and a chair.

The two microphones are Shure Model 365 unidirectional dynamic microphones with reasonably flat (±8 dB) response from 30 to 13000 Hz. These mikes are positioned approximately 12 inches from the speaker's lips and 20 degrees either side of the speakers normal face position. This 40 degree angular separation between microphones enabled successful recording of untrained speakers with minimal incidence of burst noise. The two microphones are blended into one high fidelity channel with a Shure M67 mixer.

The telephone instrument in the sound booth is placed on the console in front of the speaker. The instrument line is terminated outside of the booth with a Thevenin equivalent to the telephone line (see Section 2.1.3.2.3).

One of the two speakers in the sound booth is used for playing prerecorded instructions, directing the speaker in his recording. This speaker is driven by a Sony TC 565 tape recorder, controlled by the recording supervisor. The other speaker is an intercom, permitting the recording supervisor to communicate with the speaker during recording.

2.1.3.2.2

The two audio channels, the terminated telephone instrument, and the mixed dynamic microphone channel, were recorded on an Ampex AG 440 tape recorder. This recorder is fully upgraded to AG440 B specifications and includes Dolby Type A companding and servo capstan. The two channels were recorded simultaneously on $\frac{1}{4}$" x 1200' Ampex type 406 high-density audio recording tape. Recording was carried out at $7\frac{1}{2}$ ips in half-track mode using NAB equalization. The overall specifications of the recording system are given in Table 2.7.

Input signals to the recorders from the sound booth are controlled at the supervisor's position adjacent to the recorders by decade attenuators. The recording levels were controlled by observing recorder VU meters and correcting the range for peaks at approximately OVU. The supervisor monitored both channels with headphones, selecting either channel with a switch junction box.

Table 2.7 Specification of Ampex AG440 Recording System

Speed (ips)	$3\frac{3}{4}$	$7\frac{1}{2}$	15	30
Flutter (%)	0.1	0.08	0.06	0.05
S/N (dB)	64	68	68	68
Frequency response ±2 dB	50-7.5K	40-10K	30-18K	
Speed Accuracy (%)	0.08	0.08	0.08	0.08

2.1.3.2.3 Carbon Microphone Analysis

In order to assure that the telephone instrument employed to record speech data was typical, an experiment was conducted to evaluate telephone instrument carbon microphone elements and to select an element for SASIS analysis data acquisition.

The experiment conducted involved measuring the frequency response of five carbon microphone elements mounted in a standard telephone hand set. The measurements were made in a semi anechoic chamber in which an audio output transducer (high-quality speaker complex) was positioned 18 inches from the suspended telephone handset. A reference microphone was positioned equidistant from the audio source and $\frac{1}{2}$ inch from the handset.

A set of five microphone elements were selected at random from telephone instruments in the laboratory vicinity. These elements have been installed at various times over the past 10 years. No element had been obviously physically abused.

The telephone instrument under test was disconnected from the telephone circuit and was biased according to Figure 2.3a. This bias circuit is a Thevenin equivalent to the telephone circuit.

The audio measurments were conducted according to the instrumentation of Figure 2.3b.

The frequency response of the carbon microphone was measured at nine frequencies, and the approximate cutoff frequency of each carbon microphone was measured. The amplitude of each single-frequency tone was adjusted for 0 dB. The reference of 0 dB was established as nominal speech output from the instrument when the handset is held in a normal manner and a normal voice level is used.

The audio level at the carbon microphone was measured via the reference microphone (SHURE 365 SD). The audio level was corrected using the measured response curve of the SHURE issued by the manufacturer.

Table 2.7 gives the results of these measurements. The frequency response of the five microphone samples appears to be reasonably uniform across the 9 frequency samples. Microphone A was selected for SASIS analysis audio recordings.

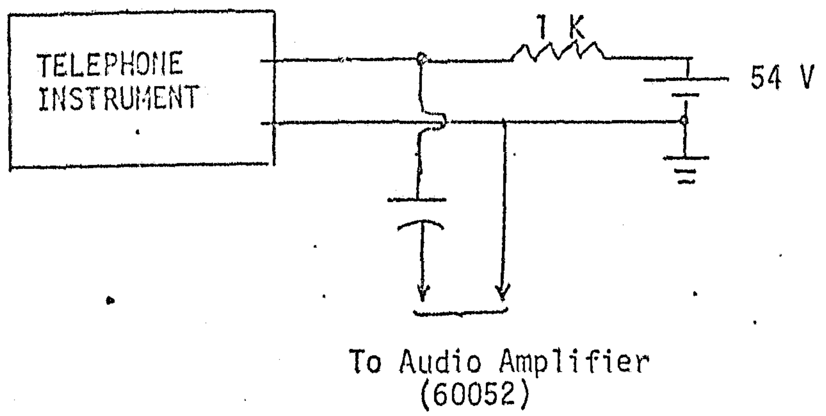


Figure 2.3a Telephone Instrument Biasing

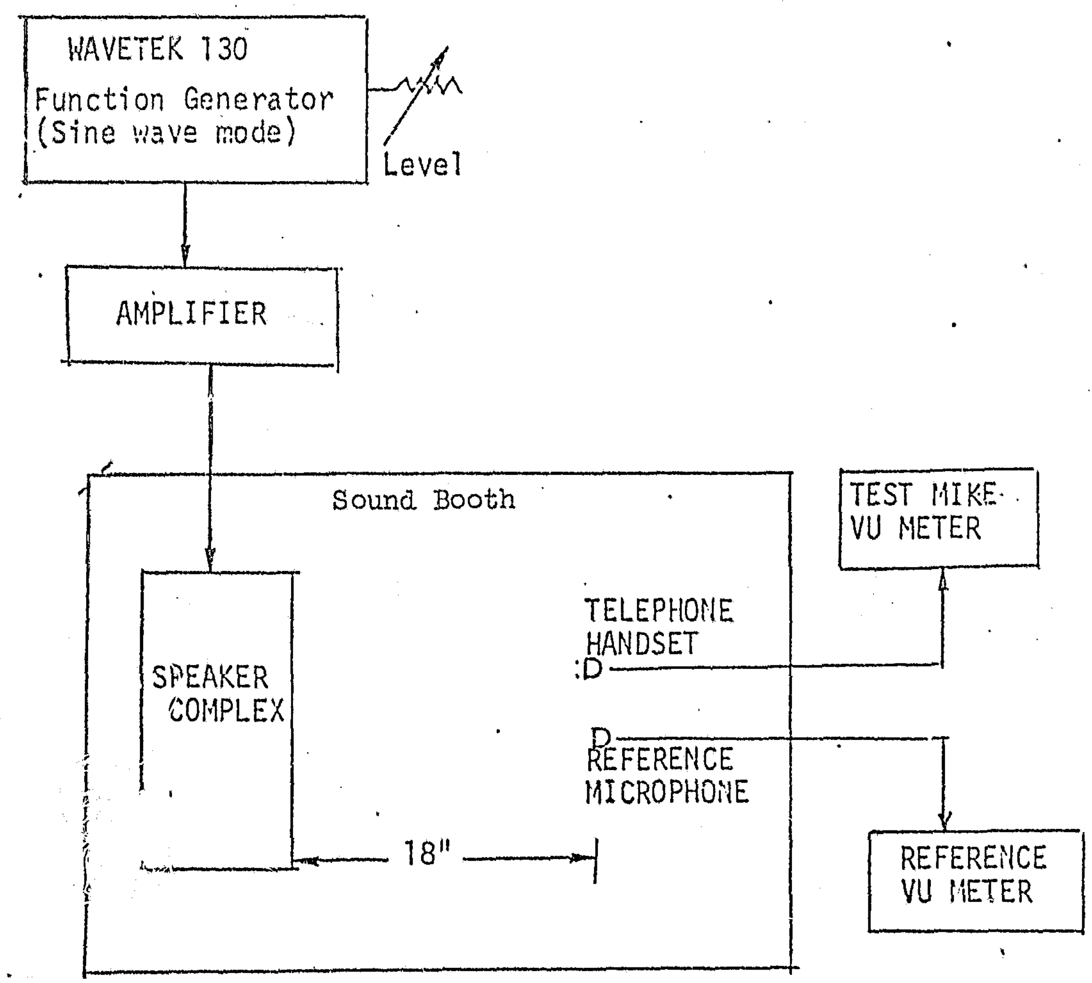


Figure 2.3b Experimental Setup for Measuring Telephone Microphone Frequency Response

2.1.3.3 Recording Procedure

2.1.3.3.1 Organization of Speaker Base

A set of 30 male adult speakers were selected from within the Advanced Technology Department to participate in Data Base I recording. These speakers were known, and their voices were familiar to the investigators organizing the speaker base. These speakers were selected on the basis of GAE dialect as broadly defined, and absence of obvious speech impediments. A surplus of 5 speakers were initially recorded in order that those whose performance was not considered satisfactory or who encountered a scheduling problem would not be recorded for the second session. The final Data Base I included two complete sessions of 25 of these speakers.

Each of the speakers was contacted first by a letter of explanation and then by telephone. He was scheduled for two appointments, separated by approximately two weeks. When arriving for the first recording session, each speaker was asked to fill out a questionnaire in which name, height, weight, age, and childhood residence were specified. An example of the questionnaire is given in Figure 2.4.

2.1.3.3.2 Speaker Recording Material

Speakers were scheduled to arrive on 20-minute intervals. Upon arrival, the speaker was given a brief explanation of the recording procedure and the purpose of his recording by the recording supervisor. He was then seated in the sound booth, shown the telephone and microphones, and the door was closed.

The recording supervisor then played to the individual in the sound booth a prerecorded directive tape, in which the purpose of and an explanation of the recording process was given. The text of this recorded message is given in Figure 2.5.

Figure 2.4 Example Questionnaire

Speaker 9

Section 1A

SPEAKER DATA SHEET

Please fill out down to the dashed line. This data is used in characterizing your voice.

Name	S. A. White	Height	5'8
Dept/Group	521-[illegible]	Weight	2[illegible]
Extension	[illegible]727	Age (Please Check One)	
Location	H1 4[illegible] C16-B/241	☐ Below 25	☐ 25 - 34
		☑ 35 - 44	☐ Over 44

During ages 3 to 12 in what state did you reside more? Illinois

☑ City or ☐ Rural? (Please Check One)

- -

Recording	Date	Remarks
1	10-3-73	SASIS 7A
2	10-22-73	SASIS 15A

Figure 2.5 Text of Data Base I Briefing Message

BRIEFING TEXT

Thank you for participating in the speech recording project. The purpose of this project is to record sentences from a large number of speakers and to analyze these spoken sentences in a computer. Various types of analyses will take place, and the end goal will be to develop a system for determining an individual's identity by analyzing his voice.

You will be asked to state your name and department number and then to speak 21 sentences. The sentences you are to speak are designed to provide a special set of sound combinations and are not necessarily meaningful. I will start with sentence number one on the list and will speak it twice. I will then pause for a brief period, during which you are to speak that same sentence. We will then repeat this process for sentence numbers 2, 3, and so forth until all 21 sentences on the list are spoken.

Please speak in a clear voice and try to say each sentence smoothly, as you might in a conversation. If you make a mistake, or mispronounce a word, pause for about a second and start that sentence from the beginning, all over again. I will repeat: if you make a mistake, or mispronounce a word, pause for about a second and start that sentence from the beginning, all over again.

If for some reason you wish to temporarily stop this session, just press the button marked STOP. This button is located on the panel in front of you and slightly right of center. The operator will then assist you.

The telephone, as well as the two microphones, will be used to record your voice. Please pick up the telephone and hold it as you normally do when you talk on the telephone. (Pause)

Now position yourself comfortably in front of the two microphones and avoid speaking directly into either of the two microphones.

We will now ask you to say your name and department number; please state your name and department number following the tone.

(Tone)
(Pause 10 seconds.)

We will now speak the sentences. Remember to wait for me to say each sentence twice and wait for the tone before you say that sentence.

(Sentence, Sentence, Tone)
(Pause 10 seconds)
(Repeat for 21 sentences)

Following this explanation, the same recording requested name and department data, and then requested that the sentences be spoken. For convenience, a copy of the sentence list was placed in the front of the speaker, and each sentence was said twice to him, from the recording, before he was to say that sentence. Each response from the speaker was preceded by a short tone.

2.1.3.3.3 Analysis of Recorded Material

Recording Data Base I resulted in a big set of high-quality voice recordings of 25 speakers. The interactive recording procedure proved to be very successful in providing a natural response from the speakers. Mispronunciations were minimal.

2.2 DATA BASE II ACQUISITION

2.2.1 Procedure and Purpose

Data Base II has as its purpose to provide a basis on which feature extraction, distance measure, and similarity measure tasks can be optimized, as well as a basis on which an overall evaluation of the SASIS can be carried out.

This data base consists of recordings from 232 speakers from three dialect groups. This data base is the result of a sequence of tasks. The first task is that of evaluating Data Base I for a coarticulative effect and defining the set of useful phonetic events as well as contexts for each selected event.

The next tasks are similar to those of Data Base I acquistion. They include designing a set of 10 sentences satisfying the design criteria and carrying out the actual recording tasks.

2.2.2 Sentence Design

Sentence design for Data Base II was more constrained than that for Data Base I, since the mean education level of speakers dropped significantly on the second data base. Semantic validity and vocabulary familiarity were a primary requirement placed upon this sentence set.

2.2.2.1 Selection of Phonetic Event Set

The phonetic event set selection was based directly on the results of the coarticulation study, Section 4.0. The final set is the 14-event set (Table 2.1) used in Data Base I, since no rationale was developed at that time to reduce the number of events. Though data was recorded and labeled for all these 14 events, a procedure was subsequently developed to eliminate the schwa, /ə/, and to merge certain pairs of events such that a coalesced set of 10 phonetic categories resulted. This overall reduction in

number of categories permitted significant simplification in the system evaluation task.

2.2.3.2 Selection of Phonetic Contexts

The phonetic hub contexts for Data Base II were finalized by the coarticulation study (Section 4.0) and are defined in Table 2.8. This table reflects a sizable consolidation in some contexts. In the case of /i/, /m/, /n/, and /ŋ/, the hub position on either side was found to have little coarticulative effect. For /ɪ/ and /U/, hub position was found to have significant influence, and the original Data Base I specification was preserved. The remaining events, except for /ə/, were found to be similarly influenced by high and middle hubs, which are grouped together, separate from low hubs.

TABLE 2.9

<u>Context Specifications for Phonetic Events</u>

/i/, /m/, /n/, and /ŋ/	high, med, or low/event/high, med, or low
/ɪ/ and /U/	high/event/high med/event/med low/event/low high, med, or low/event/high, med or low mixed
/ε/, /a/, /ɑ/, /ɔ/, /u/, /ʌ/, and /ɜ/	high or med/event/high or med low/event/lw (mixed) high, med, or low/event/high, med, or low
/ə/	the word "the" followed by any event.

The second data base also employs a mixed context across the center event. This variability permits nonsimilar hub influences at the beginning and end of triads, a condition far more representative of real world data than similar hubs on either side of the center event in a triad.

A further contextual influence was introduced into the sentence set and consists of labeled triads which have nasal and/or glide environments. Three tokens of these are employed in the Data Base II sentence set.

2.2.2.3 Derivation of Vocabulary

The vocabulary derivation procedure for Data Base II was identical to that of Data Base I. Triad charts were constructed using the phonetic event and context specifications, and words were formed from the triads.

In addition to the consideration specified for Data Base I the three following considerations were incorporated in vocabulary design.

- The /m/ and /n/ nasals should be at leading position in words for stress.
- Words selected are to be relatively common and easily readable by poorly educated individuals.
- The vocabulary should incorporate forensicly applicable words.

2.2.2.4

Sentence design for this data base followed the same rationale and procedure that was employed with Data Base I. The resultant set of 11 sentences are given in Table 2.9. Again the first sentence is a dummy, used for speaker and recording conditioning.

A tabulation of phonetic frequencies designed into the sentence set is given in Table 2.10.

TABLE 2.9

Data Base 2 Sentence Set

1. The State of California does not have the growth rate that it did in the 60's.
2. When Beverly cooks her good vegetable soup, she puts in a teaspoon of butter and a pinch of pepper.
3. Bob Dudley shipped the circuits to Boston on Thursday.
4. The people on the Long Beach dock signalled the first ship that passed through the fog bank.
5. The cops suspected that the judge's sister was peddling narcotics.
6. Dad is using a shovel to move the excess dirt from the curb.
7. A fifteen-mile section of the north causeway is in poor condition.
8. The shop boss was more than satisfied with the fabricated baffle.
9. The students climbed the path above the cabin and were pooped.
10. Todd should be putting food in his dog's dish.
11. Paupers and those near poverty substitute hamburger for better cuts of beef.

TABLE 2.11

Phonetic and Context Statistics for Data Base II Sentence Set

Event	Hub Context Position	No. Tokens for Context	Total No. Tokens for Event
/i/	Mixed	4	4
/I/	High		7
	Middle	2	
	Low	1	
	Mixed	2	
/ε/	High or Middle	2	6
	Low	2	
	Mixed	2	
/a/	High or Middle	2	6
	Low	2	
	Mixed	2	
/ɑ/	High or Middle	3	7
	Low	2	
	Mixed	2	
/ɔ/	High or Middle	2	5
	Low	1	
	Mixed	2	
/U/	High	1	4
	Middle	1	
	Low	0	
	Mixed	2	
/u/	High or Middle	1	4
	Low	1	
	Mixed	2	
/ʌ/	High or Middle	2	6
	Low	2	
	Mixed	2	
/ɝ/	Mixed	3	3
/m/	Mixed	3	3
/n/	Mixed	3	3
/ŋ/	Mixed	3	3

2.2.3 Recording Setup

The recording setup including sound booth, supervisor's control center, and recorders was identical to that used in Data Base II and is described in Section 2.1.3.2.

2.2.4 Recording Procedure

2.2.4.1 Speaker Base Organization

The scope of Data Base II includes three dialect categories, GAE, Black Urban, and Chicano. These categories are broadly defined. A discussion of the linguistic characteristics of the dialect groups will be given in Section 3.2.3, under sound discrimination.

The original size goals of the data base were

175 Male GAE
25 Male Black Urban, and
25 Male Chicano.

Because of factors to be discussed, the final speaker dialect population resulted in

193 Male GAE
18 Male Black Urban, and
21 Male Chicano speakers.

Due to the large size of the speaker population, speaker selection and initial contract was carried out through the Personnel Development Department at Rockwell. Speaker sets for Data Base I and Data Base II were disjoint. A set of criteria was established on which speaker candidate selection was based. These criteria include:

- Male GAE - graduation from high school in Southern California and no obvious regional dialect,
- Male Black Urban - obvious dialect, and
- Male Chicano - Spanish surname and obvious dialect.

Candidates were selected from various pools within the company via computer tab runs. The group supervisors were contacted to interview candidates, provide a first order dialect verification, and secure the candidates permission to record. Responses were received from the supervisors indicating eligible and available candidates.

Initially, over 200 GAE, 35 Black Urban and 35 Chicano dialect candidates were selected. Response from the GAE group was very good, but the other dialect groups were reluctant to record probably due to less familiarity with the language, lower reading skills, and to some degree, a fear of self-incrimination (though much effort was taken to avoid this impression).

Each of the selected candidates were then contacted directly, or via their supervisor, and scheduled for two appointments. Appointments were scheduled to be separated by one to two weeks. Each speaker was then sent a letter indicating the appointment times and a map directing him where to go.

2.2.4.2 Speaker Recording Procedure

The speaker recording procedure for Data Base II is very similar to that employed for Data Base I. Speaker appointments were scheduled every 15 minutes. Upon arrival at the recording location, speakers were ushered into the sound booth and briefed via prerecorded message in the same manner as in the previous data base recording. The text of the briefing message is given in Figure 2.6.

2.2.4.3 Analysis of Recorded Material

The recording process took approximately seven weeks to complete. The overall quality of the data was slightly lower than that of Data Base I, primarily due to the lower average educational level of the speakers. The acoustic quality and naturalness of the recordings is very satisfactory, but mispronunciation errors appear at a higher rate.

Figure 2.6

BRIEFING TEXT FOR DATA BASE II

Thank you for participating in the speech recording project. The purpose of this project is to record sentences from a large number of speakers and to analyze these spoken sentences in a computer. Various types of analyses will take place, and the end goal will be to develop a system for comparing two voices to determine if they come from the same person.

You will be asked to state your speaker number and then to speak 11 sentences. The sentences you are to speak are designed to provide a special set of sound combinations and don't necessarily make sense. I will start with sentence number one on the list and will speak it twice. I will then pause for a brief period, during which you are to speak that same sentence one time. We will then repeat this process for sentences number 2 and number 3, and so forth, until all 11 sentences on the list are spoken.

Please speak in a clear voice and try to say each sentence smoothly, as you might in a conversation. If you make a mistake or mispronounce a word, pause and start that sentence from the beginning all over again. At this time, please pick up the telephone and hold it normally with the telephone mouthpiece in front of your mouth and not under your chin.

The two microphones, as well as the telephone, will be used to record your voice. Position yourself comfortably in front of the two microphones and avoid speaking directly into either of these two microphones.

Before we go any further, if you have any questions, ask them at this time.

(Pause 10 seconds)

We will now ask you to say your speaker number; please state your speaker number following the tone.

(Pause 7 seconds)

We will now speak the sentences. Remember to wait for me to say each sentence twice. After I say the sentence twice, wait for the tone, then say the sentence once.

The dialect accuracy for the GAE speakers is satisfactory, with only a few tokens of deviations. For the Black Urban and Chicano, however, the accuracy is not as great. It is estimated that approximately one-third of these dialect groups show significant trend away from the classifications. These deviations are highly correlated with level of education and job position.

2.3 DATA BASE III ACQUISITION

2.3.1 Purpose and Procedure

Data Base III consists of 51 GAE speakers recorded over the telephone system, calling into the Speech Laboratory from their office or laboratory locations. The 51 speakers were selected from the 193 GAE male speakers of Data Base II. This data base has as its purpose providing a set of near real-world data set for testing the prototype system.

2.3.2 Sentence Material

The sentence set used in this data base is the same as in Data Base II, Table 2.9.

2.3.3 Recording Setup

The recording setup consisted of using the same Ampex AG440 recording system described in Section 2.1.3.2.2 and a Bell System 1001 Data Coupler interfacing the telephone lines to the recorder. Levels were controlled using an amplifier and decade attenuator between the data coupler and the recorder.

Recording was carried out using $7\frac{1}{2}$ ips along with Dolby companding. Only one half-track channel was employed, since no source of wide bandwidth speech was available in this configuration. Ampex type 406 tape was again used.

2.3.4 Recording Procedure

A total of 51 speakers were recorded for this data base. The speakers had spoken the same sentences on two previous occasions in the sound booth and were familiar with the sentence material. For this reason and to avoid some technical problems, no prerecorded briefing message was played to the speakers; rather, the selected speakers read the sentences from a typed card.

Each speaker was contacted in his office or laboratory location and asked to participate. Upon agreeing, his telephone instrument was used to call the Speech Laboratory. As soon as the telephone was answered in the Speech Laboratory, the data coupler was switched in and recording commenced. The technician accompanying the selected speaker announced the speaker's number and turned the telephone over to the speaker. The speaker had been instructed to speak normally and to pause about 5 seconds between each sentence. Recording was thus carried out for all eleven sentences.

2.3.5 Analysis of Recorded Material

The overall quality of Data Base III was noticeably inferior to that of either of the two other data bases. Some difficulty was encountered in obtaining natural utterances; rather, more artificial stress, intonation, and pronunciation patterns were developed while reading the sentence list.

The variety of background noises and acoustic effects is diverse, and this aspect of the data base makes it very useful for studying these effects.

2.4 USE AND PARTITIONING OF DATA BASE

2.4.1 Functional Organization

Data Base I has been used for 1) preliminary examination of the data, 2) intuition training, and 3) determination of the distance and similarity structures to be pursued on Data Base II. The reason for this use is primarily pragmatic: the data was available when those tasks were in progress.

Data Base II has been used for optimization (training) and evaluation of the SASIS. It's partitioning is discussed below.

Data Base III has been used to examine the degree to which the results of the evaluation on the General American English (GAE) found in Data Base II are generalizable to other dialects.

In all cases the analysis is based on the assumption that "the patterns used to test the machines are a reasonable sampling from the real life world of patterns and are not biased toward either well-formed or poorly-formed (noisy) patterns" (Highleyman, 1962).

2.4.2 Partitioning of Data Base II into Design and Test Phases

The basic question to be considered is:

> If the total sample size is fixed, what is the optimum partitioning of this sample between the design and test phases?

The following formulation of this question was originally developed by Highleyman (1962) and is known as the H-method.

We desire to study a particular method. The optimum machine based on this method will have an error rate, e. Any actual machine based on the method will have an error rate, $e \geq e_o$. Suppose we train the actual machine using part of the sample, test with rest of the sample, and generate an estimate of e, $\hat{e}$. Clearly, $\hat{e}$ is a biased estimate of e_o and we may remove this bias to generate $\hat{e}_o$, an unbiased estimate of e_o.

The leads to the following reasonably heuristic definition:

> an optimum partitioning of the total sample is that partitioning which minimizes the variance of $\hat{e}_o$.

If the number of samples available is large enough to justify a truncated Taylor series expansion of e about its minimum e_o, then an analytical solution is possible, with certain mild restrictions.

Let $e = e(\delta_1, \delta_2, \ldots, \delta_c)$

where there are c parameters of the machine with optimum values δ_{oi}, and estimated values δ_i.

Then

$$e \approx e_o + \tfrac{1}{2} \sum_{i=1}^{c} \sum_{j=1}^{c} \left.\frac{\partial^2 e}{\partial\delta_i \partial\delta_j}\right|_{\delta_o} (\delta_i - \delta_{oi})(\delta_j - \delta_{oj})$$

and

$$E(e) = e_o + \tfrac{1}{2} \sum_{i=1}^{c} \sum_{j=1}^{c} \left.\frac{\partial^2 e}{\partial\delta_i \partial\delta_j}\right|_{\delta_o} E[(\delta_i - \delta_{oi})(\delta_j - \delta_{oj})]$$

if $E(\delta_i) = \delta_{oi}$ (the parameter estimates are unbiased)

then

$$E(e) = e_o + \tfrac{1}{2} \sum_{i=1}^{c} \sum_{j=1}^{c} a_{ij}\sigma_{ij}$$

where

$$a_{ij} = a_{ji} = \left.\frac{\partial^2 e}{\partial\delta_i \partial\delta_j}\right|_{\delta_o}$$

σ_{ij} = covar. of the estimates for δ_{oi}, δ_{oj}

If (a) m samples are used to estimate each parameter

(b) these estimates are independent (this can be assured by using different sample for each or by assuring a structure such that the estimates are independent)

then

$$\sigma_{ij} = 0, \ i \neq j \text{ and } \sigma_i^2 \sim \frac{1}{m}$$

hence, $E(e) = e_o + \frac{b}{m}$, where b = a constant determined by the relations above.

Let p be the smallest number of m sets that assures this form, and let

$$\underbrace{t}_{\text{total set size}} = \underbrace{n}_{\text{test size}} + \underbrace{pm}_{\text{training size}}$$

It can be shown that the optimum n, n_o, satisfies $\frac{e_o t}{pb} = \frac{2\frac{n_o}{t} - 1}{(1-\frac{n_o}{t})^2}$

which is shown graphed below.

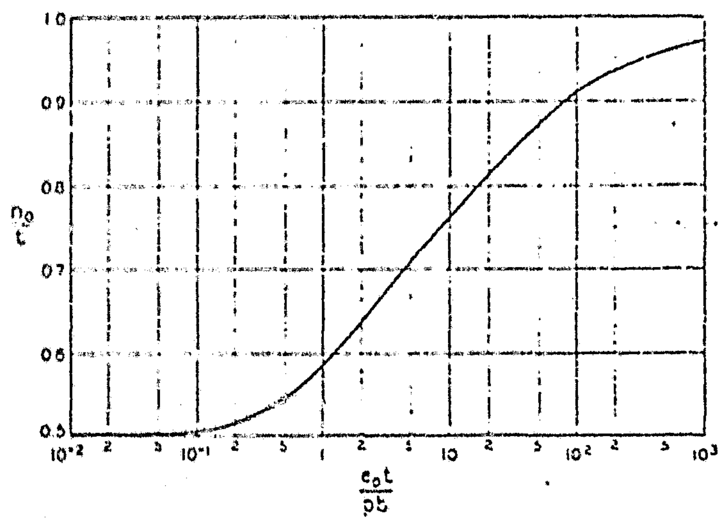


Figure 2-7. Optimum Partitioning

Other formulations involve repeating the H method with different subsets n_o (the I method) or leaving out each sample, in turn, in the design process and using the collection of single sample evaluations so obtained to evaluate the system (the U method). (Kanal, Chandraskaran, 1968, Hughes 1969).

Data Base II has been partitioned into 1) 75 random speakers for training a design, 2) the remaining 118 speakers for evaluation or testing giving an n_o/t for the H-method of .61. This partitioning was selected for

the following reasons:

1) The data manipulation routines structured for the 25 speakers of Data Base I were easily modified to handle multiples of 25 speakers.

2) The partitioning qualitatively meets the criteria of the H-method.

3.0 LABELING AND SEGMENTING PHONETIC DATA

A computer interactive audiographics procedure has been developed to assist an operator in digitizing, segmenting, and labeling the acquired audio data base. The end result of the interactive labeling process is a digital data base of approximately 35000 manually labeled and pitch-synchronously segmented phonetic events from Data Base I and II.

The procedure described for the analytical phase of SASIS development differs somewhat in detail from that of prototype development. The analytical phase was required to process a large amount of data in a constrained format, and the procedure developed was optimized for bulk data processing. The prototype, on the other hand, has as its function the processing of smaller amounts of data in open formats and maintaining close control on various aspects of the data processing.

The interactive audiographics procedure will be described in two phases, one treating the implementation, software, and data management aspects, and the other discussing the procedural and operator dependent aspects.

3.1 INTERACTIVE AUDIOGRAPHICS

This section is concerned with describing the implementation aspects of the interactive phonetic event labeling task. This task was carried out by developing procedures for providing

- sentence digitizing and editing,
- display-oriented digital spectral analysis,
- phonetic event reference inventory, and
- phonetic event segmenting and labeling.

3.1.1 Sentence Digitizing and Editing

Digitizing and editing the recorded audio sentences is the process in which the data base sentences are converted to digital form, and all extraneous audio and silences are edited out. The product of this procedure is a binary digital magnetic tape with appropriate label and sample records for each sentence. The formant of the digitized sentence tape is given in Table 3.1.

3.1.1.1 Computer Configuration

The digitizing and editing procedure involves the hardware configuration shown in Figure 3.1. This configuration involves a digitizing section, a playback and editing section, and a recording section.

The digitizing section receives prerecorded audio from the Ampex audio recorder. The telephone channel audio is employed in all SASIS processing and is passed through a lowpass filter and a C-2 telephone channel simulator. The lowpass filter characteristics are given in Table 3.2 and those of the channel simulator in Appendix 3A. The audio signal level is adjusted via a variable gain amplifier made up of a 20 dB amplifier and a decade attenuator. Signal levels are monitored on an oscilloscope in order that the analog-to-digital (ADC) converter range (±5.0 volts) is not exceeded. One channel of stereo headphones is also driven by this signal to permit the operator to monitor.

The audio signal is sampled through multiplexer (MUX) channel 0 and the ADC. The software controlling these functions has the capability to sample two channels, MUX channel 0 and 1, simultaneously, but this feature was not employed in the current SASIS program. The SEL 8600 CPU

TABLE 3.1

DIGITAL TAPE FORMAT FOR DIGITIZED SENTENCE TAPE

Tape Header 80 character alphanumeric header describing tape

Sentence 1

a) Label Record: 88 byte record with following information

byte no's	description	symbol type
1 - 6	date	alphanumeric
7 - 9	speaker no.	"
10 - 11	grammatical source	"
12 - 14	sentence no.	"
15	utterance (session no.)	"
16	dialect (G, B, or C)	"
17 - 72	spares	N/A
73 - 76	sent. sequence no.	Binary
77 - 80	no. audio channels	"
81 - 84	no. time samples	"
85 - 88	no. data records	

b) Data Records: digital samples are stored in 16-bit half-words, organized into binary records 2048 samples long. The number of records is variable to span the length of the digitized sentence.

Sentence 2-N

The remainder of the sentences are recorded identical to sentence 1.

END OF FILE

TABLE 3.2

LOWPASS FILTER CHARACTERISTICS

Filter type:	12-pole elliptical lowpass
Manufacturer:	TT Electronics, Los Angeles
Ripple:	± 0.25 dB in passband
Cutoff:	- 45 dB at 3.4 kHz ≈ 3 dB at 3.2 kHz
Cutoff slope:	> 6000 dB/octave (3.2 to 3.4 kHz)
Stop band:	down 45 dB

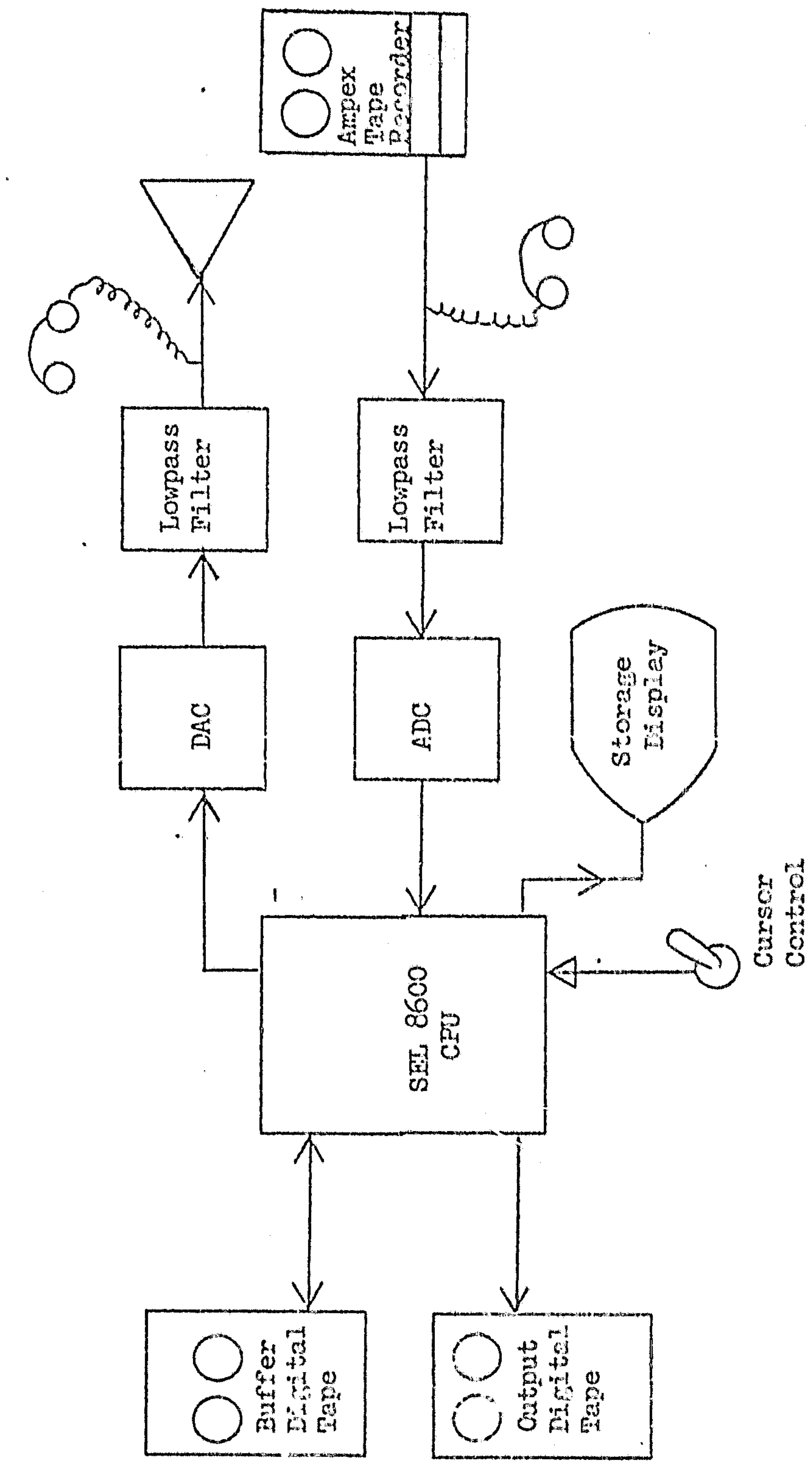


Figure 3.1 Hardware configuration used for sentence digitizing and editing.

directs the ADC to sample, and digital samples are stored on the buffer digital tape.

The playback and editing section receives data from the buffer tape and provides output to the operator through the Tektronix 611 storage CRT and audio through a digital-to-analog (DAC) converter and the other stereo channel of the operator's headset. The operator issues editing and labeling instructions to the computer through the cursor control, a two-speed variable voltage source connected to MUX channel 29, and a keyboard.

The recording section consists of the buffer and output magnetic tape units and the CIU. The selected data are transferred from the buffer tape to the output tape along with appropriate label information by the operator upon command.

3.1.1.2 Software Control

The digitizing and editing hardware is driven by a software procedure which permits the operator to perform a series of tasks with various options. The software is self-contained and performs all functions of sampling, playback, CRT control, cursor sensing, keyboard input, and tape I/O. A summary of program operation is given here.

Upon activating the program FASTY all communication is carried out via the interactive graphics console (CRT, DAC's, keyboard, and cursor control). The program requests initial input parameters consisting of

- tape header (80 character alphanumeric),
- number of audio channels (set to one),
- sample period (147 microseconds = 6.8 kHz), and
- number of samples (60,000 corresponding to 8.8 seconds).

Here, as in all subsequent data entry points, an error correction option is available to the operator for mistakes in entry parameters.

Next, the software requests the default parameters of date, speaker number, dialect, grammatical source, and utterance (Session 1 or 2). These fixed parameters are placed in the digitized sentence label until they are modified.

The program is then ready for a sample command. This point in the software is the return position with the command, the ADC begins to sample until 60000 samples are acquired at a 6.8 kHz rate. The data is double buffered in core and then output to the buffer tape. For intermediate storage the sample command is issued prior to the sentence occurrence, and sampling continues 8.8 seconds, so as to include the sentence utterance.

Next an amplitude contour is displayed on the CRT showing the broad band energy in the digitized record. This contour is computed every 128 samples (18.8 msec) according to the expression

$$A(i) = 10 \log_{10} \frac{1}{128} \sum_{k=i}^{i+127} s(k)^2 \qquad i = 1, 124, 257, \ldots .$$

The cursor then appears superimposed on the amplitude contour. The operator specifies, via keyboard entry, whether the cursor is to specify the start or end boundary of the segment to be isolated.

Once satisfied with the cursor-defined boundaries, the operator issues the sentence number. The selected segment of audio on the buffer tape is transferred along with lable information to the output tape. Typically, 200 sentences are stored on a 2400' output tape before capacity is reached.

3.1.2 Display Digital Spectrogram

The next operator processing step, following sentence digitizing and editing, is interactive phonetic event labeling. This labeling requires that a digital spectrogram be displayed on the CRT from which phonetic events are selected. An automatic processing step is inserted between the two interactive programs to provide the spectral inputs to the labeling program from the digitized sentences. The spectral data from this processing step are used only for the display and are not employed in the feature extraction or any subsequent SASIS processing.

3.1.2.1 Amplitude Normalization

In the analysis processing amplitude normalization is carried out on the sentence base. The time-domain sentence array is normalized such that the average magnitude of the stressed portion of the sentence has a reference value of 6000. This process is carried out using a combination of peak and mean-value amplitude normalization and is defined as follows:

MAX = Maximum magnitude of signal over sentence

A = Average value of samples whose value exceeds MAX/4, i.e., non-silence speech

K = Scale factor = 6000/A

$S'_t = KS_t \quad t = 1, 2, \ldots, \#$ samples

3.1.2.2 Spectral Analysis

The digital spectral analysis is carried out using a Hanning window on a 128-point (18.8 msec) discrete finite Fourier transform (via FFT). A new transform is started every 64 time samples (9.4 msec), providing a 50 percent overlap between successive epochs.

The Hanning window function for the FFT transform is computed as follows:

$$W(i) = 0.5\left(1.0 - \cos 2\pi \frac{(i - \frac{1}{2})}{X}\right), \text{ where}$$

$i = 1, \ldots, x$

X = length of epoch (128)

Each spectral sample from the FFT is squared, producing a power spectral array, P_k, and is channelized. Each channel is then logged, pre-emphasized, and expressed in $\frac{1}{4}$ dB units.

The channelized spectral measurement is computed as

$$C_i = 40 \log_{10} \sum_{k=START_i}^{END_i} P_K - 80 + 4 \text{ preemphasis}$$

The start and end boundaries along with pre-emphasis coefficients are given in Table 3.3.

An amplitude contour is computed for each epoch and is stored in channel 32, in $\frac{1}{4}$ dB units of the output array, as

$$A = 40 \cdot \log_{10}\left(\frac{1}{X}\sum_{i=1}^{X} S_t^2\right) - 140$$

Table 3.3

BOUNDARY SPECIFICATIONS FOR SASIS DISPLAY SPECTROGRAM

Channel	Channel Boundaries Start	Channel Boundaries End	Frequencies (3dB) Start	Frequencies (3dB) End	Preemphasis
1	6	10	300Hz	500Hz	8 dB
2	8	12	400	600	3
3	10	14	500	700	3
4	12	16	600	800	6
5	14	18	700	900	7
6	16	20	800	1000	8
7	18	22	900	1100	10
8	20	24	1000	1200	11
9	22	26	1100	1300	12
10	24	28	1200	1400	13
11	26	30	1300	1500	14
12	28	32	1400	1600	15
13	30	34	1500	1700	16
14	32	36	1600	1800	17
15	34	38	1700	1900	18
16	36	40	1800	2000	19
17	38	42	1900	2100	20
18	40	44	2000	2200	20
19	42	46	2100	2300	21
20	44	48	2200	2400	21
21	46	50	2300	2500	22
22	48	52	2400	2600	22
23	50	54	2500	2700	23
24	52	56	2600	2800	24
25	54	58	2700	2900	27
26	56	60	2800	3000	30
27	58	62	2900	3100	31
28	60	64	3000	3200	33

3.1.3 Interactive Phonetic Event Labeling Procedure

The purpose of the phonetic labeling process is to extract from the digitized sentences a set of three-pitch-period waveforms representing tokens of phonetic events spoken by different speakers. This process is carried out in two phases, the macro-phase and the micro-phase, using the interactive graphics capability of the SEL 8600 computer system. The macro-phase has as its function the labeling of phonetic events in the sentence based primarily on a spectrographic display. The microphase displays 75 msec surrounding each labeled event in the time domain for manual pitch-syncronous three-pitch-period segmentation of that phonetic event.

3.1.3.1 Computer Configuration

The hardware configuration to carry out interactive phonetic event labeling is shown in Figure 3.3. All input data is received from the spectrally processed input data tape generated with the process described in the previous section 3.1.2. This tape contains both the time-domain signal and its spectrographic representation along with appropriate speaker, sentence number and other label data. The output data is passed to the disk for intermediate storage until being transferred onto an output tape in a separate program. This configuration permits assigning only one tape unit to the program thus leaving the two remaining units available for concurrent programs under the 8600 real time monitor.

The interactive graphics terminal consisting of the CRT, keyboard, and cursor control along with a DAC audio playback enables the operator to carry out labeling. All communication with the system is carried out through this interactive graphics terminal.

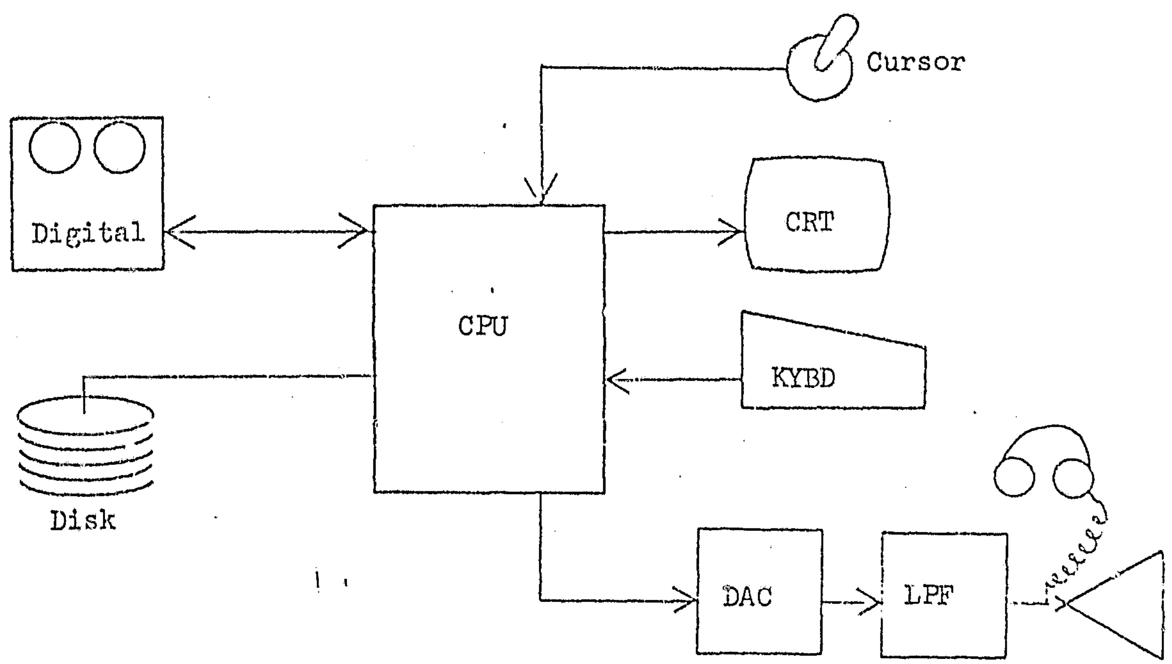


Figure 3.3 Hardware Configuration for Interactive Phonetic Labeling

3.1.3.2 Macrophase

Following initial program start-up in which the input tape is verified, the first phase of labeling is the microphase. This phase on the CRT enables the operator to identify positions on the sentence spectrogram as being the center of a desired phonetic event and to queue this position information for later segmentation in the microphase.

Figure 3.4 shows the CRT screen as it appears during the macrophase. From top to bottom, the screen indicates the options available to the operator, and is followed below by a record of the individual instructions issued to the system during this frame. Next down is a record of the triad BX EH VX, [bɛv], from the displayed segment "WHEN BEVERLY COO...", which has been labeled. Sentence label data from the input tape are next displayed. Next down is the amplitude contour, and below it is the 122 spectral-time sample (STS), approximately 1200 msec, spectrogram for this frame. Superimposed on the spectrogram is the cursor along with the entered triad label and a correlation ranking of the top 5 most likely events according to correlation with reference phonetic events. The derivation of these reference events will be discussed in section 3.1.4.

The operator has many options in the macrophase and include

- displaying the next frame of the sentence on the left or right,
- advancing to the next sentence or same specific sentence on the input tape,
- playing back the audio of the current frame on the 300-msec or 00 msec segment surrounding the cursor,
- displaying the top five correlations,
- accepting the cursor position and entering a triad label, and
- exiting the macrophase and entering the microphase.

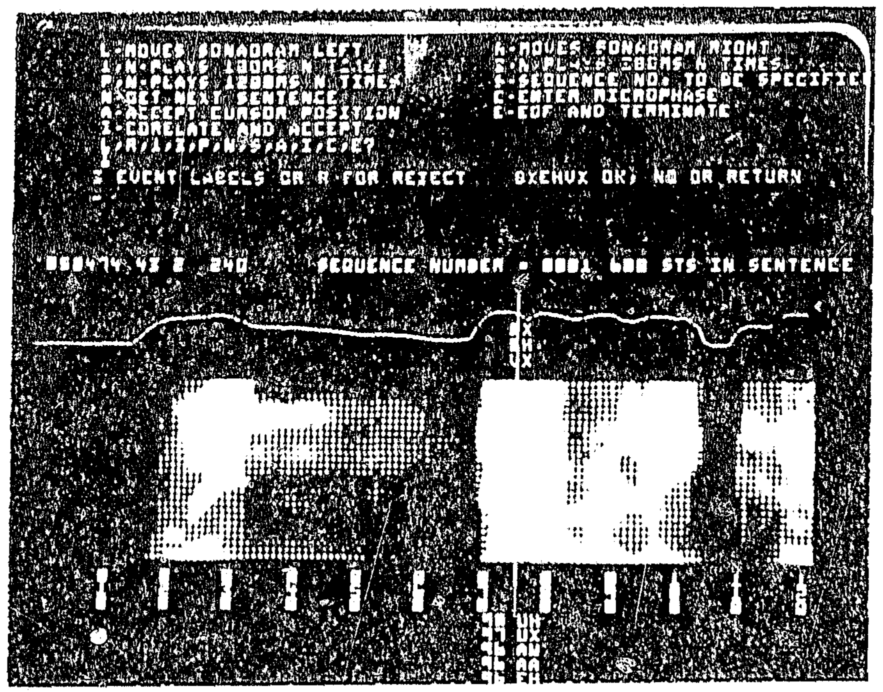


Figure 3.4 CRT Display during Macrophase

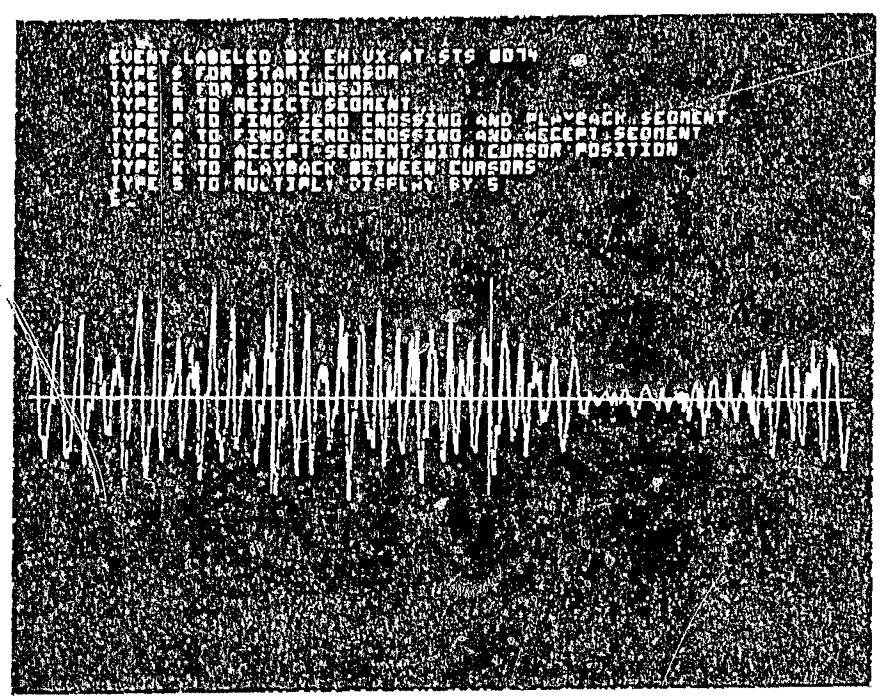


Figure 3.5 CRT Display during Microphase

In labeling, the operator makes use of four information sources to determine the position and identity of a phonetic event. These are the spectrograms, audio playback, correlations, and the amplitude contour. He makes his decision and enters the phonetic event label along with its two adjacent neighboring events in the form of a triad. This triad label information, along with the sentence label information from the input tape, is carried through to the output file, maintaining traceability through the entire SASIS process.

3.1.3.3 Microphase

The microphase operates on the queue of labeled phonetic events from the macrophase and provides the operator with the facility to segment the time-domain audio waveform.

Figure 3.5 shows the microphase corresponding to BXEHVX labeled in Figure 3.4. The operator specifies if the cursor is for the start or the end of the segment from the 75-msec time display and isolates three-pitch-periods. He can playback the segment concatenated 10 times. This gives approximately 300 msec of sustained sound to verify the label after which he either accepts or rejects the token. If accepted, the token is formatted along with label data and passed to the output file. Automatic zero-crossing detection is provided, such that the cursor positioning is less sensitive.

When the queue of labeled events has been processed by microphase, the system returns control to the macrophase, and labeling continues.

3.1.4 Correlation Reference Inventory

One of the labeling aids at the disposal of the operator during the macrophase is display of the top five correlations between the current STS spectral vector and an inventory of reference spectral vectors. The spectral vectors being correlated are the 28-channel display vectors which make up the macrophase spectrogram. The correlation carried out is defined as:

$$C_i = 100 \left[\frac{\overline{S} \cdot \overline{R}_i}{\overline{S} \quad \overline{R}_i} \right]^2 ,$$

where $\overline{S}$ is the spectral vector being compared and the $\overline{R}_i$ are the reference spectral vectors in the correlation inventory.

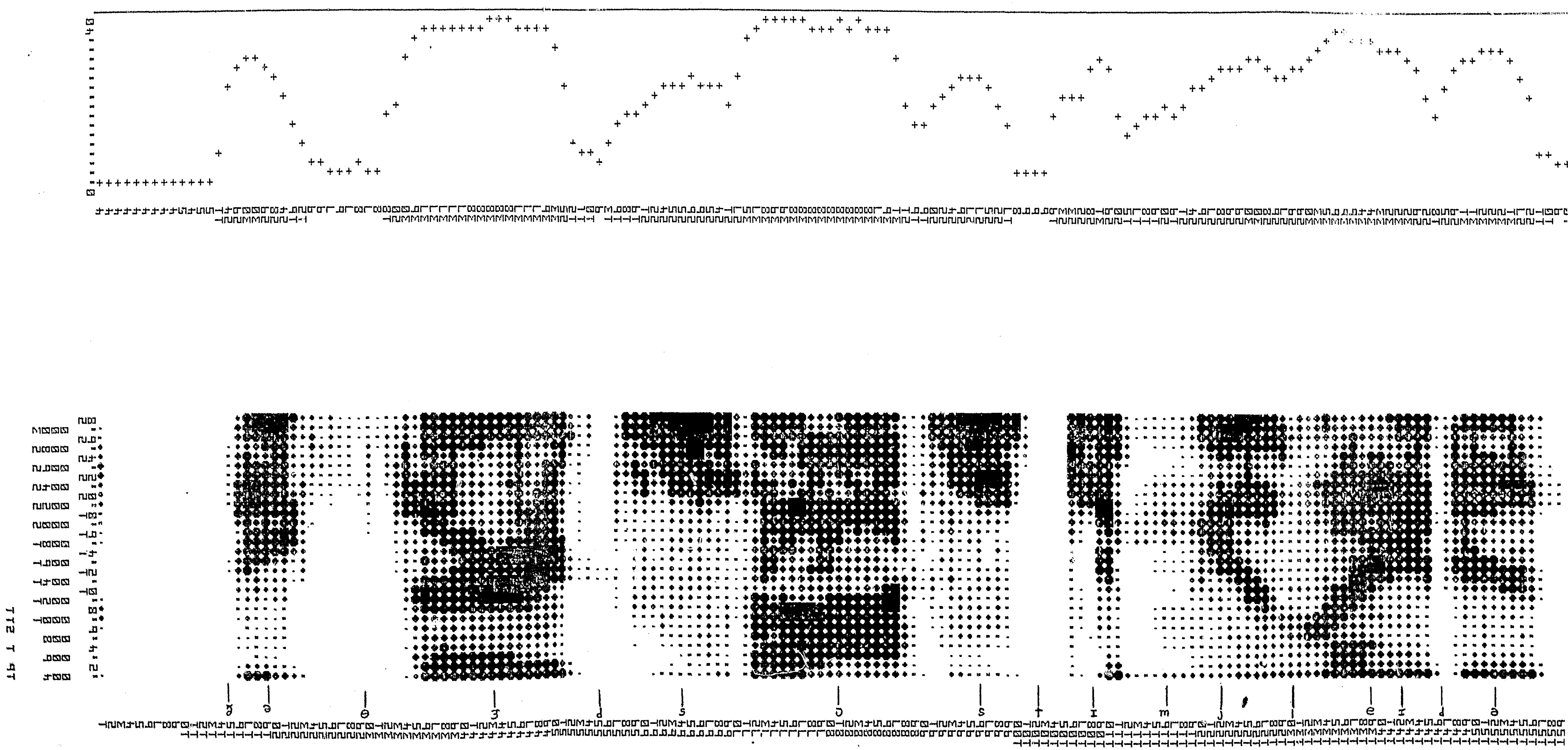
The correlation inventory was assembled prior to the development of the interactive labeling software. The procedure employed made use of a digital spectrogram in hard-copy form and a clustering algorithm. A set of token STS's for each phonetic event was manually labeled on the spectrograms and position information was passed on to the clustering algorithm for final inventory generation.

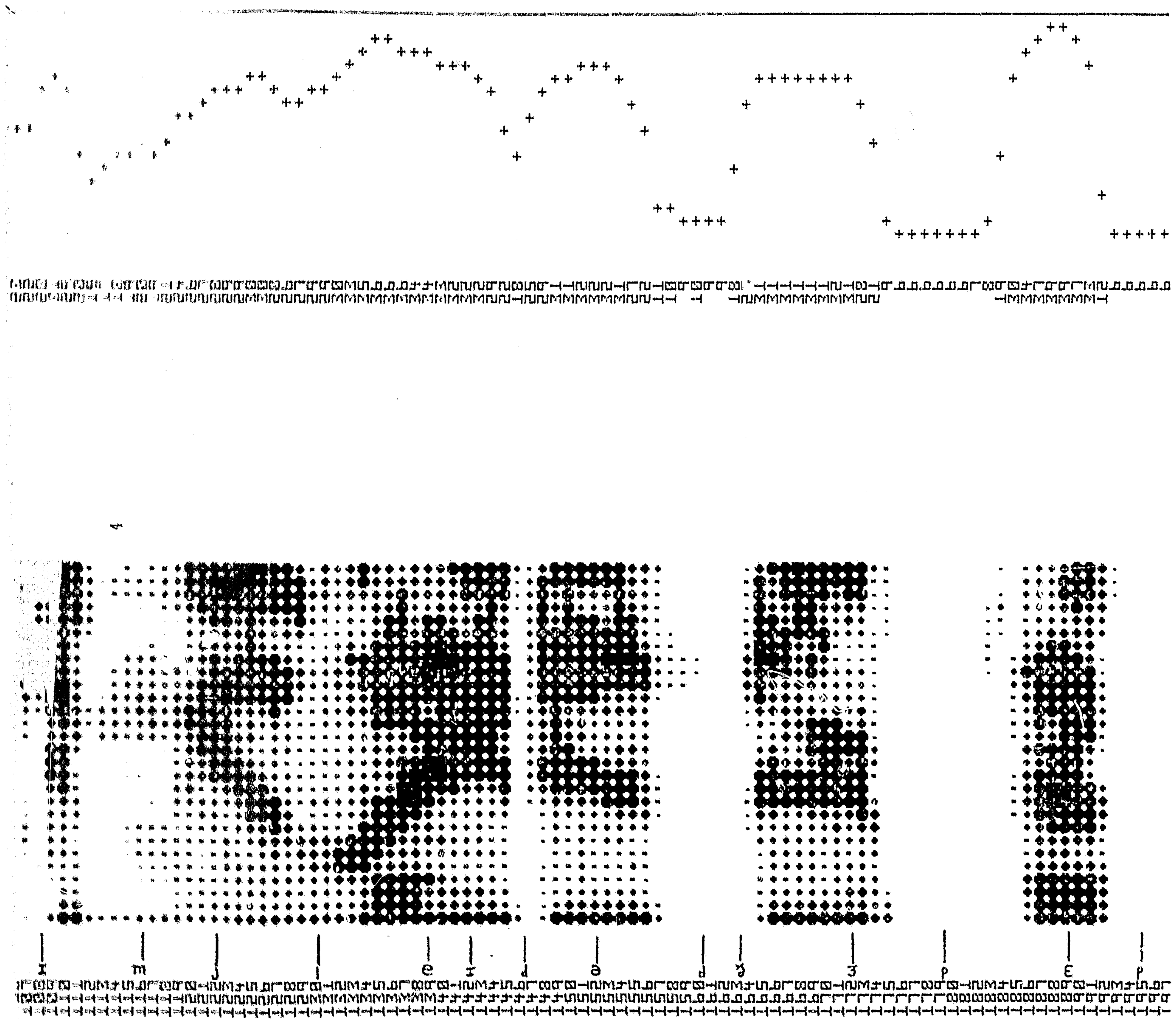
3.1.4.1 Digital Sound Spectrogram

For purposes of analysis and labeling of the referent correlation inventory, digital sound spectrograms were produced in hard-copy form using the graphics capabilities of the Gould 4800 electrostatic printer. An example of the sonogram for one utterance is provided in Figure 3.6.

The sonographic representation employs seven gray levels (including non-print). Density characters are encoded into an 8x8 grid in such a manner as to produce an image possessing half-tone characteristics. Spectral sweeps are generated by a discrete finite Fourier transforms procedure (Section 3.1.2) at 9.4 ms intervals; however, the analysis interval is overlapped to a duration of 18.8 ms. The number of spectral positions used is 28, covering a frequency range of 300 to 3200 Hz (pre-emphasized to a maximum of 33 dB at high frequencies). A time aligned amplitude contour is directly calculated as a function of the energy at the samples of the time sequence and is displayed on the sonogram in 0.25 dB units.

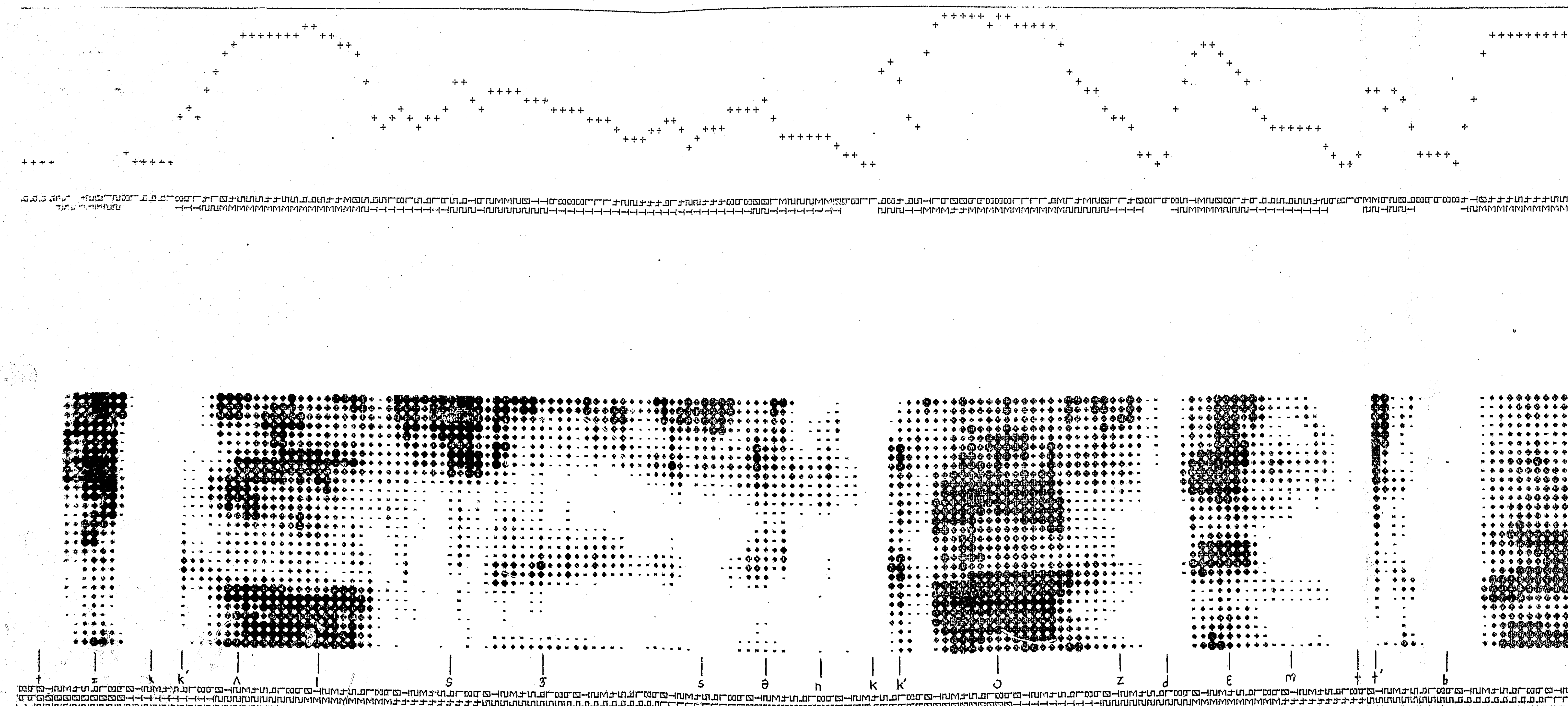
Figure 3.6 Digital sound spectrogram of the sentence "The third sauce stimulated their peptic ulcers and caused them to burp." A manually derived phonetic transcription of the sentence is also shown.

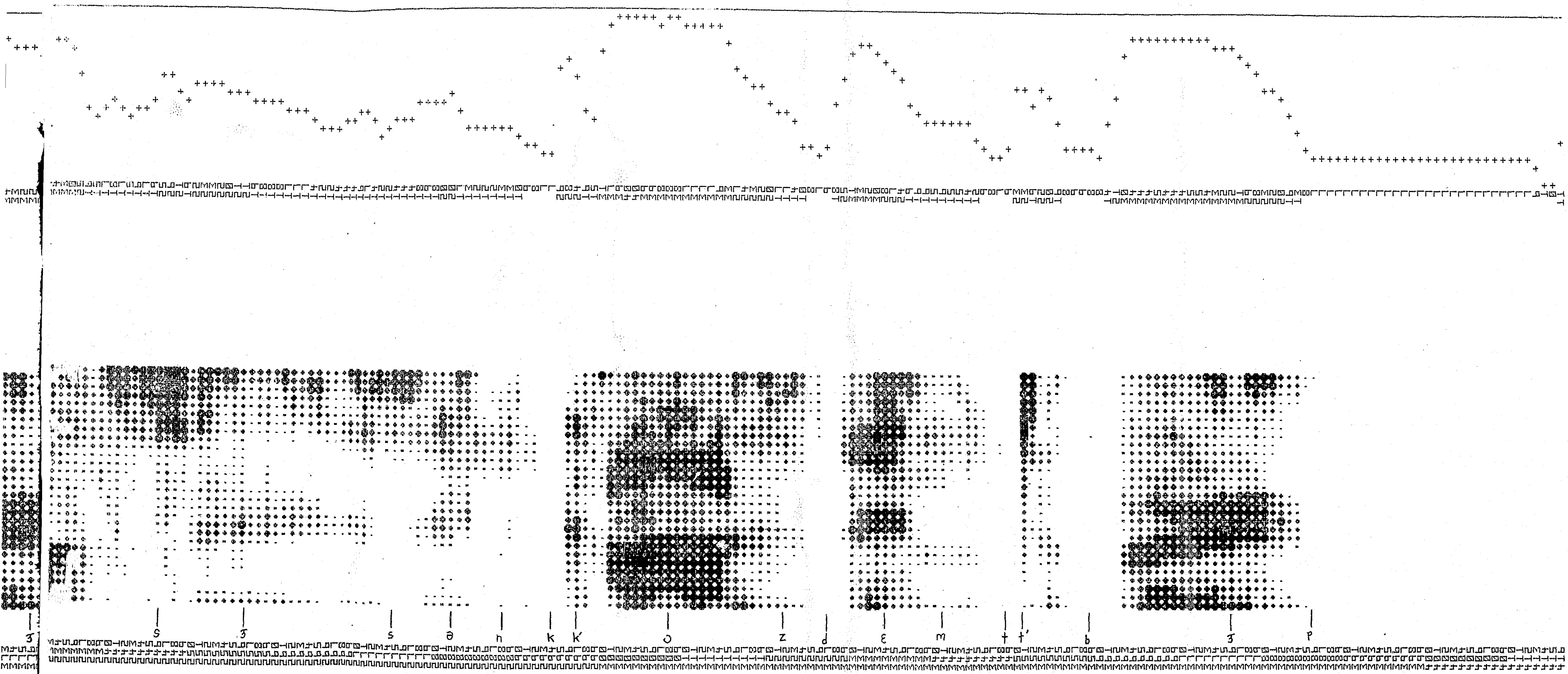




CONTINUED

1 OF 5




ʒ s ʒ s ə n k k' o z d ɛ m t t' b ʒ p

3.1.4.2 Clustering Procedure

Approximately 1000 tokens for the vowel events, /i/, /I/, /ε/, /a/, /ɑ/, /ɔ/, /ʊ/, /u/, /ɝ/, /ʌ/, and /ə/ were labeled from four speakers on digital spectrograms. The nasals, /m/, /n/, and /ŋ/ were not entered into the inventory since they are easy to identify aurally.

The tokens for each phonetic event were clustered into five groups and the average of each group was entered into the correlation inventory. The algorithm for grouping a large number of tokens into five clusters is illustrated in Figure 3.7.

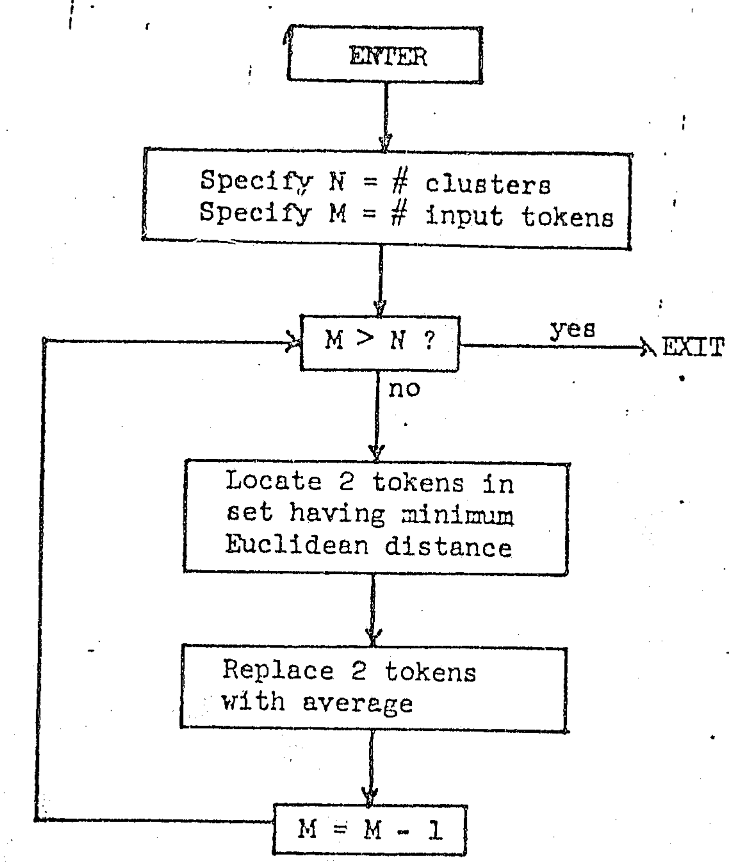


Figure 3.7

Flow Chart of Clustering Process

3.2 DATA BASE LABELING

This section deals with the procedural aspect of acquiring approximately 35000 labeled phonetic events using the procedures described in Section 3.1. This section will address digitizing and editing, labeling and segmenting, and error correcting procedures. The last subsection gives a breakdown of the resultant data collected on a per speaker, per session, per event and per triad pair basis.

3.2.1 Digitizing and Editing the Data Bases

A total of 5640 sentences were digitized and edited from Data Bases I and II. The majority of this processing was carried out by a technician, since neither the knowledge of acoustic phonetics nor the speech process is required. The procedure used by the operator was described in Section 3.1.1. Since the software occupied most of core in the SEL 8600 computer system, most sentence digitizing was carried out in non-prime time. The throughput rate using the interactive procedure was 20-30 sentences per hour.

The audio tapes, containing 40 to 50 sentences per 1200-foot tape, were digitized at the rate of 200 digitized sentences per 2400-foot tape. In total, 29 digital tapes were used to store the sentences for the two data bases. Throughout the digitizing and editing process a log was maintained of the speakers, sentences and sequence numbers on each digital tape.

3.2.2 Review of Acoustic Phonetics

3.2.2.1 Manner and Place of Articulation

Each of the sounds of English can be assigned to one of several categories in accordance with its manner of articulation (Table 3.4). These subsets are: 1) vowels - vocal cord excitation with little obstruction of the oral cavity; 2) fricatives - almost total closure in the oral cavity; 3) stops - total closure of the oral cavity with sudden release of pressure; 4) nasals - closure of oral cavity and opening of a path to the nasal cavity with vocal

TABLE 3.4

The set of sounds possessing phonemic significance in IPA symbology. Those events which would be found only in a narrow transcription are not included. An example of the pronunciation of each phoneme is provided.

STOPS

p pot
b be
t to
d do
k key
g go

FRICATIVES

low energy

f for
v very
θ thin
ð then

high energy

s see
z zoo
ʃ she
ʒ azure

ASPIRATE

h he

AFFRICATES

tʃ church
dʒ judge

GLIDES

w we
l let
r rob
j yet

NASALS

n not
m me
ŋ sing

TABLE 3.4 (cont)

VOWELS

i	eve
ɪ	it
ɛ	met
æ	at
a	ask
ɑ	father
ɒ	not
ɔ	all
o	obey
ʊ	foot
u	boot
ɝ	hurt
ə	about
ʌ	but

DIPHTHONGS

eɪ	say
aɪ	I
ɔɪ	boy
aʊ	out
oʊ	go
ɪʊ	new

cord excitation; and 5) glides - continual movement of articulatory organs with vocal cord excitation. Vowels, nasals, and glides, exhibit a well defined formant[1] structure in the power spectrum. Stops are noted by the total absence of energy at all frequency regions except perhaps at the fundamental frequency and some multiples thereof. Unvoiced stops, in particular, may have aspiration energy for 10 to 30 ms following the release of the stop. Fricatives are high-frequency sounds (as great as 10 kHz) which may be voiced or unvoiced. Some formant structure is exhibited by these events also.

In addition to the classification of phonetic events by manner of articulation, it is useful to categorize stops and fricatives, in particular, by place of articulation, i.e., by point of constriction of the oral cavity, and the presence of voicing, i.e., excitation by the vocal cords. Each specified place of articulation is associated with two phonetic events (a cognate pair). One is voiced and the other is unvoiced (Table 3.5). For example, /s/ and /z/ are articulated at essentially the same place (lingua-aveolar and in the same manner. They differ only in the presence of voicing.

The shape of the spectrum of a phonetic event is related primarily to the dimensions of the oral and nasal cavities and the positions of the articulatory bodies. Spectral rolloff, about - 6 db/octave, is a function of the shape of the glottal pulse (- 12 db/octave) and the mouth radiation transfer function (+ 6 db/octave). In general, individuals with long vocal tracts[2] have low formant frequencies, and conversely. Therefore, people should have somewhat dissimilar spectral characteristics for the same phonetic articulation. Although a strong association does exist between a

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1. Formants are local maxima found in the power spectrum of a phonetic event.

2 Average vocal tract length for the adult male is 17 cm.

TABLE 3.5

Cognate pairs of fricatives and stops

FRICATIVES

Voiced	Unvoiced	Place of Articulation
f	v	labio-dental
ð	θ	lingua-dental
z	s	lingua-aveolar
ʒ	ʃ	lingua-palatal

STOPS

Voiced	Unvoiced	Place of Articulation
b	p	bilabial
g	k	lingua-palatal
d	t	lingua-aveolar

person's physical characteristics and his/her acoustic productions, the spectra from two tokens of the same phoneme of the same speaker can be quite different while similar to that of another speaker. With reasonably high probability, though, inter-speaker distances exceed intra-speaker distances when a decision is made upon an appropriate feature base derived from the spectra. The causes of intra-speaker variation will be discussed in Section 3.2.2.3.

3.2.2.2 SASIS Comparison Sounds

Comparisons in the SASIS system are made only from vowels and nasals. These classes of sounds are used because they provide good speaker discrimination and are amenable to analysis by linear predictive encoding techniques. Other sets of phonetic types are of interest only with regard to their influence on vowels and nasals when contiguous to them.

The possible vowels used in the SASIS system are indicated in Table 3.6 and on the vowel quadrangle of Fig. 3.9 which represents the position of the highest point of the tongue. The left side of the quadrangle refers to the front of the mouth and the right side corresponds to the back. Similarly, the top refers to a high position of the hump of the tongue and the bottom to a low position. For example, /i/ is articulated with the hump (highest point) of the tongue well forward and close to the palate. Each of the positions on the vowel quadrangle represents a steady state articulatory target position. It should be apparent that there are, in fact, an infinite number of vowels that can be articulated; however, in the SASIS system it is convenient to categorize all vowels into the ten of Table 3.6. Diphthongs, which have two target positions, will not be used for comparative purposes in the SASIS system. The sounds in this category are given in Table 3.4.

TABLE 3.6

Vowels and nasals used for speaker comparisons in the SASIS system. Alphaphonetic symbols and examples are also provided.

VOWELS

i	EE	eve
ɪ	IX	it
ɛ	EH	met
æ, a	AH	at, ask
ɑ, ɒ	AA	father, not
ɔ	AW	all
ʊ	UX	foot
u	UU	boot
ɝ	ER	hurt
ʌ	UH	but

NASALS

n	NX	not
m	MX	me
ŋ	NG	sing

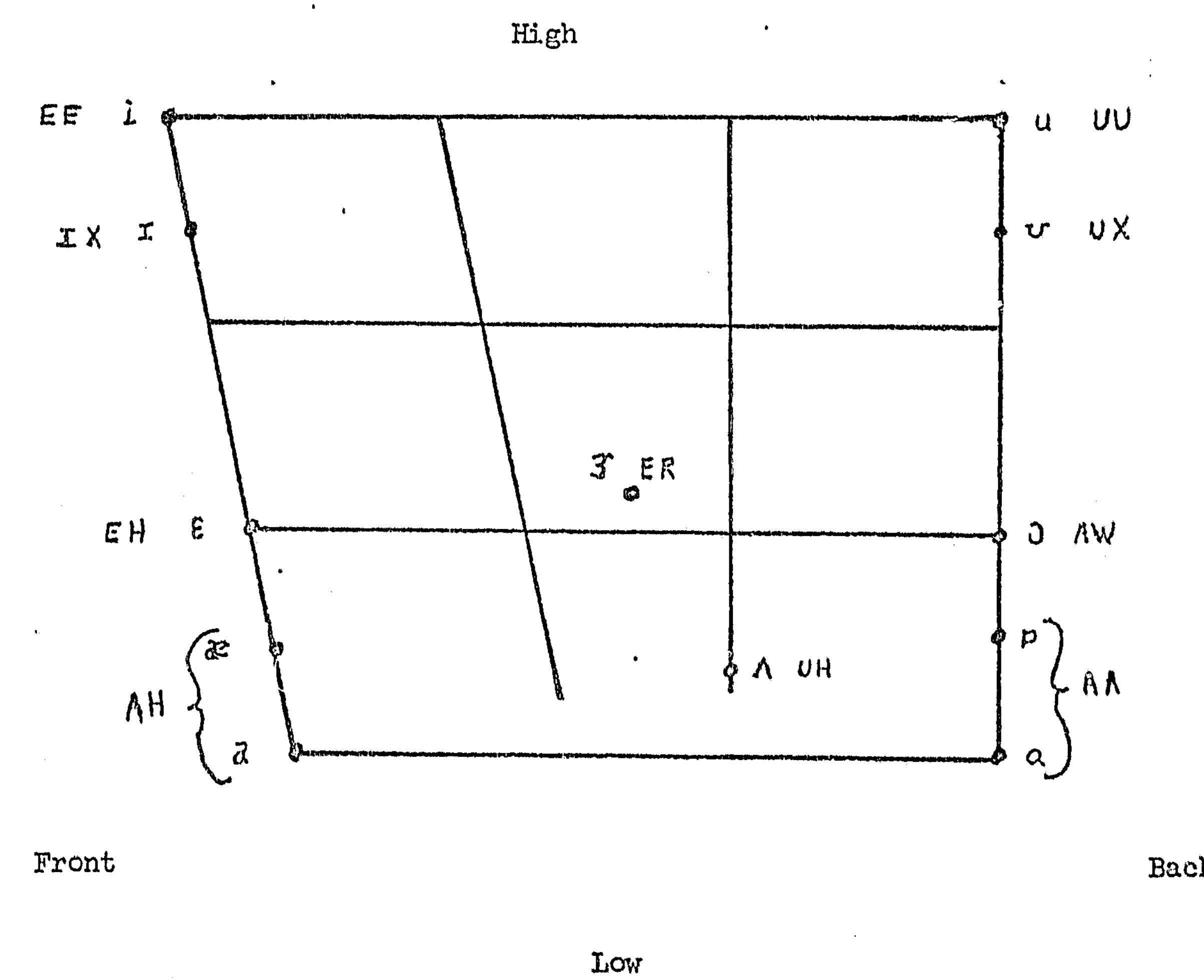


Figure 3.9

Quadrangle indicating the articulatory positions of the vowel types employed in the SASIS comparison.

Nasals are not usually represented by a chart. Their production involves the closure of the oral cavity at some point and the opening of the path through the pharyngeal and nasal cavities. Like vowels, nasals exhibit a well defined formant structure; however, with the linear predicitive technique of spectrum analysis used in SASIS, their true formant structure may be distorted due to the presence of zeros in the overall transfer function.

3.2.2.3 Acoustic Description

Events of vowel and nasal type typically exhibit three or four formants (maxima) in the frequency range of 0 to 3000 Hz.

Generally, the amplitude of formants will decrease with increasing frequency; however, in the case of telephone speech, as may be used in this system, it is possible for the second or third formant to exceed the first in amplitude due to the shaping effects of the channel. The frequency range on which the SASIS comparison is based is 300 to 3700 Hz. In practice, the telephone channel will cause very significant attenuation below 500 Hz; therefore, the fundamental voicing component will be well reduced in amplitude. A sufficient fundamental component usually exists though for the delineation of pitch periods. The dynamic range of the spectrum across frequencies (0 to 3400 Hz) is typically 20 to 30 db for telephone speech.

The power spectrum of a phonetic type for a particular speaker can vary across utterances in accordance with the time position at which the spectrum is generated and the context in which the event is located. Vowels spoken in consonantal environments can exhibit a formant structure somewhat different from that of the vowel spoken by the same speaker in isolation. Nasals, however, are not as heavily influenced by context. Formant transitions into and out of a vowel tend to be prolonged and gradual while those involving a nasal are quite rapid. The effects of coarticulation are such that differences in position of articulation and thus formant

structure between two contiguous events tend to be reduced with vowels exhibiting formant structure closer to that of an adjoining consonant. Each consonantal cognate pair can be considered to possess a second formant loci at which point an energy concentration can be found. As a result of the coarticulation process, the second formant of the vowel will tend to move, in frequency, closer to the positions of the loci of the adjoining consonants. The effects of context are typically greater on the second formant than on the first; however, some variation with environment can be found for the first with the direction of the shift opposite to that of the second formant.

The magnitude of the shift and the trajectory of the formants is a function of the vowel and its contiguous components. Generally, front vowels are less influenced by context than are the back vowels. For example, the /i/ is relatively insensitive to context while /u/ may exhibit a second formant shift of as much as 350 Hz in environments with high second formant loci. In the case of a vowel surrounded by both either high or low loci consonants, the formant target positions, as they exist for the vowel in isolation, may not be attained. Furthermore, the point in time at which the spectrum is most similar to the spectrum of the vowel uttered in isolation may be the point at which the rate of spectral change is greatest. Spectral analysis in this region will therefore result in frequency smearing. Mean position information for the first three formants of vowels and nasals is provided in Table 3.7 and second formant loci information for stops and fricatives is given in Table 3.8. Some examples of the effects of context are illustrated in Section 3.2.3.

Syntactic structure can also influence the acoustic structure of a vowel or nasal through prosodic factors such as stress and intonation. Usually a low degree of stress is physically manifested by reduced energy levels, lower fundamental frequency, and shortened duration of an event. Fundamental frequency may fluctuate as a result of varying

TABLE 3.7

Mean formant positions for event types employed in the SASIS comparison. Vowel frequencies are based on the results of Peterson and Barney (1952) for h-d environments.

VOWEL	F1	F2	F3
i	270 Hz	2290 Hz	3010 Hz
I	390	1990	2550
ɛ	530	1840	2480
æ (a)	660	1720	2410
ɑ (ɒ)	730	1090	2440
ɔ	570	840	2410
ʊ	440	1020	2240
u	300	870	2240
ɝ	490	1350	1690
ʌ	640	1190	2390
NASAL			
m	290	950	1300
n	300	1050	1450
ŋ	350	1050	1900

TABLE 3.8

Qualitative second formant locus (hub) information for stops and fricatives.

STOPS

p,b	low
k,g	variable
t,d	high

FRICATIVES

f,v	low
θ,z	middle
s,z	middle
ʃ,ʒ	high

intonation contours and consonantal context. Usually, a vowel embedded in a voiced environment will have greater duration, a lower fundamental frequency and greater energy than the same type spoken in an unvoiced environment.

This review of acoustic phonetics is representative but not complete with regard to useful background information required for accurate labelling. A reading list covering a more extensive range of topics in acoustic phonetics and speaker identification has been compiled and is presented in Appendix 3E.

3.2.3 Labelling Procedures.

3.2.3.1 Labelling Functions

The function of the labelling program is the extraction, under operator direction, of records of the time waveform from those phonetic tokens which are considered appropriate for comparisons between speakers.

The labelling process is performed on an interactive console on-line to a digital computer. During the course of the procedure, the operator possesses the capability of displaying information that will aid in the isolation and identification of the phonetic events under consideration. Instructions with regard to the display and processing of information are inputted to the computer through a keyboard.

The labelling process consists of two alternating phases which are called macrophase and microphase (Figure 3.10). In the former, a spectographic representation (frequency range: 200 to 3200 Hz) of approximately 1.2 seconds is displayed. The sonogram is generated by a succession of Fast Fourier Transforms taken at approximately 9.4 ms intervals. Each amplitude value in the spectogram is quantized into seven gray levels including blank. The quantization levels are adjusted for optimum discrimination of vowels and nasals. Low energy fricatives /f, v, θ, ð/ as well as stops, may appear as blank regions. Adjoining 1.2

second spectographic sections of the utterance can be displayed by the appropriate inputs through the keyboard. A time-aligned amplitude contour, representing total energy content of the speech waveform is displayed above the spectogram. In addition to spectographic and amplitude information, an identification header is shown on the screen during macrophase.

As a means of isolating and identifying events, a vertical cursor is superimposed over the spectogram and is positioned by the operator to a desired point in time by a thumbwheel control. Through keyboard input, the capability exists for the audio playback of a 100 ms or 300 ms section of speech centered on the cursor. A large section of the utterance may also be played back given the appropriate input. Provision exists for the generation and display of those five phonetic types which achieve the greatest correlation[3] with the time position over which the cursor is located. The associated correlation values X100 are also provided. Tentative acceptance of an event is made by inputting the phonetic triad[4] in which the desired event is centered.

In most cases, it will be found that the energy content of vowels exceeds that for fricatives and nasals. Within a vowel, the amplitude will vary over time to some degree; however, formant position rather than the maximum in the amplitude contour should determine cursor position. In the situation of a vowel between two consonants with both second formant loci either higher or lower than that of the vowel, the formant of the vowel will possess frequency maxima or minima usually near the centers of the events. The cursor, in such cases, should be placed at these extrema (Figure 3.13) since the formants are closest to their target states at this point. For the situation of a higher loci on one side and a lower loci on the

[3] Correlation between two spectral vectors is computed to be the cosine squared of their angle separation, expressed in percent.

[4] A triad is defined as a triplet of three consecutive phonetic events.

other, the formants will tend to pass through their target positions. Uncertainty in positioning the cursor is greater for this condition; therefore, it may be appropriate, if identity of the event is not in doubt, to employ the correlations in determining the position approximating the target region. Using the four sources of information (spectogram, audio playback, amplitude contour and correlations) the desired events for a frame are identified and tentatively accepted, whereupon control is passed to the microphase.

Microphase involves the selection of three consecutive pitch periods from the 100 ms time sequences of each of the events in the buffer. Each sequence, as displayed on the screen, represents the sampled time waveform centered around the previously selected cursor position. The three pitch periods are delineated by two cursors under operator control. Prior to final acceptance or rejection of a candidate event, the operator has the capability of listening to an audio playback of the speech section between the cursors (concatenated ten times). Readjustment of the cursor positions may be undertaken if desired prior to acceptance or rejection. Following the processing of all events in the buffer for that frame, macrophase is automatically returned to and isolation of events continued. The alternation between the two phases of labelling continues until the entire utterance is examined.

3.2.3.2 Techniques for Event Isolation and Identification

The purpose of this section is to describe certain phonetic situations that may cause difficulty in the consistent and accurate selection of phonemes and in associated pitch period extraction. The techniques discussed below, in no way, cover all of the labelling situations that may be encountered but rather concentrate on those which are frequently experienced.

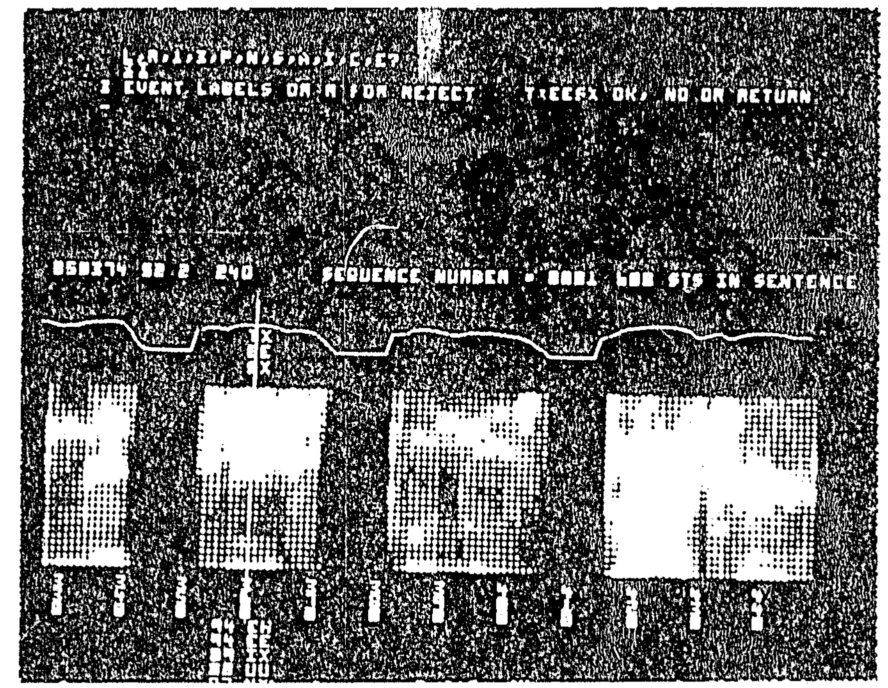
It is worthwhile to briefly consider the issue of event selection from the viewpoint of discrimination ability. In many investigative/forensic situations, the amount of speech material available for comparison will be limited particularly with regard to the criminal (basis) utterance. However, in those cases in which substantial data exists, it may be useful to limit, to some extent, the types of events to be used in the comparison. If the phonetic types being compared are taken from the same context in both the criminal and suspect utterances, it has been determined that the events /m, u, i, I/ provide the highest degree of speaker discrimination. Even in such a text dependent comparison[5] as used in the SASIS system, certain contexts are desirable to others in minimizing formant transitions into and out of the vowel. It is generally desirable to select environments possessing second formant loci not greatly dissimilar from that of the vowel. Fricatives are preferable to stops as the former result in greater duration and energy of the contiguous vowel. Of the stops, the types /k/ and /g/ tend to have variable second formant loci close to that of the contiguous vowel, and are therefore desirable in context. In general, it will be found that nasals are relatively insensitive to the effects of environment. Furthermore, the formant transitions into and out of nasals are quite rapid with the quality of the nasal itself relatively stable with time, although of considerably less energy than vowels. A vowel in the environment of a nasal may cause the elimination of the first formant of the vowel or generation of an additional peak in the vicinity of that formant; therefore, it is desirable to preclude from the comparison a vowel in such an context. An additional effect which may be encountered is the superimposition of fricative or aspiration over the time waveform of a vowel. Energy from such phenomena which falls into the frequency range of the SASIS analysis can degrade the effectiveness of the speaker comparison.

[5] A text dependent comparison is one involving the same triad for both members of the comparison.

Another factor important in the selection of events is the level of stress. It is desirable that a selected event be of a reasonably high level of stress. It should be noted, however, that stress is a perceptual entity involving temporal duration, fundamental frequency, and energy; thus, seemingly high stressed events may not possess the energy content that they subjectively appear to have. In declarative sentences, stress may become quite reduced in the terminal portion. Events from this region should be selected with care. It is also to be noted that events within a voiced environment will typically have greater duration and energy with a lower fundamental frequency than the same event in an unvoiced environment.

The labelling of speech which is not of the General American English (GAE) dialect can present special problems. In many dialects other than GAE, an almost consistent substitution of phoneme types can be found. For example, in the speech of Mexican-Americans, there exists a tendency to use higher vowels. The event /i/ is often substituted for /I/, /u/ for /ʊ/ and /ʌ/ for /a/. All too frequently, there is an undesirable tendency on the part of the operator to label an event in accordance with what should have been said rather than by what was actually generated by the speaker. It is important that the operator, in making classifications, separate, in his mind, the acoustic production of the speaker from the spelling of the enclosing word and its usual pronunciation.

In making decisions concerning phonetic identity, agreement between the subjective judgment as to event type and the highest ranked event of the angle correlations is desirable but should not be necessary for selection of an event. If sufficient confidence in the subjective opinion exists it may, in fact, be advisable to accept an event for comparison given



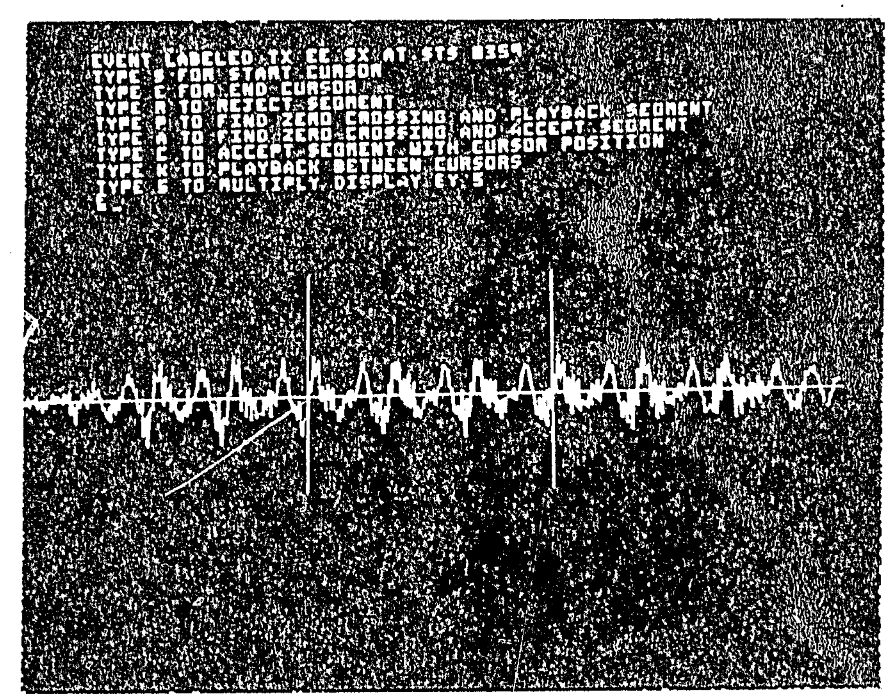


Figure 3.10. Selection of the /i/ in "teaspoon"

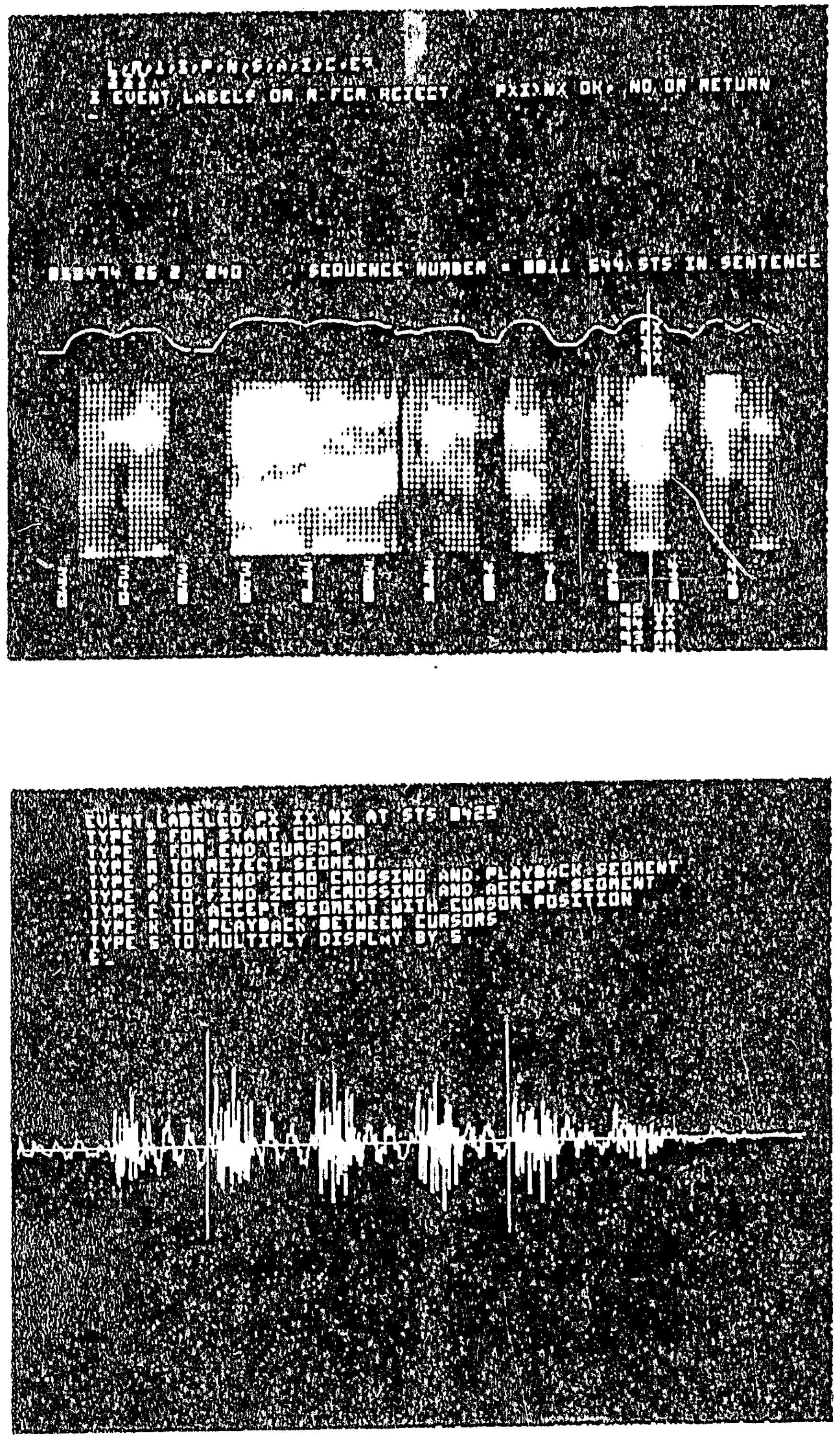


Figure 3.11. Selection of the /ɪ/ in "pinch"

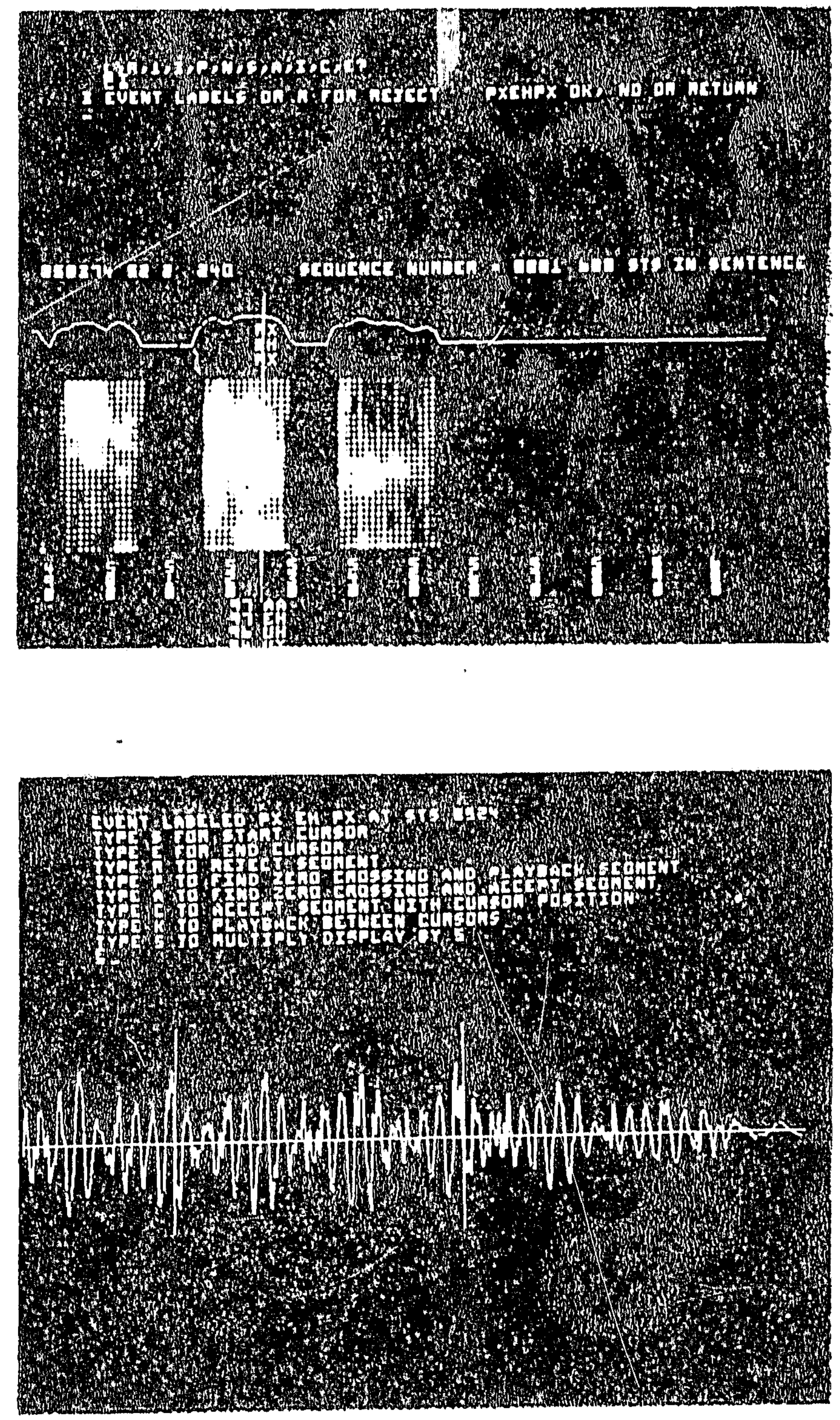


Figure 3.12. Selection of the /ɛ/ in "pepper"

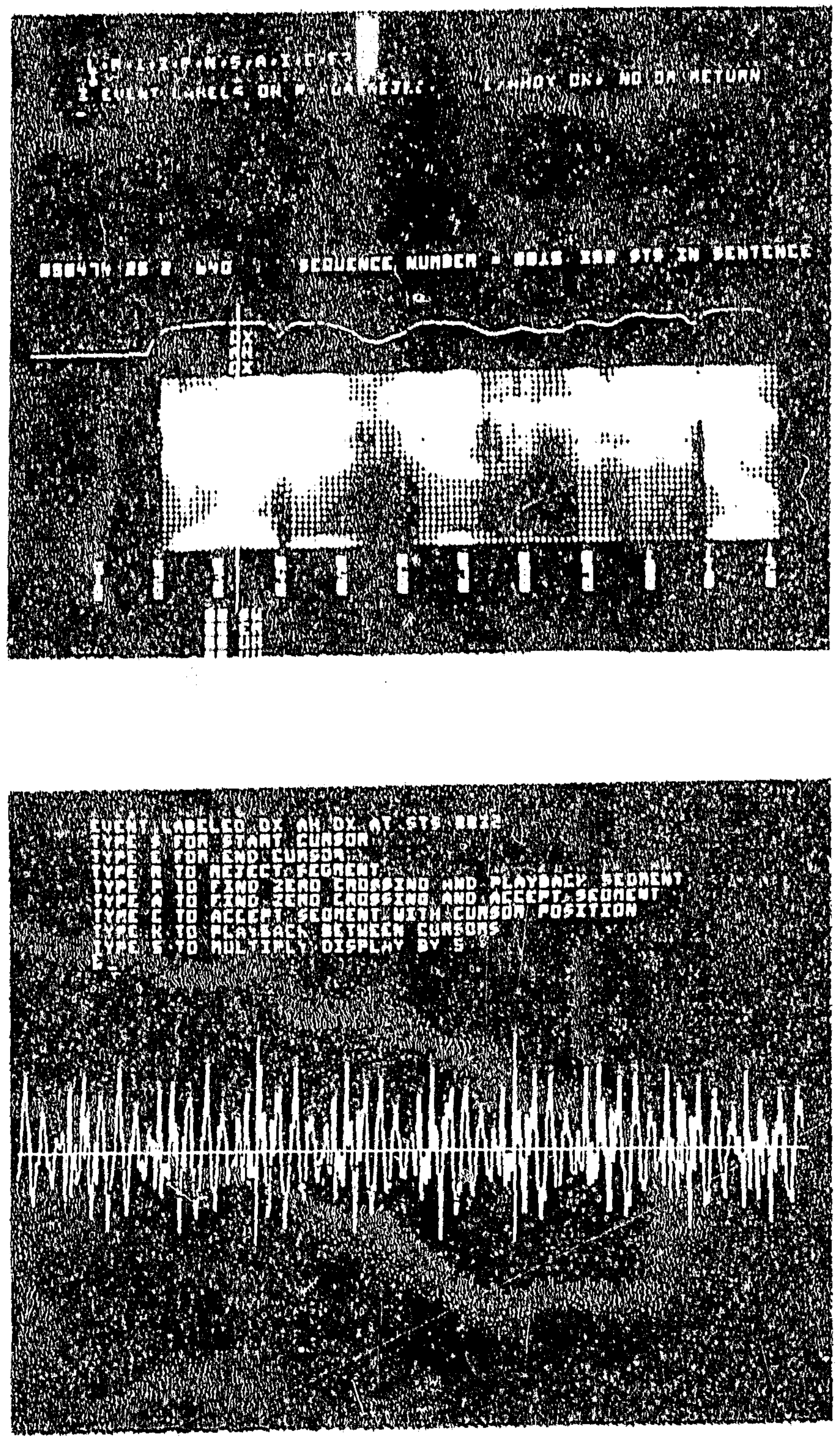


Figure 3.13. Selection of the /a/ in "dai"

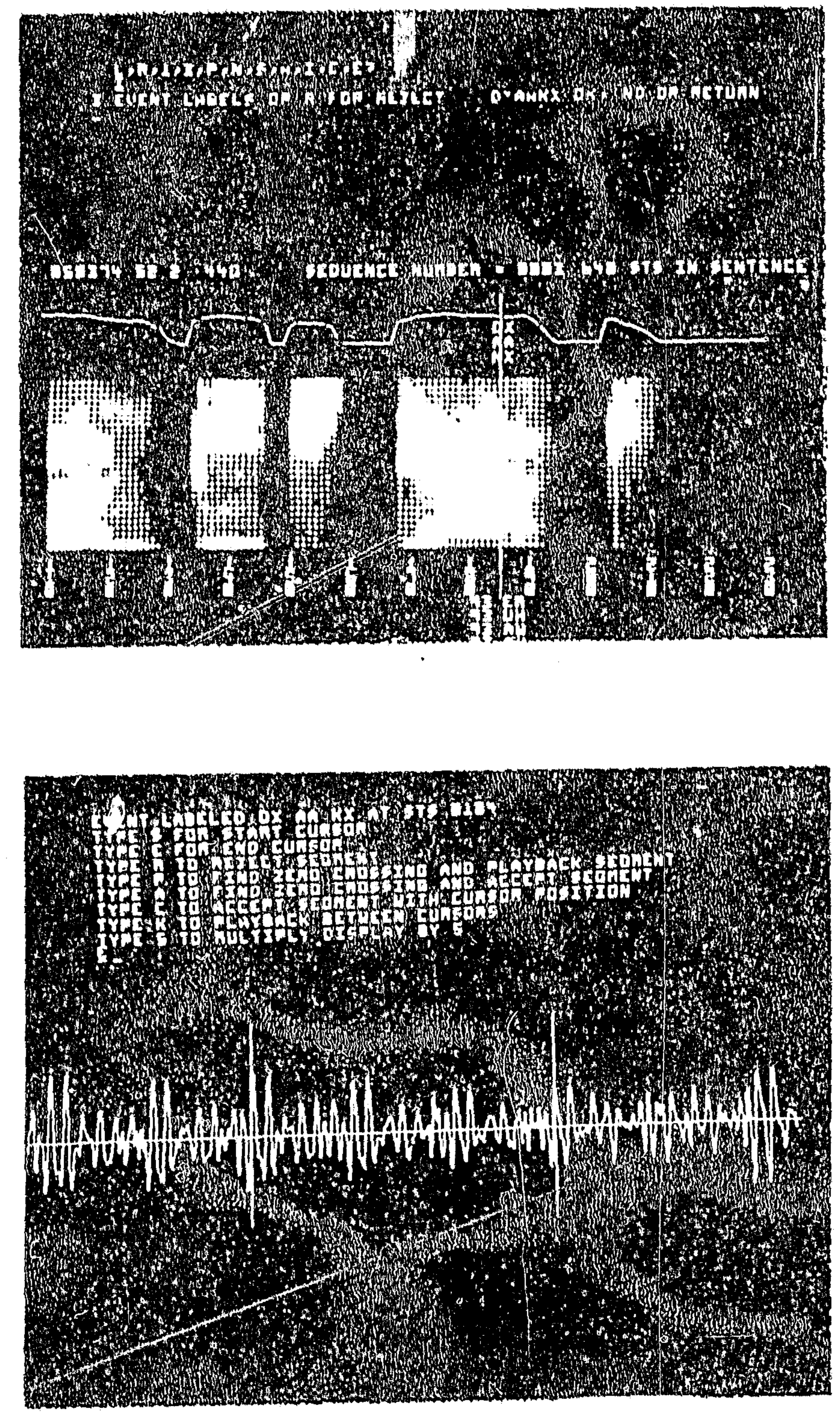


Figure 3.14. Selection of the /i/ in "dai"

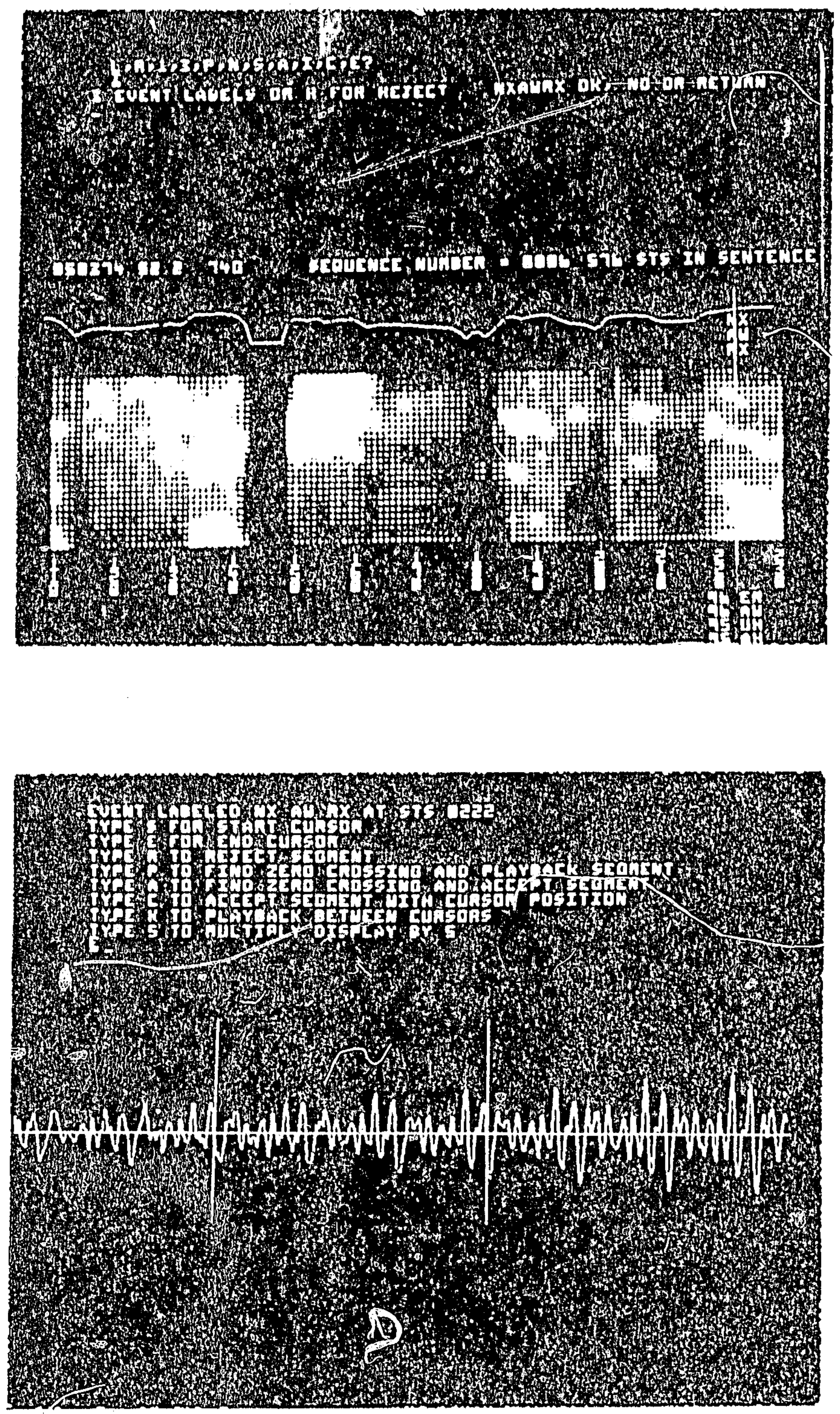


Figure 3.15. Selection of the /ɔ/ in "north"

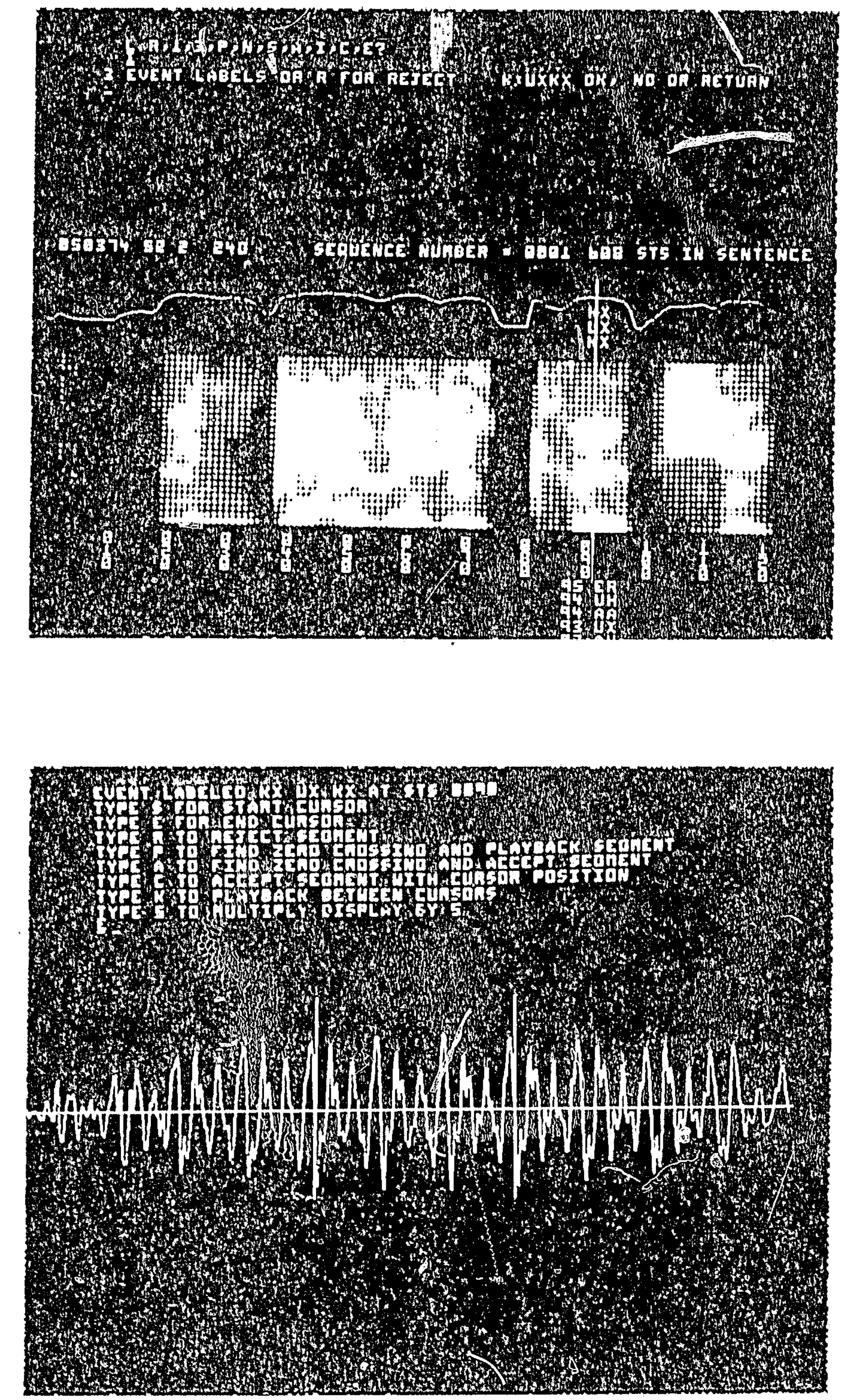


Figure 3.16. Selection of the /ʊ/ in "cook"

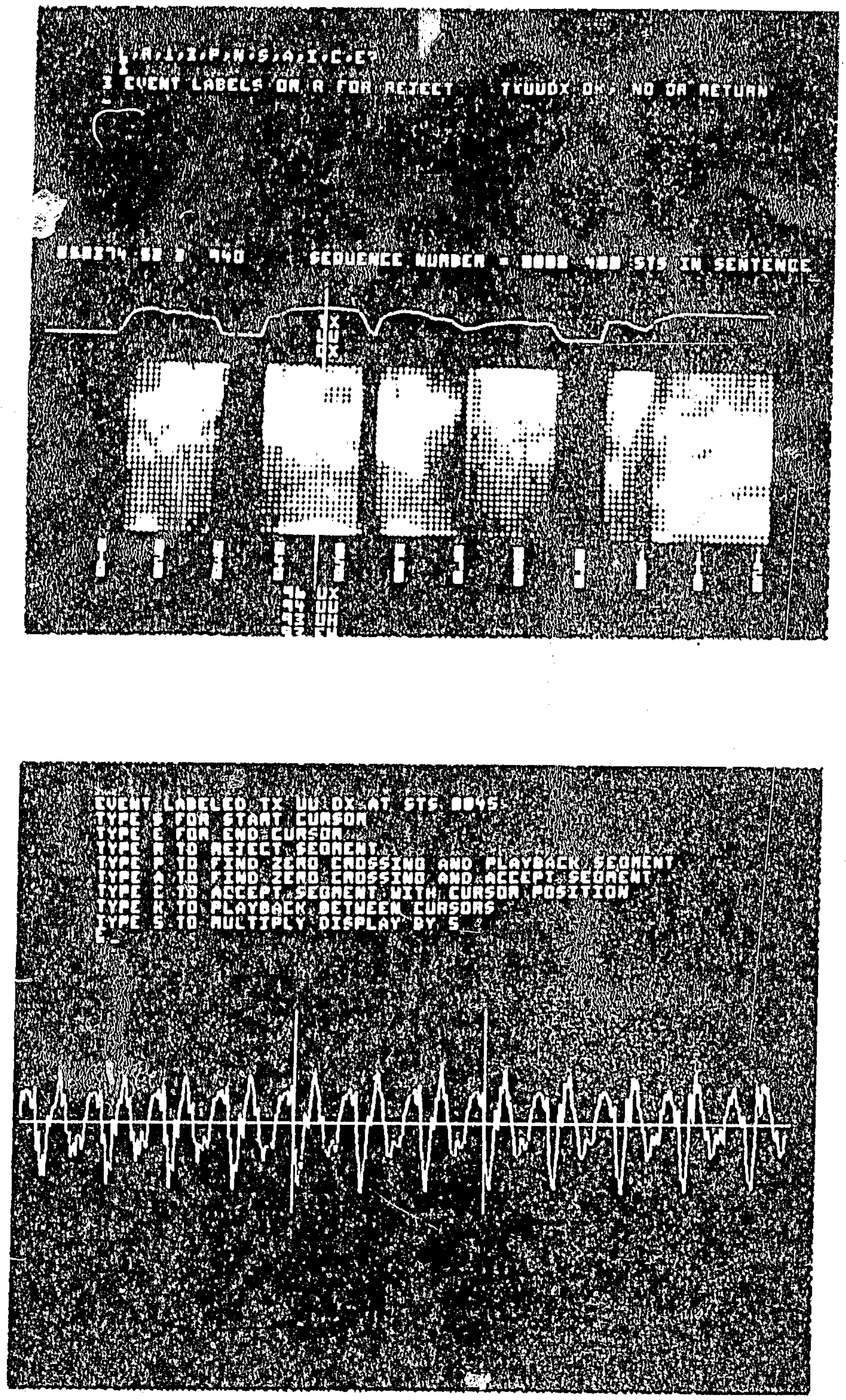


Figure 3.17. Selection of the /u/ in "students"

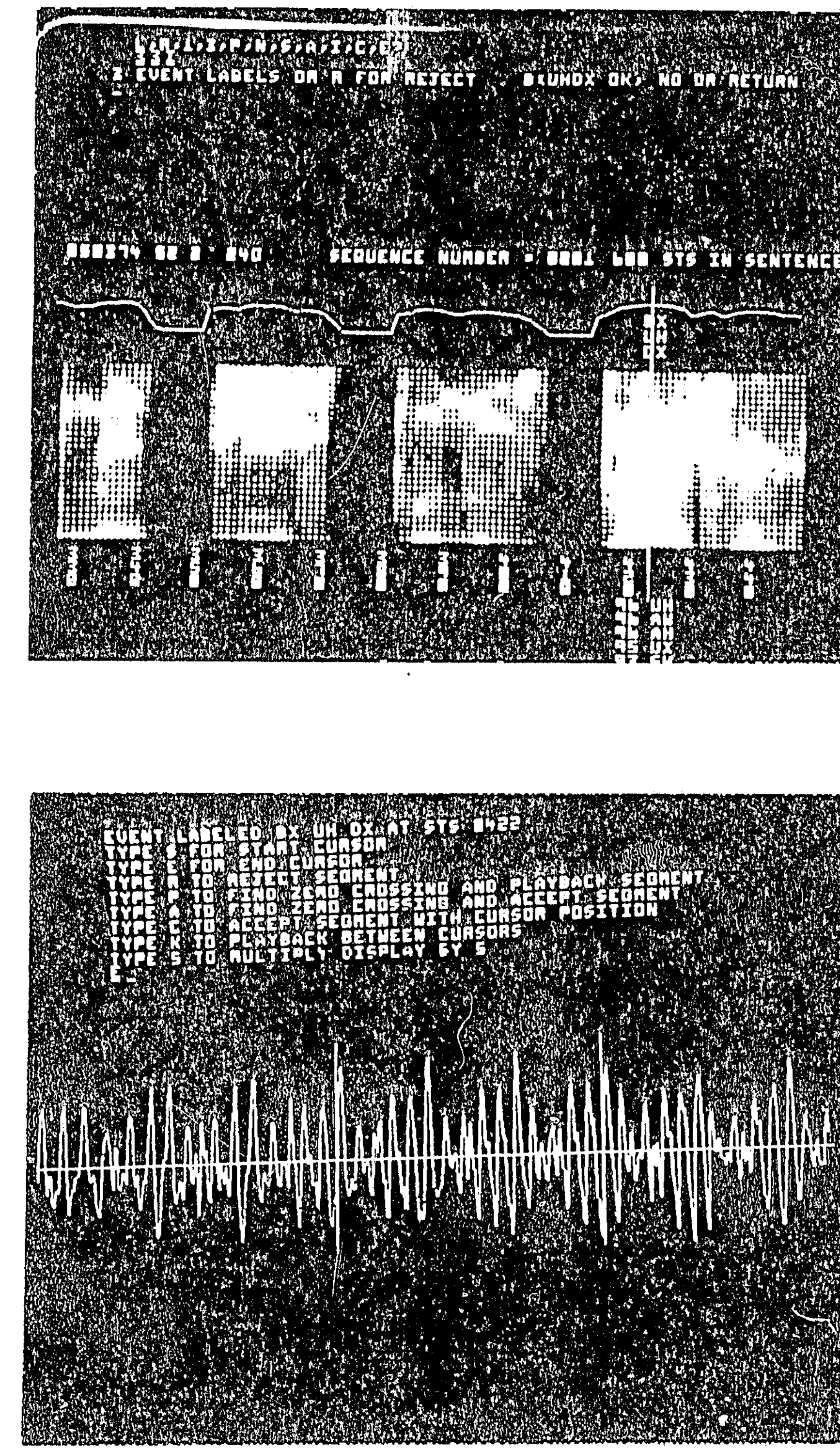


Figure 3.18. Selection of the /ʌ/ in "butter"

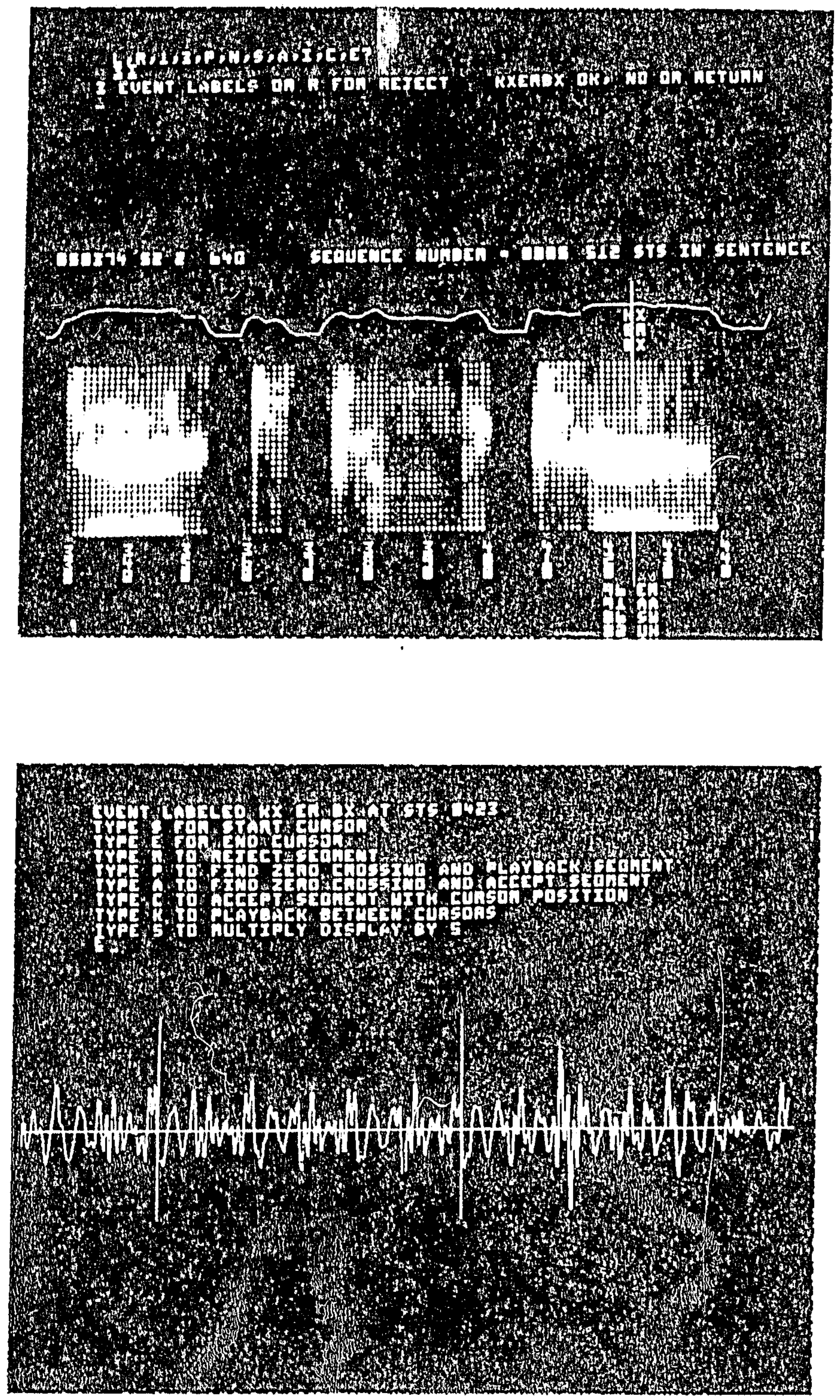


Figure 3.19. Selection of the /ɜ/ in "curb"

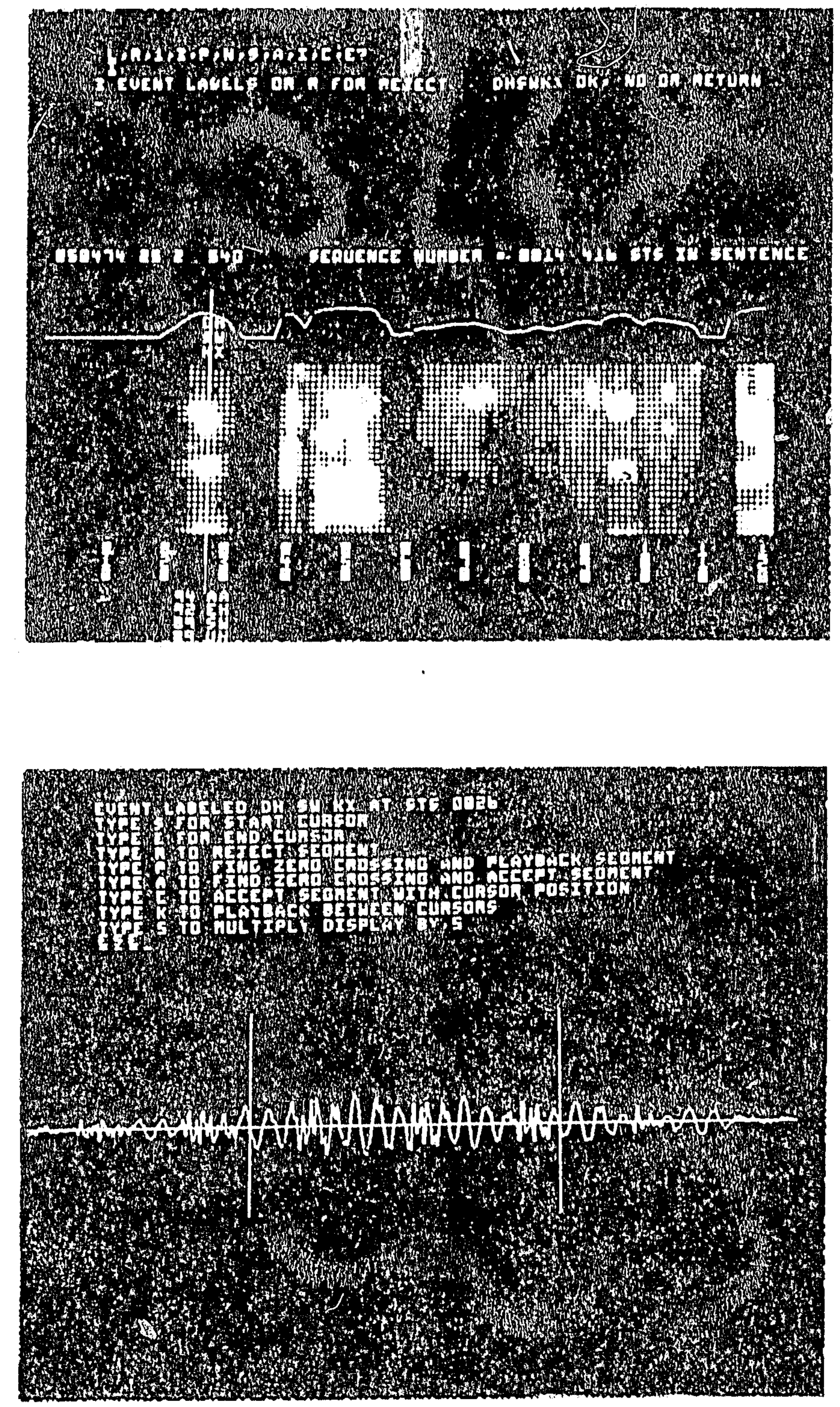


Figure 3.20. Selection of the /ə/ in "the"

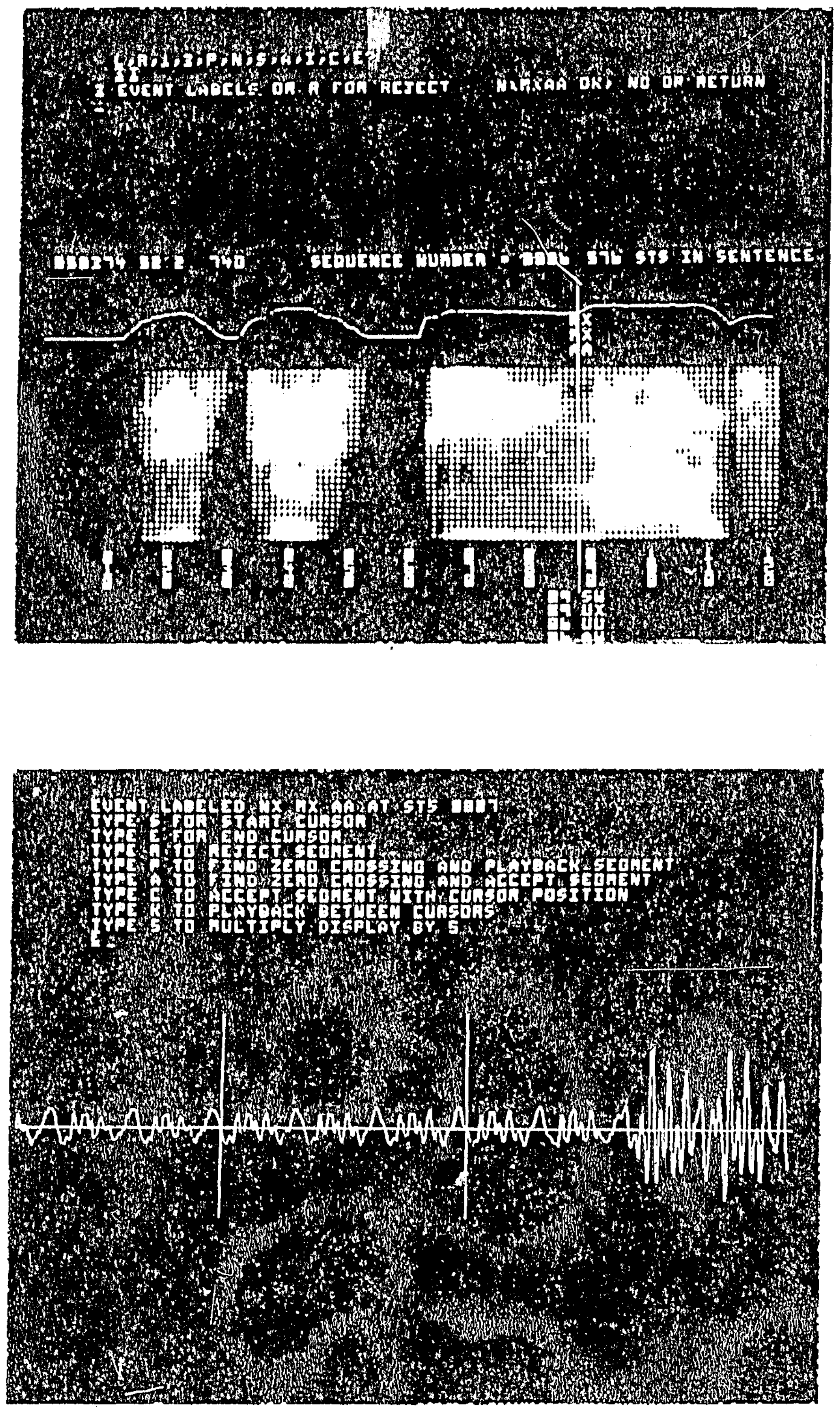


Figure 3.21. Selection of the /m/ in "mile"

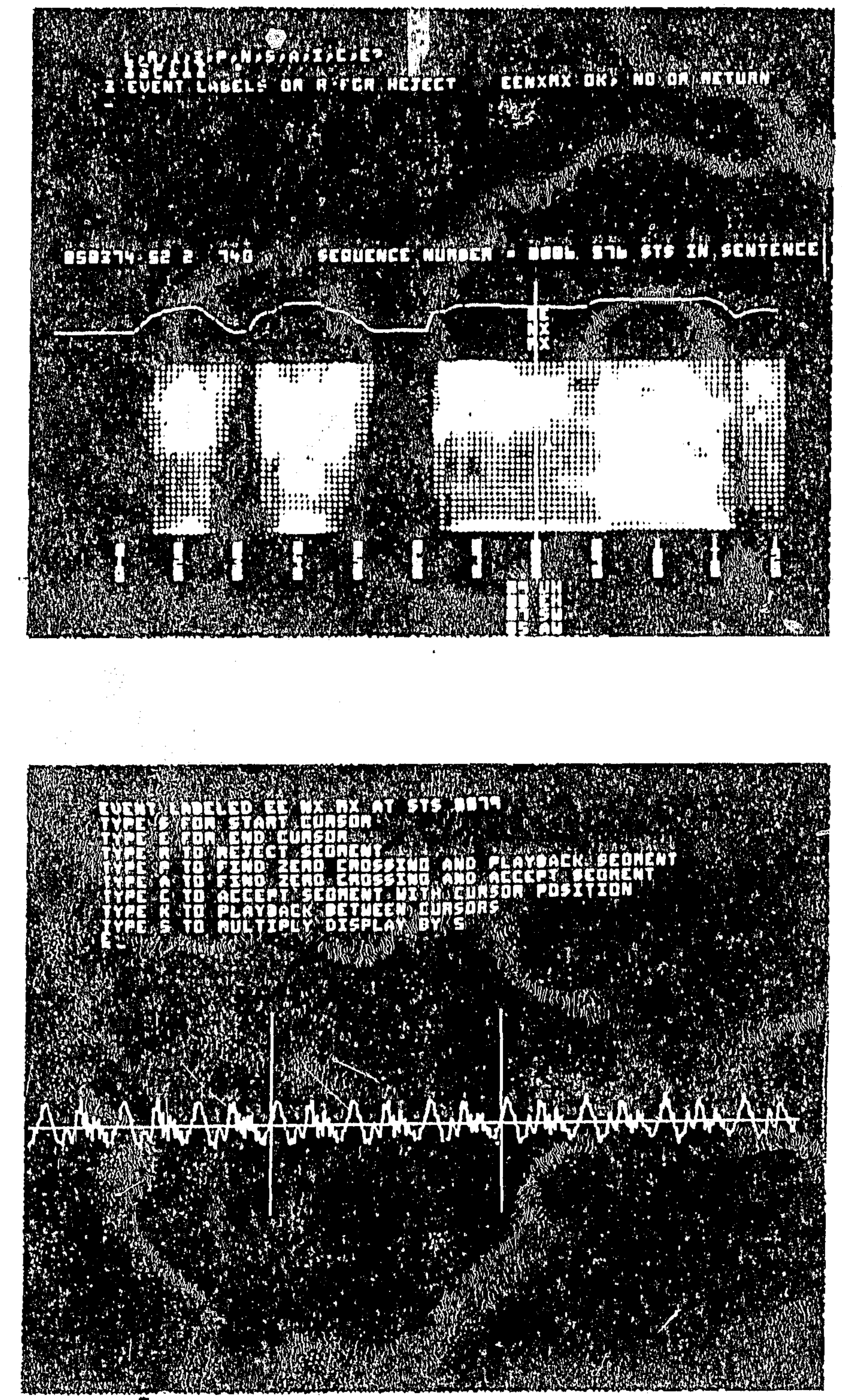


Figure 3.22. Selection of the /n/ in "fifteen"

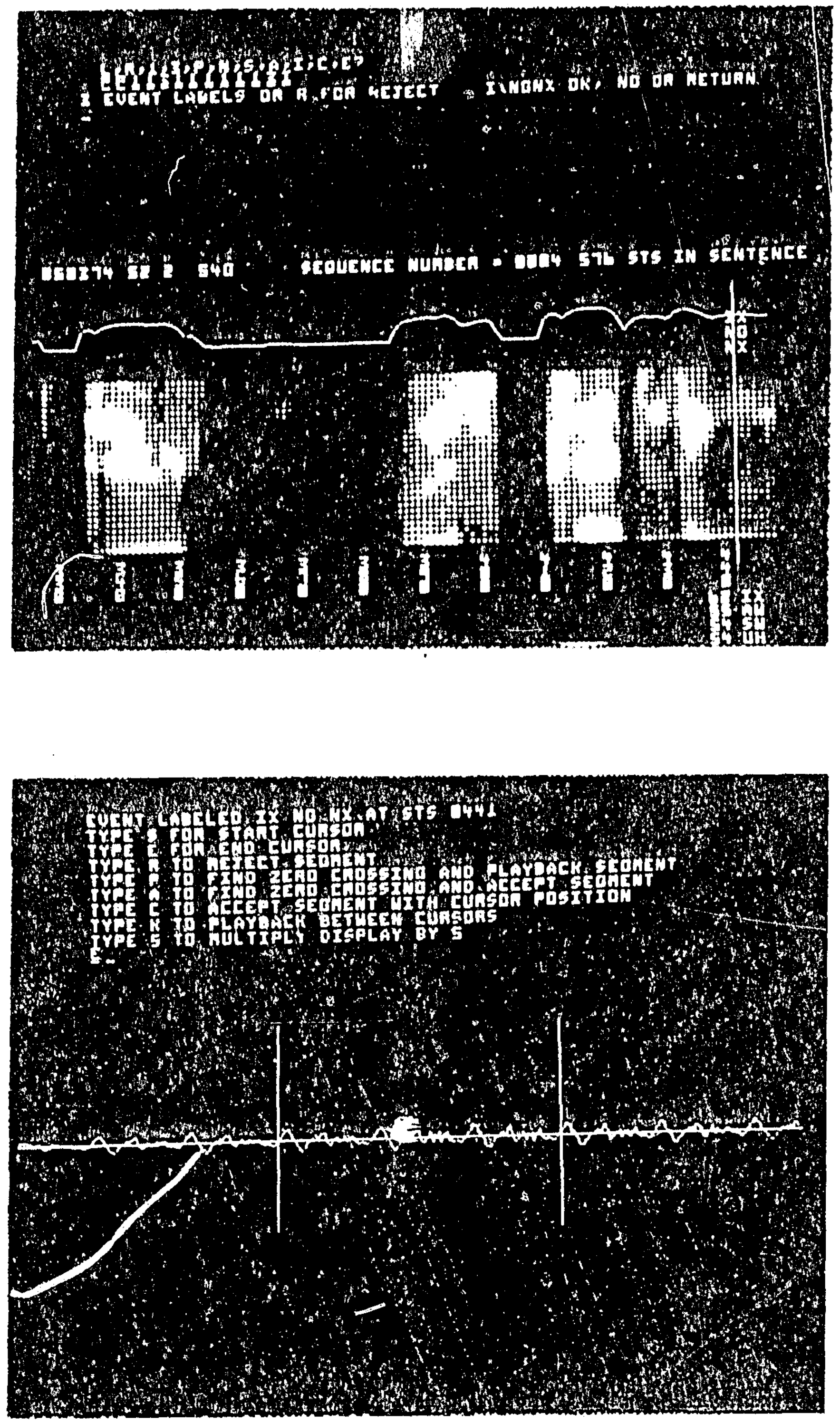


Figure 3.23. Selection of the /ŋ/ in "peddling"

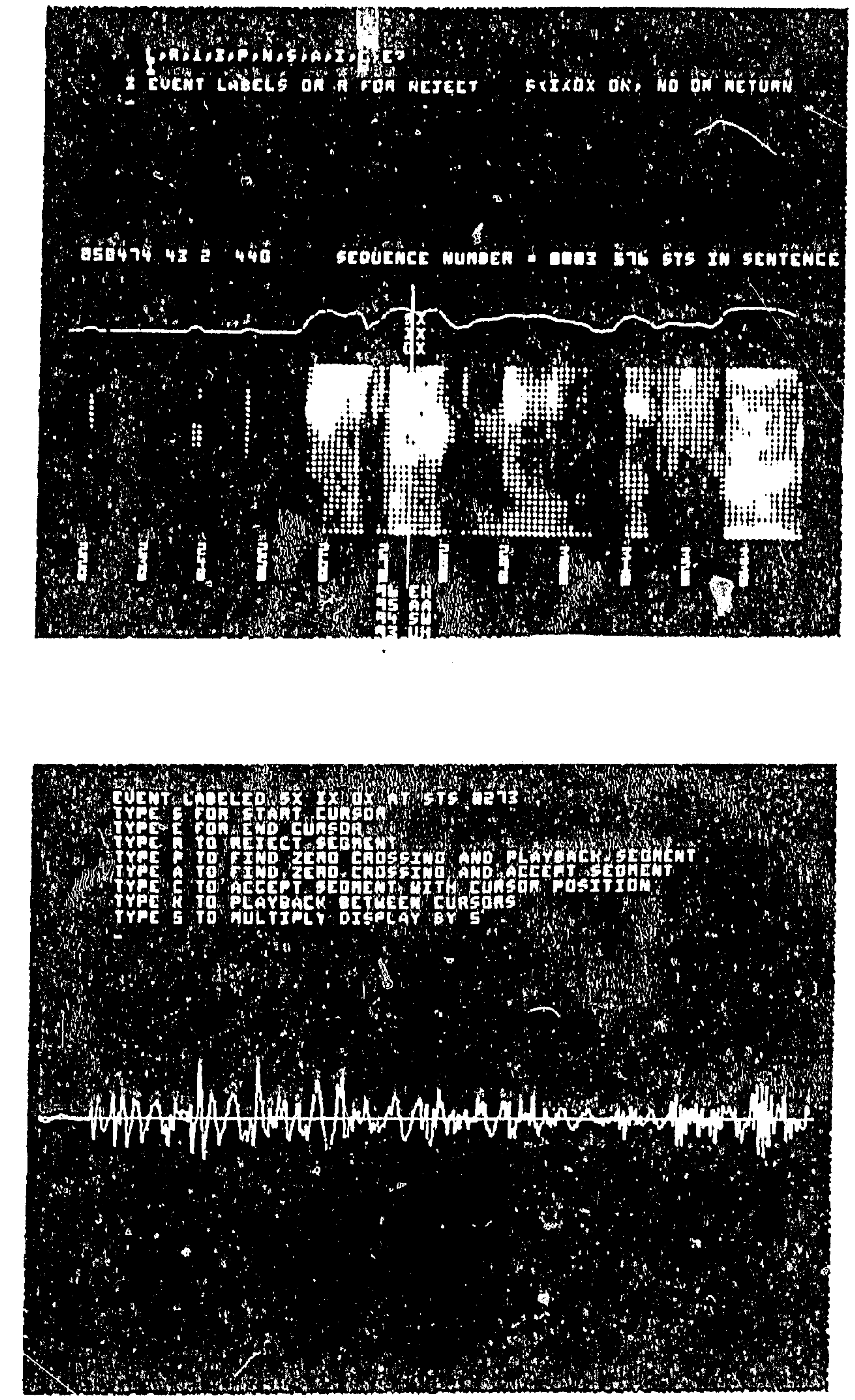


Figure 3.24. Example of a relatively aperiodic /ɪ/ in "signal"
This token should be excluded from comparison.

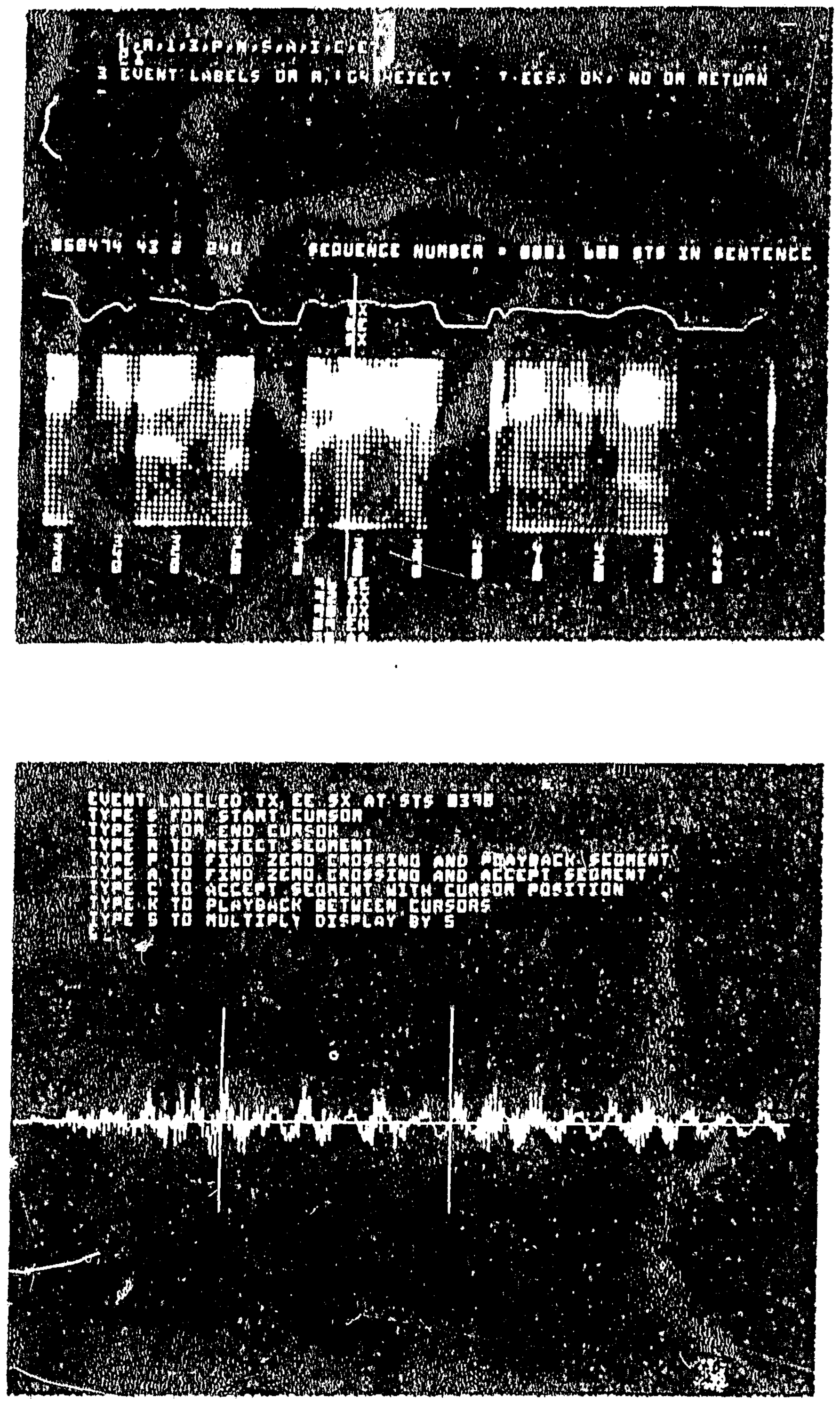


Figure 3.25. Example of a heavily aspirated /i/ in "teaspoon." This token should be considered acceptable for comparison.

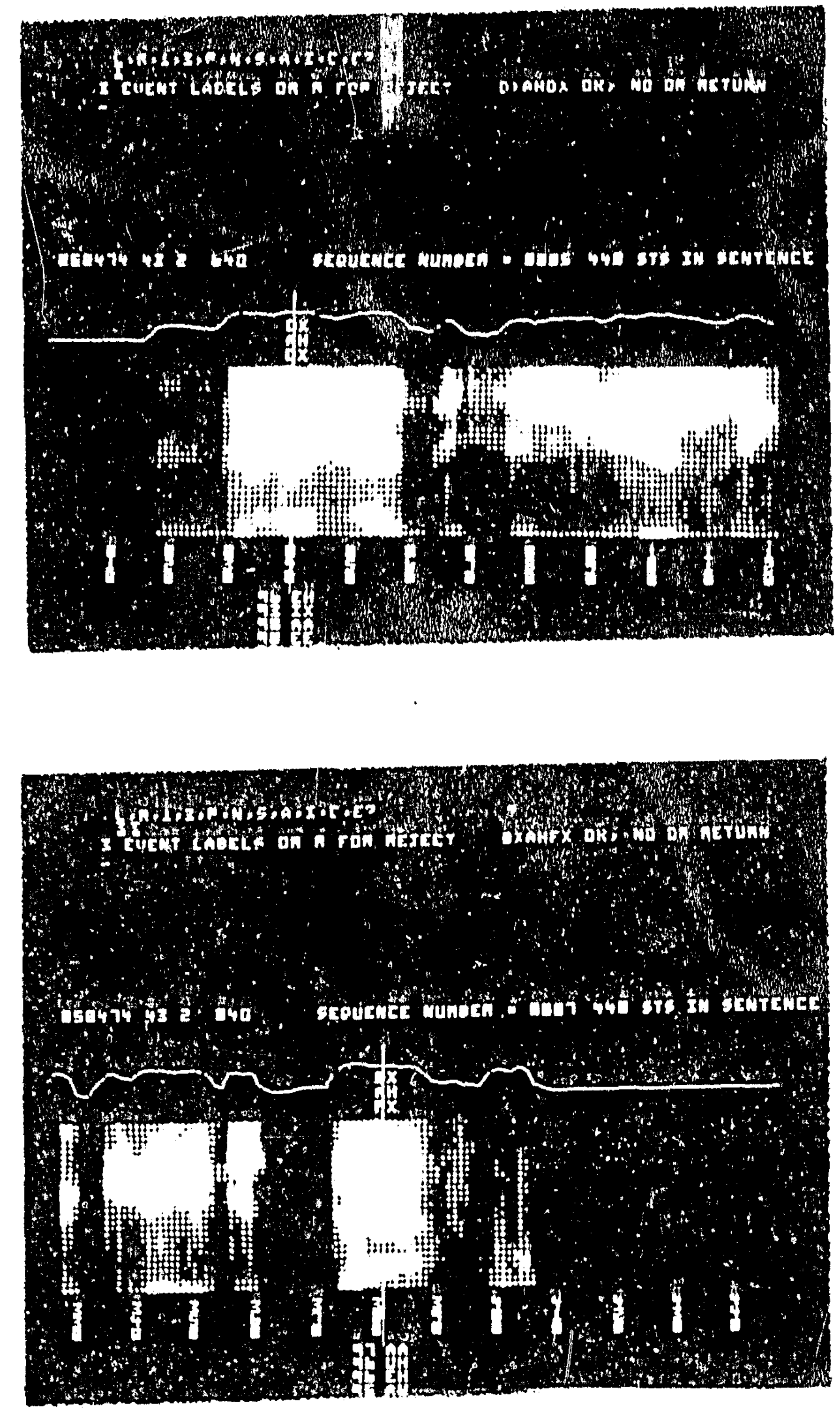


Figure 3.26. Two tokens of the type /a/ from the same speaker from different contexts. Note the variations in formant positions.

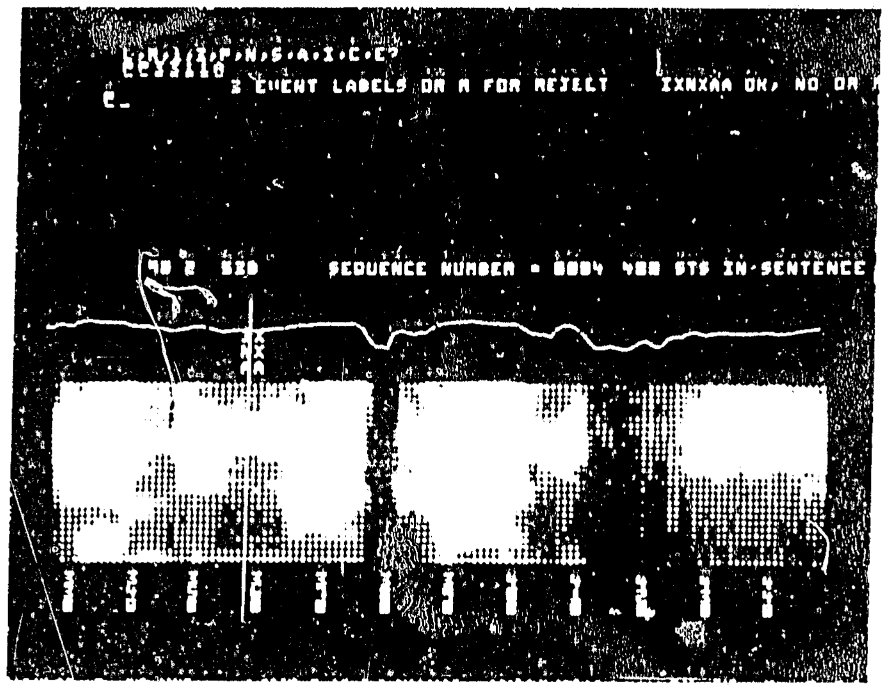


Figure 3.27. Substitution of /n/ for /ŋ/ and fusion of two adjacent nasals by a speaker of the black dialect. The phrase is "peddling narcotics."

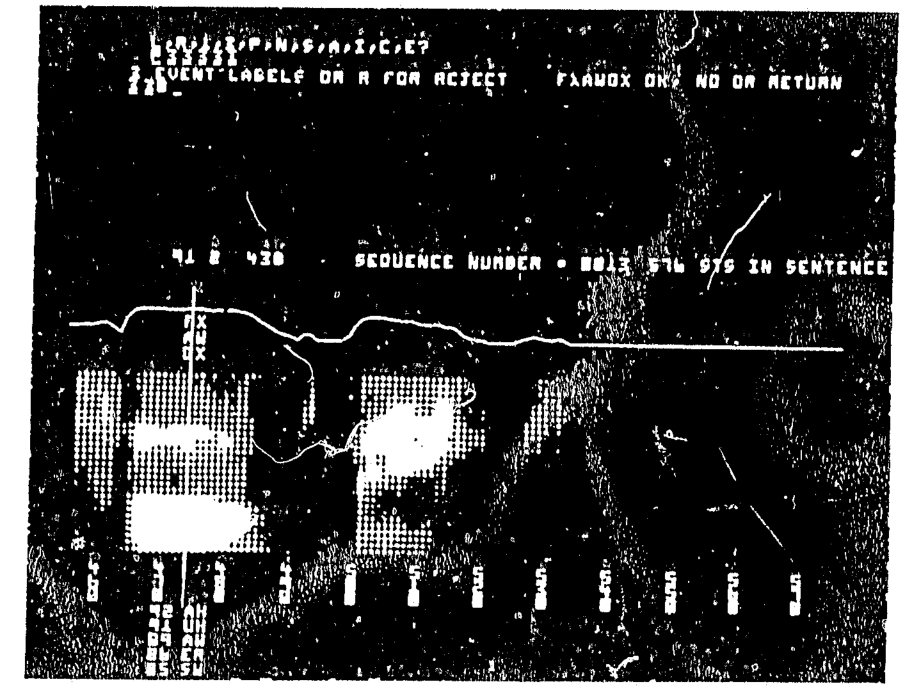


Figure 3.28. Substitution of /ɔ/ for /ʌ/ by a speaker of the black dialect. The phrase is "for bonk."

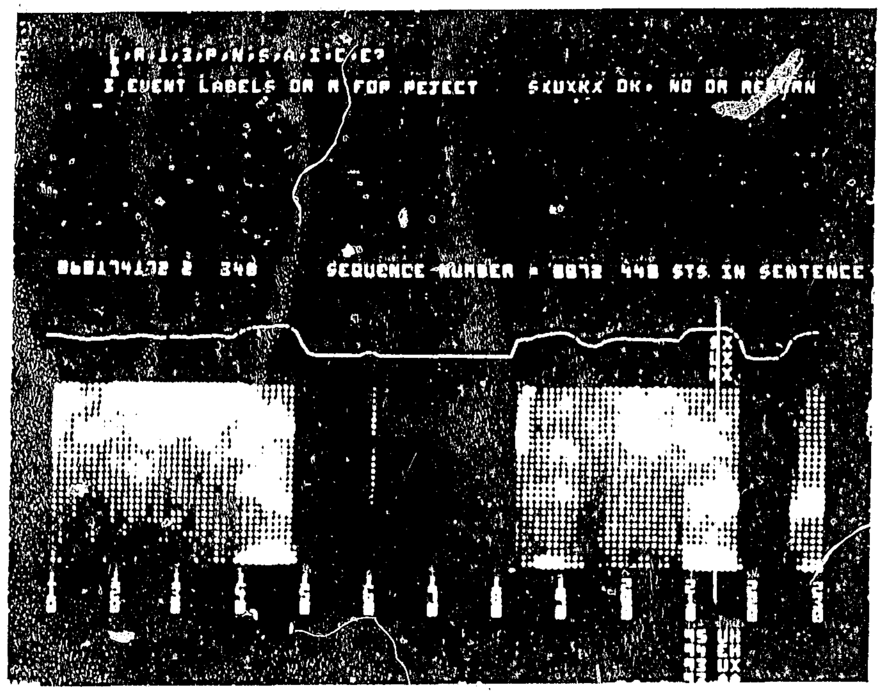


Figure 3.29. Substitution of /ɤ/ for /ɜ/ by a speaker of the black dialect. The phrase is "shipped the circuits."

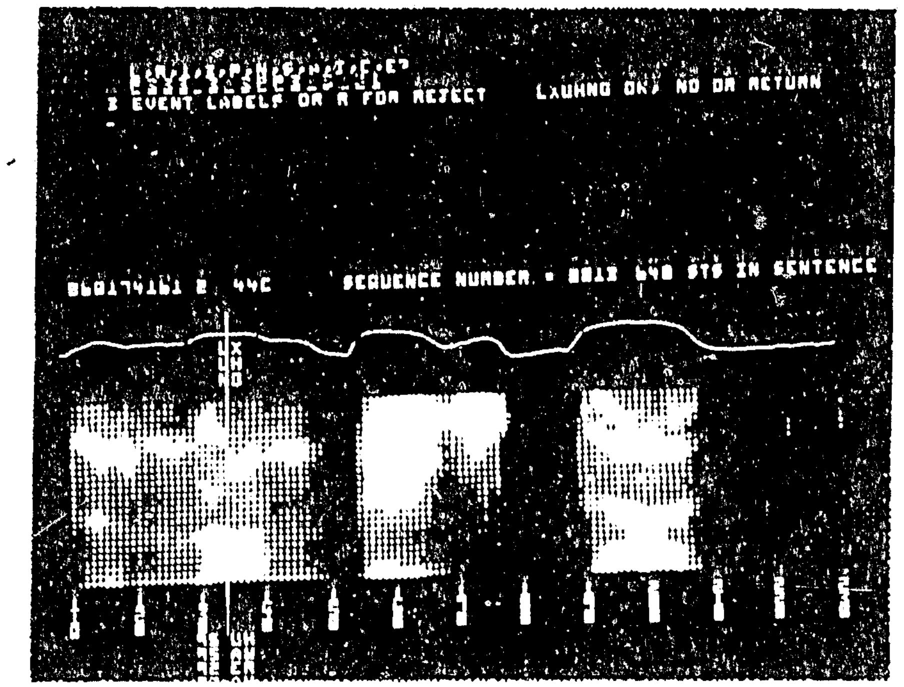


Figure 3.30. Substitution of /ʌ/ for /ɔ/ by a speaker of the Mexican-American dialect. The phrase is "the Long Beach Dock."

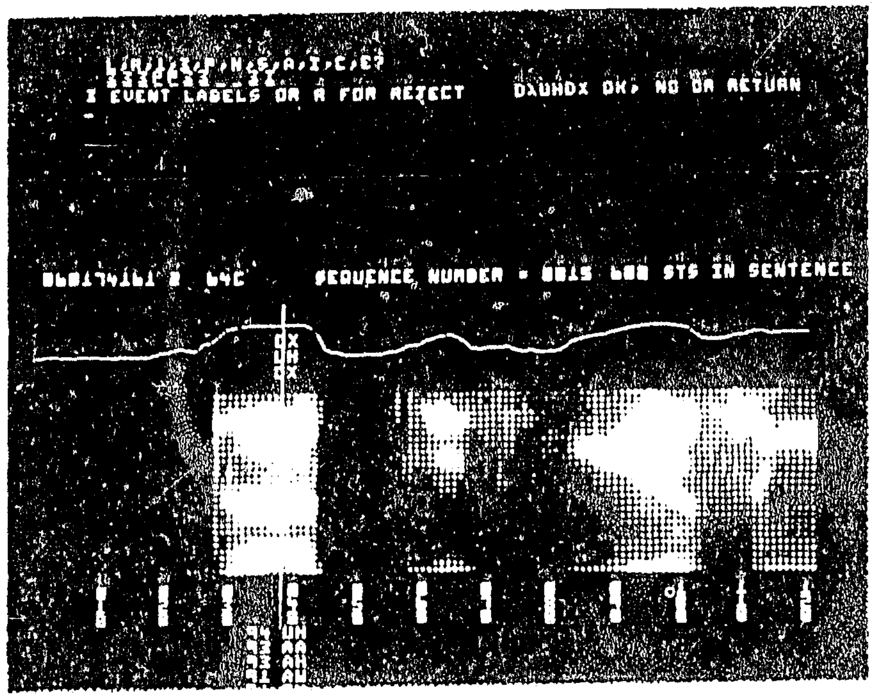


Figure 3.31. Substitution of /ʌ/ for /a/ by a speaker of the Mexican-American dialect. The phrase is "Dad is using."

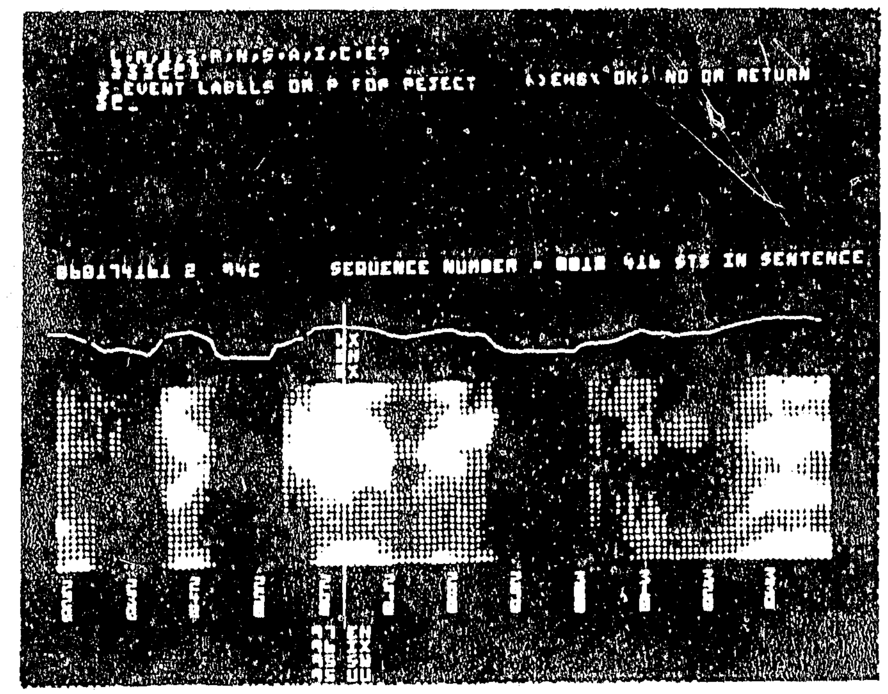
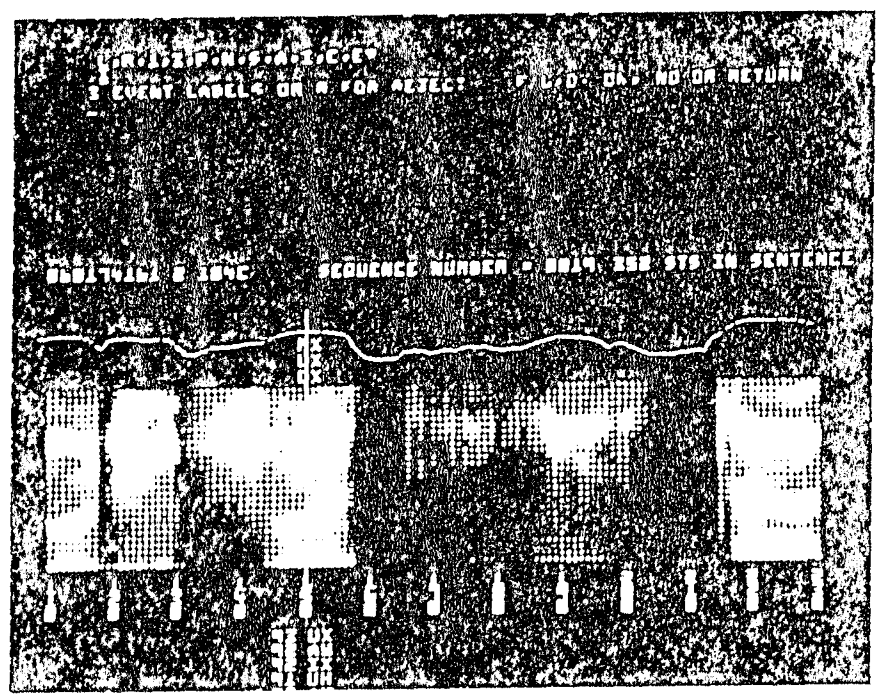


Figure 3.32. Substitution of /ɛ/ for /a/ by a speaker of the Mexican-American dialect. The phrase is "the cabin and were."



its absence from the five greatest correlations. In situations in which a high level of noise can be found within the acoustic structure of the event, however, it is appropriate to place more emphasis on the indications given by the correlations. Another point to be noted is that a sudden but brief drop in energy will be found in noisefree events at the region at which it is desired to position the cursor. Examination of the time waveform in microphase may indicate the desirability of rejecting the event due to gross variations in energy and spectral content at that point.

3.2.3.3 Examples of Labelling Situations

This section gives photographic illustrations of the labelling process. In most cases, macrophase and microphase are shown with the cursor positions appropriately placed for the particular token. Figures 3.10 through 3.23 are examples of events from General American English which can be considered typical (albiet noisefree) and acceptable for comparison. Figures 3.24 through 3.26 are examples of typical tokens from GAE which may not be acceptable or illustrations of intraspeaker variation. Figures 3.27 through 3.33 represent some frequently occurring phonetic substitutions in the Black and Mexican-American dialects. Note: The interactive display shown in these photographs differs in format somewhat from that of the prototype SASIS system.

3.2.3.4 SASIS Sound Discrimination Example Tape

An audio tape was generated (7½ ips, NAB) which contains the examples of Section 3.2.3.3. The entire sentence for each example is provided. The order of the sentences is the same as that of the examples. There are several examples which were derived from the same sentence. For these cases, the sentence is repeated.

Three dialects are represented on the tape: General American, Black, and Mexican-American. The speech of the tape consists of phonetically diverse sentence material read by seven speakers in a soundbooth. In actual operational situations it is anticipated that the rate of speech and the level of noise will be somewhat greater than manifested in this data base.

3.2.4 Lexicon

As an aid in the labelling of Data Bases I and II, a phonetic labelling map (lexicon) was established. The purpose of this map was threefold: (1) to limit the labelling of each speaker to the same set of triads, allowing for free variation at a position, (2) to enable the inclusion, in software, of triads resulting from free variation, and (3) to expedite the human factors aspects of labelling, particularly with regard to rapid label entry. Each triad is represented in the lexicon by the alphaphonetic characters that are used for input to the keyboard. The lexicon of Data Base I is given in Table 3.9 and the Data Base II lexicon in Table 3.10.

3.2.5 Labelling Error Correction

During the process of sentnce digitizing and phonetic event labelling, a number of errors were introduced by the operator. These errors fall into several categories including

1) incorrect sentence number,
2) incorrect speaker number,
3) illegitimate phonetic label,
4) legitimate but incorrect label,
5) incorrect boundaries, and
6) miscellaneous sentence label errors.

TABLE 3.9

Lexicon used in the labelling of Data Base I. Each triad of interest is shown in alphaphonetic form with possible free variation

SENTENCE 2

Keith	Dudley	taught	his	daughter	Susan	to	cook	a	fabulous	pudding	dish.
KX TH / EE	DX DX / UH	TX TX / AA, AW		DX DX / AW, AA	SX SX / UU		KX KX / UX		FX BX / AH	PX DX / UX	DX SH / IX

SENTENCE 3

The	thug	ransacked		the	shed	with	ceaseless	determination		to	do
DH TH / SW	TH GX / UH	AH SX / NX	SX KX / AH	DH SH / SW	SH DX / EH, AH		SX SX / EE	DX TX / EE	SW TX / NX		DX DX / UU

damage.
AH SW / MX

SENTENCE 4

Above all,	the	judge	was	baffled	by	the	dirty	revolver	which	shot
	DH DX / SW	ZH DX / UH		BX FX / AH		DH DX / SW	DX DX / ER	VX VX / AA, AW		SH TX / AA

the	guest
DH GX / SW	GX SX / EH

3.63

SENTENCE 5

Thus the excessively shoddy book caused the tudor's enthusiasm to

DH SX   SX SX   SH DX   BX KX   KX ZX   DH TX   TX DX   TH ZX   ZX TX
UH   EH   AA   UX   AW   SW   UU   UU   MX
UH
AA

deteriorate.

DX TX
EE

SENTENCE 6

Did Bev's giggling sister kick the sassy dude.

DX DX   BX VX   GX GX   IX SX   SX SX   KX KX   DH SX   SX SX   DX DX
IX   EH   IX   NG   IX   IX   SW   AH   UU
EH

SENTENCE 7

Few people guessed that Vivian's daughter performed this

PX PX   GX SX   VX VX   SW ZX   DX DX   PX FX   RX DX   DH SX
EE   EH   IX   NX   AW   ER   MX   IX
AA
AW

involved process.

VX VX   SX SX
AW   EH
AA

3.64

SENTENCE 8

Dad dashed from the shed to kick the puppy chewing his new shirt.

DX DX   DX SH   UH DH   DH SH   SH DX   KX KX   DH PX   PX PX   WX HX   ZX UU   SH TX
AH   AH   MX   SW   EH   IX   SW   UH   NG   NX   ER
AH

SENTENCE 9

These people shuddered in disgust when Cagney made a caustic and uncouth

DH ZX   PX PX   SH DX   SW DX   GX SX   SW KX   KX GX   EE EH   KX SX   UH KX   KX TH
EE   EE   UH   NX   UH   NX   AH   MX   AW   NX   UU
AA   EH   AA

rebuff.

BX FX
UH

SENTENCE 10

The teacher should have popped the beef dish into the

DH TX   TX TX   SH SH   SH DX   PX PX   DH BX   BX FX   DX SH   SW TX
SW   EE   ER   UX   AA   SW   EE   IX   NX

sizzling oven.

SX ZX   LX UH
IX   NG
EH

SENTENCE 11

Is it the duty of the packers to perform each detail.

DH DX / SW · DX DX / UU · DH DX / SW · KX ZX / ER · PX FX / ER · RX EE / MX · DX TX / EE

SENTENCE 12

Ted's shirt, together with his socks, were ruined by the booby trap.

TX DX / EH · SH TX / ER · GX DH / EH, AH · SX KX / AA · DH BX / SW · BX BX / UU

SENTENCE 13

Fifty talkers babbled casually as the cooks jittered

FX FX / IX · DX TX / EE · KX SX / ER · BX BX / AH · DH KX / SW · KX KX / UX · ZH DX / IX, EH · DX DX / ER

dirty dishes on the buffet.

DX DX / ER · DX SH / IX · AW DH / NX · DH BX / SW · BX FX / UH, UU

SENTENCE 14

Bob determined that people in Dunkirk caught puppies in sacks as a gag.

BX BX / AA · DX TX / EE, IX · PX PX / EE · UH KX / NX · KX KX / ER · PX PX / UH · SX KX / AH · GX GX / AH

SENTENCE 15

Susan's enthusiasm should not cause backers of Ted to persist in

SX SX / UU · IX TH / NX · TH ZX / UU · ZX SH / MX · SH DX / UX · KX ZX / AW, UH · KX ZX / ER · TX DX / EH · SX SX / IX

their attitude.

TX DX / UU

SENTENCE 16

Because the cost involves steadily performing the process, Tod should

KX ZX / AW, UH, AA · KX SX / AW, AA · VX VX / AW, AA · TX DX / EH · PX FX / ER · IX DH / NG · SX SX / EH · TX DX / AA · SH DX / UX

not dash into debt.

DX AA / NX · DX SH / AH · DX TX / EH

SENTENCE 17

Beverly was baffled by the pauper who fibbed about his populous family.

BX VX / EH   BX FX / AH   PX PX / AW / AA   FX BX / IX   PX PX / AA   AH LX / MX

SENTENCE 18

Tod's feet should be hurting because he has a pebble in his sock.

TX DX / AA   SH DX / UX / EH   IX BX / NG   KX ZX / AW / UH   PX BX / EH   SX KX / AA

SENTENCE 19

The singing officers asked for a third song

IX IX / NG   IX AW / NG   SX ZX / ER   ZX SX / AH   AW XX / NG

SENTENCE 20

Did Dutch's daughter chat with the goggle eyed circus clown.

DX DX / IX / EH   DX TX / UH   DX DX / AW / AA   SH TX / AH   GX GX / AA   SX KX / ER

SENTENCE 21

The third sauce stimulated their peptic ulcer and caused them to burp.

SX SX / AW / AA   IX YX / MX   PX PX / EH   KZ ZX / AW / UH / AA   SW TX / MX   BX PX / ER

TABLE 3.10

Lexicon used in the labelling of Data Base II. Each triad of interest is shown in alphaphonetic form with possible free variation.

SENTENCE 2

When	Beverly	cooks	her	good	vegetable	soup,	she	puts	in	a	teaspoon	of
	BX VX / EH	KX KX / UX / UU		GX DX / UX		SX PX / UU	SH PX / EE	PX TX / UX			TX SX / EE / IX	

butter	and	a	pinch	of	pepper.
BX DX / UH / AA					PX PX / EH

SENTENCE 3

Bob	Dudley	shipped	the	circuits	to	Boston	on	Thursday.
BX BX / AA / UH	DX DX / UH; DX LX / UH	SH PX / IX / EE	DH SX / SW	SX KX / ER / UH		BX SX / AW / AA / UH		TH ZX / ER / UH

SENTENCE 4

The	people	on	the	Long	Beach	dock	signalled	the	first	ship	that	passed
	PX PX / EE			LX NG / AW / UH	AW BX / NG	DX KX / AA / UH	SX GX / IX / EE		FX SX / ER	SH PX / IX / EE		

through	the	fog	bank.
	DH FX / SW		

SENTENCE 5

The	cops	suspected	that	the	judge's	sister	was	peddling
	KX PX / AA / UH	PX KX / EH		DH DX / SW	ZH DX / UH / AA / AH	SX SX / IX / UH / EE		PX DX / EH; PX LX / EH; IX NX / NG

narcotics.
NG AA / NX; NX RX / AA
NG UH / NX; NX KX / AA / UH

/

SENTENCE 6

```
Dad    is   using   a  shovel  to   move   the excess   dirt   from  the   curb.

DX DX       IX SW     SH VX    SW UV        SX SX    DX TX               KX BX
 AH          NG        UH       UU           EH       ER                  ER
 AA          NX        EH                    IX       EH                  EH
                       AH                             UH                  UH
                                                      IX
```

SENTENCE 7

```
A fifteen-mile   section  of  the     north      causeway  is in  poor  condition.

 FX FX  NX AA  SX KX           SW AW  NX RX   KX ZX                DX     SH
  IX     MX     EH              NX     AW      AW                     IX
                                      NX TH    AA                     EE
                                       AW      UH
```

SENTENCE 8

```
The   shop   boss   was   more  than  satisfied  with  the  fabricated   baffle.

    SH PX  BX SX      ZX AW       SX      DX            FX       BX   BX FX
     AA     AW         MX          AH                      AH          AH
     UH     AA                     EH                      EH          AA
                                   UH                      UH
```


SENTENCE 9

```
The  students   climbed  the  path   above  the cabin  and  were  pooped.

    TX   DX                   PX TH         KX BX            PX PX
     UU                        AH            AH               UU
                               AA            EH               UX
```

SENTENCE 10

```
Tod   should  be  putting       food   in  his  dog's    dish.

TX DX  SH DX     PX DX  IX FX  FX DX           DX GX  DX SH
 AA     UX        UX     NG     UU              AW     IX
                         NX     UX              AA     EE
                 PX IX                          UH
                  UX
```

SENTENCE 11

```
Paupers  and  those  near   poverty  substitute  hamburger for better cuts of beef.

PX  PX              ZX IX  PX  VX  SX BX  TX TX                           BX FX
 AW                  NX     AA      UH     UU                              EE
 AA                         UH      EH
 UH                 ZX EE   AW
                     NX
```

Error detection and correction was carried out in three steps. The first step treated errors of the category 3 and 5. Software automatically rejected any alphaphonetic label which did not conform to a legitimate entry in the phonetic symbol table. This same software rejected events having cursor positions reversed or separated by an amount in excess of 70 msec.

In the second step, errors in categories 1, 2, and 6 were deleted by printing out the phoneme labels for the entire 35000 phonetic events, and comparing speaker and sentence numbers to the labelling and digitizing logs. This task was quite laborious, but permitted correcting a number of errors within the label fields.

The final step of error detection was directed at errors in category 4. Errors in this category would be more difficult to detect if each sentence were labelled only once for each speaker. Each speaker recorded two sessions, however, and a comparison of phonetic event labels for the same positions in corresponding sentences was carried. Assuming that the phonetic content of the observed positions was the same for the same speaker across the two recordings, a consistency check was carried out and unconsistent pairs were rejected.

While it is obvious that all errors were not detected, it is felt that the majority were found and rejected or corrected.

4.0 COARTICULATION AND PHONETIC ANALYSIS STUDY

4.1 INTRODUCTION

In speech, consonantal environments and overriding linguistic framework significantly influence the physiological and acoustical structure of embedded vowels and, to a lesser degree, nasals. In many cases, a sound displays more of the characteristics of an adjacent phoneme than would be exhibited in a null environment (assimilation). In less frequent circumstances, contiguous sounds acquire a state of greater dissimilarity (dissimilation). Heffner (1969) discusses the physiological implications of speech sounds in context. The acoustical effects of such phenomena, which are of more immediate concern, are manifested in vowels and nasals as 1) deviations in formant structure (frequency, bandwidth, relative amplitude), 2) variations in event duration, 3) differences in the fundamental frequency, 4) changes in the level of amplitude, and 5) possible superposition of frication and aspiration. The precise nature of these effects is a function of the particular articulatory characteristics of the consonant types in the environment and the syntactic structure.

Of primary interest in the context of the SASIS concept is the variation in vowel and nasal spectral structure (number 1 above) as it contributes to a lessening of the separation between intra- and inter-speaker distance distributions of a phonetic type. Variations in event duration are related to achievement of formant targets and, therefore, are also relatively important while the remaining three effects listed above are somewhat secondary except, perhaps, in an analysis of features extending beyond the basic LPC spectrum. The major goal of this study has been to determine, through empirical means, those phonetic types, of the set of fourteen previously selected for use in this work, least sensitive to diverse consonantal environments under differing levels of contextual constraint in a pairwise token comparison. A secondary consideration, from the opposing viewpoint, involves a determination of those context types which tend to maximize the speaker discrimination abilities of an arbitrary vocalic event. Experimentation in this study has been directed towards a quantification of intra-speaker variance and the development of mean F-ratios for each type indicating separation of intra- and inter-speaker distributions.

Conclusions related to the context viewpoint are based on previously established knowledge in the area of acoustic phonetics. Consonant contexts in this work are distinguished on the basis of place of articulation through categorization by consonant type and by the separation of second formant loci frequencies (hubs) into low, medium, and high positions (Potter, Kopp, and, Kopp, 1966). A breakdown of contexts by manner of articulation and voicing is also of interest; however, spectral variation along these dimensions is less significant and such distinctions were not empirically made. Experimental work is divided into four phases: 1) generation of the mean spectrum for each contextual hub category for each phonetic type of each speaker, 2) determination of the intra-speaker spectral variance as a function of frequency and the mean spectral variance for each type of each speaker, 3) computation of the mean F-ratio, based on intra- and inter-speaker distance distributions, for each type under three conditions of contextual constraint, and 4) generation of modified F-ratios and SOC curves, under the highest level of contextual constraint, for each type using a weighted Euclidean distance measure. All experimental work is based on Data Base 1 (25 speakers) from which approximately 6700 triads were labelled. The overall frequency of occurrence of events is provided by type in Table 4.1.

TABLE 4.1

Phonetic Type Frequencies of Data Base I

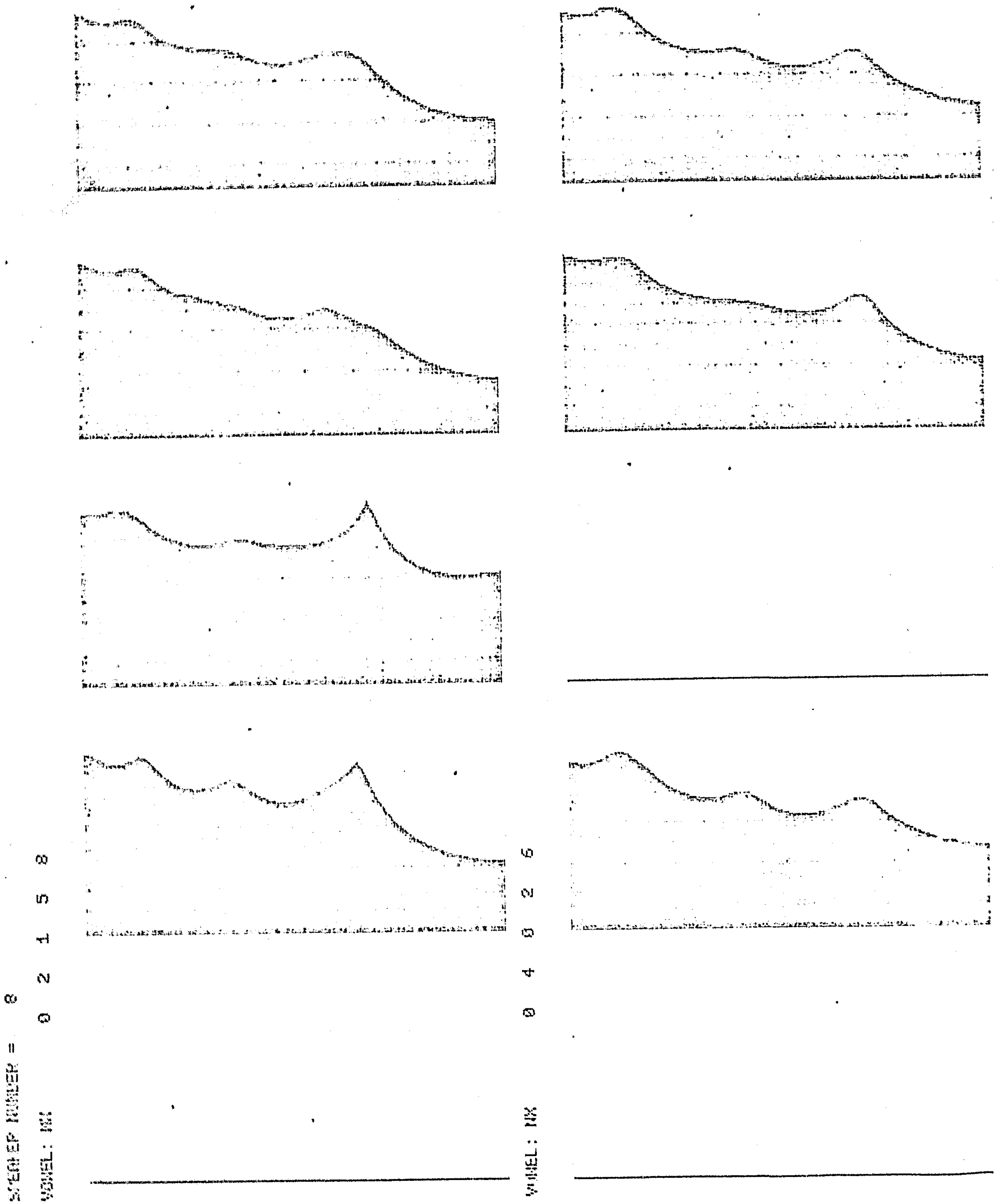
Type	Freq.	Type	Freq.
MX	0.0525	AH	0.0915
NX	0.0626	AW	0.0713
NG	0.0489	UX	0.0391
EE	0.0693	UU	0.0701
IX	0.0965	UH	0.0839
EH	0.0967	ER	0.0370
AA	0.0919	SW	0.0379

4.2 QUALITATIVE SPECTRUM EVALUATION

The 64 point LPC spectra of the labelled tokens of Data Base I were processed for the purpose of generating and displaying the mean spectrum, under each hub context condition, of each phonetic type of each speaker (Figure 4.1). The context cases averaged were 1) low adjacent second formant locus on each side /p,b,f,v/ (bilabial, labiodental), 2) middle adjacent second formant locus on each side /k,g,θ,ð,s,z/ (lingua-palatal, lingua-dental, lingua-aveolar, 3) high adjacent second formant locus on each side /t,d,ʃ,ʒ)/ (lingua-aveolar, lingua-palatal), and 4) mixed adjacent second formant loci.[1] In addition, the mean spectrum for all tokens of each type of each speaker was developed. Some context categories for certain types did not possess any tokens due to the lack of words in the sentence set containing these triads.

The mean spectra generated were visually examined for the purposes of developing qualitative conclusions with regard to intra-speaker effects and verifying the validity of the procedures used in labelling.

[1] To be more precise, the hubs of the values /k/ and /g/ are variable and tend to be slightly higher in frequency than the hubs of the vowels with which they are combined.



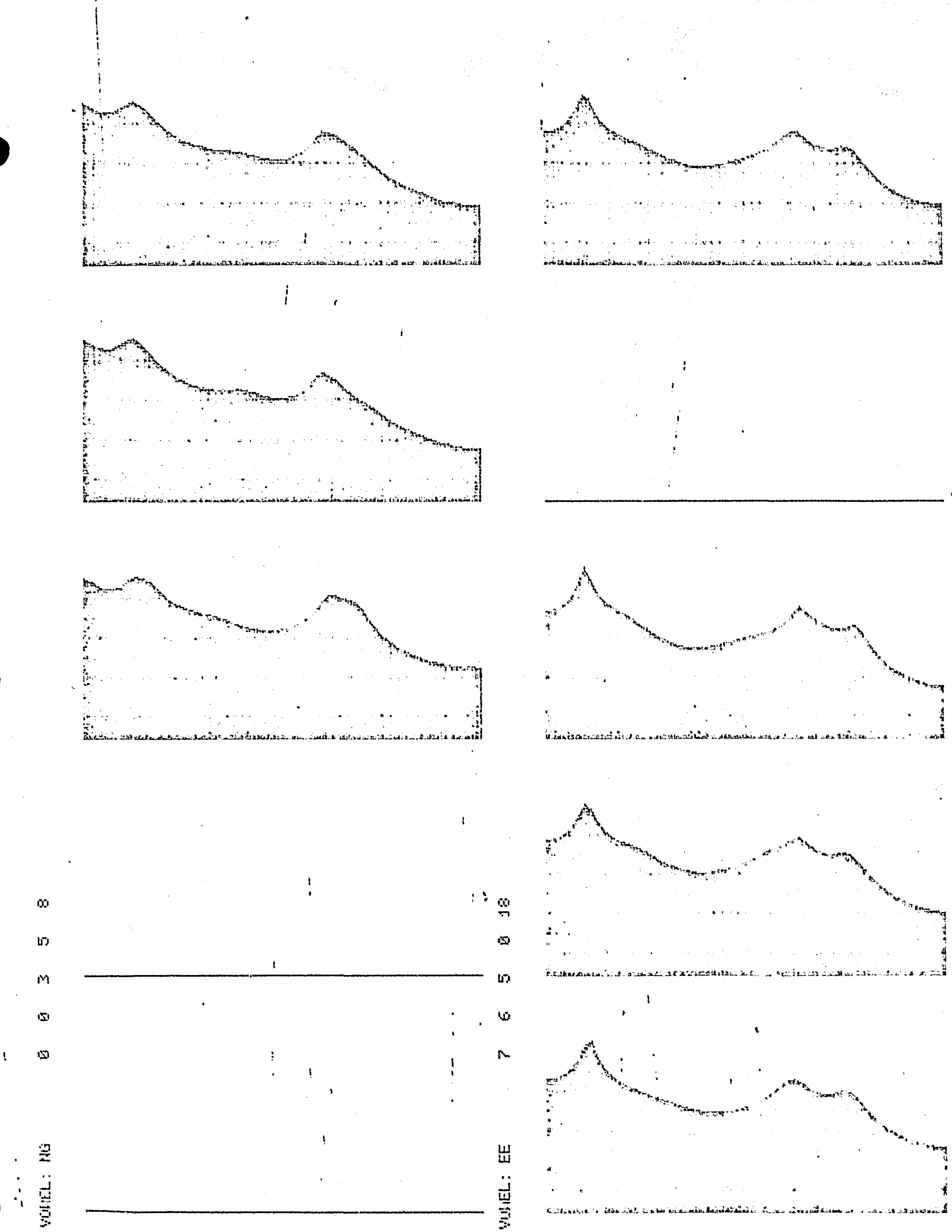
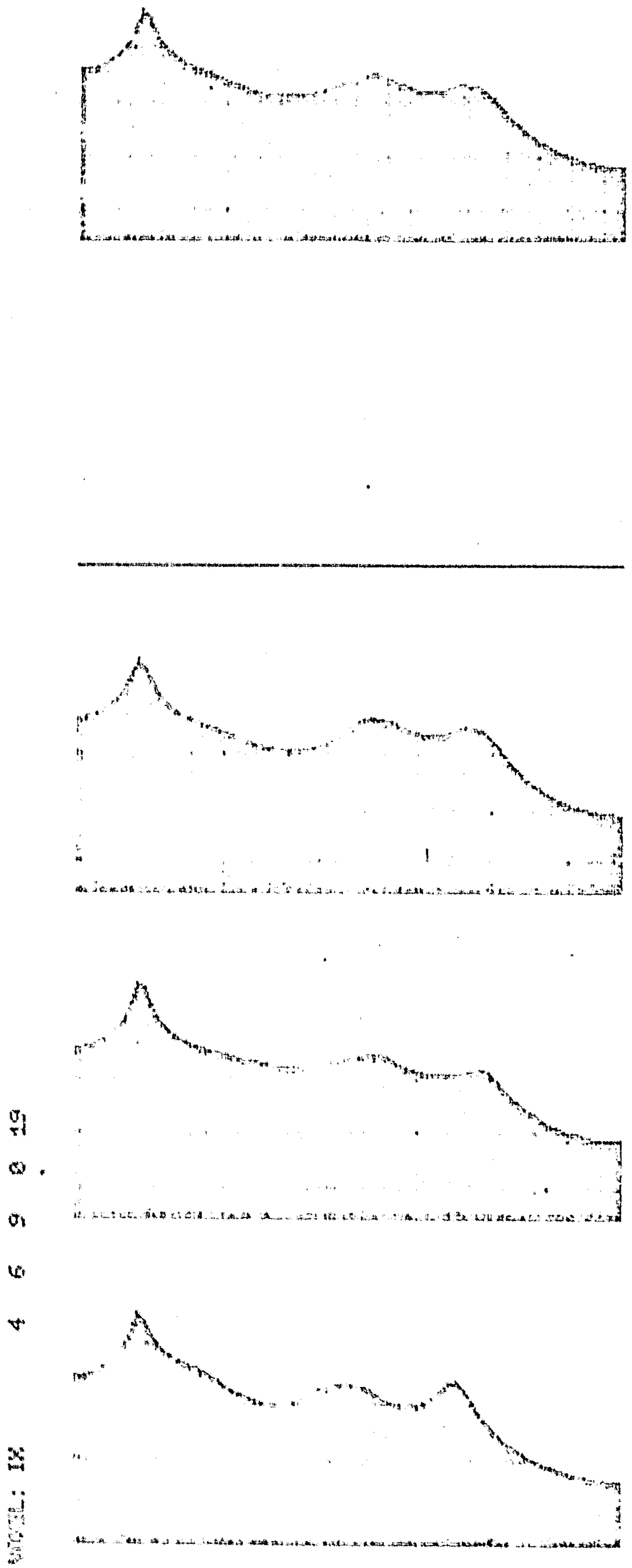
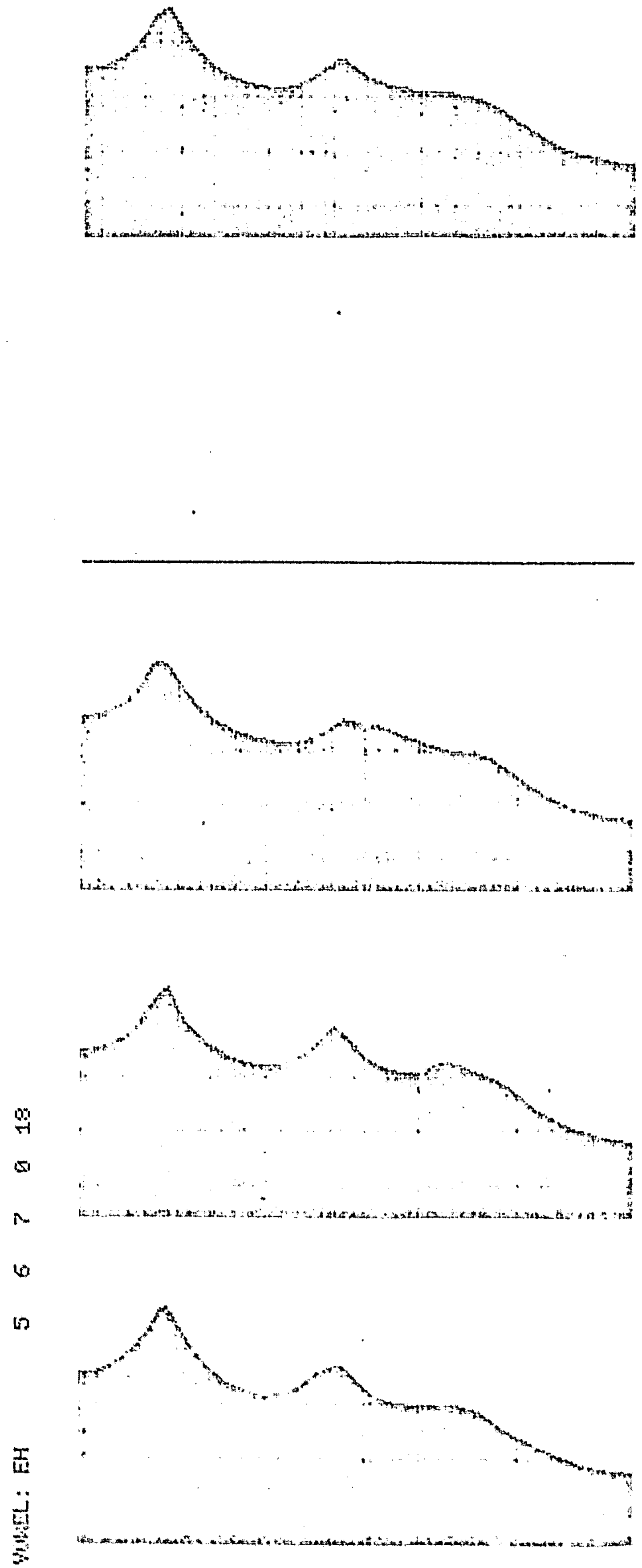
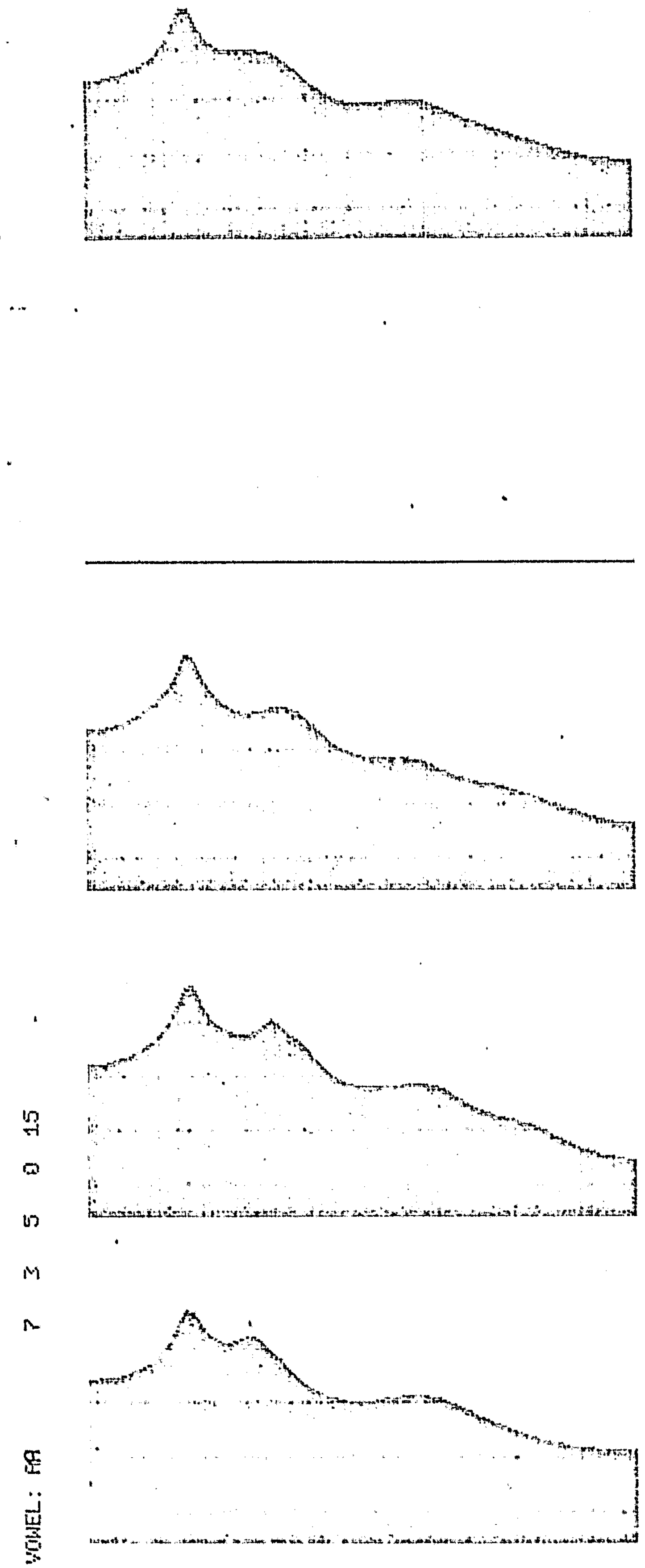


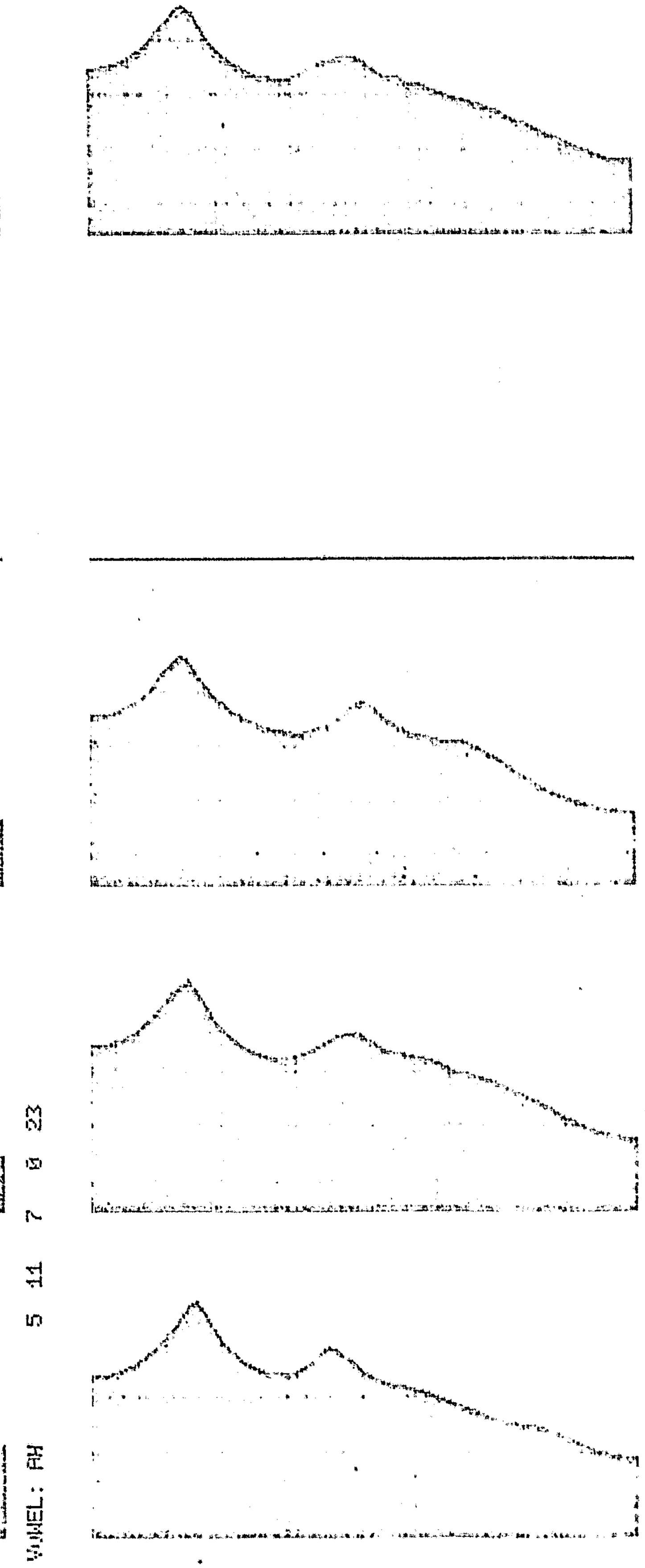
Figure 4.1

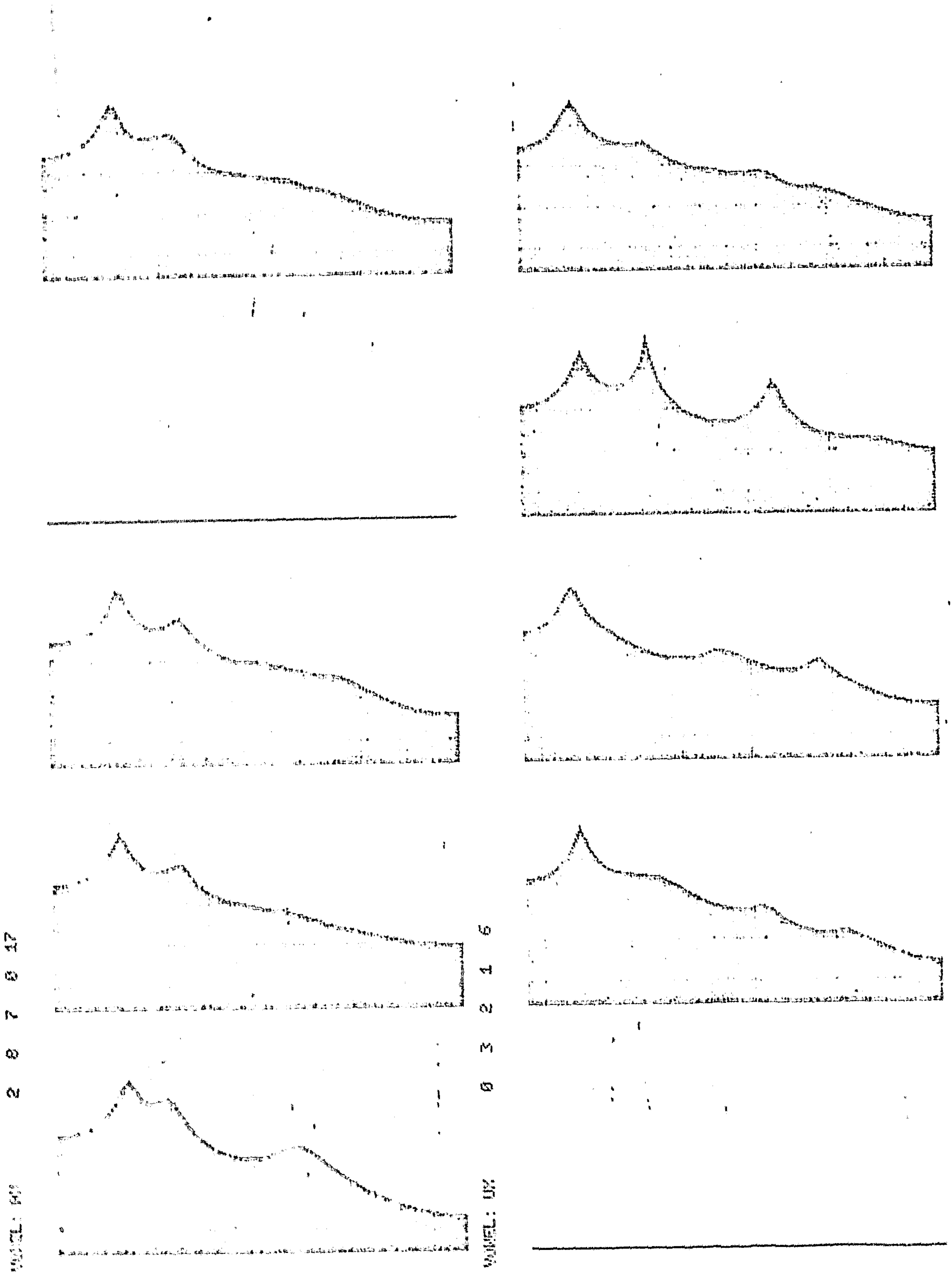
Mean spectra for each type of one speaker (No. 8) under various context conditions. From top to bottom, each spectrum represents the mean of a) all tokens for that type, b) mixed and valuable hub context, c) high hub context, d) medium hub context, and e) low hub context. The counts associated with each type represent the number of tokens for each of the respective context conditions.

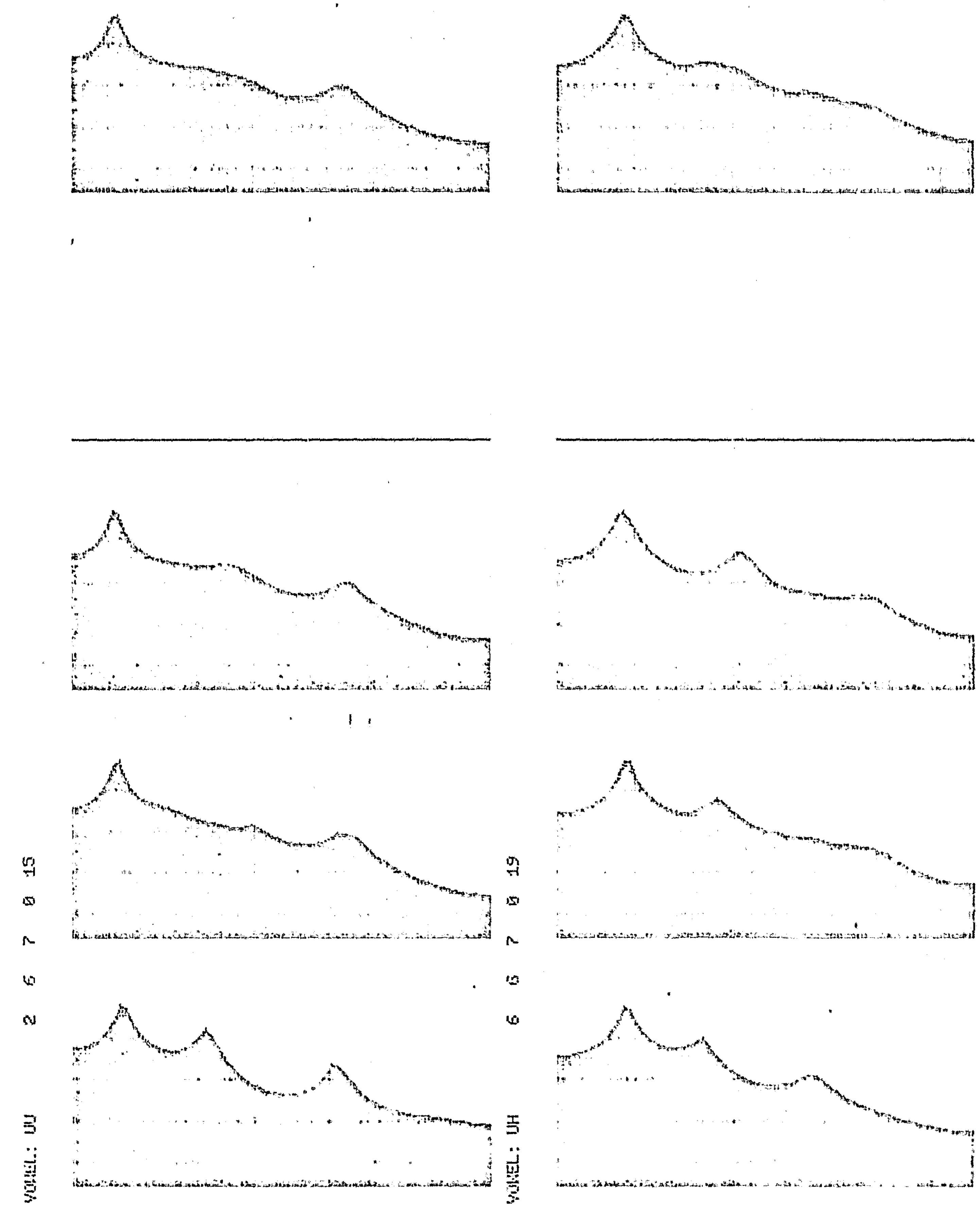

VOWEL: IX
4 6 9 0 19

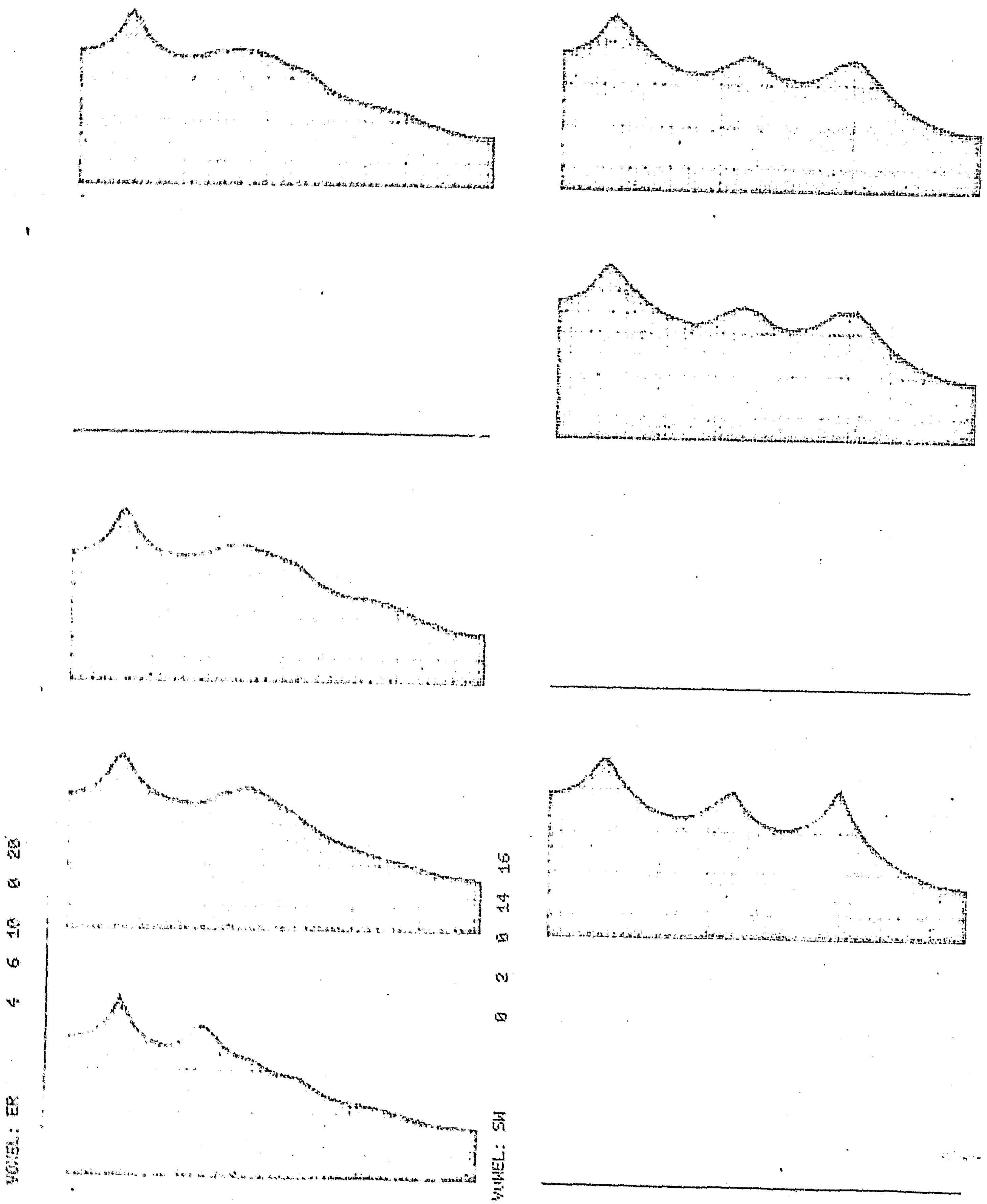

VOWEL: EH
5 6 7 0 18


VOWEL: AA
7 3 5 0 15


VOWEL: AH
5 11 7 0 23


2 0 7 0 17


VOWEL: UU
2 6 7 0 15
VOWEL: UH
6 6 7 0 19



As anticipated, the second formant frequency generally increased and the first formant frequency decreased with contexts of increasingly higher hub position indicating that minor differences in labelling technique were secondary with respect to the variance introduced by contextual effects. In a few cases, however, there was an inverse movement of formants with increasing contextual hub position. For the events /ɛ, a,ɑ, ɔ, ʌ, ɜ, i/, it was observed that the mean spectrum for the high and medium contexts were assonant but rather dissimilar from the spectra of low contexts.[2] In the remaining events, all three contexts displayed considerable deviation from each other.

Most inter-context variation was exhibited by neutral and rounded vowels. The existence of a high degree of intra-speaker variation for rounded vowels is attributed by Stevens and House (1963) to the slow rate of lip movement relative to the rate of movement of the other articulatory organs. For the type /ʊ/ it was noticed that, for virtually every speaker, the second formant of the high context position was at a considerably greater frequency that that of the middle hub context. However, only one word type was used for each context condition of this vowel; thus the statistical significance for this particular case can be considered low. A similar, though more infrequent situation, of greater statistical validity was observed for the middle and low context positions of /ɜ, ʌ, ɔ, u/. The only anomalies observed among front vowels were some large differences in second formant frequency between the middle and low context cases of /I/. The type /i/ exhibited remarkable inter-context consistency. This result is in agreement with the findings of Stevens and House. The schwa /ə/ was found to be reasonably consistent in spectral shape probably as a result of it being labelled only in the context of the word type "the." Inter-context spectral variance appeared to be significantly greater for /m/ than for the nasals /n, ŋ/.

[2] The type /i/ exhibited little dissimilarity between the medium/high and the low mean spectra.

4.3 INTRA-SPEAKER SPECTRAL VARIANCE

Inter-context variance was calculated at each of the 64 frequency points for each phonetic type of all speakers of Data Base I. Results were plotted (Figure 4.2). A mean variance across frequency positions was computed for each calculated resultant vector. These values were averaged across speakers for each type to provide the intra-speaker variance ranking shown in Table 4.2. A ranking by the mean of the distance function ($1-\cos^2\theta$) is given in Table 4.3. Weighting by the number of tokens for each speaker was not employed in computing the average.

TABLE 4.2

Ranking of Mean Intra-Speaker Spectral Variance by Type

Type	Mean Spectral Variance	Type	Mean Spectral Variance
AW	247.10	AH	297.50
EE	255.23	EH	299.21
SW	267.20	ER	322.66
UH	286.98	UX	351.66
AA	295.10	NX	353.41
IX	296.34	NG	389.01
UU	296.34	MX	431.87

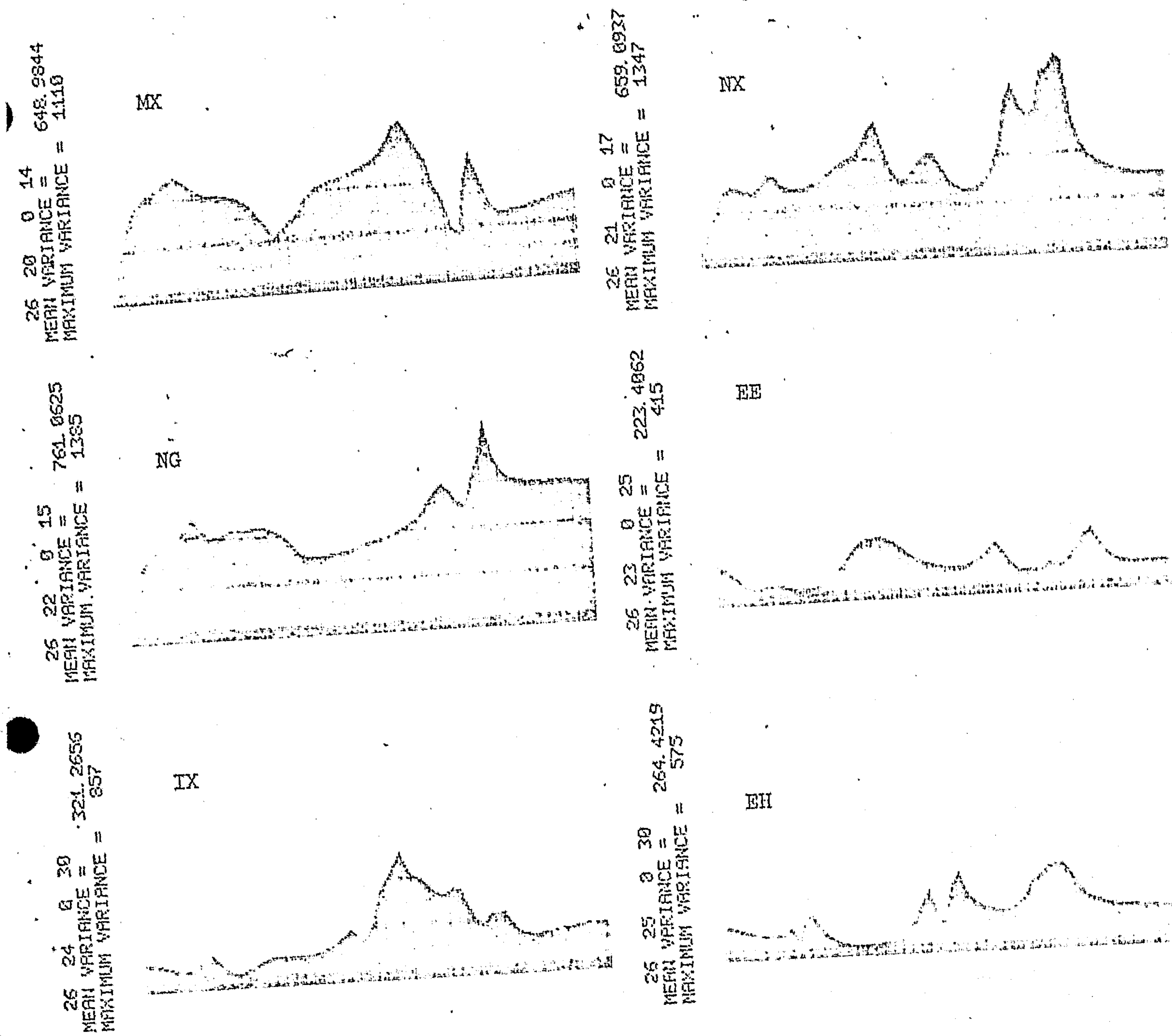


Figure 4.2. Inter-context spectral variance as a function of frequency for each phonetic type of speaker 26. The frequency range is 0 to 3400 Hz.

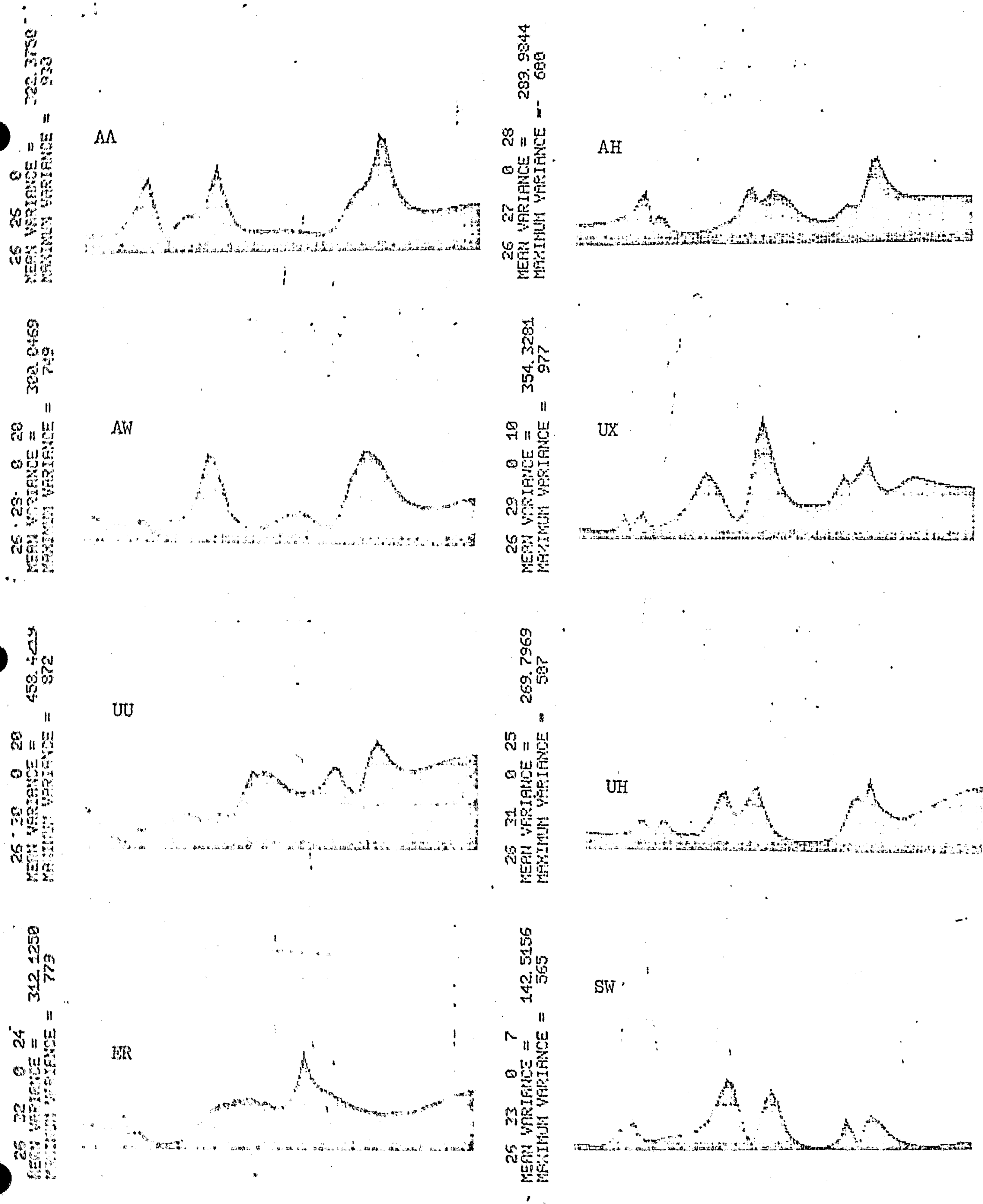


TABLE 4.3

Ranking of Mean Intra-Speaker Distance
$(1-\cos^2\theta)$ by Type

Type	Mean Distance
EE	0.7913
AW	0.9252
AH	1.0668
AA	1.0708
EH	1.1533
SW	1.1558
IX	1.1767
NX	1.1784
UU	1.2385
NG	1.3142
ER	1.4330
MX	1.6859
UX	1.7934
UH	1.9430

Mean intra-speaker spectral variance was found to be less for long vowels /i, a, ɑ/ than for short vowels as the former tend to achieve formant target positions with greater probability. Nasals exhibited the highest intra-speaker variance. This result is somewhat surprising since the articulatory configuration is essentially stationary during nasal production and therefore relatively insensitive to the effects of context (Glenn and Kleiner, 1968). It is probable that the variance can be attributed to differences in stress levels causing inconsistency in nasal production. Otherwise, it was found that variance was typically greater at higher frequencies as a result of the fact that the highest peak of each spectrum, which is usually the first formant, was pinned to 255 quarter db. Thus, small differences in spectral rolloff between tokens of the same type for a speaker became more pronounced at higher frequencies. An additional observation concerns maxima in the variance vector. The number of local maxima was usually greater than four. In most cases, either a single maximum or a double peak could be found centered at the position of each of the mean formant frequencies for that type. It is hypothesized that the peak splitting is the result of minor frequency shifting of formants possessing very similar amplitude values. Considerable inter-speaker dissimilarity was noted in the overall shape of variance vector plots. A mean variance was computed for each speaker by averaging across phonetic types. The ratio of the variance of the least consistent speaker to that of the most consistent was found to be approximately 2 to 1.

4.4 SPEAKER DISCRIMINATION AND CONTEXTUAL CONSTRAINT

4.4.1 Overview

The primary goal of the experimentation described in sections 4.4.2 and 4.4.3 is the determination of those phonetic types that provide the greatest speaker separation on a single type basis independent of correlations with the distances of other types. A ranking of this nature is useful in providing some foundation on which an operater, in forensic/investigative situations, can select the most discriminating subset of types from the speech material available in basis and query recordings. A secondary goal concerns the increment in discrimination that can be achieved by the use of comparisons involving tokens taken from similar phonetic environments relative to comparisons made irrespective of context.

Section 4.4.2 discusses empirical work that was undertaken prior to the initiation of those tasks involving 1) selection of a feature set which is a function of the phonetic type under consideration and 2) the exploration and adaption of an appropriate distance function. The criterion of performance emphasized in the section is the traditional F-ratio computed on intra- and inter-distance distributions.

Section 4.4.3 presents results developed subsequent to a valid, although not finalized, feature set. Events are ranked for the text dependent constraint on the basis of SOC curves and two measures of F-ratio.

4.4.2 Performance Under Three Constraint Conditions

The distance measure utilized in this stage of the analysis is a function of the angle θ between the feature vectors $\overline{X}_i$ and $\overline{X}_j$ derived from speakers i and j:

$$d = \sin^2\theta$$

$$\text{or} \quad d = 1-\cos^2\theta$$

where

$$\cos\theta = \frac{\overline{X}_i \cdot \overline{X}_j}{|\overline{X}_i|\ |\overline{X}_j|}$$

The basic LPC spectrum of 64 frequency points was taken as the feature vector for all phonetic types. As previously mentioned, the highest peak of each spectrum was set to 255 quarter db. An alternate normalization procedure involves forcing each vector to a fixed length; however, with the distance measure stated above, the two methods of normalization will give similar results on a local basis. In the case of all vectors normalized to the same length, the discriminant function of $(1-\cos^2\theta)$ gives relative results identical to the unweighted Euclidean distance metric. The angular distance measure was chosen prior to completion of the task involving distance function evaluation; thus, the results of that investigation concerning a more optimal discriminant could not be used in the phoneme analysis/coarticulation study.

The measure of intra- and inter-speaker distribution separation employed was the F-ratio defined traditionally as

$$F = \frac{\text{variance of means}}{\text{mean of variances}}.$$

The intra-distribution for each type of each speaker was established by computing the distances between all possible intra pairs, subject to one of the constraint conditions stated below. The inter distribution was developed by computation of all possible distances between the tokens of the intra set and those of different speakers, subject to the constraint condition. From the resulting distributions, an F-ratio was computed for each phonetic type for each speaker. A mean F-ratio was calculated for each type by averaging across speakers. Three constraint conditions were used in distribution generation: 1) context-independent case - comparison of two tokens of the same type independent of context, 2) context-dependent case - comparison of two tokens of the same type from the same environment with regard to contextual hub positions, e.g., comparison of [HIGH - ʌ́ - HIGH] with [HIGH - ʌ - HIGH] , and 3) text-dependent - comparison of two tokens of the same type possessing the same phonetic type environment, e.g., comparison of [P - ʒ - P] with [P - ʒ́ - P] . Mean ratios were computed for each of the three constraint conditions and are shown ranked in Table 4.4.

Histograms of the intra- and inter-speaker distances for two types of one speaker are shown in Figures 4.3 and 4.4. The approximate density functions generated were found to be basically unimodal in all cases. Means and variances compute for the intra sets were based on anywhere from 70 to 250 comparisons with the context-independent condition and from 5 to 35 comparisons in the text-dependent case. Obviously, the statistical significance of the F-ratios of the text-dependent ranking should be qualitatively deemed less than that of the context-independent ranking.

It can be stated that the F-ratios for the particular distance function and feature set used are low with considerable overlap between distributions. However, the major interest in the phoneme analysis/co-articulation study is the relative value of various types in a discrimination situation rather than absolute probability of error; thus, the metric and features employed are believed to be adequate for this goal. Furthermore, the use of more than a single type in an overall similarity measure is expected to greatly enhance speaker separability.

TABLE 4.4

The ranking of mean F-ratios, based on intra- and inter-speaker distribution by type, for three constraint conditions used in comparisons.

Context Independent		Context Dependent		Text Dependent	
Type	F-Ratio	Type	F-Ratio	Type	F-Ratio
EE	0.29	UX	0.40	MX	0.51
NX	0.20	EE	0.34	EE	0.39
AH	0.18	MX	0.30	IX	0.34
AW	0.16	AW	0.26	AH	0.34
NG	0.16	SW	0.24	NX	0.33
SW	0.15	NX	0.23	NG	0.33
MX	0.13	NG	0.20	UX	0.33
EH	0.13	EH	0.19	AW	0.28
IX	0.13	AH	0.19	UU	0.27
UU	0.12	UU	0.17	SW	0.27
UH	0.10	UH	0.15	AA	0.27
AA	0.08	IX	0.12	UH	0.24
UX	0.07	AA	0.12	EH	0.19
ER	0.06	ER	0.06	ER	0.14

Figure 4.3 Intra- and inter-speaker histograms on $(1-\cos^2\theta)$ for phonetic type /i/ of speaker 5. (Text independent, F = 0.160)

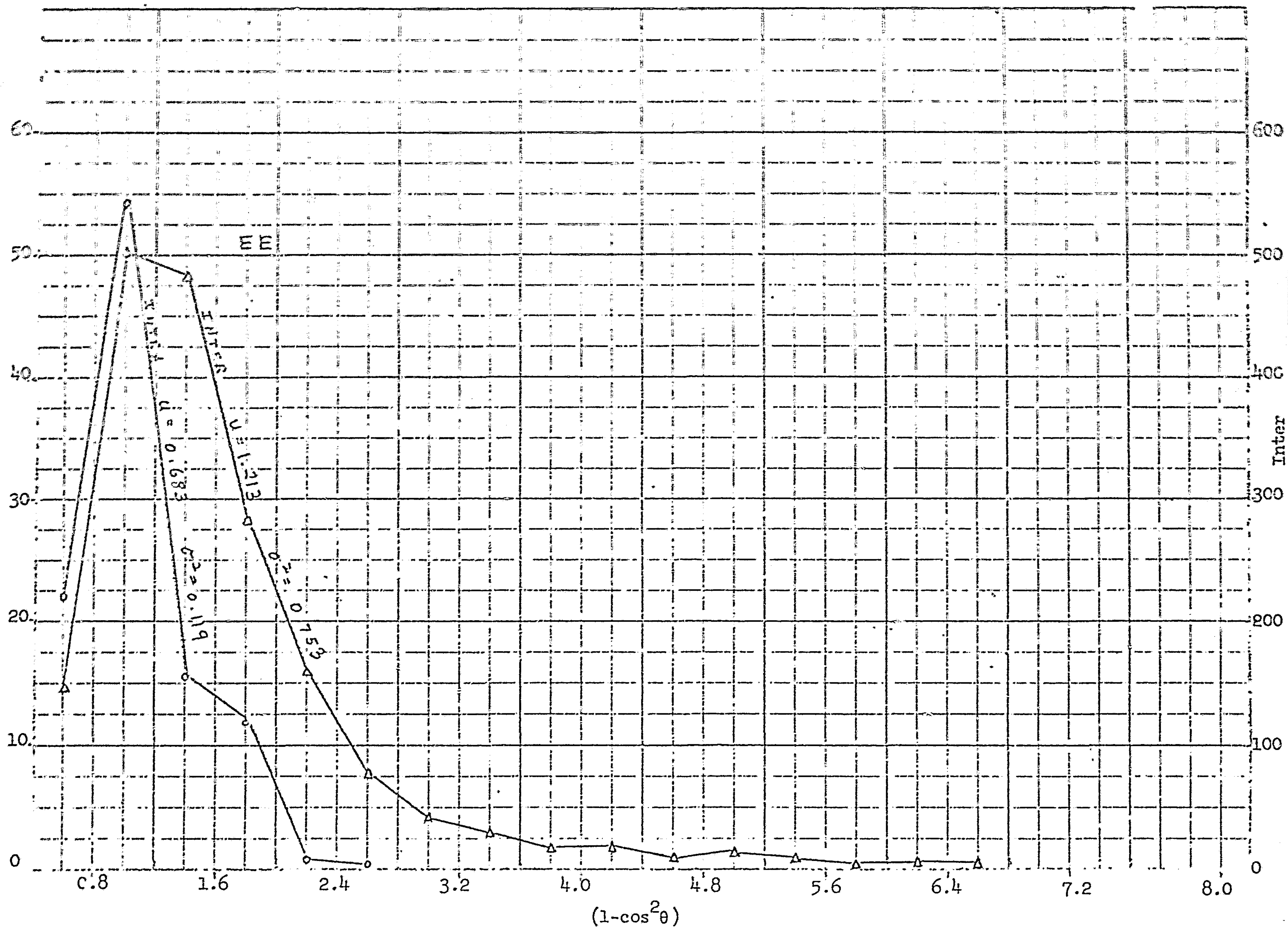
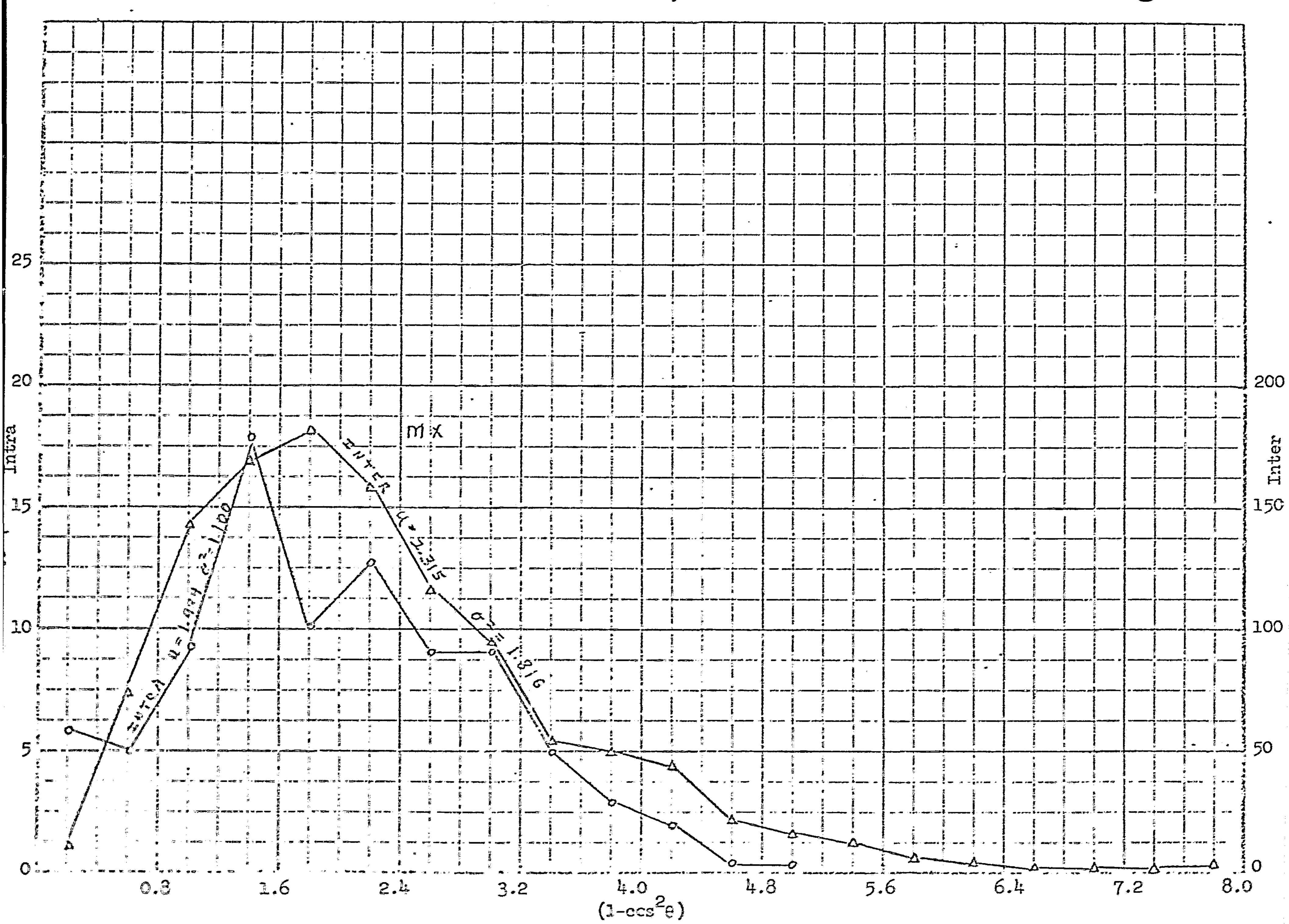


Figure 4.4 Intra- and inter-speaker histograms on $(1-\cos^2\theta)$ for phonetic type /m/ of speaker 5. (Text independent, F = 0.018)



As expected, F-ratios became greater as the level of contextual constraint was increased. The ratio of the F-ratio of the highest ranked type in the text-dependent case (/m/) to that of the highest type in the context-independent ranking (/i/) was 1.77 while the ratio for the lowest ranked types was 2.37. Under the text-dependent constraint, the ratio of F-ratios of the highest and lowest ranked type was 3.64. The increase in F-ratio as greater constraint was imposed is attributed primarily to a significant (as much as an order of magnitude in the intra case) reduction in the variance of the distributions. Increases in the difference between intra- and inter-speaker means were much less noticeable.

Similarity of the ordering of types across constraint conditions was only moderate although some types exhibited strong consistency. The event /i/ attained the greatest or second greatest F-ratio for each of the three constraint conditions while /ʒ/ ranked lowest for all cases. Nasals were in the upper half of each of the rankings. Thus, while exhibiting high degrees of intra-speaker mean spectral variance, there are sufficient inter-speaker spectral differences between nasals to achieve a higher than median F-ratio. Given these results and the observations of others (Fant, 1960; Fujimura, 1962), it is reasonable to state that the inter-speaker differences in the nasal cavity are greater than those of the oral cavity. The position of /ʊ/ across rankings varied considerably due to the limited number of tokens obtained for this type. The schwa, which was labelled only in the context of "the" was intermediate in value in the context-independent and dependent rankings but dropped in position somewhat for the text-dependent condition due to other types achieving greater gains in F-ratio as the phonetic type on both sides of the event was fixed in the comparison. With regard to position of articulation, front vowels and nasals were found to be better discriminators than back vowels. This result is particularly prominent under the text-dependent constraint. A strong correlation was not found between discrimination capability and the categorization of vowels by duration as long or short.

4.4.3 Performance Under the Text Dependent Constraint

Using near optimum sets of feature vectors which are a function of the phonetic type, performance for each phoneme was empirically established on a text dependent basis employing, as a criterion, SOC curves and two measures of F-ratio. The distance measure used was the unaveraged weighted Euclidean metric described in Section 7.2. The SOC curves and ranking are shown in Figure 4.5 and Table 4.5 respectively. Two F-ratio measures, F2 and F4 defined in Section 7.2.3.1 were also calculated under the same metric and constraints and are shown ranked by phonetic type in Table 4.6.

Comparing the ranking of traditional F-ratios for the text dependent case given in Section 4.4.3 with the SOC ranking of Table 4.5 it is useful to consider those events which differ little in F-ratio or SOC area as interchangeable members of a group. Thus, by switching the positions of members within a group to minimize differences between the rankings, it is apparent that excluding the types /ʊ/, for which there exists little data, and /u/ good qualitative agreement is found between the two criteria. Reasonable agreement can be found between F2 and the traditional F-ratio. Agreement with F4 is less apparent. The large values of F2 and F4 relative to the traditional F-ratio can be attributed to both the quality of the matric and the nature of the criteria. The F4 criterion is a function of the separate variances for the two distributions and is, therefore, not directly comparable in absolute value with the traditional F-ratio.

4.5 DISCUSSION

The influence of context on distance and mean variance measures can be traced to amplitude shifts in specific frequency regions. House and Stevens indicate that deviations in first formant position under diverse contexts are minor in relation to those of the second formant. Vowels with low first formants are especially insensitive to variations in that formant. The shift in second formant frequency is roughly in proportion to the difference between the second formant frequency of the vowel spoken in a null environment and the

TABLE 4.5

Ranking of event by SOC curve under the text dependent constraint. The distance measure used was the weighted Euclidean operating on 30 features. The schwa was not ranked.

Highest Ranked
UX
UU
EE
MX
IX
AH
AW
NX
NG
UH
ER
AA
EH
Lowest Ranked

combined effective second formant locus of the adjacent consonants. The direction of the displacement is towards the positions of the loci of the surrounding consonants. In the case of /u/ in a postdental environment, second formant shifts of as much as 350 Hz have been found by Stevens and House. At the other extreme /i/ and /a/ typically exhibited inter-context differences in second formant of no greater than approximately 100 Hz. The mean spectral variance findings of this work for those three vowels tend to generally agree with these observations.

With regard to the frequency of phonetic types, Denes (1963) has noted that the frequency of front vowels exceeds the rate of occurrence of central and back vowels combined. Thus, in the text-dependent case especially, the frequency and discrimination capability of phonetic types is coincidental.

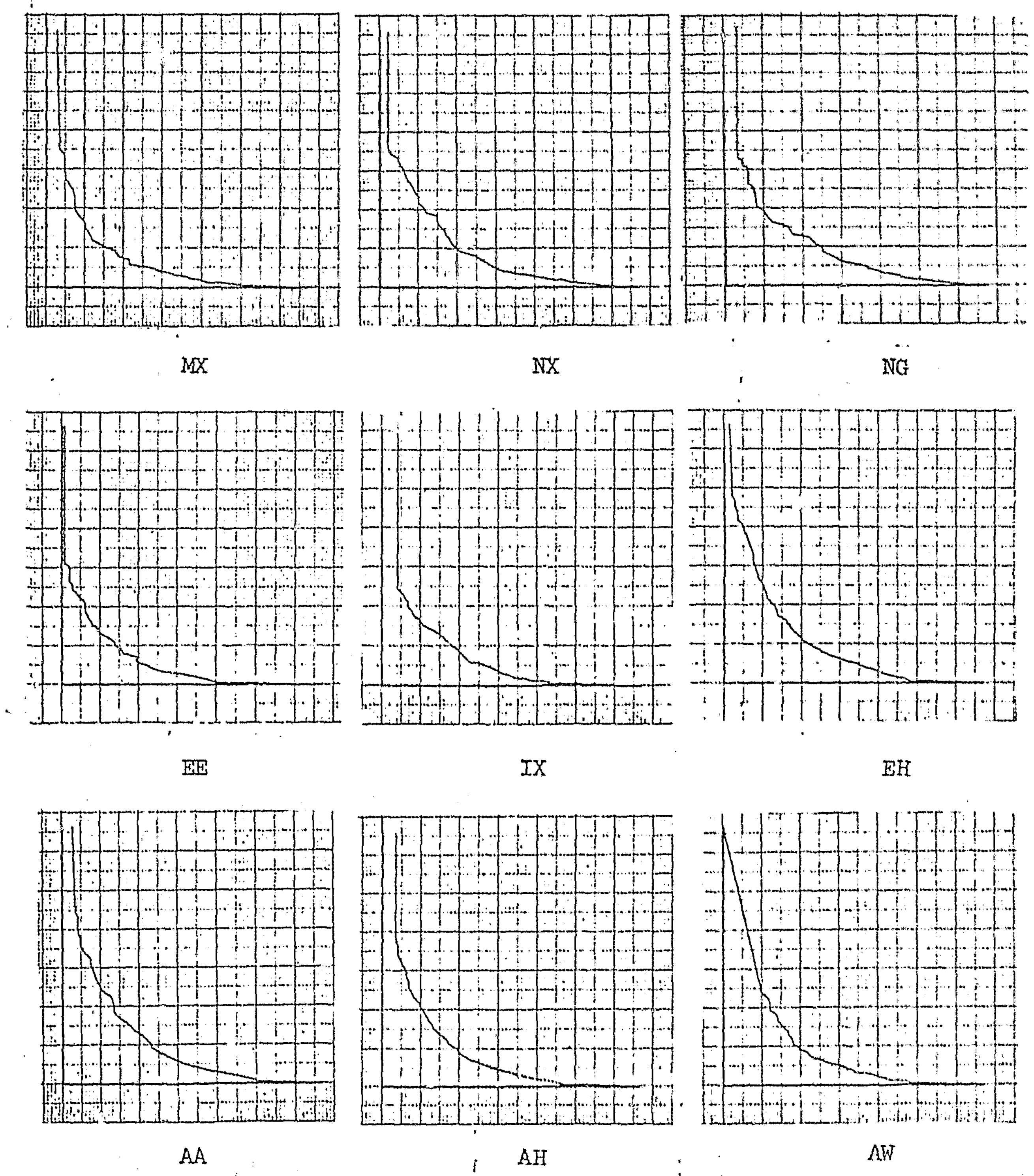


Figure 4.5 SOC curves for each phonetic type based on the weighted Euclidean distances of Data Base I under the text dependent constraint.

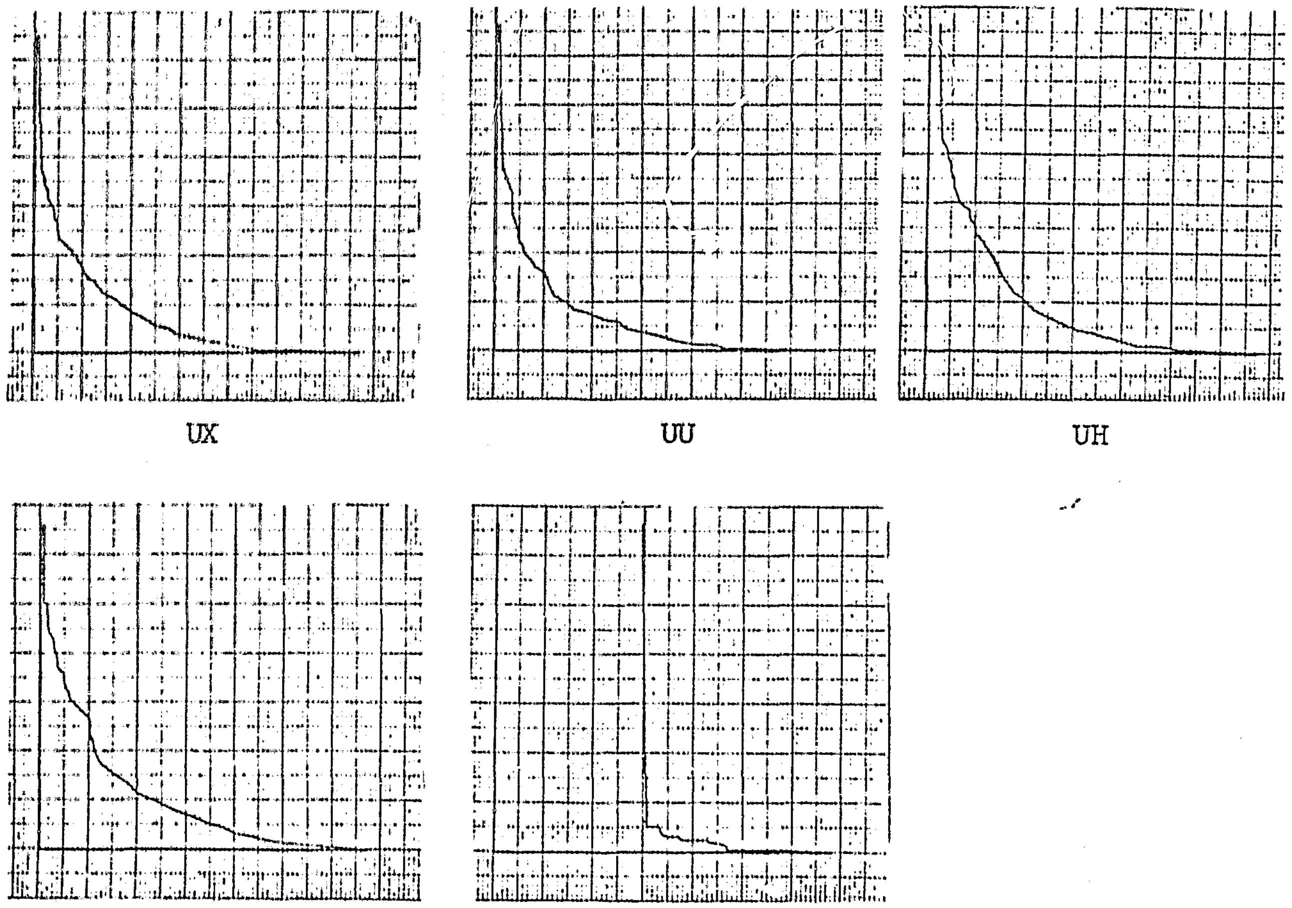


Figure 4.5 (continued)

TABLE 4.6

Ranking of event by F2 and F4 under the text dependent constraint. The distance measure used was the weighted Euclidean operating on 30 features.

Event	F2	Event	F4
UX	3.0	UU	6.5
UU	2.4	IX	4.8
EE	2.1	EE	4.4
IX	1.8	AH	4.1
AH	1.7	AW	3.8
AW	1.6	EA	3.7
NX	1.5	MX	3.6
MX	1.4	ER	3.3
UH	1.3	AA	3.2
AA	1.3	UH	3.1
SW	1.3	UX	2.7
NG	1.2	NX	2.7
EH	1.2	NG	2.6
ER	1.1	SW	0.2

Although empirical work was not done in this study from the context viewpoint, it is possible to draw some conclusions concerning the desirability of certain environments. Certainly to minimize the extent of formant undershoot it is preferable to select consonant-vocalic combinations containing hub position differences which are not greatly dissimilar. The |k| and |g| consonantal environments are highly desirable because of their tendency to maintain a variable hub only slightly higher than the vowel second formant frequency. To a lesser extent the locus of the glide /l/ also tends to be variable with the place of articulation of the vowel. Formant target region undershoot for any vowel in velar or /l/ contexts should therefore be minimized.[3] Other glide environment of reduced influence are: 1) /w/

[3] There is some evidence that the initial /l/ in combination with certain vowels, /u/ in particular, accentuates the interspeaker differences of the vowel (Potter, Kopp, and Kopp, 1966).

with back vowels, 2) /j/ with front vowels, and 3) /r/ with low vowels. Nasal environments are to be avoided because of their tendency to introduce zeros in the vowel spectrum. In a text-dependent case, however, this matter is of less significance. Stevens and House state that a voiced environment, relative to an unvoiced, causes a lower first formant frequency and a higher second formant frequency. Relative to manner of articulation, higher second formant frequencies are obtained for front vowels in stop environments relative to fricative environments and for fricative environments in the case of /u/ and /v/. However these formant deviations are probably secondary. Of greater interest, perhaps, are the results of House and Fairbanks (1953) indicating that vowels in fricative environments tend to be of greater duration and power than those in stop environments and are therefore somewhat less susceptible to formant undershoot and labelling jitter. As is well known, duration for a voiced environment is greater than for an unvoiced environment.

It is worthwhile to briefly consider the extent to which Data Base 1 is representative of the type of speech material that might typically be encountered in an investigative/forensic situation. It has been demonstrated (Molter, 1973) that individual content words in listed sentences, such as was used for Data Base 1, average 7 percent longer than the same words in connected text. Thus, because of the concomitant reduction in vowel duration in non-controlled conversational speech, it is expected that target positions will be attained by formants with a slightly reduced probability. Furthermore, the presence of possible backgound or channel noise will increase operator labelling uncertainty and associated spectral variation. Nasals, while likely to be especially vulnerable to noise due to their inherent low energy levels, will be affected to a lesser degree by rate of speech. Another factor to be considered is the spectral variation caused by overriding linguistic structure and end effects. The sentence material of Data Base 1 was principally declarative and labelling was undertaken in predominantly stressed environments. In forensic/investigative applications the syntactic framework is likely to be more diverse and the range of amplitude more extreme.

4.6 MAJOR RESULTS AND CONCLUSIONS

The significant results and conclusions of this study are as follows:

1) The mean spectrum of most vocalic types embedded in high hub consonantal contexts differs little from those of middle hub contexts. The mean spectra for the high and middle cases of a type are usually substantially different from that of the low hub consonantal context.

2) The intra-speaker spectral variance of a phonetic type across diverse consonant contexts typically exhibits one or two local maxima in the regions of each of the three mean formant frequencies for that type.

3) The F-ratio, based on the intra- and inter-speaker distributions of a $(1-\cos^2\theta)$ distance measure using the LPC spectrum as the feature vector, increases by a factor of approximately two as constraint is increased from a context-independent to a text-dependent comparison. The highest context-dependent F-ratio is midway to that for other two constraint conditions while the lowest is quite close in value to the lowest of the context-independent ranking. The general order of phonetic types differs between constraint conditions with the exception of two types /i/ and /ʒ/ which consistently rank high and low respectively. The range of F-ratios within a ranking varied from about 3.6 to 1 (text-dependent) to 6.3 to 1 (context-dependent).

4) Front vowels, high vowels, and nasals appear to possess greater speaker discrimination capability than other types in a text-dependent situation. The categorization is clouded to some degree in the context-independent and context-dependent cases.

5) Vowels traditionally classified as long vowels /i, a, ɑ/ have lower intra-speaker mean spectral variance across diverse contexts; however, the advantage of these types in a speaker discrimination situation does not seem significant when the ranking by F-ratio is considered.

5.0 FEATURE EXTRACTION

The feature extraction task for the SASIS was carried out in two phases. The first phase provided a feature selection procedure and derived a preliminary feature set all based on Data Base I; the second phase involved optimizing the feature selection procedure and deriving an improved feature set.

5.1 FEATURE SELECTION: PHASE I

5.1.1 Summary

As part of the SASIS development, a task was under taken to define a set of digital parameters on which to base distance calculations. This feature selection process was carried out in three phases, as follows:

1) Define a large set of features using a heuristic procedure;
2) evaluate each feature on a first-order (without regard to interfeature dependencies) basis and derive weights for each feature, and
3) select a subset of features for each phonetic event category using a second-order (interfeature correlation) selection procedure.

The end goal of this task was to obtain a unique set of features for each phonetic event category along with a set of weights for each selected feature. The weights are for distance calculations. The process was conducted for each phonetic event category independently.

5.1.2 Feature Definition

The first step in the feature selection process was definition of a candidate set of features. This set is designed to extract information from the speech process. No consideration was given to interfeature dependencies in defining the candidate set, since the feature selection phase has as its task decorrelation of features.

The features selected are of a static nature, i.e., they are extracted from the isolated three-pitch-period interval of acoustic speech data. No information is derived from the acoustic signal external to this interval. This static constraint prohibits use of transitional information used in the subjective voice-spectrogram-comparison procedures (Papcun, et al, 1973). Two additional constraints have been factored into the definition process and include observing the telephone channel bandwidth and requiring that feature rules be implemental on the prototype system without excessive complexity.

The candidate features are defined in Table 5.1 with term definitions given at the end of the table. The 162 features are partitioned into several groups based on the nature of the feature subset. These groups consist of linear-predictive-filter measurements, Fourier measurements, time-domain features, and a special feature group. Table 5.1 gives information relating to feature number, feature location in the feature vectory array, and a mathematical definition of the feature.

5.1.2.1 Linear Predictive Filter Features

The group of features numbered 94 through 100 and 101 through 164 in Table 5.1 are measurements derived directly from the linear predictive coefficient (LPC) process. The first feature subgroup (features 94 through 100) represents special parameters obtained via the process. Derived here are the estimated positions and bandwidths of the first three formants and a measure of LPC estimation error. This latter feature measures the degree to which the LPC filter can estimate the individual speech process. The second group (features 101 through 164) is the set of spectral estimates derived via the LPC spectrum. A tenth-order filter, in which no pre-emphasis is employed, is used. The spectrum is sampled every 53 Hz.

TABLE 5.1

SASIS Candidate Descriptions

Feature Number	Feature Location	Feature Description (See explanation at end of table)	
	--Spectral Derivatives--		
1	217	S(.5, .7) -	S(.3, .5)
2	218	S(.7, .9) -	S(.5, .7)
3	219	S(.9, 1.1) -	S(.7, .9)
4	220	S(1.1, 1.3) -	S(.9, 1.1)
5	221	S(1.3, 1.5) -	S(1.1, 1.3)
6	222	S(1.5, 1.7) -	S(1.3, 1.5
7	223	S(1.7, 1.9) -	S(1.5, 1.7)
8	224	S(1.9, 2.1) -	S(1.7, 1.9)
9	225	S(2.1, 2.3) -	S(1.9, 2.1)
10	226	S(2.3, 2.5) -	S(2.1, 2.3)
11	227	S(2.5, 2.7) -	S(2.3, 2.5)
12	228	S(2.7, 2.9) -	S(2.5, 2.7)
13	229	S(2.9, 3.1) -	S(2.7, 2.9)
	--Special Features Sensitive to /a/--		
14	230	S(2.1, 2.6) -	S(2.6, 3.4)
15	231	S(1.9, 2.9) -	S(3.0, 3.2)
16	232	S(1.9, 2.3) -	S(1.9, 3.2)
17	233	S(.3, .5) -	S(1.9, 2.3)
	--Special Features Sensitive to /i/--		
18	234	S(2.0, 2.3) -	S(2.2, 2.7)
19	235	S(2.0, 2.3) -	S(2.7, 3.3)
	--Special Features Sensitive to /o/--		
20	236	S(1.6, 2.0) -	S(2.2, 3.2)
21	237	S(0.3, 2.0) -	S(2.0, 3.2)
22	238	S(1.8, 2.6) -	S(2.2, 3.2)
23	239	S(0.3, 1.0) -	S(2.0, 2.2)
	--Special Features Sensitive to (I)--		
24	240	S(2.3, 2.9) -	S(3.0, 3.2)
25	241	S(1.7, 2.3) -	S(2.3, 2.9)
26	242	S(1.7, 2.3) -	S(3.0, 3.2)

Feature Number	Feature Location	Feature Description (See explanation at end of table)	
27	243	S(0.3, 0.7) -	S(1.5, 3.2)
28	244	S(1.7, 3.2)	
	--Special Features Sensitive to /n/--		
29	245	S(1.0, 1.7) -	S(1.7, 3.2)
30	246	S(2.0, 2.4) -	S(2.4, 3.0)
31	247	S(1.6, 2.0) -	S(2.0, 2.4)
	--Time-Domain Features--		
32	249	Auto-Correlation coefficient between the first and second pitch period waveforms	
33	250	Pitch period	
34	251	nonlinear form of pitch period period	
35	252	not meaningful	
	--Fourier Spectral Measurements--		
36	509	Not used	
37	510	S(.3, .5)	P = 2 dB
38	511	S(.4, .6)	P = 0
39	512	S(.5, .7)	P = 2
40	513	S(.6, .8)	P = 5
41	514	S(.7, .9)	P = 6
42	515	S(.8, 1.0)	P = 8
43	516	S(.9, 1.1	P = 10
44	517	S(1.0, 1.2)	P = 11
45	518	S(1.1, 1.3)	P = 12
46	519	S(1.2, 1.4)	P = 13
47	520	S(1.3, 1.5)	P = 14
48	521	S(1.4, 1.6)	P = 15
49	522	S(1.5, 1.7)	P = 16
50	523	S(1.6, 1.8)	P = 17
51	524	S(1.7, 1.9)	P = 18
52	525	S(1.8, 2.0)	P = 19
53	526	S(1.9, 2.1)	P = 20
54	527	S(2.0, 2.2)	P = 20

Feature Number	Feature Location	Feature Description (See explanation at end of table)	
55	528	S(2.1, 2.3)	P = 21
56	529	S(2.2, 2.4)	P = 21
57	530	S(2.3, 2.5)	P = 22
58	531	S(2.4, 2.6)	P = 22
59	532	S(2.5, 2.7)	P = 23
60	533	S(2.6, 2.8)	P = 23
61	534	S(2.7, 2.9)	P = 24
62	535	S(2.8, 3.0)	P = 24
63	536	S(2.9, 3.1)	P = 25
64	537	S(3.0, 3.2)	P = 25
65	538	S(1.6, 2.0)	P = 18
66	539	S(2.0, 2.4)	P = 21
67	540	S(2.4, 3.0)	P = 23
68	541	S(1.0, 1.7)	P = 13
69	542	S(1.7, 3.2)	P = 21
70	543	S(.3, .7)	P = 2
71	544	S(1.5, 3.2)	P = 21
72	545	S(1.7, 2.3)	P = 20
73	546	S(2.3, 2.9)	P = 22
74	547	S(.3, 1.0)	P = 0
75	548	S(2.0, 3.2)	P = 23
76	549	S(1.8, 2.6)	P = 21
77	550	S(2.2, 3.2)	P = 23
78	551	S(.3, 2.0)	P = 10
79	552	S(2.0, 2.3)	P = 21
80	553	S(2.7, 3.2)	P = 25
81	554	S(2.2, 2.7)	P = 22
82	555	S(1.9, 2.3)	P = 20
83	556	S(1.9, 3.2)	P = 20
84	557	S(1.9, 2.9)	P = 22
85	558	S(2.1, 2.6)	P = 22
86	559	S(2.6, 3.2)	P = 24
87	560	S(.3, .6)	P = 0
88	561	S(1.6, 3.2)	P = 22
89	562	S(1.6, 2.2)	P = 20

Feature Number	Feature Location	Feature Description (See explanation at end of table)	
90	563	S(2.2, 2.8)	P = 22
91	564	S(2.8, 3.2)	P = 23
92	565	S(1.9, 2.5)	P = 21
93	566	S(2.5, 3.2)	P = 24
	--LPC-Derived Special Features--		
94	210	LPC prediction error (rms)/input signal (rms)	
95	211	BW_{F3}	
96	212	BW_{F2}	
97	213	BW_{F1}	
98	214	F3/16	
99	215	F2/10	
100	216	F1/4	
	--LPC-Derived Spectral Estimates--		
101	253	Not used	
102	254	L(.0)	
103	255	L(.053)	
104	256	L(.106)	
105	257	L(.159)	
106	258	L(.212)	
107	259	L(.265)	
108	260	L(.318)	
109	261	L(.371)	
110	262	L(.425)	
111	263	L(.478)	
112	264	L(.531)	
113	265	L(.584)	
114	266	L(.637)	
115	267	L(.690)	
116	268	L(.743)	
117	269	L(.796)	
118	270	L(.850)	
119	271	L(.903)	
120	272	L(.956)	

Feature Number	Feature Location	Feature Description (See explanation at end of table)
121	273	L(1.009)
122	274	L(1.062)
123	275	L(1.115)
124	276	L(1.168)
125	277	L(1.221)
126	278	L(1.275)
127	279	L(1.328)
128	280	L(1.381)
129	281	L(1.434)
130	282	L(1.487)
131	283	L(1.540)
132	284	L(1.593)
133	285	L(1.646)
134	286	L(1.700)
135	287	L(1.753)
136	288	L(1.806)
137	289	L(1.859)
138	~~290~~	L(1.912)
139	291	L(1.965)
140	292	L(2.018)
141	293	L(2.071)
142	294	L(2.125)
143	295	L(2.178)
144	296	L(2.231)
145	297	L(2.284)
146	298	L(2.337)
147	29[illegible]	L(2.390)
148	300	L(2.443)
149	301	L(2.496)
150	302	L(2.550)
151	303	L(2.603)
152	304	L(2.656)
153	305	L(2.709)
154	306	L(2.762)
155	307	L(2.868)

CONTINUED

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Feature Number	Feature Location	Feature Description (See explanation at end of table)
156	308	L(2.921)
157	309	L(2.975)
158	310	L(3.028)
159	311	L(3.081)
160	312	L(3.134)
161	313	L(3.187)
162	314	L(3.240)
163	315	L(3.293)
164	316	L(3.346)

DEFINITIONS

S(n,m) is an estimate of spectral energy derived by summing the Fourier power spectral estimates of n kHz through m kHz, inclusively and taking the $\log_{10}$.

P pre-emphasis applied to Fourier spectral measurement to reduce dynamic range over the spectrum. P = 2 reads: pre-emphasis of 2 dB is applied.

BW_{F1} Bandwidth of first formant

F1 Frequency of first formant

L(n) spectral sample at n kHz of spectrum estimated via LPC analysis of isolated phonetic event data. Sixty-four samples are taken over 3.40 kHz.

5.1.2.1.1 Background

In the utilization of linear predictive encoding techniques, it is useful to establish a model of speech production based on the following assumptions:

1) During the analysis interval the overall transfer function of the vocal tract (glottal source, mouth configuration, lip radiation) can be represented by a linear time-invariant friter consisting only of filter poles.

2) during the analysis interval, the vocal tract configuration is assumed to remain fixed in shape.

In the SASIS system, only vowels and nasals are used for speaker comparisons. For vowels the assumption of an all pole representation is quite appropriate. However, in the case of non-velar nasals below 5 kHz, a zero is introduced by the coupling to the occluded oral cavity. Thus, those features derived from a linear predictive analysis can be considered of less value for nasals than for vowels. The assumption of a fixed vocal tract shape will be discussed briefly in relation to analysis interval length in Section 5.1.2.1.3.

Implementations of linear predictive encoding procedures can invariably be associated with one of two formulations: 1) the covariance method, and 2) the autocorrelation method. In the covariance method (Prony, 1795; Atal and Hanauer, 1971) the signal is defined for M+N consecutive values where M is the number of time samples on which a prediction is based and N is an integer defining record length. Mean squared error is then minimized over the record of N samples. In the autocorrelation approach (Wiener, 1966; Itakura and Saito, 1970, Markel, 1971), the signal is defined for all time but windowed to be non-zero for record length N. Minimization of mean squared error is taken over all time.

Other points regarding the formulations deserve mention. Theoretically, it is not possible to achieve unstable results with the autocorrelation method; while in the covariance formulation, such anomalies are possible. Computationally, the autocorrelation method has less complexity than does the covariance method in the calculation of the linear equation coefficients and the subsequent solution. It should be noted, however, that under the assumption of stationarity the covariance method reduces to the autocorrelation method.

On the basis of computational simplicity and excellent experimental results that have been obtained by other researchers, the autocorrelation procedure was chosen as the method of analysis for this work. It is of value at this point to review the autocorrelation formulation in more detail. Let the sampled speech signal be denoted by s_n where $n = t/T$ (T is the sampling period). After windowing it is assumed that s_n is non-zero over a record length of N. It is desired to approximate s_n by a linear weighted sum of the preceding M samples

$$\hat{s}_n = - \sum_{\ell=1}^{M} a_\ell s_{n-\ell}$$

The error between the actual signal and the predicted value at a discrete time point is then given by

$$e_n = s_n + \sum_{\ell=1}^{M} a_\ell \, s_{n-\ell} \qquad (5.1)$$

and the total energy of the error record by

$$E = \sum_n e_n^2 .$$

The problem is thus one of minimizing E with respect to the predictor coefficients a_ℓ, $\ell = 1, 2, \ldots, M$. Upon taking the partial derivative with respect to each of the a_ℓ and inserting an appropriate change of variables we obtain the set of autocorrelation normal equations:

$$r_{\ell} = - \sum_{j=1}^{M} a_j r_{j-\ell} \qquad \ell = 1, 2, \ldots, M \tag{5.2}$$

where for an arbitrary ℓ,

$$r_{\ell} = \sum_{n=0}^{N-1-|\ell|} s_n s_{n+|\ell|} .$$

The matrix represented by this set of M linear equations is a Toeplitz form and therefore readily amenable to an efficient solution by a recursive procedure requiring less than the order of M^3 computations.

From equation 5.1, it is apparent that the discrete transfer function of the inverse linear filter is given by

$$A_I(z) = 1 + \sum_{\ell=1}^{M} a_{\ell} z^{-\ell} \tag{5.3}$$

The effect of the inverse filter is to grossly transform the speech spectrum into a spectrum of constant amplitude. Effectively, the signal is reduced to white noise but with superimposed impulses at the fundamental frequency. The transfer function of the vocal tract including the effects of glottal source, oral and nasal cavity configuration, and lip radiation can then be represented by the all pole model

$$A(z) = \frac{1}{1 + \sum_{\ell=1}^{M} a_{\ell} z^{-\ell}} \tag{5.4}$$

As M approaches infinity, the mean squared spectral error is reduced. In this study, however, that fine spectral structure resulting from harmonics of the fundamental frequency is not of interest. The order of the filter is, therefore, limited to exhibit overall formant structure only.

The power spectrum of the vocal tract transfer function is obtained by evaluating A(z) on the unit circle,[1]

$$S(\omega) = |A(z)|^2_{z=e^{j\omega T}}$$

An alternate method of computing the spectrum, which is used in this work, is the discrete Fast Fourier Transformation of the sequence representing the impulse response of the inverse filter as given by $[1, a_1, a_2, \ldots, a_M, 0, \ldots, 0]$.

Formant frequencies and bandwidths are easily computed by solving for the poles of equation (5.4). Equating amplitudes and angles between the z and s domains, we obtain for the j^{th} formant

$$\omega_{\ell} = -f_s \tan^{-1} \frac{z_{\ell i}}{z_{\ell r}}$$

and

$$\sigma_{\ell} = - \frac{f_s}{2} \ln (z_{\ell r}^2 + z_{\ell i}^2)$$

where the poles of (5.4) are $z_{\ell} = z_{\ell r} + jz_{\ell i}$.

5.1.2.1.2 Sample Frequency Tradeoffs

In selecting a sample rate, consideration was given to the use of a sampling frequency other than the 10.0 kHz rate with a 4.0 kHz cutoff originally proposed. Certainly the use of a 10.0 kHz rate would be a prelude to the utilization of speech of bandwidth greater than that obtained from a telephone channel, if such data were to be available. However, it is anticipated that most speech material operationally inputted will be derived from

[1] In some circumstances involving the precise selection of formants, it is useful to compute the spectrum along a circle interior to and concentric with the unit circle; however, in this work, off-axis spectra are not utilized.

a telephone channel and thus bandlimited to 3.2 kHz. The use of a 10.0 kHz rate on data of this nature can be expected to introduce degradations into the analysis process. Since no significant speech energy will be found in the frequency region between 3.2 and 5.0 kHz, the spectrum generation process employing linear predictive analysis will be modeling a noise spectrum above 3.2 kHz as well as a signal spectrum below that frequency. Qualitatively, the result is an increase in mean spectral error over the frequency range of the signal and thus a concomitant reduction of the value of features derived from the LPC analysis. The difficulty is not limited to LPC derived parameters. Other features and derived system statistics would lack optimization with 3.2 kHz speech.

Given 1) the practical impossibility of developing and implementing two sets of features and statistics, one for each bandwidth, and 2) the expected low use of wide bandwidth material, for basis and query utterances, relative to telephone material, it was decided to employ a sampling rate of 6800 Hz all analysis and implementation. The prototype system will, however, have the capability, in hardware, of sampling at higher rates should it be deemed desirable in future situations.

5.1.2.1.3 Implementation

The purpose of this section is to describe the specific LPC implementation employed in the SASIS software and to discuss the experimentation and considerations relevant to the selection of parameters effecting the analysis. Those factors which are significant include

1) the number of pitch periods to be extracted,
2) pre-emphasis of the input signal,
3) the order of the inverse filter, and
4) the number of spectral estimates derived.

The selection of the number of pitch periods to be consistently extracted for analysis was made on the basis of qualitative judgments. In general, it is desirable to avoid record lengths which are of such excessive duration that frequency smearing results from the non-stationarity of the vocal tract. Furthermore, the use of such a length may, all too frequently, exclude from the comparison events which are quite short in duration. For these reasons, the utilization of four pitch periods was eliminated as a possibility.

On the other hand, the use of extremely short analysis intervals has undesirable effects including 1) an unduly heavy reliance on the skills of the operator in extracting the desired time segment, and 2) of more dubious significance, a loss of intrinsic frequency resolution. The limiting case of short duration is, of course, that of a single pitch period. Frequency resolution for an 8 ms pitch period is 125 Hz. More importantly, however, the results of a single pitch period analysis will be highly dependent on any environmental/background noise or undesirable speaker effects superimposed on the signal at the point at which the steady-state characteristics of the event are most closely approximated.

The choice of analysis interval is then one of either two or three pitch periods. To further lessen that intra-token variation that may arise from differing operator choices, a decision was made to extract three pitch periods from all tokens. Windowing of the extracted time sequence is not employed since the analysis is pitch synchronous.

The second factor requiring attention in the analysis is pre-emphasis of the input signal. As a means of determining the desirability of spectral flattening, unpre-emphasized LPC derived spectra (M=12) were generated from the five phonetic events [i, u, a, ɑ, n] of each of three speakers (No's. 3, 13, and 27 of data Base I). For three of these events [i, a, n] pre-emphasized spectra were produced from the same data records. All records were comprised of three pitch periods. The pre-emphasis transfer frunction employed was $H_p(z) = 1 - cz^{-1}$ where $c = r(1)/r(0)$. The values of r(1)/r(0) derived in the first case for each event were used as the pre-emphasis constants for the second case. The length of the data records used varied from 27.6 to 41.3 ms (73 to 108 Hz mean fundamental frequency). Quantitative results are presented in Table 5.2a.

Without pre-emphasis dynamic range varied from 25 to 49 dB. Due to the effects of the SEG 3002 telephone channel simulator, the peak of the first formant was typically reduced by 3 to 10 dB relative to the second in the unpre-emphasized data. The maximum difference in amplitude between the first and second formant was approximately 10 dB. For the vowels [i, a, ɑ] of speaker 27, the peak of the second formant was greater in amplitude than that of the first. The normalized autocorrelation value c displayed considerable inter-phonetic and intra-speaker variation (-0.336 to 0.812).

The use of pre-emphasis reduced dynamic range of the spectra as much as 14 dB. The mean square inverse filter error was, in some cases, reduced by pre-emphasis and, in other cases, increased. As expected, the first formant frequency was raised by typically 10 to 50 Hz.

Given the results of the experimentation described above, it was decided not to employ pre-emphasis for the following reasons: 1) The telephone channel effects a considerable reduction in dynamic range. In some cases, attenuation of the first formant is such that without pre-emphasis it is exceeded in peak amplitude by the second formant. 2) The optimal first-order pre-emphasis constant given by r(1)/r(0) is extremely variable thus complicating the issue of selection of this variable on a fixed basis. Furthermore, there exists no single fixed value for this constant that can be assumed to reduce dynamic range for all inputs since suppression of the higher frequencies is occassionally required by use of a negative pre-emphasis constant. 3) Because the fundamental frequency is heavily attenuated, there exists little chance for confusion between the

TABLE 5.2a

Dynamic range and normalized autocorrelation with and without pre-emphasis for events of three speakers of Data Base [illegible].

Event	Without Pre-emphasis		With Pre-emphasis	
	Dynamic Range	c	Dynamic Range	c
Spkr 3				
i	27 db	-0.0017	27 db	-0.0006
	35	0.5207	28	0.2357
n	25	0.6394	24	-0.2445
Spkr 13				
i	37	0.6113	29	-0.1344
	49	0.7636	42	0.5255
n	48	0.8048	36	0.0510
Spkr 27				
i	28	-0.3368	42	0.6038
	38	0.5448	28	0.5613
n	41	0.8121	29	-0.1396

glottal source and the first formant, thereby obviating the need for pre-emphasis. 5) The distance measures employed in this work are based on log spectra. The significance of log spectral differences in the distance measure is essentially equal from low frequencies to high frequencies which may be reduced in amplitude.

In addition to consideration of the use of pre-emphasis it is necessary to determine the desired order of the inverse filter. The spectra of two vowels and one nasal [i, ɑ, n] of each of three speakers were generated without pre-emphasis for the purpose of establishing an appropriate value. The speakers and data records employed were the same as those of the pre-emphasis experimentation. The ratio of the mean square error signal to the mean square input signal was computed for each of the six tokens as a function of M. Plots for two events of one speaker are shown in Figure 5.1a. In general, no significant decrease in normalized error was achieved as M was increased above 8. However, from an examination of spectral outputs it was determined that some cases did exist in which primary formant structure was not fully developed until the use of a filter of order 10[1]. For these reasons a tenth order filter was selected for this work. This value is somewhat less than would be required for speech that has not been exposed to the effects of a telephone channel (Makhoul and Wolf, 1972).

An additional parameter requiring quantification is the number of spectral estimates to be derived from the linear encoding process. Selection of this parameter is not overly critical since fine spectral structure is not of interest in this work. A suitable number of zeros was appended to the sequence of predictor coefficients to yield 65 frequency positions (including zero frequency) from the discrete finite

[1] In the case of M=10, the normalized error power ranged from 0.068 to 0.355.

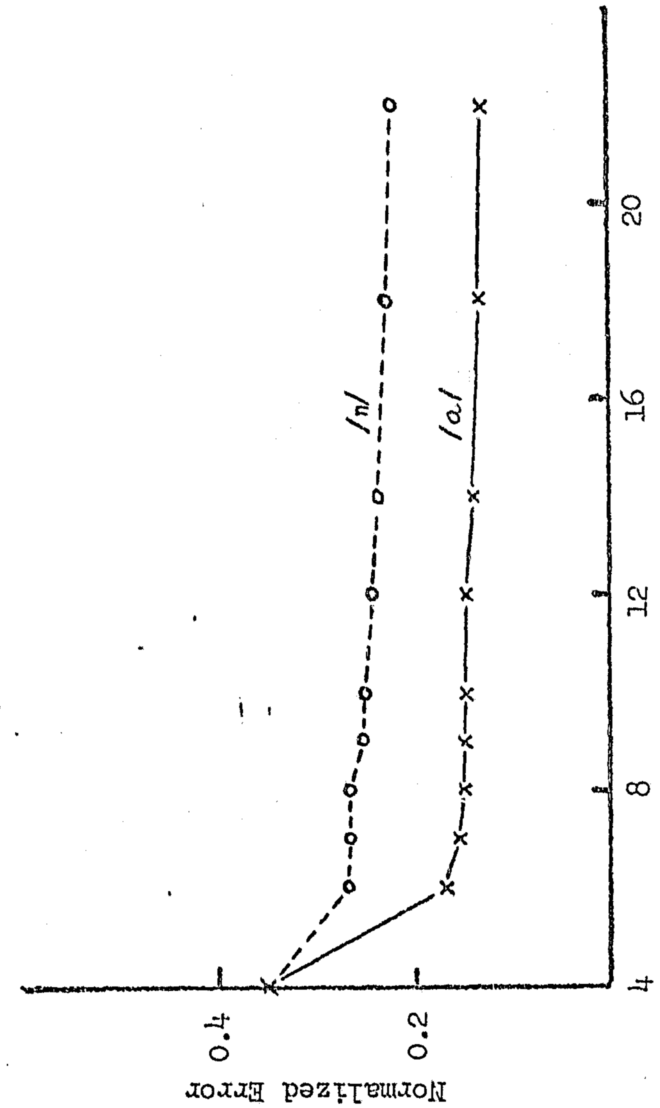

Figure 5.1a Normalized error power ($\sum_n e_n^2 / \sum_n s_n^2$) as a function of M for the events /a/ and /n/ of speaker 3 of Data Base I.

Fourier transform. Frequency spacing was, therefore, 50 Hz. Thus, from these spectral estimates a formant frequency can be determined to within 50 Hz and two formants no less than 100 Hz apart will be discernible. Such resolution is more than adequate given that the separation between two formants is rarely less than 200 Hz.

A block diagram of the stages of processing used for developing spectral feature information in both the analytic and prototype systems is given in Figure 5.1b. Following scaling to 12 bits, the autocorrelation vector r_i, i = 0, 1, ..., 10 is generated by simply summing the lagged products. Since M is only 10 and data record lengths are almost invariably greater than 150, normalization to compensate for a varying number of terms in the sum is not employed. The Toeplitz form is solved recursively by Robinson's method and the frequencies and bandwidths of three first three formants computed by finding the roots of the inverse filter polynomial using POLRT (single precision) in the IBM Scientific Subroutine Package. The first three formants are defined as those resulting from those three poles closest to the ω avis, excluding real roots. A discrete finite Fourier transform is taken of the sequence of predictor coefficients with zeros concatenated. The power spectrum is then computed , inverted and expressed in quarter dB with the greatest value set to 255 quarter dB. The word lengths primarily used in the analytic and prototype systems are 16 bits for integer operations and 32 bits for floating point operations. Floating point calculations are used extensively in the spectrum generation process.

An example of a spectrum resulting from the linear predictive encoding process is shown in Figure 5.1c.

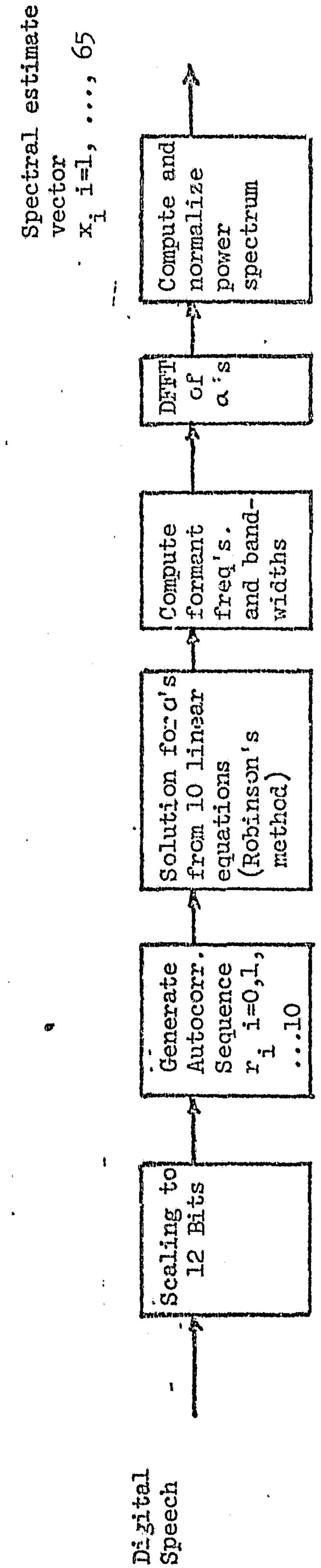

Figure 5.1b

Block diagram of the processing implemented in obtaining spectral estimates by linear predictive encoding techniques.

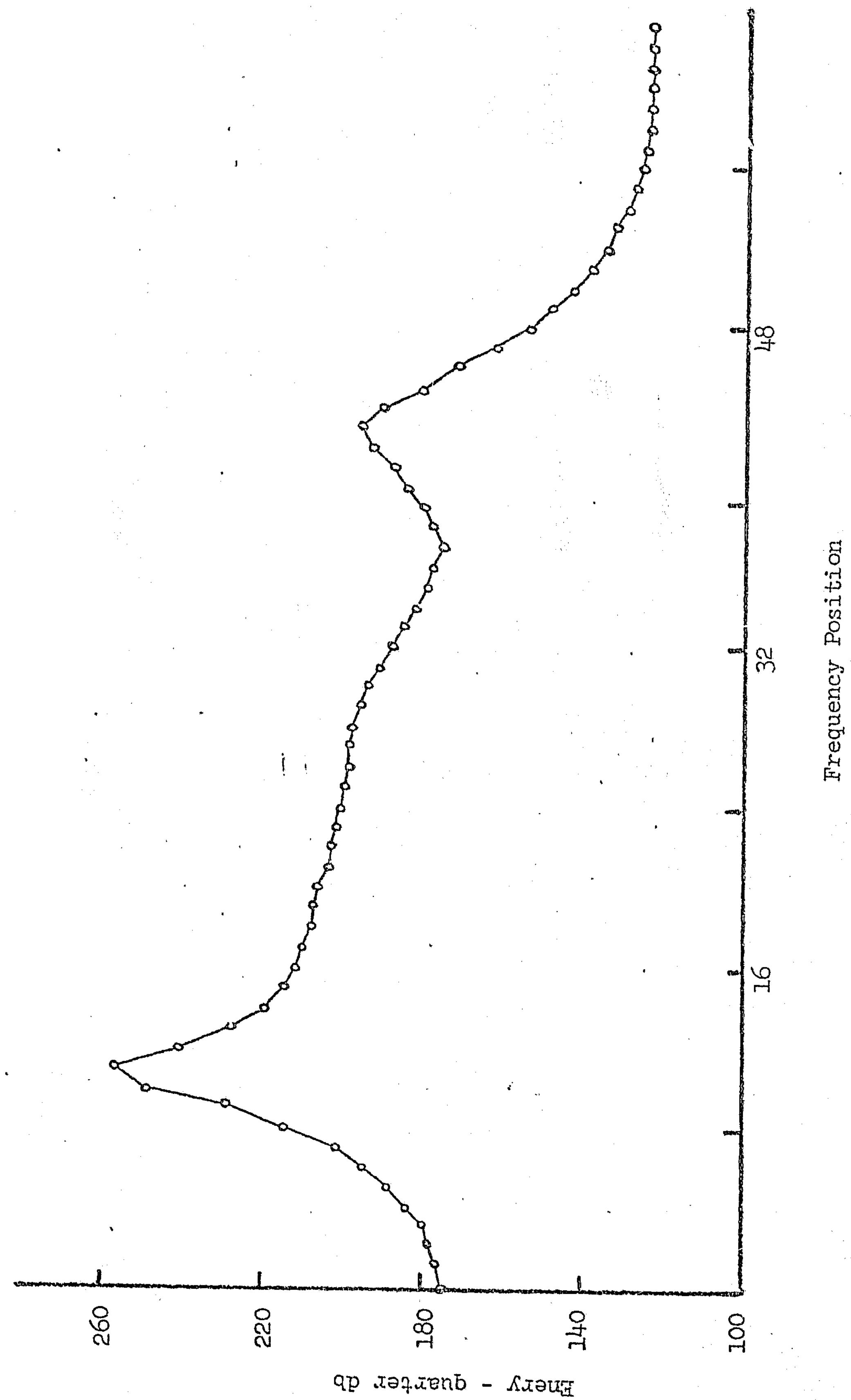

Figure 51c Spectrum of a token of the vowel /ε/ of speaker 43 of Data Base II derived by linear predictive analysis techniques. The zero frequency component is shown at position zero.

5.1.2.2 Fourier Measurements

The Fourier measurements consist of a Fourier spectral measurements group and a Fourier spectral derivatives group.

The Fourier spectral measurements group (features 36 through 100 in Table 5.1) are derived by analyzing the 3 pitch periods using a 512-point fast Fourier transform. No window is used, since exactly 3 periods are represented and array points outside the 3 pitch periods are set to zero. The transform yields a complex spectral estimate every 13.3 Hz which is squared to provide real power estimates and then integrated over specified spectral channel intervals. The resulting estimate is then $\log_{10}$ transformed, and a spectral flattening pre-emphasis (given in Table 5.1 by P = N dB) is applied to reduce the dynamic range. The expression describing the measurement is

$$s(i,j) = 40 \log_{10} \left\{ \frac{1}{c(j)-c(i)+1} \sum_{n=c(i)}^{c(j)} F^2(n) \right\}$$

where $s(i,j)$ = spectral measurement for the interval i kHz to j kHz, expressed in 0.25 dB,

$c(i)$ = Fourier sample corresponding to i kHz, and

$F(n)$ = magnitude of the n^{th} Fourier coefficient.

The Fourier group is divided into two segments. The first subgroup, features 36 through 64, are 29 bandpass spectral measurements, each representing a 200 Hz segment of the spectrum, and a new measurement starting every 100 Hz from 300 Hz. The second subgroup, features 65 through 93, are special bandpass estimates of varying bandwidths and positions. These features are employed in the ratio definition of the feature group sensitive to specific phonetic events (features 14 through 31).

The spectral derivative group (features 1 through 13) measures the slope of the spectrum in 200 Hz segments from 300 Hz to 3100 Hz. Each resulting measurement is the $\log_{10}$ of ratio of two contiguous 200 Hz bandpass segments of the Fourier spectrum. Note that these derivatives are along the frequency axis and do not measure temporal effects.

5.1.2.3 Time-Domain Features

The time-domain feature group (features 32 through 35 in Table 5.1) measure certain temporal parameters about the three-pitch-period event segment. These include pitch period length, T, and periodicity, R(T).

5.1.2.4 Special Feature Group

The special feature group (features 14 through 31) is sensitive to events /a/, /i/, /I/, /O/, and /n/ are similar to those used in the Texas Instruments voice identification study (Hair and Rekieta, 1972). These features measure the ratios of power in certain bandpass segments of the Fourier spectrum expressed in 0.25 dB units.

5.1.3 Feature Evaluation

The second step in the feature selection process is evaluation of individual features. The evaluation process is carried out for each phonetic event category separately. Each feature is evaluated based on its ability to discriminate among speaker categories.

The purpose of feature evaluation is to provide a measure of individual feature value to a classification process and to provide a quantitative weight to be employed in the distance computation.

The data base used in these experiments is Data Base I and consists of over 6000 labeled phonetic events from the 14 categories across 25 speakers.

Feature evaluation is based on the F-ratio (Pruzansky and Mathews 1964) and measures the degree of interclass spread compared to the mean intraclass spread for values of the feature under consideration. The F-ratio is defined as

$$F = \frac{\text{variance of class means}}{\text{mean of individual class variances}}$$

The F-ratio used in this first phase is based on context independency, i.e., phonetic events are grouped on the basis of the phonetic classification, without regard to coarticulative influence of adjacent events. The advantage of this approach is that it makes the F-ratio computation much simpler. The expression for the F-ratio used in this phase is further expressed as

$$FR1 = \frac{\frac{1}{N_c - 1} \sum_{c=1}^{N_c} (\hat{F}_c - \hat{\hat{F}})^2}{\frac{1}{N_c} \sum_{i=1}^{N_c} \frac{1}{T_i - 1} \sum_{t=1}^{T_i} (F_{tc} - \hat{F}_c)} ,$$

where

$$\hat{F}_c = \frac{1}{T_c} \sum_{t=1}^{T_c} F_{tc} ,$$

$$\hat{\hat{F}} = \frac{1}{N_c} \sum_{c=1}^{N_c} F_c ;$$

F_{tc} = the t^{th} token of feature F in class c,

T_c = total number of tokens in class c, and

N_c = total number of classes.

As will be pointed out in Section 5.2.3, this F-ratio was enhanced, introducing context consideration (text dependency). The final feature set is based on the enhancement.

Table 5.2b is the figure of merit matrix giving the feature location in the first column and the square root of the F-ratio expressed in percent in the remaining 14 columns, for event numbers 20 to 33. Feature locations and numbers are mapped on Table 5.1.

TABLE 5.2b

FIGURE OF MERIT MATRIX

FEATURE NO.	Event No. m	n	ŋ	i	ɪ	ε	ɑ	a	ɔ	ʊ	u	ʌ	ɝ	ə
217	83	90	77	46	51	63	52	61	80	50	59	53	50	72
218	70	64	67	44	54	36	95	66	83	55	54	56	48	86
219	81	99	90	68	53	39	58	55	60	52	54	63	49	68
220	95	59	105	57	41	60	61	64	79	68	34	46	59	92
221	68	39	76	64	38	47	46	59	62	51	63	32	57	61
222	69	45	50	64	36	53	46	58	69	60	47	35	45	113
223	71	49	59	56	35	56	31	50	54	67	49	39	61	78
224	61	64	78	77	39	42	42	58	52	77	67	57	39	120
225	85	103	94	108	59	71	62	86	72	90	89	75	38	84
226	55	77	82	83	69	62	77	76	68	94	91	68	38	110
227	50	64	59	84	78	62	69	81	65	81	72	67	47	106
228	37	53	73	64	76	60	51	53	65	92	68	82	45	86
229	39	62	58	74	78	58	42	50	56	52	69	33	53	87
230	57	71	68	106	93	86	74	78	79	92	94	77	70	148
231	72	49	68	80	83	63	51	45	76	91	98	64	58	79
232	57	87	81	84	71	75	95	92	77	110	102	83	66	123
233	77	76	87	88	69	82	70	94	101	124	88	85	58	116
234	53	87	88	89	79	71	83	93	77	100	122	80	45	118
235	71	71	79	106	80	71	68	62	80	98	109	65	68	120
236	77	102	104	146	70	79	89	102	96	118	116	92	55	110
237	68	74	76	106	84	88	84	107	103	111	88	101	59	117
238	68	99	91	124	70	65	79	93	79	104	121	77	72	84
239	70	56	67	97	84	87	84	103	107	111	87	102	69	115
240	58	44	79	90	88	69	67	64	71	85	96	70	54	83
241	65	91	100	112	74	70	94	90	88	106	112	78	66	116
242	78	67	83	93	68	55	51	39	77	84	100	57	69	100
243	82	75	76	89	79	74	87	88	102	97	79	93	71	107
244	80	53	63	74	64	62	52	63	84	86	50	59	53	105
245	79	58	58	91	59	79	53	81	71	77	80	77	64	99
246	64	78	91	96	83	71	91	82	86	100	81	84	65	129
247	73	79	79	130	66	73	71	97	78	110	85	83	40	139
249	46	29	38	30	22	22	24	23	32	50	20	19	31	54
250	89	73	78	81	78	65	62	75	72	100	79	84	90	158
251	87	44	74	80	88	74	34	36	46	101	90	94	84	137
252	75	84	75	81	91	50	67	111	114	110	81	80	80	158
509	0	0	0	0	0	0	0	0	0	0	0	0	0	0
510	93	112	78	58	44	57	76	76	87	83	56	64	59	90
511	77	104	55	61	40	45	85	76	83	75	46	50	44	70
512	67	74	45	62	43	41	64	59	63	61	52	33	50	62
513	65	82	46	64	46	42	44	41	48	67	46	41	51	96
514	73	84	56	48	47	36	48	46	57	81	46	39	53	95
515	71	74	68	49	37	37	46	48	73	73	53	41	52	85
516	75	92	65	53	40	34	42	44	57	61	52	44	49	87
517	74	84	61	62	50	34	37	37	52	62	48	41	55	85
518	86	84	77	66	59	50	46	44	71	82	46	36	60	88
519	86	87	82	65	64	63	53	52	75	75	48	39	54	108
520	73	69	67	62	69	63	44	58	57	63	54	29	51	110
521	73	71	63	64	72	48	35	51	49	66	52	27	52	89
522	72	74	63	73	64	43	38	43	62	53	41	25	52	85
523	60	68	70	81	51	39	42	45	64	65	35	27	52	97
524	81	71	80	82	40	42	41	48	66	85	38	32	56	101

525	90	85	101	94	43	52	41	50	80	84	55	50	52	101
526	85	78	103	87	52	55	45	58	79	90	68	63	44	91
527	79	67	83	88	57	57	52	64	77	99	65	64	44	89
528	82	60	71	98	62	63	62	74	81	91	59	70	45	98
529	79	44	65	79	71	70	65	86	83	91	69	69	46	108
530	62	41	74	83	79	72	71	89	85	91	73	65	46	120
531	62	59	77	85	85	76	74	88	93	88	59	70	47	134
532	69	73	75	89	91	74	75	80	92	86	48	73	51	137
533	68	80	68	91	83	69	72	75	79	92	44	60	58	142
534	59	82	56	88	81	70	63	63	76	94	48	48	63	114
535	55	78	52	84	91	65	55	56	77	91	60	51	62	115
536	53	72	47	77	94	62	49	51	74	81	65	50	61	119
537	45	67	40	70	85	57	42	48	65	69	59	46	56	110
538	88	82	94	95	47	41	41	46	77	80	47	37	54	100
539	77	52	69	86	68	65	59	75	84	96	56	69	45	107
540	69	64	76	89	86	77	80	89	97	90	56	68	57	135
541	81	83	64	67	84	56	36	51	56	91	48	39	56	99
542	80	53	63	74	64	62	52	63	84	86	50	59	55	105
543	93	112	73	59	42	42	66	64	67	82	55	42	50	89
544	78	55	63	74	66	51	51	54	80	78	49	51	52	101
545	81	62	79	78	52	49	59	52	79	87	52	57	55	95
546	67	53	74	86	82	74	77	68	91	92	67	66	52	122
547	93	108	64	59	42	42	51	59	62	82	55	40	58	89
548	78	54	63	80	71	69	62	75	91	95	56	69	48	106
549	80	50	64	77	66	64	53	65	86	88	53	62	50	110
550	77	52	66	81	79	73	71	85	92	91	65	70	52	109
551	85	100	73	62	42	36	44	45	54	80	52	32	49	90
552	77	61	75	86	61	58	58	69	79	97	58	69	45	100
553	57	77	53	83	90	65	57	57	76	91	58	50	61	114
554	73	51	66	82	79	73	71	87	93	91	67	71	49	109
555	79	61	78	89	58	54	54	61	79	91	56	65	44	99
556	80	53	63	76	69	67	56	69	88	90	54	66	46	106
557	80	53	63	76	69	67	56	69	88	90	54	66	45	105
558	77	49	65	85	74	74	66	80	93	90	60	72	47	111
559	68	83	64	90	88	69	70	71	80	89	51	57	62	139
560	96	113	73	58	42	46	86	77	84	82	56	52	59	89
561	80	54	63	74	64	56	51	57	82	81	58	55	53	103
562	84	68	88	86	50	45	46	47	78	88	55	49	54	92
563	76	51	66	82	79	73	71	85	92	91	66	71	50	110
564	54	78	58	82	91	64	53	54	75	88	61	50	61	115
565	79	48	65	81	69	66	55	70	86	90	54	65	45	111
566	73	76	71	90	93	75	76	79	90	86	49	68	60	136
210	83	63	87	72	88	73	61	80	81	84	77	70	61	114
211	42	44	40	46	30	30	29	28	28	47	36	28	28	71
212	33	30	30	27	32	32	32	39	33	55	24	35	25	76
213	38	41	39	39	39	42	58	54	75	78	56	37	63	77
214	38	41	40	70	65	51	37	44	63	56	41	48	43	80
215	51	48	39	70	30	26	40	32	49	51	47	23	34	43
216	57	59	48	56	65	67	38	51	63	51	60	57	24	64
253	0	0	0	0	0	0	0	0	0	0	0	0	0	0
254	75	82	69	49	41	55	54	54	67	84	52	47	58	82
255	64	73	50	49	41	55	54	51	67	84	52	47	58	82
256	51	65	40	50	42	56	55	54	67	84	52	47	57	81
257	46	65	44	53	43	57	56	55	67	83	52	48	56	80
258	57	74	54	57	46	58	57	56	67	81	52	48	54	79
259	87	90	65	61	52	60	58	57	66	77	54	48	52	78

260	72	93	73	58	64	63	59	60	66	70	54	48	47	80
261	73	90	80	56	59	66	60	62	66	57	53	48	44	84
262	71	86	79	51	48	67	60	64	65	67	45	48	33	67
263	68	77	74	49	54	58	58	66	68	58	43	53	35	89
264	66	71	69	49	46	33	59	64	73	62	43	62	46	91
265	64	70	66	49	40	48	72	53	48	60	44	27	49	83
266	63	71	64	49	36	55	65	31	95	56	46	71	50	78
267	63	72	65	47	34	52	76	56	103	51	48	69	49	70
268	65	73	68	44	33	48	94	70	97	46	48	59	49	65
269	68	72	70	41	33	45	93	71	89	44	48	53	48	61
270	71	70	71	49	35	44	89	68	84	45	49	49	49	62
271	74	69	71	42	37	43	82	64	83	49	53	48	50	65
272	75	70	72	46	44	43	74	61	84	52	58	49	52	68
273	73	72	73	51	52	44	67	68	86	53	62	51	54	73
274	71	74	76	57	59	45	62	59	78	55	63	51	57	77
275	69	75	79	63	66	48	57	59	75	61	63	47	60	82
276	73	75	84	67	71	51	54	60	85	71	63	45	64	87
277	80	78	88	70	75	55	55	62	94	81	65	47	69	91
278	83	83	92	71	78	58	62	65	96	91	67	50	73	96
279	87	89	94	71	79	63	66	69	92	94	69	51	75	106
280	87	92	95	70	78	68	69	72	87	84	73	49	76	117
281	88	91	93	68	77	68	71	71	82	72	77	45	76	119
282	88	90	91	66	78	65	71	71	78	63	79	47	77	118
283	89	87	90	64	79	60	70	68	74	57	78	49	77	96
284	89	85	91	65	77	58	67	61	71	56	73	50	75	82
285	90	83	92	66	75	59	64	57	69	59	69	50	73	77
286	92	82	95	70	71	57	61	60	68	64	67	51	72	75
287	94	82	99	77	64	55	58	61	68	68	66	52	70	79
288	96	83	103	85	57	55	56	63	69	74	65	54	70	82
289	99	85	107	95	50	56	56	64	70	83	66	57	71	83
290	101	89	110	103	46	58	57	64	73	92	69	62	70	85
291	103	94	113	106	46	61	61	65	77	102	72	67	69	86
292	103	97	116	105	49	63	66	67	83	112	78	73	65	89
293	101	99	118	104	53	65	68	73	90	120	85	79	62	92
294	91	96	118	99	57	68	67	80	95	124	98	84	60	97
295	82	89	110	94	62	69	67	86	94	119	106	84	60	102
296	74	77	93	94	66	70	68	88	88	114	104	82	61	105
297	70	69	75	97	68	74	71	89	82	109	95	82	61	115
298	67	64	70	95	70	75	78	90	80	103	89	83	61	118
299	65	57	69	93	76	73	82	93	78	102	91	83	62	115
300	66	51	66	91	79	72	85	95	78	100	96	81	63	109
301	66	51	68	88	81	77	88	97	81	94	96	81	64	113
302	62	54	74	86	82	86	90	101	87	94	94	85	65	117
303	63	61	79	85	84	89	92	103	94	95	88	90	68	128
304	68	67	81	91	88	87	91	100	96	92	84	91	71	131
305	74	69	81	101	93	85	92	98	94	92	84	88	75	137
306	76	73	78	110	91	84	91	93	90	94	85	82	79	132
307	77	75	75	112	88	83	87	88	86	96	87	78	81	126
308	76	75	73	111	87	81	82	84	84	100	90	75	81	124
309	76	70	71	110	87	78	77	82	81	102	91	73	81	120
310	76	68	70	108	88	77	73	80	79	105	93	71	81	116
311	75	66	69	105	89	75	69	78	76	108	93	69	81	114
312	74	64	69	103	89	74	66	77	74	110	94	68	81	112
313	72	64	68	101	88	73	63	76	72	112	94	67	81	110
314	72	62	68	99	88	72	61	75	70	113	94	67	81	109
315	70	62	68	98	87	72	59	74	69	113	94	66	80	107

5.1.4 FEATURE SUBSET SELECTION

5.1.4.1 Procedure

The final phase of the feature selection task is that of selecting a subset of the 162 candidate features for each phonetic event category. The subset selected is the set of features used in the distance measure computation for that phonetic event. The selection process employed is based on the F-ratio derived in the feature evaluation phase and on the 162-dimensional feature correlation matrix.

As in the feature evaluation phase, each phonetic event is treated individually, and experiments are conducted on Data Base 1. The feature subset selection endeavors to select the best subset of features for each phonetic event category. This selection procedure is designed to sequentially select a subset of features which have large F-ratios and, at the same time, are correlated less than a specified factor with all other features in the subset.

The correlation matrix is derived on a context-free basis and is the mean correlation matrix across the individual correlation matrices for each of the 25 speakers represented in Data Base 1. The correlation matrix is derived as follows:

$$C_{ij} = \frac{1}{25} \sum_{k=1}^{25} C_{ij}^{k} ,$$

where C_{ij} is the mean correlation coefficient between features i and j, and C_{ij}^{k} is the correlation coefficient for speaker k.

$$C_{ij}^{k} = \frac{E\{ (x_i^k - \hat{x}_i^k)(x_j^k - \hat{x}_j^k) \}}{[E\{(x_i^k - \hat{x}_i^k)^2\} \, E\{(x_j^k - \hat{x}_j^k)^2\}]^{\frac{1}{2}}}$$

where x_i^k is the i^{th} feature of the k^{th} speaker, and

$$\hat{x}_i^k = E\{x_i^k\} .$$

The feature subset selection algorithm first selects the best single feature (based on the F-ratios), and then rules out all other features as candidate features, which have correlation greater than T with the selected feature. The threshold, T, is determined empirically. Of the remaining candidate features, the second feature is selected as that having the greatest F-ratio. Again, all remaining candidate features are eliminated as candidates if their correlation with the currently selected feature exceeds T. This process continues until no candidate feature exists for consideration. Appendicies 5A and 5B define alternate procedures for defining a feature space.

5.1.4.2 Parameter Derivation

The two parameters specified are the correlation threshold and the number of features to be employed. In order to determine these two parameters, a sequence of experiments were conducted using three phonetic events. The events used are /i/, the best performing of the set, /ɔ/, whose performance is about middle in the group, and /ɛ/, with very poor performance.

The parameters were determined sequentially, assuming independence between the threshold and number of features. The performance criterion was the SASIS operation characteristic, SOC, curve which measures interclass confusion versus intraclass accuracy based on the weighted Euclidean distance metric.

The first parameter to be determined was correlation threshold, T. Figures 5.2a 5.2b and 5.3 show SOC curves for the three events for T=30, 40, 50, 60, and 70, and with the best 18 features. Events appear to perform optimally with T=50 to 60. A threshold of T-60 was selected. The effect of correlation undiscriminatory power is discussed in Appendix 5C.

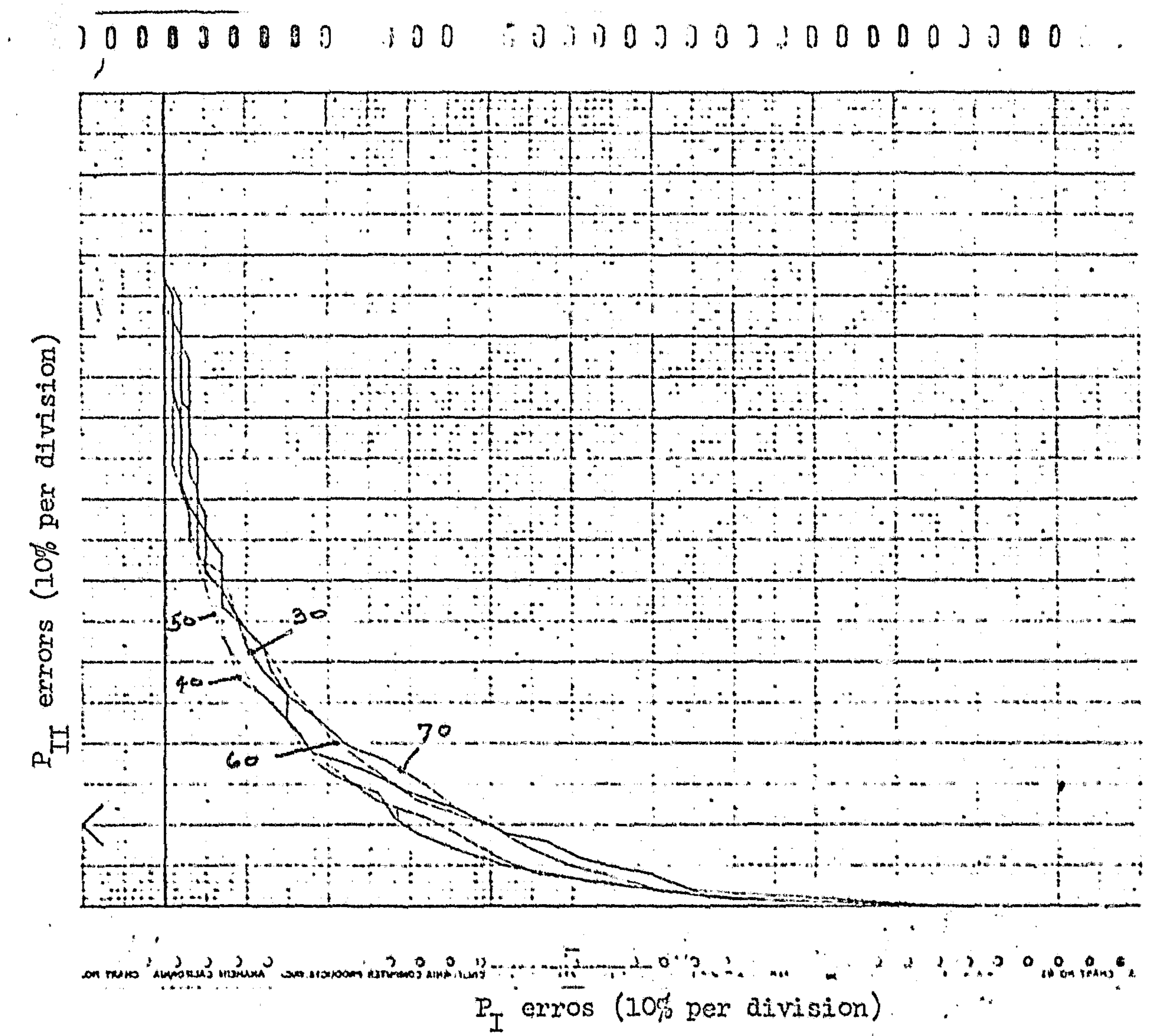

Figure 5.2a SOC curves for the event /i/ based on varying the correlation threshold for accepting features and selecting the top 18 features.

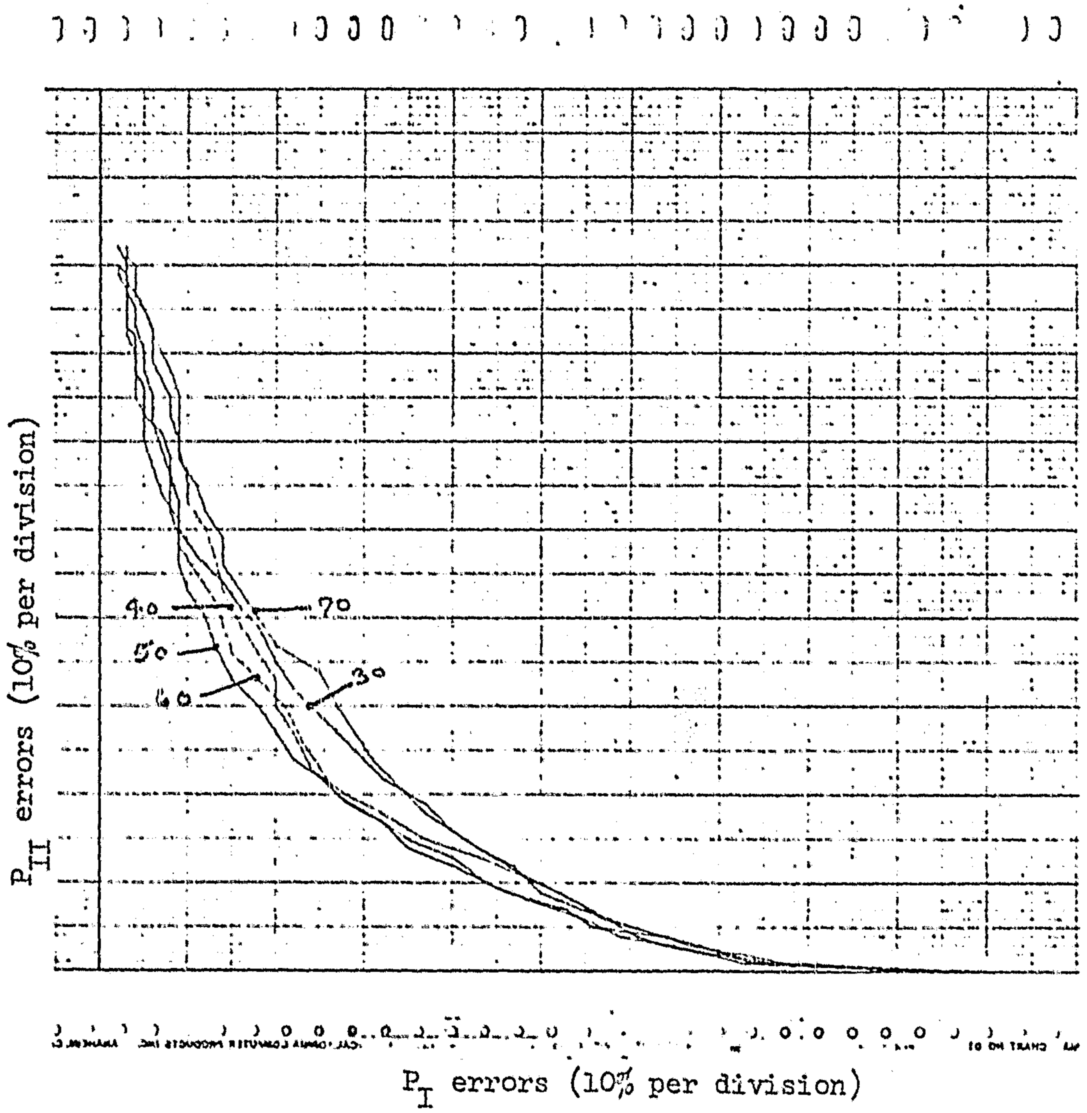

Figure 5.2b SOC curves for the event /ɛ/ based on varying the correlation threshold for accepting features and selecting th top 18 features

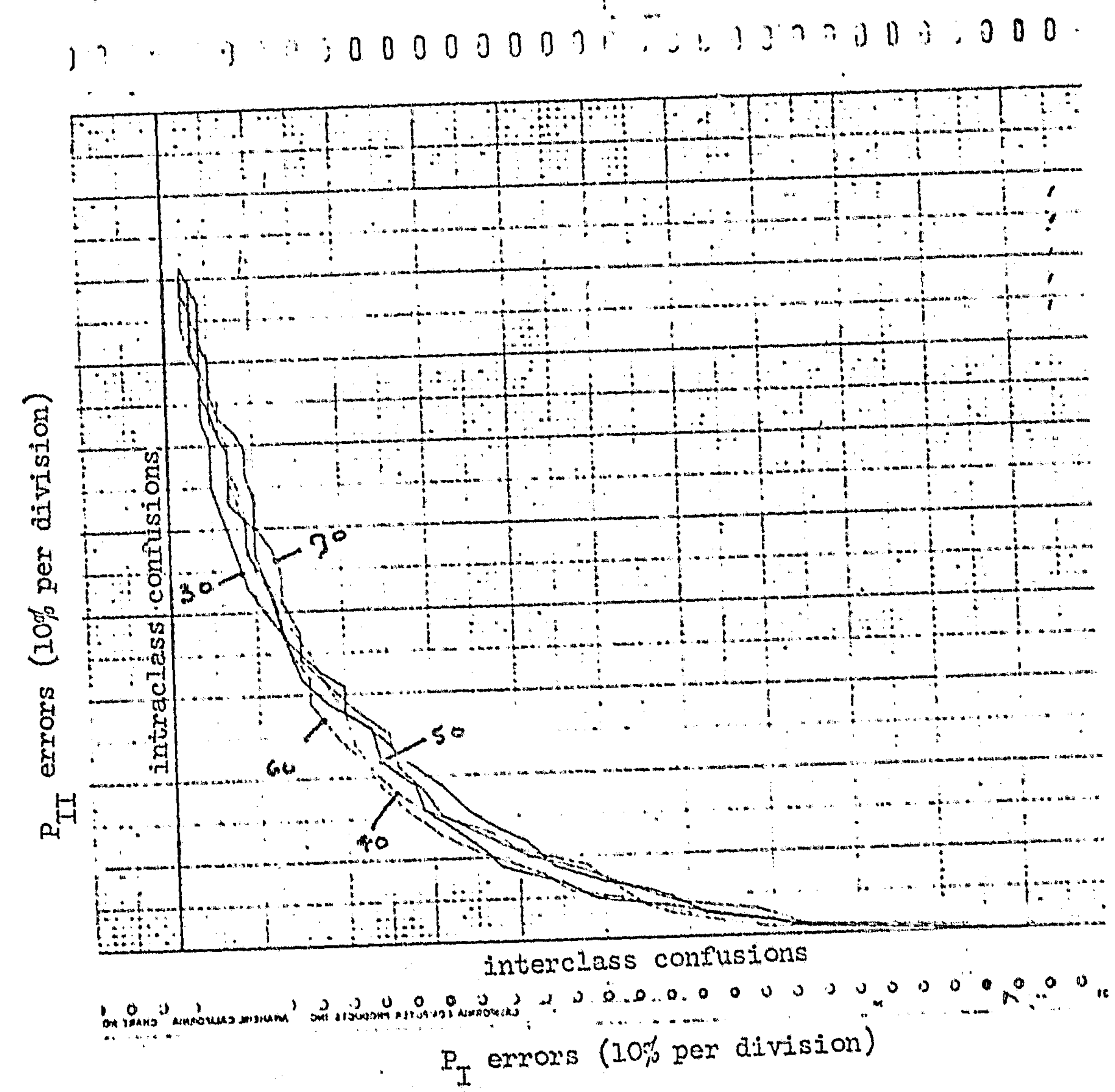

Figure 5.3 SOC curves for the event /ɔ/ based on varying the correlation threshold for accepting features and selecting the top 18 features.

The next experiment conducted was to determine the number of features to be used in the distance measure. Again SOC curves were employed and were based on weighted Euclidean distance. Figures 5.4, 5.5, and 5.6 show results for the three phonetic events where several sets of features and T=60 were used. The numbers of feature making up each set were determined by using the selected features with F-ratios greater than 1.0, 0.7, 0.5, 0.3, and the highest ranked (according to F-ratio) 30 features. Performance, in general, improved as the number of features increased up to 20. Above 20 performance appeared to vary only slightly. This is probably due to the low weights assigned to the last feature selected. It was also observed that performance did not deteriorate as the size of the feature base was increased. This observation, tends to verify the validity of the correlation selection and weighting procedure in that contributions by additional features are appropriately weighted and decorrelated with existing feature information.

A feature set size of 30 was selected for subsequent processing.

5.1.4.3 Feature Sets Selected

Table 5.3 lists the features selected for all 14 phonetic event categories from this first phase of feature extraction. Features are listed by feature numbers and are ranked 1 through 30. Only the top 30 selected features (with exception of event number 29, where only 29 were selected) are shown in the table.

The features selected are predominantly those which measure energies or energy differentials in the second and third formant regions. The first formant regions are also represented in the low vowels, where the first formant positions are high enough to pass through the communications channel. Other features are scattered throughout the sets; however, it appears that the feature information is greatest in regions near these formant positions.

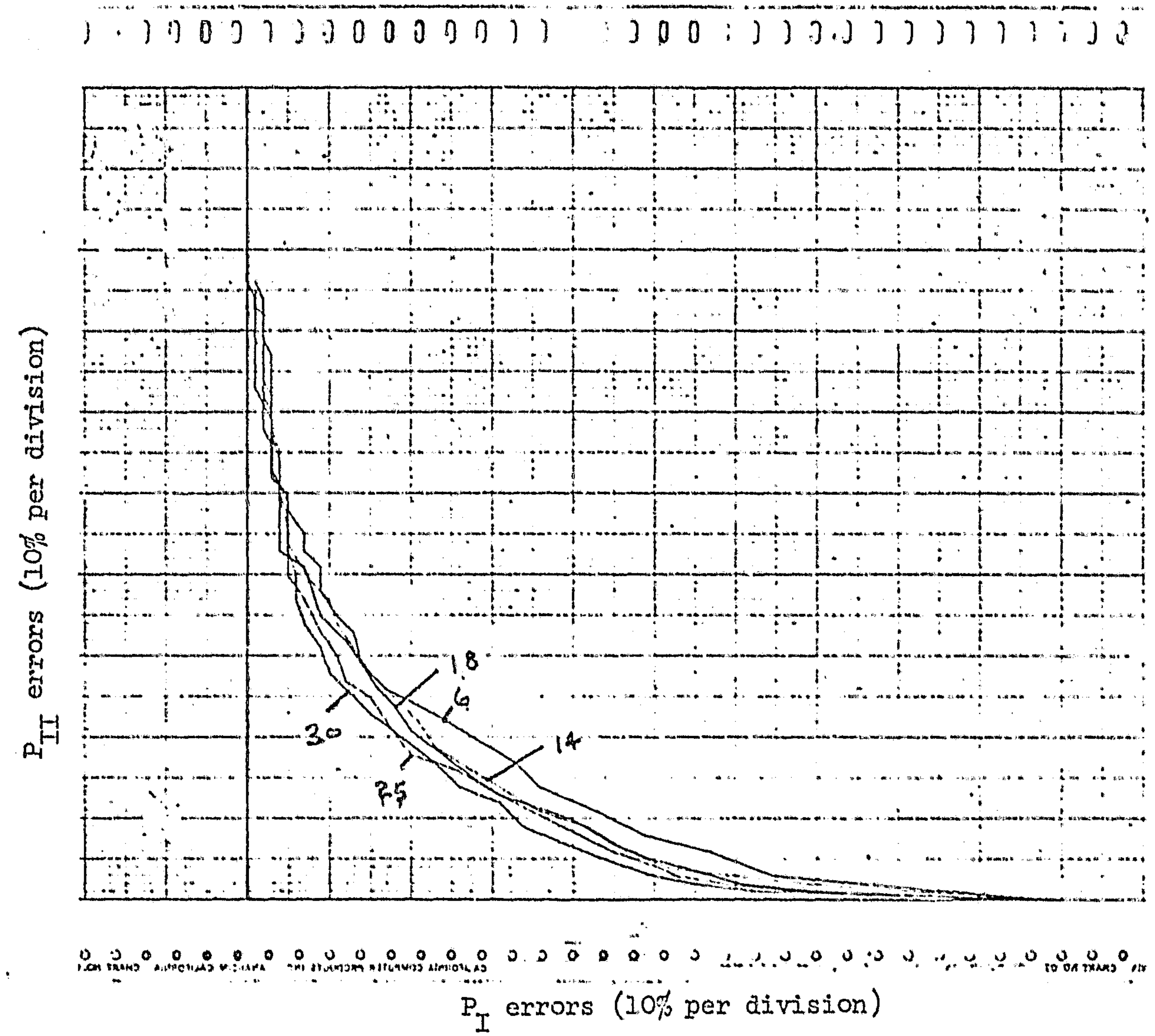

Figure 5.4 SOC curves for the event /i/ using inter-feature correlation threshold of 60 and varying the number of features.

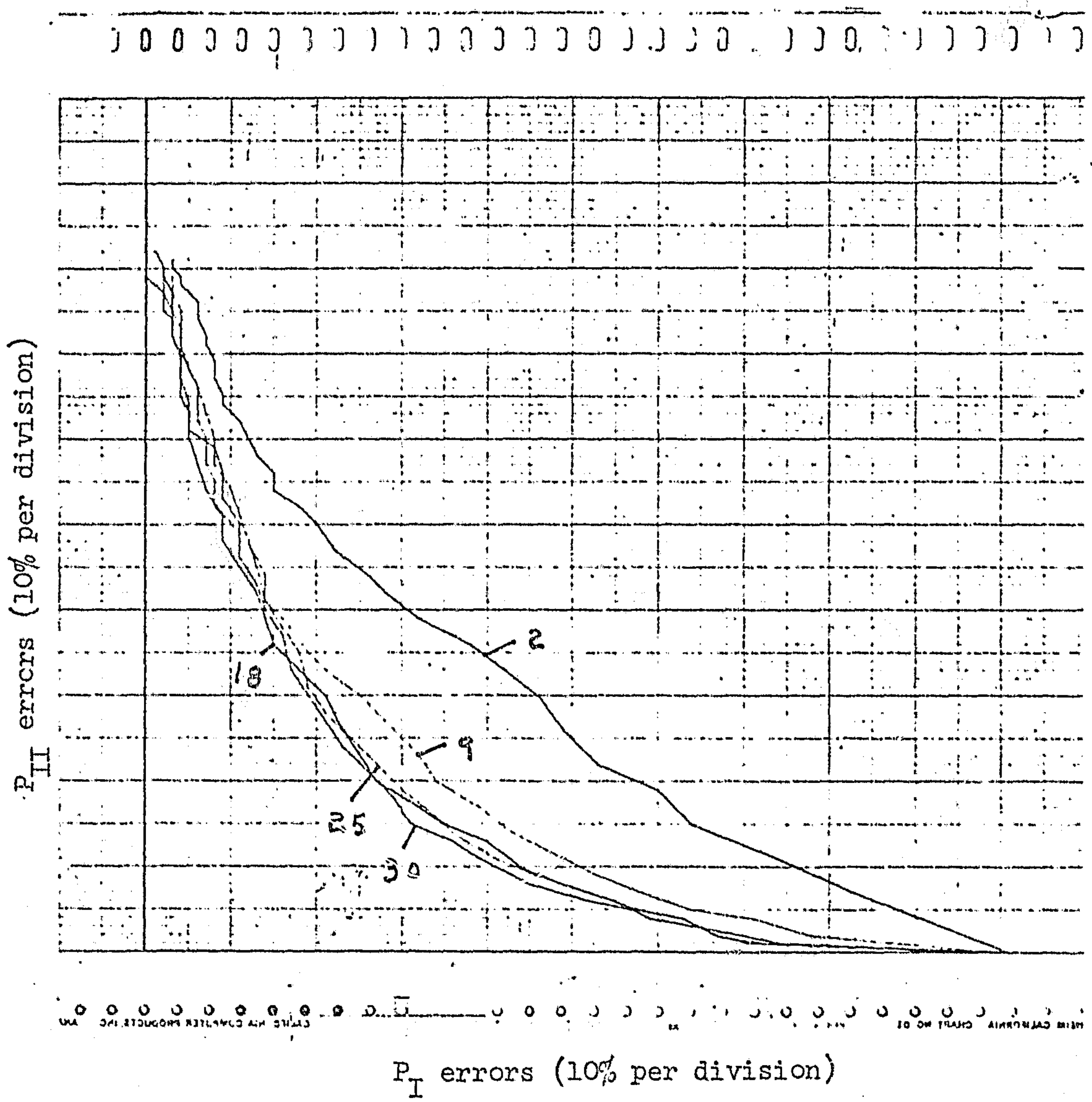

Figure 5.5 SOC curves for the event /ε/ using interfeature correlation threshold of 60 and varying the number of features.

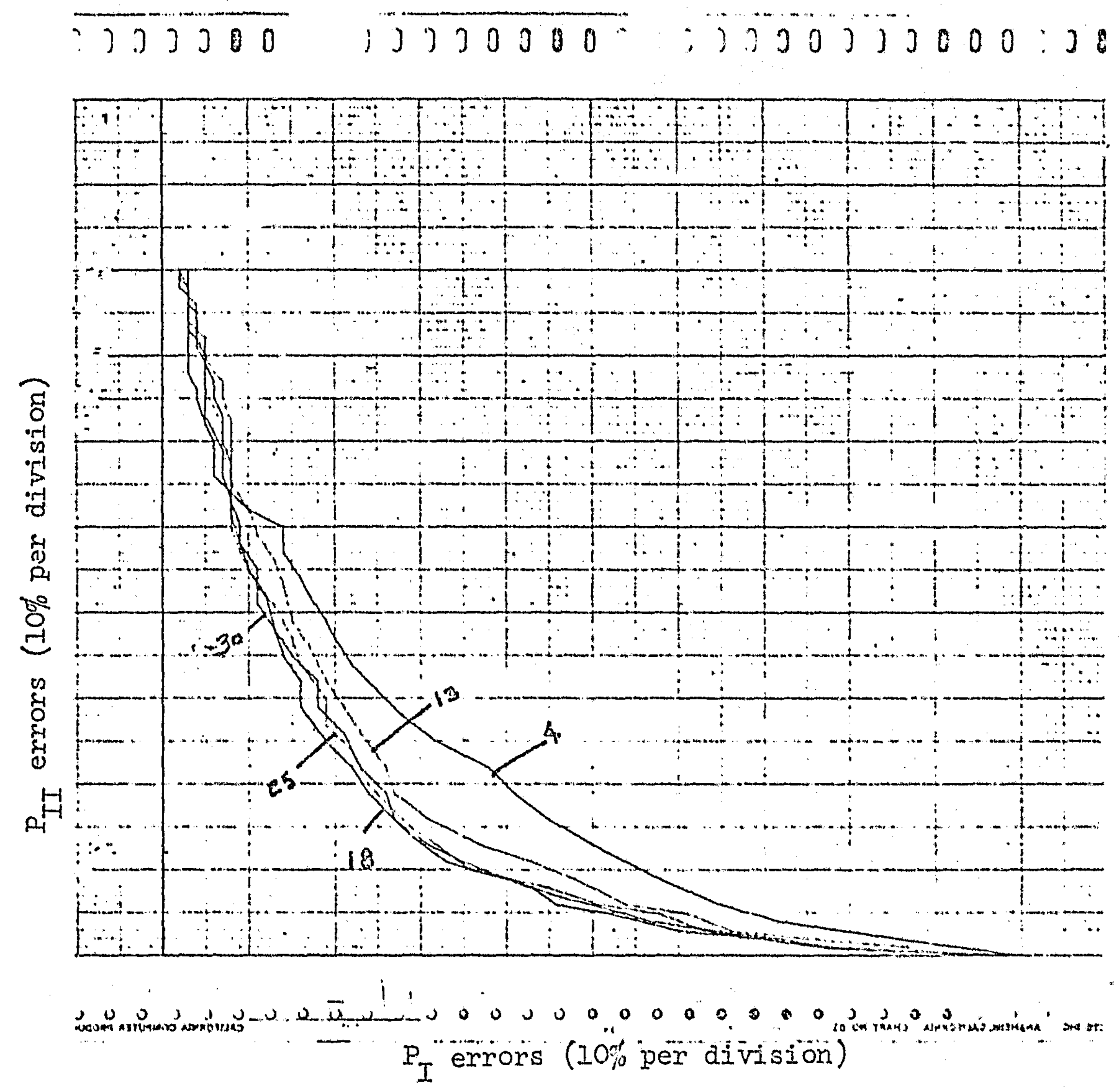

Figure 5.6 SOC curves for the event /i/ using interfeature correlation threshold of 60 and varying the number of features.

TABLE 5.3

Features Selected for Individual Phonetic Events

Feature Rank	Event No. 20	21	22	23	24	25	26	27	28	29	30	31	32	33
1	139	87	141	20	63	151	2	35	35	17	18	23	33	33
2	87	9	4	25	14	14	16	21	23	20	19	34	155	35
3	4	20	20	155	153	17	153	151	115	16	143	20	130	14
4	33	3	53	9	35	20	20	20	17	35	24	152	129	60
5	127	4	25	14	24	93	87	17	67	19	148	17	22	31
6	9	141	128	21	94	34	21	18	20	151	34	30	134	153
7	53	108	3	139	68	94	67	57	126	61	9	142	14	8
8	94	1	17	142	73	9	115	9	114	127	31	12	26	129
9	3	16	94	65	18	30	14	11	142	12	35	14	29	18
10	68	35	46	147	127	56	120	142	154	63	29	114	124	146
11	29	44	109	29	148	24	113	87	37	53	130	24	97	21
12	56	86	8	24	11	128	129	33	30	24	11	77	63	47
13	35	102	33	67	13	100	11	128	121	102	12	11	45	56
14	102	17	1	54	132	109	141	117	56	11	8	161	70	51
15	120	123	5	150	12	46	24	131	1	41	126	37	20	26
16	144	33	35	33	134	4	35	111	52	8	54	3	13	40
17	41	14	59	8	20	12	114	4	4	124	5	53	1	126
18	93	48	150	13	17	131	33	24	14	4	121	112	114	131
19	109	153	102	126	26	133	55	54	26	7	100	8	11	4
20	5	64	14	64	100	13	4	61	62	110	1	26	6	112
21	39	2	2	98	9	37	1	19	46	48	37	2	12	13
22	151	8	7	3	29	54	3	5	97	6	2	136	98	2
23	6	100	6	5	3	64	97	8	123	109	3	1	8	12
24	100	150	100	6	2	7	123	47	33	98	107	122	9	9
25	62	12	64	12	107	26	102	133	29	96	7	127	99	109
26	99	77	95	40	137	115	29	3	137	99	6	98	110	24
27	11	7	98	107	41	90	12	97	6	115	99	105	32	102
28	32	99	97	37	120	35	26	12	102	32	111	130	10	98
29	95	6	99	108	4	48	41	113	12	95	98	64	95	135
30	13	95	32	4	39	8	5	100	39	N/A	95	40	96	7

Among the features selected, the LPC spectral estimates, special features sensitive to certain events (but not necessarily those events for which selection was made), and spectral derivatives are most popular. The FFT spectral measurements were not as well represented as were the LPC, probably due to finer gradation of the LPC measurements.

5.2 FEATURE EXTRACTION - PHASE II

5.2.1 Summary

A second phase of feature extraction was undertaken. The purpose of the task is to optimize the feature base on the training portion (75 speakers) of Data Base II.

In order to carry out feature optimization, two factors were considered. First, an effort has been applied to measure the standard deviation of each feature's value across disjoint data bases. Second, a measure of consistency in performance of a single feature set across several data bases was made. This latter factor resulted in a modification of the F-ratio feature evaluation procedure. The modified F-ratio utilizes a text dependency constraint and has been determined to produce a more consistently performing feature set across both data bases.

As described in Section 5.1.1, the feature selection procedure is partitioned into three phases, as follows:

1) Define a large set of features using a heuristic procedure.
2) Evaluate each feature on a first-order (without regard to interfeature dependencies) basis and derive weights for each feature.
3) Select a subset of features for each phonetic event category using a second-order (interfeature correlation) selection procedure.

The selection process is carried out for each phonetic event independently.

The resultant of this procedure is a unique set of 30 features for each phonetic event along with a weight for each feature.

In the first phase, feature definition, a set of 162 features were defined based on DFFT special estimates and ratios, time-domain measurements, and LPC-derived measurements. These features form a base from which a subset for each phonetic event is selected and are defined in Table 5.1.

The next phase in the selection procedure is that of evaluating each feature for each phonetic event. The evaluation procedure applies a figure of merit to each feature independently.

The final phase, feature subset selection, selects a subset of the 162 candidate features for each phonetic event. The selection procedure is a sequential procedure which makes use of the features, ranked on the basis of F-ratio, and the interfeature correlation coefficient. The selection process accepts the next feature which is

- highest in F-ratio, and
- has a correlation coefficient no greater than .6 (empirically derived) with features already selected.

The selection process continues until either 30 features have been selected or no candidate features remain, whichever occurs first.

5.2.2 Verifying Feature Statistics

A task was carried out to verify the feature selection task, based on consistency of results when features are dextracted from two independent data bases.

5.2.2.1 Verification Based on Analysis of Selected Feature Sets

A possible procedure for measuring the validity of the feature selection procedure is to perform the same process on different data bases and to compare resultant feature sets and their weights. The disadvantage of this approach is that the selection process is nonlinear in nature and is sensitive to minor variations in variances and correlations. This is not to imply that this sensitivity might produce an unacceptable feature set, but that many equally valid feature subsets of 30 features exist for each phonetic event. The 162 candidate features have many subsets with high internal correlations, one element of which might be selected with one data base and another for a different data base. For these reasons, this verification procedure was not used.

5.2.2.2 Verification Based on Analysis of Interclass and Intraclass Standard Deviations

A more acceptable verification procedure is to evaluate the features individually on several data bases and to compare their intraclass and interclass standard deviations. For the purpose of this experiment and subsequent experiments defined in this section, the following definitions will be employed:

DBI - Data Base I

DBIIA - A randomly selected set of 75 speakers from Data Base II

DBIIB - A randomly selected set of 75 speakers of Data Base II and disjoint from DBIIA

An experiment was carried out in which DBI, DBIIA, and DBIIB were analyzed on the basis of interclass and intraclass standard deviations. These standard deviations are computed on a context free basis in the following manner.

If F_{cj} is the j^{th} token of feature F from speaker (class) c,

$$\hat{F}_c = \underset{j}{E}\left\{F_{cj}\right\},$$

$$\hat{F} = \underset{c}{E}\left\{\hat{F}_c\right\}, \text{ then}$$

$$\sigma_{\text{interclass}} = \left(\underset{c}{E}\left\{(\hat{F}_c - \hat{F})^2\right\}\right)^{1/2}, \text{ and}$$

$$\sigma_{\text{intraclass}} = \left[\underset{c}{E}\left[\underset{j}{E}\left\{(F_{cj} - \hat{F}_c)^2\right\}\right]\right]^{1/2}.$$

The F-ratio, FR1, is defined as

$$FR1 = (\sigma_{\text{interclass}})^2 / (\sigma_{\text{intraclass}})^2$$

Tables 5.4, 5.5, and 5.6 show the results of the analysis performed on the first 46 features for the event /I/ from DBI, DBIIA, and DBIIB. This example is typical of other events and other features.

In these tables, the first column refers to feature number; the second column is feature location and is not relevant to this explanation; the third column is the intraclass standard deviation; the fourth, the interclass standard deviation; the fourth, the interclass standard deviation; the fifth, the F-ratio, FR1; and the last column is the feature weight ($\sqrt{FR1}$ x 100).

Comparison is based on standard deviations, std, by measuring the variation between the estimated statistics for the same features across different data bases. If we define the interclass sample variance as τ^2 and the intraclass sample variance as ω^2, then from Appendix 5D we can estimate the standard deviation across features between two data bases as

$$\text{std}\left(\frac{\tau_1^2 - \tau_2^2}{\tau_1^2 + \tau_2^2}\right) \simeq \frac{1}{\sqrt{S-1}} \quad \text{and}$$

$$\text{std}\left(\frac{\omega_1^2 - \omega_2^2}{\omega_1^2 + \omega_2^2}\right) \simeq \frac{1}{\sqrt{(N-1)S}},$$

where S is the number of speakers, and N is the number of tokens per speaker.

Table 5.7 shows these values estimated from the data and the theoretical values.

NO. TOKENS = 648

FEAT NO. 1,	LOCATION 217,	INTRA SD 12.6558,	INTER SD 6.5335,	F-RATIO 0.2665	WGHT 51
FEAT NO. 2,	LOCATION 218,	INTRA SD 14.8316,	INTER SD 8.0641,	F-RATIO 0.2956	WGHT 54
FEAT NO. 3,	LOCATION 219,	INTRA SD 12.9189,	INTER SD 7.5924,	F-RATIO 0.3454	WGHT 58
FEAT NO. 4,	LOCATION 220,	INTRA SD 13.0908,	INTER SD 5.4534,	F-RATIO 0.1733	WGHT 41
FEAT NO. 5,	LOCATION 221,	INTRA SD 16.2745,	INTER SD 6.3119,	F-RATIO 0.1504	WGHT 38
FEAT NO. 6,	LOCATION 222,	INTRA SD 26.0617,	INTER SD 9.5342,	F-RATIO 0.1328	WGHT 36
FEAT NO. 7,	LOCATION 223,	INTRA SD 26.0372,	INTER SD 9.2174,	F-RATIO 0.1254	WGHT 35
FEAT NO. 8,	LOCATION 224,	INTRA SD 17.5252,	INTER SD 7.0006,	F-RATIO 0.1598	WGHT 39
FEAT NO. 9,	LOCATION 225,	INTRA SD 15.7919,	INTER SD 9.4085,	F-RATIO 0.3595	WGHT 59
FEAT NO. 10,	LOCATION 226,	INTRA SD 21.0509,	INTER SD 14.0441,	F-RATIO 0.4644	WGHT 68
FEAT NO. 11,	LOCATION 227,	INTRA SD 15.7061,	INTER SD 12.3981,	F-RATIO 0.6179	WGHT 78
FEAT NO. 12,	LOCATION 228,	INTRA SD 14.6256,	INTER SD 11.1582,	F-RATIO 0.5813	WGHT 76
FEAT NO. 13,	LOCATION 229,	INTRA SD 10.1204,	INTER SD 7.9245,	F-RATIO 0.6119	WGHT 78
FEAT NO. 14,	LOCATION 230,	INTRA SD 12.8422,	INTER SD 11.9796,	F-RATIO 0.8700	WGHT 93
FEAT NO. 15,	LOCATION 231,	INTRA SD 15.2019,	INTER SD 12.7463,	F-RATIO 0.7070	WGHT 83
FEAT NO. 16,	LOCATION 232,	INTRA SD 10.4206,	INTER SD 7.4942,	F-RATIO 0.5166	WGHT 71
FEAT NO. 17,	LOCATION 233,	INTRA SD 19.1227,	INTER SD 13.2900,	F-RATIO 0.4807	WGHT 69
FEAT NO. 18,	LOCATION 234,	INTRA SD 15.8039,	INTER SD 12.6034,	F-RATIO 0.6361	WGHT 79
FEAT NO. 19,	LOCATION 235,	INTRA SD 16.5144,	INTER SD 13.2985,	F-RATIO 0.6477	WGHT 80
FEAT NO. 20,	LOCATION 236,	INTRA SD 19.0805,	INTER SD 13.4814,	F-RATIO 0.5026	WGHT 70
FEAT NO. 21,	LOCATION 237,	INTRA SD 14.4122,	INTER SD 12.2367,	F-RATIO 0.7209	WGHT 84
FEAT NO. 22,	LOCATION 238,	INTRA SD 8.8752,	INTER SD 6.2160,	F-RATIO 0.4905	WGHT 70
FEAT NO. 23,	LOCATION 239,	INTRA SD 16.6441,	INTER SD 14.0376,	F-RATIO 0.7193	WGHT 84
FEAT NO. 24,	LOCATION 240,	INTRA SD 13.1000,	INTER SD 16.0069,	F-RATIO 0.7810	WGHT 88
FEAT NO. 25,	LOCATION 241,	INTRA SD 20.5316,	INTER SD 15.3450,	F-RATIO 0.5585	WGHT 74
FEAT NO. 26,	LOCATION 242,	INTRA SD 18.3705,	INTER SD 12.6771,	F-RATIO 0.4759	WGHT 68
FEAT NO. 27,	LOCATION 243,	INTRA SD 15.7157,	INTER SD 12.5212,	F-RATIO 0.6348	WGHT 79
FEAT NO. 28,	LOCATION 244,	INTRA SD 16.2011,	INTER SD 10.4562,	F-RATIO 0.4165	WGHT 64
FEAT NO. 29,	LOCATION 245,	INTRA SD 15.7506	INTER SD 9.3721,	F-RATIO 0.3541	WGHT 59
FEAT NO. 30,	LOCATION 246,	INTRA SD 19.1771,	INTER SD 16.0234,	F-RATIO 0.6993	WGHT 83
FEAT NO. 31,	LOCATION 247,	INTRA SD 16.3735,	INTER SD 10.8672,	F-RATIO 0.4405	WGHT 66
FEAT NO. 32,	LOCATION 249,	INTRA SD113.7900,	INTER SD 25.4482,	F-RATIO 0.0500	WGHT 22
FEAT NO. 33,	LOCATION 250,	INTRA SD 8.2434,	INTER SD 6.4062,	F-RATIO 0.6153	WGHT 78
FEAT NO. 34,	LOCATION 251,	INTRA SD 1.7460,	INTER SD 1.5499,	F-RATIO 0.7080	WGHT 88
FEAT NO. 35,	LOCATION 252,	INTRA SD 21.9116,	INTER SD 20.0771,	F-RATIO 0.8396	WGHT 91
FEAT NO. 36,	LOCATION 509,	INTRA SD 0.0000,	INTER SD 0.0000,	F-RATIO 0.0000	WGHT 0
FEAT NO. 37,	LOCATION 510,	INTRA SD 12.7313,	INTER SD 5.6085,	F-RATIO 0.1941	WGHT 44
FEAT NO. 38,	LOCATION 511,	INTRA SD 17.3239,	INTER SD 6.9508,	F-RATIO 0.1614	WGHT 40
FEAT NO. 39,	LOCATION 512,	INTRA SD 16.0903,	INTER SD 6.4876,	F-RATIO 0.1619	WGHT 40
FEAT NO. 40,	LOCATION 513,	INTRA SD 15.3427,	INTER SD 7.1193,	F-RATIO 0.2153	WGHT 46
FEAT NO. 41,	LOCATION 514,	INTRA SD 16.8461,	INTER SD 8.0110,	F-RATIO 0.2261	WGHT 47
FEAT NO. 42,	LOCATION 515,	INTRA SD 18.5105,	INTER SD 6.9101,	F-RATIO 0.1394	WGHT 37
FEAT NO. 43,	LOCATION 516,	INTRA SD 18.0169,	INTER SD 7.2078,	F-RATIO 0.1600	WGHT 40
FEAT NO. 44,	LOCATION 517,	INTRA SD 17.5321,	INTER SD 8.8102,	F-RATIO 0.2525	WGHT 50
FEAT NO. 45,	LOCATION 518,	INTRA SD 17.0312,	INTER SD 10.1555,	F-RATIO 0.3556	WGHT 59
FEAT NO. 46,	LOCATION 519,	INTRA SD 18.8725,	INTER SD 12.1270,	F-RATIO 0.4136	WGHT 64
FEAT NO. 47,	LOCATION 520,	INTRA SD 20.0741,	INTER SD 13.8817,	F-RATIO 0.4768	WGHT 69
FEAT NO. 48,	LOCATION 521,	INTRA SD 19.4225,	INTER SD 13.9992,	F-RATIO 0.5195	WGHT 72
FEAT NO. 49,	LOCATION 522,	INTRA SD 20.5508,	INTER SD 13.2770,	F-RATIO 0.4170	WGHT 64
FEAT NO. 50,	LOCATION 523,	INTRA SD 23.3253,	INTER SD 12.1134,	F-RATIO 0.2697	WGHT 51

TABLE 5.4

Feature values for event I based on DBI

NO. TOKENS = 901

FEAT NO. 1,	LOCATION 217,	INTRA SD 14.2254,	INTER SD 9.8186,	F-RATIO 0.4764	WGHT 69
FEAT NO. 2,	LOCATION 218,	INTRA SD 15.1616,	INTER SD 11.6231,	F-RATIO 0.5877	WGHT 76
FEAT NO. 3,	LOCATION 219,	INTRA SD 11.8806,	INTER SD 7.2050,	F-RATIO 0.3678	WGHT 60
FEAT NO. 4,	LOCATION 220,	INTRA SD 11.5899,	INTER SD 6.3743,	F-RATIO 0.3025	WGHT 54
FEAT NO. 5,	LOCATION 221,	INTRA SD 15.6594,	INTER SD 9.8453,	F-RATIO 0.3953	WGHT 62
FEAT NO. 6,	LOCATION 222,	INTRA SD 22.5922,	INTER SD 11.7115,	F-RATIO 0.2690	WGHT 51
FEAT NO. 7,	LOCATION 223,	INTRA SD 19.9970,	INTER SD 12.2129,	F-RATIO 0.3792	WGHT 61
FEAT NO. 8,	LOCATION 224,	INTRA SD 14.8104,	INTER SD 10.8333,	F-RATIO 0.5203	WGHT 72
FEAT NO. 9,	LOCATION 225,	INTRA SD 16.0738,	INTER SD 8.8337,	F-RATIO 0.3021	WGHT 54
FEAT NO. 10,	LOCATION 226,	INTRA SD 20.1615,	INTER SD 13.6026,	F-RATIO 0.4604	WGHT 67
FEAT NO. 11,	LOCATION 227,	INTRA SD 17.0252,	INTER SD 10.1502,	F-RATIO 0.3702	WGHT 60
FEAT NO. 12,	LOCATION 228,	INTRA SD 14.8144,	INTER SD 5.5726,	F-RATIO 0.4010	WGHT 67
FEAT NO. 13,	LOCATION 229,	INTRA SD 11.9761,	INTER SD 6.9124,	F-RATIO 0.3391	WGHT 57
FEAT NO. 14,	LOCATION 230,	INTRA SD 13.5119,	INTER SD 9.6034,	F-RATIO 0.5117	WGHT 71
FEAT NO. 15,	LOCATION 231,	INTRA SD 15.9042,	INTER SD 8.2919,	F-RATIO 0.3198	WGHT 56
FEAT NO. 16,	LOCATION 232,	INTRA SD [illegible].1416,	INTER SD 5.8944,	F-RATIO 0.4136	WGHT 64
FEAT NO. 17,	LOCATION 233,	INTRA SD 16.2419,	INTER SD 14.0826,	F-RATIO 0.6092	WGHT 83
FEAT NO. 18,	LOCATION 234,	INTRA SD 15.4321,	INTER SD 10.5969,	F-RATIO 0.4717	WGHT 68
FEAT NO. 19,	LOCATION 235,	INTRA SD 16.0610,	INTER SD 11.2107,	F-RATIO 0.4434	WGHT 66
FEAT NO. 20,	LOCATION 236,	INTRA SD 18.1503,	INTER SD 11.4518,	F-RATIO 0.3981	WGHT 63
FEAT NO. 21,	LOCATION 237,	INTRA SD 14.0355,	INTER SD 13.0906,	F-RATIO 0.8024	WGHT 92
FEAT NO. 22,	LOCATION 238,	INTRA SD [illegible],	INTER SD 5.1178,	F-RATIO 0.3606	WGHT 60
FEAT NO. 23,	LOCATION 239,	INTRA SD 15.4691,	INTER SD 14.3920,	F-RATIO 0.8056	WGHT 93
FEAT NO. 24,	LOCATION 240,	INTRA SD 19.2879,	INTER SD 12.3546,	F-RATIO 0.4103	WGHT 64
FEAT NO. 25,	LOCATION 241,	INTRA SD 18.7781,	INTER SD 12.1428,	F-RATIO 0.4181	WGHT 64
FEAT NO. 26,	LOCATION 242,	INTRA SD 17.9154,	INTER SD 9.3014,	F-RATIO 0.3056	WGHT 55
FEAT NO. 27,	LOCATION 243,	INTRA SD 17.7248,	INTER SD 11.7225,	F-RATIO 0.7200	WGHT 85
FEAT NO. 28,	LOCATION 244,	INTRA SD 17.7049,	INTER SD 10.4204,	F-RATIO 0.5792	WGHT 76
FEAT NO. 29,	LOCATION 245,	INTRA SD 14.5002,	INTER SD 12.4188,	F-RATIO 0.7325	WGHT 85
FEAT NO. 30,	LOCATION 246,	INTRA SD 19.3707,	INTER SD 14.8102,	F-RATIO 0.5349	WGHT 76
FEAT NO. 31,	LOCATION 247,	INTRA SD 17.0800,	INTER SD 12.0515,	F-RATIO 0.7529	WGHT 86
FEAT NO. 32,	LOCATION 249,	INTRA SD103.6024,	INTER SD 38.1292,	F-RATIO 0.1354	WGHT 36
FEAT NO. 33,	LOCATION 250,	INTRA SD 8.2755,	INTER SD 9.7513,	F-RATIO 1.3555	WGHT 116
FEAT NO. 34,	LOCATION 251,	INTRA SD 1.0792,	INTER SD 2.3351,	F-RATIO 1.3942	WGHT 118
FEAT NO. 35,	LOCATION 252,	INTRA SD [illegible],	INTER SD 24.0831,	F-RATIO 0.6309	WGHT 79
FEAT NO. 36,	LOCATION 509,	INTRA SD 0.0000,	INTER SD 0.0000,	F-RATIO 0.0000	WGHT 0
FEAT NO. 37,	LOCATION 510,	INTRA SD 10.7970,	INTER SD 7.5164,	F-RATIO 0.4804	WGHT 69
FEAT NO. 38,	LOCATION 511,	INTRA SD 19.1527,	INTER SD 9.7324,	F-RATIO 0.4125	WGHT 64
FEAT NO. 39,	LOCATION 512,	INTRA SD [illegible],	INTER SD 9.9372,	F-RATIO 0.3566	WGHT 59
FEAT NO. 40,	LOCATION 513,	INTRA SD 15.[illegible],	INTER SD 6.7743,	F-RATIO 0.1985	WGHT 44
FEAT NO. 41,	LOCATION 514,	INTRA SD 16.7182,	INTER SD 8.3876,	F-RATIO 0.2666	WGHT 51
FEAT NO. 42,	LOCATION 515,	INTRA SD [illegible],	INTER SD 9.1601,	F-RATIO 0.2971	WGHT 54
FEAT NO. 43,	LOCATION 516,	INTRA SD [illegible],	INTER SD 9.5102,	F-RATIO 0.3619	WGHT 60
FEAT NO. 44,	LOCATION 517,	INTRA SD [illegible],	INTER SD 9.6323,	F-RATIO 0.3723	WGHT 61
FEAT NO. 45,	LOCATION 518,	INTRA SD 16.7156,	INTER SD 9.8021,	F-RATIO 0.1585	WGHT 59
FEAT NO. 46,	LOCATION 519,	INTRA SD 16.8957,	INTER SD 11.5576,	F-RATIO 0.4687	WGHT 68

TABLE 5.5

Feature values for event I based on DBIIA

```
NO. TOKENS =  832
FEAT NO.   1, LOCATION 217, INTRA SD 12.9946, INTER SD  8.4787, F-RATIO  0.4257 WGHT  65
FEAT NO.   2, LOCATION 218, INTRA SD 15.2225, INTER SD  9.8553, F-RATIO  0.4192 WGHT  64
FEAT NO.   3, LOCATION 219, INTRA SD 12.2203; INTER SD  6.2111, F-RATIO  0.2583 WGHT  50
FEAT NO.   4, LOCATION 220, INTRA SD 12.1513, INTER SD  6.8403, F-RATIO  0.3169 WGHT  56
FEAT NO.   5, LOCATION 221, INTRA SD 17.5036, INTER SD  8.9791, F-RATIO  0.2612 WGHT  51
FEAT NO.   6, LOCATION 222, INTRA SD 22.7025, INTER SD  9.2961, F-RATIO  0.1676 WGHT  40
FEAT NO.   7, LOCATION 223, INTRA SD 20.1505, INTER SD 13.8005, F-RATIO  0.4692 WGHT  68
FEAT NO.   8, LOCATION 224, INTRA SD 15.8[illegible], INTER SD 11.0[illegible], F-RATIO  0.5[illegible] WGHT  74
FEAT NO.   9, LOCATION 225, INTRA SD 15.4173, INTER SD  9.4171, F-RATIO  0.3749 WGHT  61
FEAT NO.  10, LOCATION 226, INTRA SD 21.0564, INTER SD 14.1[illegible], F-RATIO  0.4540 WGHT  67
FEAT NO.  11, LOCATION 227, INTRA SD 16.4030, INTER SD 12.1008, F-RATIO  0.5675 WGHT  75
FEAT NO.  12, LOCATION 228, INTRA SD 14.9005, INTER SD 11.3025, F-RATIO  0.5754 WGHT  75
FEAT NO.  13, LOCATION 229, INTRA SD 12.0273, INTER SD  7.6170, F-RATIO  0.4004 WGHT  63
FEAT NO.  14, LOCATION 230, INTRA SD 13.4331, INTER SD 12.4377, F-RATIO  0.8643 WGHT  92
FEAT NO.  15, LOCATION 231, INTRA SD 16.9139, INTER SD 11.1774, F-RATIO  0.4354 WGHT  65
FEAT NO.  16, LOCATION 232, INTRA SD  9.9012, INTER SD  6.8812, F-RATIO  0.4748 WGHT  68
FEAT NO.  17, LOCATION 233, INTRA SD 16.2054, INTER SD 14.2237, F-RATIO  0.7703 WGHT  87
FEAT NO.  18, LOCATION 234, INTRA SD 15.5004, INTER SD 11.8464, F-RATIO  0.5495 WGHT  74
FEAT NO.  19, LOCATION 235, INTRA SD 17.1147, INTER SD 14.5681, F-RATIO  0.7245 WGHT  85
FEAT NO.  20, LOCATION 236, INTRA SD 17.6173, INTER SD 11.0085, F-RATIO  0.3962 WGHT  62
FEAT NO.  21, LOCATION 237, INTRA SD 13.8032, INTER SD 12.6513, F-RATIO  0.9423 WGHT  97
FEAT NO.  22, LOCATION 238, INTRA SD  8.0198, INTER SD  5.3099, F-RATIO  0.4202 WGHT  66
FEAT NO.  23, LOCATION 239, INTRA SD 14.2774, INTER SD 14.1703, F-RATIO  0.9781 WGHT  98
FEAT NO.  24, LOCATION 240, INTRA SD 20.0144, INTER SD 13.6417, F-RATIO  0.4624 WGHT  68
FEAT NO.  25, LOCATION 241, INTRA SD 19.1013, INTER SD 12.4179, F-RATIO  0.4224 WGHT  64
FEAT NO.  26, LOCATION 242, INTRA SD 18.7334, INTER SD 12.5746, F-RATIO  0.4503 WGHT  67
FEAT NO.  27, LOCATION 243, INTRA SD 13.7436, INTER SD 11.5928, F-RATIO  0.8269 WGHT  90
FEAT NO.  28, LOCATION 244, INTRA SD 12.9519, INTER SD  8.5756, F-RATIO  0.4384 WGHT  66
FEAT NO.  29, LOCATION 245, INTRA SD 13.7167, INTER SD 11.7183, F-RATIO  0.7324 WGHT  85
FEAT NO.  30, LOCATION 246, INTRA SD 19.7923, INTER SD 15.6199, F-RATIO  0.6905 WGHT  83
FEAT NO.  31, LOCATION 247, INTRA SD 14.2930, INTER SD 11.2793, F-RATIO  0.6222 WGHT  78
FEAT NO.  32, LOCATION 249, INTRA SD105.4984, INTER SD 31.8933, F-RATIO  0.0914 WGHT  30
FEAT NO.  33, LOCATION 250, INTRA SD  7.5127, INTER SD  7.6463, F-RATIO  1.0260 WGHT 101
FEAT NO.  34, LOCATION 251, INTRA SD  1.8140, INTER SD  1.8565, F-RATIO  1.0407 WGHT 102
FEAT NO.  35, LOCATION 252, INTRA SD 23.6105, INTER SD 21.8473, F-RATIO  0.8562 WGHT  92
FEAT NO.  36, LOCATION 509, INTRA SD  0.0000, INTER SD  0.0000, F-RATIO  0.0000 WGHT   0
FEAT NO.  37, LOCATION 510, INTRA SD  9.3503, INTER SD  8.0145, F-RATIO  0.6488 WGHT  80
FEAT NO.  38, LOCATION 511, INTRA SD 13.4357, INTER SD  8.6159, F-RATIO  0.4092 WGHT  63
FEAT NO.  39, LOCATION 512, INTRA SD 15.2519, INTER SD  9.3770, F-RATIO  0.3762 WGHT  61
FEAT NO.  40, LOCATION 513, INTRA SD 14.5234, INTER SD  8.2999, F-RATIO  0.3266 WGHT  57
FEAT NO.  41, LOCATION 514, INTRA SD 15.4461, INTER SD  8.9125, F-RATIO  0.3344 WGHT  57
FEAT NO.  42, LOCATION 515, INTRA SD 16.1242, INTER SD  8.6200, F-RATIO  0.2863 WGHT  53
FEAT NO.  43, LOCATION 516, INTRA SD 16.3216, INTER SD  9.1627, F-RATIO  0.3152 WGHT  56
FEAT NO.  44, LOCATION 517, INTRA SD 15.7376, INTER SD  9.7524, F-RATIO  0.3816 WGHT  61
FEAT NO.  45, LOCATION 518, INTRA SD 15.5191, INTER SD  9.9444, F-RATIO  0.4106 WGHT  64
FEAT NO.  46, LOCATION 519, INTRA SD 16.3171, INTER SD 10.7015, F-RATIO  0.4301 WGHT  65
```

TABLE 5.6

Feature values for event I based on DBIIB

TABLE 5.7

Case	Estimated from Data	Theoretical
Inter (DBIIA,DBIIB)	0.1334	0.1162
Intra (DBIIA,DBIIB)	0.0673	0.0516
Inter (DBI,DBIIA)	0.2780	0.2040
Intra (DBI,DBIIA)	0.1322	0.089

The estimated and theoretical standard deviations for DBIIA and DBIIB agree very closely, indicating that the level of sample variance is approximately as expected. The estimated and theoretical statistics between DBI and DBIIA disagree by approximately 40 percent, indicating that either the speaker populations had different characteristics or, more likely, the spoken material was sufficiently different between the two data bases as to introduce greater feature variability. This latter hypothesis seems more plausible for the following two reasons. First, the procedure for specifying phonetic context for Data Base II did not require hub positions to be in the same position before and after the event of interest, as did Data Base I. Second, there were fewer tokens in Data Base II from which to estimate the speaker standard deviations.

5.2.3 Introduction of Text Dependency into F-Ratio

An underlying consideration of the FR1 F-ratio feature evaluation is that the procedure used is context free; i.e., it does not consider phonetic contextual influences on the event of interest when estimating the statistics for features of that event. Obviously, context plays a significant role in determining the position of formants and source of excitation. It is hypothesized that the FR1 F-ratio might display greater variation between data bases having varying degrees of contextual variations.

The availability of a second data base has made it possible to rate the effectiveness of FR1 as an evaluation tool. A second F-ratio, FR2, has thus been introduced to compare with FR1. The new F-ratio utilizes the text dependency constraint; i.e., it requires that statistics be computed based on identical phonetic contexts and positions within the utterances. FR2 will be defined with the aid of Figure 5.7 as follows:

F_{CTS} is the feature value where

C = speaker number
T = triad number, and
S = token of the triad, in this case S = 1 or 2

In Figure 5.7, the following definitions apply:

d_{CT} = intra-triad, intra-class distance

$D_{C_1C_2T}$ = intra-triad, inter-class (between C_1 and C_2) distance.

NOTE: Distances are measured on a one-dimensional basis and are, therefore, the magnitude of the difference in feature values.

The F-ratio, FR2, is thus defined as

$$FR2 = \frac{\underset{C_1, C_2, T}{E}\left\{D_{C_1C_2T}^{\,2}\right\}}{\underset{C,T}{E}\left\{d_{CT}^{\,2}\right\}},$$

which may be computed as follows:

$$FR2 = \frac{\frac{1}{NS}\sum_{C_1=1}^{NS}\frac{1}{NS}\sum_{C_2=1}^{NS}\frac{1}{NT}\sum_{T=1}^{NT}\left(\left(\frac{F_{C_1T1} - F_{C_1T2}}{2}\right) - \left(\frac{F_{C_2T1} - F_{C_2T2}}{2}\right)\right)^2}{\frac{1}{NS}\sum_{C=1}^{NS}\frac{1}{NT}\sum_{T=1}^{NT}\left(F_{CT1} - F_{CT2}\right)^2}$$

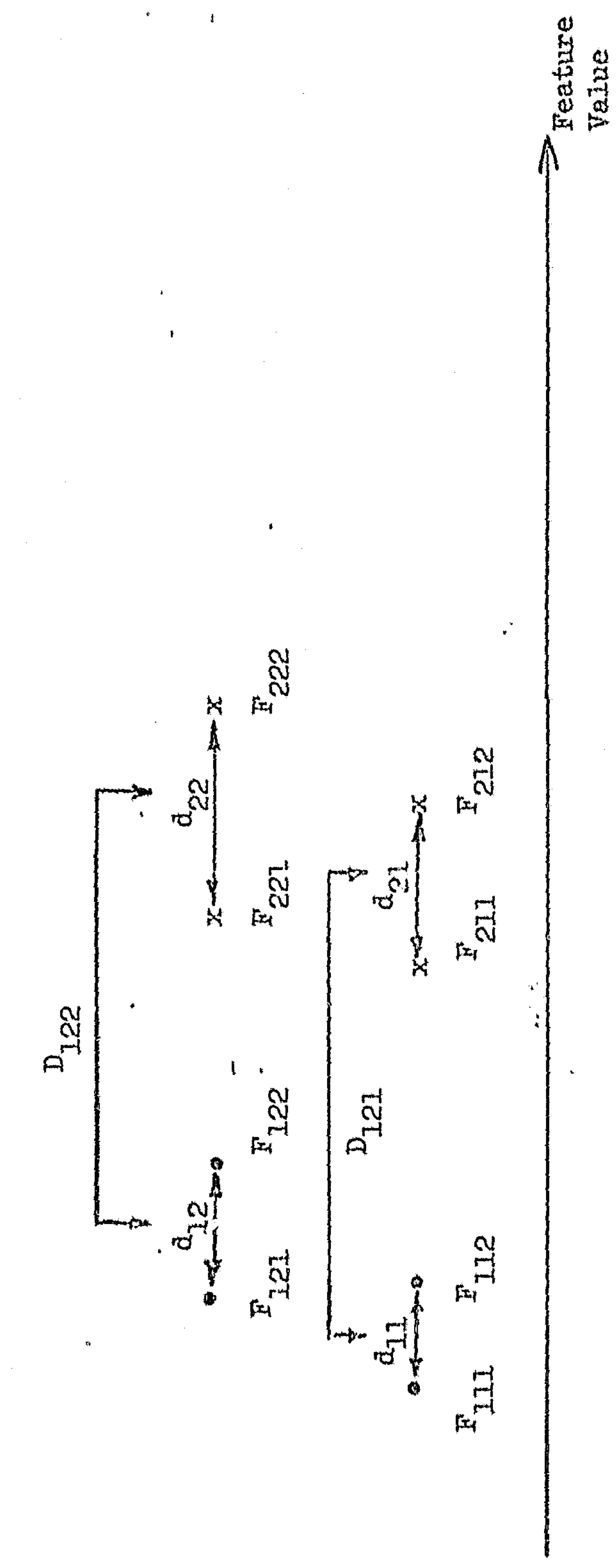

Figure 5-7. Illustration of distance measurements for F-Ratio FR_2

5.2.4 Final SASIS Features

Appendix 5E lists the features, F-ratios (FR2), byte location, and feature weights on a per phonetic event basis. The top 30 features for each event are the final SASIS features.

The numerator and denominator of this expression are estimates of interclass and intraclass variances averaged across triads and speakers.

An experiment was conducted to determine the effectiveness of FR1 and FR2 in selecting feature sets for the different phonetic events. The purpose of this experiment was to determine the value of the F-ratios in selecting a feature set and the ability of the F-ratios to derive a feature set on one data base and perform well on a different data base.

Tables 5.8 and 5.9 summarize the results of the experiments carried out. Three separate feature sets were compared on a SOC curve basis using DBI (Table 5.8) and DBIIA (Table 5.9). The three feature sets are defined as follows:

CASE 1 - Features derived from DBI using FR1,
CASE 2 - Features derived from DBIIA using FR1, and
CASE 3 - Features derived from DBIIA using FR2.

Comparison was carried out by ranking the performance of each feature set (case) for each phonetic event separately. Ranking was subjectively based on SOC curves. Table 5.8 indicates events /ŋ/, /a/, and /ɑ/ are missing, and Table 5.9 has event /ŋ/ missing due to technical problems in the experiment.

Though ad hoc, this experiment provides insight into the average ranking of the feature sets across two different data bases. Note that CASE 1, whose features were designed on DBI, performed best on DBI but poorly on DBIIA. Likewise, CASE 2 performed well on DBIIA, but poorly on DBI. CASE 3 seemed to perform consistently well on both data bases. These results, though based on limited analysis, are accepted as a verification of the text dependency criterion. As a result, the resultant features are those derived using FR2 and DBIIA.

TABLE 5.8 Relative feature ranking based on SOC curves for DBI and three feature sets

Event No.		Case 1	Case 2	Case 3
20	m	1	3	2
21	n	1	2	2
23	i	2	2	1
24	I	3	2	1
25	ɛ	1	2	3
28	ɔ	1	1	1
29	ʊ	3	1	2
30	u	1	3	2
31	ʌ	2	1	2
32	ɝ	2	1	1
33	ə	1	3	2
Avg. rank		1.64	1.91	1.72

TABLE 5.9 Relative feature ranking based on SOC curves for DBIIA and three feature sets

Event No.		Case 1	Case 2	Case 3
20	m	3	2	1
21	n	1	2	1
23	i	2	1	1
24	I	3	2	1
25	ɛ	2	1	2
26	a	3	2	1
27	ɑ	2	1	1
28	ɔ	3	1	2
29	ʊ	3	1	2
30	u	3	2	1
31	ʌ	3	1	2
32	ɝ	3	2	1
33	ə	2	3	1
Avg. rank		2.54	1.62	1.30

5.3 STATISTICAL ANALYSIS OF FEATURE DATA

5.3.1 Feature Data Normalization

The features discussed above represent different physical quantities. Before being used in subsequent processing they are normalized by the following procedure. The mean and standard deviation of each feature over all training data is computed. The new feature values are then $[\frac{64}{\sigma_f} \cdot (f-\bar{f})] + 127$ where σ_f in the standard deviation of feature f of mean $\bar{f}$. That is, the features are scaled to fit in the 256 levels available in an 8-bit byte. The common mean is 127; the 0 and 256 values are set at 2σ

For Data Base 2, the reasonableness of this normalization was examined by comparing the resulting means and standard deviations calculated separately over the 75 speaker training and 118 speaker evaluation portion. The percent differences are listed in Table 5-10 below. They are generally small and the normalization procedure is reasonable.

5.3.2 Correlation Coefficients: Interutterance and Intertriadal

Here we present empirically determined estimates of inter-utterance and inter-triad correlation coefficients. As usual we introduce the state vector whose components are x_{setnf} for speaker s, phonetic event e, triad t, sample n, and feature f. The interutterance correlation coefficient γ_t and the inter-triad correlation coefficient $\gamma_{tt'}$ are defined by the equations

(1) $\sigma^2_{etf} = \mathrm{Var}(x_{setnf}) = E(\Delta x_{setnf})^2$

(2) $\gamma_t = \sigma^{-2}_{etf}\, E\Delta x_{set1f}\, \Delta x_{set2f}$

(3) $\gamma_{tt'} = \sigma^{-1}_{etf}\, \sigma^{-1}_{et'f}\, E\Delta x_{set1f}\, \Delta x_{set'1f},\ t \neq t'$,

where

(4) $\Delta(\cdot) = (\cdot) - E(\cdot)$.

TABLE 5-10. Consistency of the Feature Normalization Over Training & Testing Portions of Data Base II

EVENT NO. 20

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
107.913	108.217	0.3	0.3	16.155	15.490	0.7	4.2
136.148	136.295	0.1	0.1	15.145	13.720	1.4	9.9
135.816	137.388	1.6	1.2	19.284	18.677	0.6	3.2
116.693	119.264	2.6	2.2	16.899	17.769	1.0	5.6
126.281	125.031	1.3	1.0	11.909	13.552	1.6	12.9
129.757	129.610	0.1	0.1	10.114	10.319	0.2	2.0
136.944	138.214	1.3	0.9	12.634	11.918	0.7	5.8
150.258	149.272	1.0	0.7	18.548	18.100	0.4	2.4
144.811	141.250	3.6	2.5	20.455	19.349	1.1	5.6
123.494	124.224	0.7	0.6	22.367	24.049	1.7	7.2
102.506	103.478	1.0	0.9	23.128	23.008	0.1	0.6
107.309	105.357	2.0	1.8	22.071	20.970	1.1	5.1
119.169	121.341	2.2	1.8	13.579	12.120	1.5	11.4
174.619	174.872	0.3	0.1	23.611	23.626	0.0	0.1
182.619	181.431	1.2	0.7	25.403	24.893	0.5	2.0
124.355	123.993	0.4	0.3	9.689	9.540	0.1	1.5
92.547	91.588	1.0	1.0	29.257	26.417	2.8	10.2
139.312	139.157	0.2	0.1	16.796	18.393	1.6	9.1
177.555	177.447	0.1	0.1	25.659	27.798	2.1	8.0
103.010	103.460	3.5	3.4	24.907	24.097	0.8	3.3
98.281	97.790	0.5	0.5	26.677	22.917	3.8	15.2
133.013	133.995	1.0	0.7	10.259	11.855	1.6	14.4
73.412	72.612	0.8	1.1	26.062	23.611	2.5	9.9
171.153	169.560	1.6	0.9	27.607	26.030	1.6	5.9
131.711	132.174	0.5	0.4	22.426	23.930	1.6	6.7
175.898	174.734	1.2	0.7	25.811	26.693	0.9	3.4
93.430	92.098	1.3	1.4	25.659	22.745	2.9	12.0
64.509	62.226	2.3	3.6	25.023	23.283	1.7	7.2
90.859	93.533	2.7	2.9	21.906	19.656	2.2	10.8
152.611	151.129	1.5	1.0	23.246	25.001	1.8	7.3
89.215	92.795	3.6	3.9	21.536	20.247	1 3	6.2
154.519	154.431	0.1	0.1	110.848	111.238	0.4	0.4
62.550	64.140	1.6	2.5	11.720	13.012	1.3	10.4
85.826	86.195	0.4	0.4	2.509	2.231	0.3	11.4
158.465	164.448	6.0	3.7	35.284	30.607	4.5	13.6
57.009	57.000	0.0	0.0	0.000	0.000	0.0	0.0
36.120	32.419	3.7	10.8	21.345	19.927	1.4	6.9
14.941	11.484	3.5	25.2	16.957	14.988	2.0	12.3
17.033	13.636	3.4	22.2	18.522	17.132	1.4	7.8
24.893	21.336	3.6	15.4	21.400	20.120	1.3	6.2
26.182	22.931	3.3	13.2	22.183	20.605	1.6	7.4
32.435	29.172	3.3	10.6	23.865	22.844	1.0	4.4
34.997	33.319	1.7	4.9	25.463	25.041	0.4	1.7
29.627	29.910	0.3	1.0	24.176	24.391	0.2	0.9
24.660	25.583	0.9	3.6	21.896	22.621	0.7	3.3
23.558	23.824	0.3	1.2	21.065	21.025	0.0	0.2
23.962	23.614	0.3	1.5	20.829	20.539	0.3	1.4
24.026	24.228	0.2	0.8	20.886	20.469	0.4	2.0
26.719	26.224	0.5	1.9	21.818	20.855	1.0	4.5
31.256	30.657	0.6	1.9	22.928	21.952	[illegible]	[illegible]

36.662	37.438	0.8	2.1	23.669	23.791	0.1	0.5
45.276	47.112	0.8	1.8	25.406	26.581	1.2	4.5
59.921	59.710	0.2	0.4	27.781	28.481	0.7	2.5
69.366	66.441	2.9	4.3	28.844	29.102	0.3	0.9
77.731	73.960	3.8	5.0	29.564	27.936	1.6	5.7
77.302	73.298	4.0	5.3	30.339	27.867	2.5	8.5
74.225	71.184	3.0	4.2	31.689	29.336	2.4	7.7
60.752	59.412	1.3	2.2	32.020	29.795	2.2	7.2
49.731	47.662	2.1	4.2	30.089	28.809	1.3	4.3
36.233	32.859	3.4	9.8	26.315	25.191	1.1	4.4
30.041	26.019	4.0	14.3	24.115	22.896	1.2	5.2
24.877	21.703	3.2	13.6	22.163	21.581	0.6	2.7
22.230	20.360	1.9	8.8	21.193	21.596	0.4	1.9
17.737	16.503	1.2	7.2	19.797	20.204	0.4	2.0
40.394	40.633	0.2	0.6	23.880	24.392	0.5	2.1
78.179	74.838	3.3	4.4	27.633	26.112	1.5	5.7
52.568	50.709	1.9	3.6	29.477	27.328	2.1	7.6
28.368	28.759	0.4	1.4	22.285	22.204	0.1	0.4
64.509	62.226	2.3	3.6	25.023	23.283	1.7	7.2
30.036	25.422	3.6	12.8	20.592	19.172	1.4	7.1
63.606	61.324	2.3	3.7	24.530	23.001	1.5	6.4
65.634	64.238	2.4	3.7	26.291	25.731	0.6	2.2
61.923	59.054	2.9	4.7	29.288	26.996	2.3	8.1
19.437	15.990	3.4	19.5	17.824	16.446	1.4	8.0
73.026	70.378	2.6	3.7	26.325	24.021	2.3	9.2
73.396	71.167	2.2	3.1	25.818	24.045	1.8	7.1
67.384	64.172	3.2	4.9	28.001	25.191	2.8	10.6
44.307	41.167	3.1	7.3	21.214	20.296	0.9	4.4
76.726	73.405	3.3	4.4	28.427	27.440	1.0	3.5
25.164	22.959	3.2	13.0	22.387	22.162	0.2	1.0
64.414	61.248	3.2	5.0	28.510	25.569	2.9	10.9
70.573	67.821	2.7	4.0	27.625	26.779	0.8	3.1
73.217	70.838	2.4	3.3	25.802	23.827	2.0	8.0
73.368	70.934	2.4	3.4	26.027	23.904	2.1	8.5
79.074	76.162	2.9	3.8	27.954	25.069	2.9	10.9
31.455	28.290	3.2	10.6	24.392	23.305	1.1	4.6
25.315	21.776	3.5	15.0	19.699	18.153	1.5	8.2
68.020	65.709	2.3	3.5	24.822	23.162	1.7	6.9
60.754	59.029	1.7	2.9	25.511	26.103	0.6	2.3
71.115	67.897	3.2	4.6	28.489	25.631	2.9	10.6
24.471	21.484	3.0	13.0	21.956	21.684	0.3	1.2
76.084	73.526	2.6	3.4	26.569	24.797	1.8	6.9
41.373	38.650	2.7	6.8	27.228	26.073	1.2	4.3
95.350	107.133	11.8	11.6	49.923	53.012	3.1	6.0
86.913	81.243	5.7	6.7	49.711	47.185	2.5	5.2
107.795	110.350	2.6	2.4	55.858	54.637	1.2	2.2
53.588	57.238	3.6	6.6	31.431	29.226	2.2	7.3
150.522	151.024	0.5	0.3	19.462	20.982	1.5	7.5
130.359	129.752	0.6	0.5	59.890	56.958	2.9	5.0
81.565	83.317	1.8	2.1	18.933	21.925	4.0	19.8
65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
203.972	206.816	2.8	1.4	13.715	13.094	0.6	4.6
205.074	207.872	2.8	1.4	13.641	13.031	0.6	4.6
208.512	211.219	2.7	1.3	13.538	12.805	0.7	5.6
214.834	217.308	2.5	1.1	13.361	12.451	0.9	7.0
225.047	227.042	1.9	0.9	13.458	12.025	1.4	11.2

240.125	241.222	1.1	0.5	13.853	11.514	2.2	17.6
247.455	249.416	2.0	0.8	12.272	9.168	3.1	28.9
226.532	232.186	2.7	1.1	15.522	12.808	2.7	19.2
223.647	226.516	2.9	1.3	17.520	15.557	2.0	11.8
214.049	216.914	2.9	1.3	18.322	16.685	1.6	9.4
207.421	210.201	2.8	1.3	18.705	17.199	1.5	8.2
203.186	205.148	2.8	1.3	19.284	17.822	1.5	7.9
201.262	203.978	2.7	1.3	19.956	18.391	1.6	8.2
203.801	203.519	2.7	1.3	20.853	19.160	1.7	8.5
201.559	204.260	2.7	1.3	21.854	19.839	2.0	9.7
202.829	205.428	2.6	1.3	22.756	19.932	2.8	13.2
203.962	206.619	2.7	1.3	23.600	20.222	3.4	15.7
203.798	207.166	3.4	1.6	24.209	21.113	3.1	13.7
202.251	206.514	4.3	2.1	25.259	22.795	2.5	10.3
198.570	203.705	5.1	2.6	25.895	23.576	2.3	9.4
193.458	199.231	5.8	2.9	25.521	23.559	2.0	8.0
187.923	194.271	6.3	3.3	24.522	23.318	1.2	5.0
182.831	189.536	6.7	3.6	23.594	23.037	0.6	2.4
178.624	185.324	6.7	3.7	22.903	22.814	0.1	0.4
175.194	181.740	6.5	3.7	22.556	22.746	0.2	0.8
172.494	178.698	6.2	3.5	22.455	22.600	0.1	0.6
170.274	176.197	5.9	3.4	22.452	22.525	0.1	0.3
168.425	174.141	5.7	3.3	22.422	22.563	0.1	0.6
166.818	172.495	5.7	3.3	22.333	22.645	0.3	1.4
165.463	171.184	5.7	3.4	22.230	22.745	0.5	2.3
164.386	170.209	5.8	3.5	22.192	22.937	0.7	3.3
163.660	169.528	5.9	3.5	22.206	23.077	0.9	3.8
163.223	169.219	6.0	3.6	22.259	23.143	0.9	3.9
163.292	169.381	6.1	3.7	22.345	23.274	0.9	4.1
163.887	170.045	6.2	3.7	22.539	23.430	0.9	3.9
165.064	171.367	6.3	3.7	22.814	23.659	0.8	3.6
166.936	173.355	6.4	3.8	23.195	24.018	0.8	3.5
169.591	176.004	6.5	3.8	23.852	24.486	0.6	2.6
173.004	179.516	6.4	3.6	24.611	25.011	0.4	1.6
177.414	183.610	6.2	3.4	25.506	25.833	0.2	1.0
182.419	188.317	5.9	3.2	26.787	27.059	0.3	1.0
187.655	192.871	5.2	2.7	28.154	27.886	0.3	1.0
192.015	196.767	4.8	2.4	28.811	28.733	0.1	0.3
195.698	199.047	3.3	1.7	29.979	29.237	0.7	2.5
197.813	199.388	1.6	0.8	31.499	29.260	2.2	7.4
197.031	198.400	1.4	0.7	31.825	29.004	2.8	9.3
194.317	195.893	2.6	1.3	31.649	28.971	2.7	8.8
190.271	194.533	4.3	2.2	31.420	29.745	1.7	5.5
185.194	190.245	5.1	2.7	31.515	30.232	1.3	4.2
179.271	184.336	5.1	2.8	31.973	30.862	1.1	3.5
171.555	176.598	5.0	2.9	30.955	30.578	0.4	1.2
163.197	167.828	4.6	2.8	29.250	28.995	0.3	0.9
155.151	159.174	4.0	2.6	27.403	27.531	0.1	0.5
147.849	151.334	3.5	2.3	26.112	26.444	0.3	1.3
141.269	144.490	3.2	2.3	25.237	25.838	0.6	2.4
135.419	138.540	3.1	2.3	24.542	25.404	0.9	3.5
130.332	133.419	3.1	2.3	24.092	25.112	1.0	4.2
126.002	129.009	3.0	2.4	23.822	24.949	1.1	4.6
122.363	125.308	3.0	2.4	23.723	24.893	1.2	4.8
119.384	122.391	3.0	2.5	23.671	24.962	1.3	5.3
116.705	120.014	3.0	2.6	23.663	25.059	1.4	5.7

115.179	118.224	3.0	2.6	23.707	25.154	1.4	5.9
113.875	116.991	3.1	2.7	23.723	25.298	1.6	6.4

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75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
107.259	109.128	1.9	1.7	17.172	14.317	2.9	18.1
129.546	129.548	0.0	0.0	11.318	9.044	2.3	22.3
132.655	131.699	1.0	0.7	14.609	11.717	2.9	22.0
129.000	130.053	1.1	0.8	16.561	15.019	1.5	9.8
126.666	128.689	2.0	1.6	15.313	15.533	0.2	1.4
128.830	128.094	0.7	0.6	12.056	12.678	0.6	5.0
134.565	135.719	1.2	0.9	11.725	12.465	0.7	6.1
147.437	147.672	0.2	0.2	17.389	17.199	0.2	1.1
147.426	143.539	3.9	2.7	19.491	18.823	0.7	3.5
133.883	135.305	1.4	1.1	21.859	23.332	1.5	6.5
102.237	105.674	3.4	3.3	25.274	24.863	0.4	1.6
97.674	96.783	0.9	0.9	20.937	23.096	2.2	9.8
120.284	119.603	0.7	0.6	10.925	11.985	1.1	9.3
177.162	174.051	3.1	1.8	24.591	24.567	0.0	0.1
183.465	181.714	1.8	1.0	24.897	25.027	0.1	0.5
119.159	118.224	0.9	0.8	11.183	12.769	1.6	13.2
94.875	92.889	2.0	2.1	28.512	25.528	3.0	11.0
130.340	129.510	0.8	0.6	16.795	19.439	2.6	14.6
176.106	173.458	2.6	1.5	27.795	28.102	0.3	1.1
91.906	93.925	1.9	2.1	23.559	22.693	0.9	3.7
91.733	89.501	2.2	2.5	24.879	21.719	3.2	13.6
129.148	129.473	0.3	0.3	8.339	9.803	1.5	16.1
69.671	67.311	2.4	3.4	24.226	21.956	2.3	9.8
178.251	176.390	1.9	1.0	26.892	28.122	1.2	4.5
120.418	119.821	0.6	0.5	22.739	24.027	1.3	5.5
171.669	169.211	2.5	1.4	26.434	26.344	0.1	0.3
90.747	88.017	2.7	3.1	23.687	21.111	2.6	11.5
62.284	59.863	2.4	4.0	23.494	21.919	1.6	6.9
87.783	87.414	0.4	0.4	21.259	18.241	3.0	15.3
143.173	140.119	3.1	2.2	25.973	27.161	1.2	4.5
87.409	90.354	2.9	3.3	21.411	19.751	1.7	8.1
159.160	158.314	1.2	0.8	108.995	109.403	0.4	0.4
66.546	68.452	1.9	2.8	12.779	14.087	1.3	9.7
85.625	87.011	0.4	0.4	2.268	2.199	0.1	3.1
167.092	172.179	5.1	3.0	36.585	36.342	0.2	0.7
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
31.384	26.[illegible]	5.3	18.4	23.521	13.873	4.1	19.8
12.057	8.073	4.0	39.7	17.821	12.193	5.6	37.6
11.642	8.217	3.4	34.5	18.303	12.745	5.6	35.8
15.562	12.162	3.2	22.9	19.991	15.514	4.5	25.2
14.189	10.765	3.4	27.4	18.678	15.309	3.4	19.8
17.479	12.224	5.1	34.6	20.449	16.404	4.0	21.9
19.844	15.463	4.4	24.8	22.022	18.114	3.9	19.5
20.911	17.006	3.5	19.6	21.722	18.203	3.5	17.6

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21.844	18.516	3.3	16.5	21.717	18.361	3.4	16.7
22.181	19.709	2.5	11.8	20.729	18.182	2.5	13.1
21.519	20.295	1.3	6.3	21.044	18.663	2.4	12.0
21.920	20.499	1.5	6.9	21.185	19.084	2.1	10.4
23.348	21.299	2.0	9.1	21.576	19.548	2.4	11.7
26.070	24.506	1.5	5.9	22.165	20.532	1.6	7.6
30.965	30.019	0.9	2.9	22.852	21.418	1.4	6.5
39.279	38.684	0.6	1.5	25.365	23.026	2.3	9.6
51.243	50.691	0.7	1.3	27.579	24.920	2.7	10.1
60.700	57.609	3.1	5.2	29.230	25.569	2.7	9.5
71.769	67.230	4.5	6.5	28.927	27.036	1.9	6.8
75.318	71.644	4.7	6.3	27.914	27.133	0.8	2.8
78.692	75.535	3.1	4.0	27.999	28.559	0.6	-2.0
68.028	57.879	0.9	1.4	29.492	31.051	1.6	5.2
53.889	54.229	0.3	0.6	30.035	31.869	1.8	5.9
34.922	35.126	0.2	0.6	27.043	27.414	0.4	1.4
24.563	23.992	0.6	2.3	23.161	22.572	0.6	2.6
19.407	17.934	1.6	8.5	20.999	20.362	0.6	3.1
17.847	16.595	1.3	7.3	20.314	20.311	0.0	0.0
14.992	14.392	0.6	4.3	19.184	19.405	0.2	1.1
34.895	33.137	0.9	2.8	23.966	21.424	2.5	11.2
73.677	69.783	3.9	5.4	26.898	25.035	1.9	7.2
57.504	56.665	0.8	1.5	27.616	29.421	1.8	6.3
23.067	20.277	2.8	12.9	21.325	17.867	3.5	17.6
62.284	59.863	2.4	4.0	23.494	21.919	1.6	6.9
25.078	19.812	5.3	23.5	21.881	17.165	4.7	24.2
61.331	58.795	2.5	4.2	23.272	21.694	1.7	7.4
59.600	55.573	3.1	5.3	26.395	23.745	2.7	10.6
66.242	63.751	2.5	3.8	26.199	27.084	0.9	3.3
14.276	9.412	4.9	41.1	17.670	12.897	4.8	31.2
71.635	69.102	2.5	3.6	24.236	22.860	1.4	5.8
71.248	68.686	2.6	3.7	24.229	22.550	1.7	7.2
69.100	66.213	2.9	4.3	24.789	24.892	0.1	0.4
36.368	31.693	4.8	14.0	23.337	18.483	4.9	23.2
69.813	66.077	3.7	5.5	28.255	26.046	2.2	8.1
20.768	19.620	1.1	5.4	21.632	21.376	0.3	1.2
66.474	63.567	2.9	4.5	25.019	25.017	0.0	0.0
63.510	60.290	3.3	5.4	27.531	24.910	2.6	10.0
71.351	68.976	2.4	3.4	24.092	22.400	1.7	7.2
71.457	69.075	2.4	3.4	24.170	22.484	1.7	7.2
79.050	75.959	3.1	4.0	24.975	24.022	1.0	3.9
28.889	28.988	0.0	0.1	24.750	24.909	0.2	0.6
21.320	16.055	5.3	28.2	20.678	16.003	4.7	25.5
65.799	63.243	2.6	4.0	23.378	21.836	1.5	6.8
52.944	50.719	2.2	4.3	26.027	23.056	3.0	12.1
72.072	70.175	2.9	4.0	25.031	25.095	0.1	0.2
19.376	18.013	1.4	7.3	21.129	20.786	0.3	1.6
73.047	70.200	2.8	4.0	25.327	23.487	1.8	7.5
42.529	43.090	0.5	1.3	27.616	28.949	1.3	4.7
97.933	109.770	11.8	11.4	48.664	51.498	3.4	6.9
67.655	65.017	2.6	4.9	43.451	42.065	1.4	3.2
114.100	118.356	4.3	3.7	53.562	56.662	3.1	5.6
52.510	50.957	6.4	11.6	26.543	29.425	2.9	10.3
155.050	156.508	1.5	0.9	22.324	19.405	2.9	14.0
160.446	165.235	4.8	2.9	62.720	62.760	1.0	1.5
85.412	85.331	0.1	0.1	20.712	17.426	3.3	17.2

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65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
202.501	205.433	2.9	1.4	13.737	13.952	0.2	1.6
203.490	206.397	2.9	1.4	13.671	13.892	0.2	1.6
206.702	209.480	2.8	1.3	13.536	13.702	0.2	1.2
212.492	214.996	2.5	1.2	13.368	13.341	0.0	0.2
221.828	223.774	1.9	0.9	13.448	13.011	0.4	3.3
235.863	236.829	1.0	0.4	13.989	13.875	0.8	6.2
246.694	247.701	1.0	0.4	12.153	11.169	1.0	8.4
238.894	241.249	2.4	1.0	14.816	12.949	1.9	13.5
225.939	229.126	3.2	1.4	17.315	15.811	1.5	9.1
215.421	218.823	3.4	1.6	18.133	16.917	1.2	6.9
207.958	211.143	3.2	1.5	18.823	17.231	1.6	8.8
202.694	205.648	3.0	1.5	19.176	17.338	1.8	10.1
198.811	201.992	3.2	1.6	19.089	17.706	1.4	7.5
196.334	199.627	3.3	1.7	19.436	18.379	1.1	5.6
194.774	197.962	3.2	1.6	20.102	19.018	1.1	5.5
193.643	196.463	2.8	1.4	20.857	19.542	1.3	6.5
192.412	194.798	2.4	1.2	21.514	20.061	1.5	7.0
190.861	192.731	1.9	1.0	22.192	20.459	1.7	8.1
188.969	190.454	1.5	0.8	22.597	20.812	1.8	8.2
186.830	188.149	1.3	0.7	22.918	21.077	1.8	8.4
184.891	185.147	1.3	0.7	23.565	21.649	1.9	8.5
183.181	184.522	1.3	0.7	24.408	22.459	2.0	8.6
181.616	183.301	1.7	0.9	25.257	23.286	2.0	8.1
180.069	182.290	2.3	1.3	25.303	23.979	1.3	5.4
178.304	181.493	3.0	1.7	24.981	24.267	0.7	2.9
176.947	180.444	3.5	2.0	24.772	24.211	0.6	2.3
175.616	179.370	3.7	2.1	24.522	23.813	0.7	3.0
174.070	178.281	4.2	2.4	23.969	23.705	0.3	1.1
172.454	177.104	4.6	2.7	23.583	23.591	0.0	0.0
170.724	175.882	5.1	2.9	23.271	23.453	0.2	0.8
168.900	174.347	5.4	3.2	23.116	23.409	0.3	1.3
167.290	172.983	5.7	3.3	23.034	23.312	0.3	1.2
165.972	171.766	5.8	3.4	22.748	23.129	0.4	1.7
165.206	170.921	5.7	3.4	22.664	23.101	0.4	1.9
165.075	170.659	5.6	3.3	22.732	23.147	0.4	1.8
165.699	171.059	5.4	3.2	22.977	23.374	0.4	1.5
167.170	172.299	5.1	3.0	23.492	23.680	0.2	0.8
169.443	174.441	5.0	2.9	24.211	24.115	0.1	0.4
172.610	177.505	4.9	2.8	24.979	24.798	0.2	0.7
176.602	181.628	5.0	2.8	26.006	25.988	0.0	0.1
181.304	186.469	5.1	2.8	27.296	27.045	0.3	0.9
186.699	191.699	5.0	2.6	28.492	28.058	0.4	1.5
192.052	196.514	4.5	2.3	29.574	28.479	1.1	3.8
196.418	200.222	3.8	1.9	29.828	28.513	1.3	4.5
199.487	202.460	3.0	1.5	30.092	28.257	1.8	6.3
201.017	203.282	2.3	1.1	29.849	27.729	2.1	7.4
201.844	203.493	1.6	0.8	29.923	27.673	2.2	7.8
201.565	203.613	2.1	1.9	30.717	29.693	1.9	6.0
199.515	202.210	2.7	1.8	30.177	29.726	0.5	1.5
192.203	198.499	6.2	2.2	29.935	32.141	2.2	7.1
184.227	191.345	7.1	2.3	31.128	34.159	3.0	9.3
174.173	180.701	6.6	3.7	31.649	33.557	1.9	5.9
162.673	169.049	6.4	3.8	[illegible]	31.220	1.9	6.1
152.593	158.510	6.0	3.9	27.197	28.902	1.8	6.4
[illegible]	149.400	5.4	3.7	25.971	27.393	1.4	5.2

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137.047	142.851	5.0	3.6	25.232	26.337	1.1	4.3
131.179	135.821	4.7	3.5	24.851	25.779	0.9	3.7
126.192	130.692	4.5	3.5	24.508	25.463	0.9	3.4
122.089	125.401	4.3	3.5	24.504	25.213	0.7	2.9
118.709	122.940	4.2	3.5	24.432	25.127	0.7	2.8
116.145	120.200	4.1	3.4	24.452	25.089	0.6	2.6
114.037	118.137	4.0	3.5	24.490	25.074	0.6	2.4
112.694	116.649	3.9	3.4	24.553	25.101	0.5	2.2

EVENT NO. 22

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75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
104.204	107.277	3.1	2.9	16.293	15.084	1.2	7.7
130.020	129.013	1.0	0.8	12.644	11.415	1.2	10.2
132.266	131.415	0.9	0.6	14.394	15.169	0.8	5.2
120.812	124.354	3.5	2.9	17.168	15.847	1.3	8.0
127.462	126.319	1.1	0.9	12.092	13.137	1.0	8.3
131.716	132.176	0.5	0.3	11.409	11.683	0.3	2.4
139.387	139.940	0.6	0.4	13.757	13.451	0.3	2.2
151.546	151.976	0.4	0.3	19.768	19.423	0.7	3.4
147.510	143.952	3.5	2.4	20.378	20.638	0.3	1.3
125.490	127.169	1.7	1.4	24.360	24.228	0.1	0.5
102.030	101.101	0.9	0.9	21.906	24.294	2.3	10.0
98.573	98.695	0.1	0.1	22.812	21.734	0.9	4.3
118.724	119.723	1.0	0.8	12.398	11.757	0.6	5.3
181.516	181.022	0.5	0.3	23.756	26.323	2.6	10.2
189.847	189.258	0.6	0.3	24.547	25.546	1.0	4.0
122.645	122.143	0.5	0.4	11.175	11.716	0.5	4.7
93.177	90.452	2.7	3.0	28.683	27.811	0.9	3.1
136.900	136.503	0.5	0.3	19.139	20.102	1.0	4.9
185.226	184.296	0.9	0.5	26.847	29.899	3.0	10.7
95.113	96.796	1.7	1.8	26.852	26.259	0.6	2.2
93.196	91.609	1.6	1.7	25.032	22.658	2.4	10.0
132.544	132.870	0.3	0.2	11.297	12.381	1.1	9.2
69.016	66.754	2.3	3.3	25.018	22.963	2.1	8.6
178.744	178.433	0.3	0.2	28.491	28.562	0.1	0.2
129.107	128.698	0.4	0.3	26.277	26.343	0.1	0.3
180.851	180.121	0.7	0.4	25.907	27.405	1.5	5.6
92.206	89.645	2.6	2.8	24.180	22.270	1.9	8.2
69.871	68.466	1.4	2.0	23.968	22.548	1.4	6.1
80.685	81.520	0.8	1.0	20.332	20.051	0.3	1.4
151.709	150.698	1.0	0.7	27.073	29.081	2.0	7.2
85.611	87.905	2.3	2.6	20.703	21.058	0.4	1.7
147.902	156.420	8.5	5.6	111.519	110.408	1.1	1.0
62.125	63.860	1.7	2.8	12.308	13.873	1.6	12.0
85.698	86.055	0.4	0.4	2.629	2.356	0.3	11.0
159.280	161.905	2.6	1.6	32.960	33.308	0.3	1.0
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
40.738	36.034	4.7	12.3	22.347	20.372	2.0	9.2
19.685	17.064	2.6	14.0	17.994	16.336	1.7	9.7

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17.942	16.312	1.6	9.5	17.483	16.386	1.1	6.5
23.005	21.204	1.8	8.2	19.835	18.794	1.0	5.4
20.972	18.324	2.6	13.5	20.078	18.147	1.9	10.1
24.024	19.769	4.3	19.4	21.810	18.714	3.1	15.3
26.238	22.739	3.5	14.3	22.069	20.493	1.6	7.4
22.611	22.073	0.5	2.4	19.424	20.185	0.8	3.8
20.050	20.093	0.0	0.2	18.787	18.514	0.3	1.5
20.113	18.955	1.2	5.9	19.145	17.407	1.7	9.5
20.512	19.413	1.1	5.5	19.114	17.173	1.9	10.7
22.205	21.051	1.1	5.3	20.170	17.575	2.5	13.2
25.228	24.589	0.6	2.6	21.139	18.954	2.2	10.9
29.944	30.042	0.1	0.3	21.704	20.826	0.9	4.1
37.615	37.529	0.1	0.2	22.721	22.936	0.2	0.9
48.496	48.414	0.1	0.2	25.325	25.117	0.2	0.8
62.161	62.465	0.3	0.5	27.414	27.318	0.1	0.4
72.105	70.782	1.3	1.9	28.294	28.354	0.1	0.2
82.671	79.427	3.2	4.0	28.766	28.503	0.3	0.9
83.290	80.312	3.0	3.6	29.605	28.557	1.0	3.6
81.121	79.595	1.5	1.9	31.373	29.907	1.5	4.8
68.488	66.889	1.6	2.4	33.025	31.422	1.6	5.0
56.141	53.696	2.4	4.5	31.247	30.288	1.0	3.1
37.550	35.393	2.2	5.9	26.697	26.176	0.5	2.0
27.714	25.381	2.3	8.8	23.211	22.212	1.0	4.4
21.131	19.428	1.7	8.4	20.845	20.509	0.3	1.6
19.438	18.103	1.3	7.1	20.489	20.554	0.1	0.3
16.278	15.407	0.9	5.5	19.650	19.520	0.1	0.7
41.696	41.476	0.2	0.5	23.489	23.132	0.4	1.5
83.095	80.571	2.5	3.1	26.741	25.869	0.7	2.5
58.305	56.883	1.5	2.6	30.734	29.278	1.5	4.9
23.556	22.936	0.6	2.4	19.089	18.189	0.9	4.8
69.871	68.456	1.4	2.0	23.968	22.548	1.4	6.1
33.800	29.762	4.0	12.7	20.979	18.948	2.0	10.2
68.593	67.117	1.5	2.2	23.663	22.192	1.5	6.4
70.129	68.529	1.6	2.3	25.645	25.189	0.5	1.8
68.022	66.840	1.2	1.8	29.716	27.946	1.8	6.1
20.921	16.949	4.0	21.0	17.916	15.914	2.0	11.8
78.915	77.195	1.7	2.2	25.179	23.639	1.5	6.3
79.127	77.550	1.6	2.0	24.669	23.242	1.4	6.0
73.583	71.681	1.9	2.6	27.521	25.822	1.7	6.3
45.111	41.865	3.3	7.6	21.609	19.176	2.5	12.2
80.972	78.503	2.5	3.1	27.604	27.323	0.3	1.0
22.745	21.292	1.5	7.0	21.525	21.133	0.4	1.8
71.012	69.075	2.0	2.9	27.846	26.206	1.6	6.1
74.562	72.592	2.0	2.7	26.792	26.316	0.5	1.8
78.917	77.439	1.5	1.9	24.743	23.065	1.7	7.0
79.135	77.616	1.5	1.9	24.999	23.164	1.6	6.9
83.720	81.377	2.3	2.8	26.522	25.352	1.2	4.5
31.204	29.345	1.9	6.1	24.679	24.166	0.5	2.1
29.419	25.221	4.2	15.4	20.337	18.336	2.0	10.3
73.108	71.741	1.4	2.0	23.858	22.438	1.4	6.3
62.813	62.173	0.7	1.1	25.132	24.991	0.1	0.6
77.619	75.612	2.0	2.6	27.555	25.220	1.7	6.4
20.955	19.464	1.5	7.4	21.047	20.828	0.2	1.1
81.507	79.713	1.8	2.3	25.597	24.356	1.2	5.0
[illegible]	42.817	2.2	5.0	28.704	27.660	1.0	3.7
[illegible]	95.113	7.0	8.4	[illegible]	44.164	4.6	11.1

76.978	71.227	5.7	7.6	44.786	42.603	2.2	5.0
121.153	121.178	0.0	0.0	54.774	57.094	2.3	4.1
54.317	60.517	6.2	10.8	23.291	20.356	2.1	7.0
149.976	152.810	2.8	1.9	26.712	22.573	4.1	16.8
152.660	160.279	7.6	4.8	67.550	65.965	0.6	0.9
84.954	88.641	3.7	4.2	17.197	21.886	4.7	24.0
65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
233.327	235.319	2.0	1.0	13.999	14.033	0.2	1.3
204.347	206.239	1.9	0.9	13.805	13.958	0.2	1.1
227.510	229.262	1.8	0.8	13.703	13.728	0.0	0.2
213.266	214.636	1.4	0.6	13.611	13.415	0.2	1.5
222.466	223.146	0.7	0.3	13.712	13.196	0.5	4.1
235.010	235.612	0.4	0.2	13.804	13.275	0.5	3.9
245.653	245.839	0.2	0.1	11.527	11.241	0.7	6.6
241.613	243.252	1.6	0.7	13.355	12.266	1.1	8.5
229.161	232.356	3.2	1.4	13.795	15.022	1.2	7.2
218.460	222.591	4.1	1.9	17.821	17.184	0.6	3.6
210.722	215.192	4.5	2.1	17.947	17.578	0.4	2.1
205.558	210.017	4.5	2.1	17.977	17.526	0.5	2.5
202.319	206.677	4.4	2.1	18.172	17.551	0.6	3.5
200.440	204.725	4.3	2.1	18.726	17.918	0.8	4.5
199.419	203.435	4.0	2.0	19.675	18.410	1.3	6.6
198.302	201.711	3.4	1.7	20.241	18.687	1.6	8.0
196.732	199.395	2.7	1.3	20.827	19.106	1.7	8.6
194.460	196.373	1.9	1.0	21.436	19.575	1.9	9.1
191.157	192.954	1.8	0.9	21.725	20.265	1.5	7.0
187.065	189.443	2.4	1.3	21.639	21.085	0.6	2.6
182.081	185.082	3.1	1.7	21.472	21.551	0.1	0.4
178.487	182.257	3.8	2.1	21.270	21.738	0.4	2.0
174.621	179.001	4.4	2.5	21.096	21.629	0.5	2.5
171.400	176.139	4.7	2.7	21.107	21.545	0.4	2.1
168.965	173.765	4.8	2.8	21.300	21.551	0.3	1.2
167.022	171.773	4.8	2.8	21.533	21.418	0.1	0.5
165.458	170.082	4.6	2.8	21.715	21.201	0.5	2.4
164.236	168.768	4.5	2.7	21.652	21.088	0.6	2.7
163.228	167.659	4.4	2.7	21.572	20.952	0.6	2.9
162.431	166.816	4.4	2.7	21.431	20.924	0.5	2.3
161.097	165.385	4.4	2.7	21.259	21.071	0.2	0.9
161.671	166.019	4.3	2.7	21.360	21.310	0.1	0.2
161.716	166.082	4.4	2.7	21.525	21.579	0.1	0.3
162.107	166.607	4.5	2.7	21.648	22.089	0.4	2.0
162.998	167.715	4.7	2.9	21.900	22.803	0.9	4.0
164.605	169.452	4.8	2.9	22.427	23.695	1.3	5.5
166.004	171.969	5.2	3.0	23.094	24.659	1.6	6.6
169.805	175.254	5.4	3.1	23.935	25.688	1.8	7.1
173.778	179.313	5.5	3.1	25.128	26.773	1.6	6.3
178.546	184.123	5.6	3.1	26.449	27.738	1.3	4.8
184.143	189.695	5.6	3.0	27.910	28.965	1.0	3.4
189.889	195.193	5.3	2.8	28.943	29.740	0.8	2.7
194.944	199.577	4.7	2.4	29.259	30.021	0.9	2.6
198.831	202.323	3.5	1.7	29.591	29.741	0.2	0.5
200.522	203.625	3.1	1.5	29.324	29.640	0.3	1.0
200.605	203.606	2.9	1.5	29.462	29.629	0.2	0.6
199.502	202.235	2.7	1.4	30.407	29.370	1.1	3.6
196.645	199.699	3.1	1.5	31.261	29.255	2.0	6.6
192.067	195.973	3.9	2.0	31.596	29.963	1.9	6.1

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185.927	189.625	3.7	2.0	32.571	30.741	1.8	5.8
177.278	181.018	3.7	2.1	31.877	30.925	1.0	3.0
167.067	171.000	3.9	2.3	29.926	29.734	0.2	0.6
157.239	160.958	3.7	2.3	27.798	27.938	0.1	0.5
148.462	151.872	3.4	2.3	25.767	26.094	0.3	1.3
140.893	144.143	3.3	2.3	24.287	25.071	0.8	3.2
134.493	137.556	3.1	2.3	23.339	24.461	1.1	4.7
129.095	132.040	2.9	2.3	22.879	24.120	1.3	5.5
124.522	127.378	2.9	2.3	22.487	23.984	1.5	6.4
120.758	123.402	2.7	2.2	22.353	23.301	1.5	6.7
117.695	120.350	2.7	2.3	22.209	23.953	1.7	7.2
115.223	117.928	2.6	2.2	22.303	24.011	1.7	7.4
113.343	115.926	2.6	2.3	22.322	24.134	1.8	7.8
112.054	114.612	2.6	2.3	22.367	24.224	1.9	8.0

EVENT NO. 23

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
86.020	86.336	0.3	0.4	15.729	15.441	0.3	1.8
127.003	127.229	0.2	0.2	13.442	13.945	0.5	3.7
133.964	135.111	1.2	0.9	14.698	14.645	0.1	0.4
133.438	132.842	0.4	0.3	12.101	12.211	0.1	0.9
136.722	136.067	0.7	0.5	13.035	13.245	0.3	2.0
141.219	141.194	0.0	0.0	14.404	13.171	1.2	8.9
155.626	156.275	0.6	0.4	17.079	16.134	0.9	5.6
155.620	155.914	0.7	0.5	23.249	22.780	0.5	2.0
131.098	131.806	0.2	0.2	21.611	23.765	1.9	8.3
133.636	133.151	0.5	0.3	19.629	18.624	1.0	5.3
111.972	113.104	1.1	1.0	19.749	20.447	0.7	3.5
94.904	95.707	0.8	0.8	17.783	17.813	0.0	0.2
110.397	110.155	0.2	0.2	14.351	15.224	0.9	5.9
170.941	169.727	1.2	0.7	19.129	20.596	1.5	7.4
133.337	132.132	1.2	0.6	19.883	21.759	1.9	9.0
134.342	134.375	0.1	0.1	7.403	7.911	0.5	6.4
65.949	67.772	1.8	2.7	23.002	23.292	0.6	2.5
117.166	116.561	0.6	0.4	15.175	14.555	0.6	4.2
181.307	179.029	2.3	1.3	22.444	24.287	1.8	7.9
104.843	104.561	0.3	0.3	24.301	25.002	0.7	2.9
71.119	72.403	1.3	1.8	19.493	18.905	0.4	1.9
114.214	114.259	0.0	0.0	9.127	9.150	0.0	0.2
41.503	40.201	1.7	4.2	21.955	21.716	0.2	1.1
191.770	190.970	0.8	0.4	23.823	22.303	1.6	7.5
133.542	133.913	0.4	0.3	17.017	17.504	0.4	2.4
[illegible]	[illegible]	1.2	0.6	21.773	23.589	2.2	9.6
65.822	64.742	2.1	3.1	21.486	20.403	1.1	5.2
124.685	125.149	0.7	0.5	19.272	19.609	0.3	1.7
50.456	50.819	0.4	0.3	15.370	14.603	0.8	5.0
143.074	141.807	1.6	1.2	19.167	18.660	0.5	2.7
[illegible]	[illegible]	0.5	0.5	21.644	23.303	1.7	7.4
[illegible]	[illegible]	21.5	14.8	[illegible]	109.490	4.1	3.7

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69.3?	69.278	0.1	0.1	13.836	12.288	1.4	11.0
95.07?	95.269	0.1	0.2	3.148	2.857	0.3	9.7
155.433	153.394	3.0	1.9	41.259	36.493	4.8	12.3
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
72.091	70.941	1.3	1.9	20.529	20.333	0.2	1.0
34.390	33.302	1.0	3.1	19.141	19.195	0.1	0.3
31.321	30.277	1.0	3.4	19.748	19.305	0.4	2.3
35.806	36.563	0.3	0.8	22.017	21.586	0.4	2.0
31.244	30.516	0.8	2.7	21.171	20.759	0.4	2.0
33.456	32.460	1.0	3.0	21.613	21.561	0.1	0.2
39.209	39.627	0.4	1.1	22.162	22.769	0.6	2.7
40.405	41.574	1.2	2.9	22.269	23.898	1.6	7.1
44.695	45.459	0.8	1.7	23.652	24.693	1.0	4.3
49.309	49.725	0.4	0.7	24.958	24.872	0.1	0.3
54.418	54.536	0.1	0.2	25.017	24.936	0.1	0.3
59.962	60.817	0.9	1.4	24.605	24.598	0.0	0.0
63.637	63.719	0.1	0.1	24.174	24.149	0.0	0.1
80.877	80.281	0.6	0.7	25.573	25.721	0.1	0.6
97.253	98.005	0.7	0.8	25.752	27.986	1.2	4.5
114.998	115.702	0.7	0.6	26.460	28.399	1.9	7.1
125.883	126.920	0.0	0.0	24.839	26.413	1.6	6.1
128.191	128.311	0.1	0.1	24.489	25.267	0.8	3.1
131.979	131.816	0.2	0.1	23.945	25.397	1.4	5.5
132.357	132.198	0.2	0.1	24.391	25.547	1.2	4.6
133.675	135.967	0.3	0.2	24.597	24.912	0.3	1.3
129.340	130.659	1.3	1.0	25.212	24.352	0.9	3.5
120.648	122.071	1.4	1.2	24.948	23.657	1.3	5.3
102.265	103.210	0.9	0.9	23.493	22.261	1.2	5.4
82.571	99.778	2.2	2.5	22.789	22.100	0.7	3.1
78.486	80.930	2.4	3.1	22.833	22.256	0.6	2.6
71.958	73.933	2.0	2.7	22.504	23.239	0.7	3.2
59.900	61.699	1.8	3.0	22.283	23.724	1.5	6.3
104.200	104.505	0.3	0.3	25.144	26.890	1.7	6.7
134.996	134.838	0.2	0.1	21.651	23.037	1.4	6.2
119.312	120.801	1.5	1.2	23.562	22.491	1.1	4.7
54.121	54.368	0.2	0.5	22.688	23.134	0.4	1.9
124.665	125.349	0.7	0.5	19.272	19.609	0.3	1.7
62.887	61.369	1.4	2.3	19.965	19.840	0.1	0.6
122.985	123.607	0.6	0.5	19.129	19.501	0.4	1.9
126.894	127.519	0.6	0.5	20.715	21.912	1.2	5.6
124.631	125.697	1.0	0.8	22.445	22.110	0.3	1.5
46.505	45.120	1.4	3.0	19.267	19.146	0.1	0.6
131.728	132.004	0.3	0.2	20.023	20.614	0.6	2.9
133.671	134.303	0.6	0.5	19.853	20.449	0.6	3.0
126.357	127.004	0.6	0.5	21.423	21.497	0.1	0.3
78.457	77.?57	1.0	1.3	18.586	19.272	0.7	3.6
133.887	133.865	0.0	0.0	22.641	23.827	1.2	5.1
79.601	81.836	2.2	2.8	22.066	21.744	0.3	1.5
123.722	124.314	0.5	0.5	21.759	21.961	0.2	0.9
130.374	130.865	0.5	0.4	21.286	22.696	1.4	6.4
133.032	133.806	0.6	0.4	19.592	20.129	0.5	2.7
133.263	133.848	0.6	0.4	19.617	20.212	0.6	3.0
137.193	137.225	0.0	0.0	21.227	22.115	0.9	4.1
93.253	94.499	1.2	1.3	22.241	21.324	0.9	4.2
58.726	57.311	1.4	2.4	20.036	19.957	0.1	0.4
127.860	128.473	0.6	0.5	19.152	19.530	0.4	2.0

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122.476	123.170	0.7	0.6	21.706	22.867	1.2	5.2
130.439	131.028	0.6	0.5	21.667	21.832	0.2	0.8
75.943	78.221	2.3	3.0	22.246	22.039	0.2	0.9
135.301	135.603	0.3	0.2	20.439	21.436	1.0	4.8
107.779	109.392	1.6	1.5	23.601	22.250	1.4	5.9
115.403	119.590	4.2	3.6	39.967	41.852	1.9	4.6
77.824	75.291	2.5	3.3	39.290	39.441	0.2	0.4
89.541	86.201	3.3	3.8	42.670	41.881	0.8	1.9
33.495	33.695	0.2	0.6	17.908	17.202	0.7	4.0
160.966	160.604	0.4	0.2	12.058	15.580	3.5	25.5
205.490	206.702	1.2	0.6	30.555	29.850	0.7	2.3
83.711	84.044	0.3	0.4	7.165	7.560	0.4	5.4
65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
188.342	188.509	0.2	0.1	13.826	13.214	0.6	4.5
189.300	189.541	0.2	0.1	13.859	13.195	0.7	4.9
192.628	192.774	0.1	0.1	13.874	13.207	0.7	4.9
198.571	198.652	0.1	0.0	13.953	13.295	0.7	4.8
208.323	208.329	0.0	0.0	14.285	13.693	0.6	4.2
224.673	224.491	0.2	0.1	15.684	15.305	0.4	2.4
245.291	244.811	0.5	0.2	13.896	13.844	0.1	0.4
236.529	236.406	0.1	0.1	16.155	15.884	0.3	1.7
215.981	216.372	0.4	0.2	16.290	16.246	0.0	0.3
201.951	202.183	0.2	0.1	15.606	15.304	0.3	1.9
192.652	192.631	0.0	0.0	15.287	14.709	0.6	3.9
186.297	186.036	0.3	0.1	15.269	14.511	0.8	5.1
181.890	181.421	0.5	0.3	15.477	14.478	1.0	6.7
178.794	178.139	0.7	0.4	15.569	14.521	1.0	7.0
176.408	175.714	0.7	0.4	15.472	14.541	0.9	6.2
174.454	173.878	0.6	0.3	15.299	14.606	0.7	4.6
172.726	172.360	0.4	0.2	15.161	14.825	0.3	2.2
171.151	171.056	0.1	0.0	15.390	15.392	0.0	0.0
169.609	169.900	0.2	0.1	16.016	16.336	0.3	2.0
168.242	168.793	0.5	0.3	16.915	17.609	0.7	4.0
166.826	167.672	0.8	0.5	17.911	18.921	1.0	5.5
165.265	166.426	1.1	0.7	18.749	20.005	1.3	6.5
163.777	165.039	1.3	0.8	19.374	20.605	1.2	6.2
162.278	163.596	1.3	0.8	19.648	20.716	1.1	5.3
161.047	162.322	1.3	0.8	19.553	20.359	0.8	4.0
160.166	161.401	1.2	0.8	19.246	19.792	0.5	2.8
159.858	161.001	1.1	0.7	18.901	19.261	0.4	1.9
160.123	161.213	1.1	0.7	18.542	18.775	0.2	1.2
161.053	162.016	1.0	0.6	18.268	18.389	0.1	0.7
162.752	163.531	0.8	0.5	18.127	18.102	0.0	0.1
165.119	165.777	0.7	0.4	18.150	18.029	0.1	0.7
168.229	168.745	0.5	0.3	18.490	18.179	0.3	1.7
172.106	172.459	0.4	0.2	19.182	18.631	0.6	2.9
176.769	176.916	0.1	0.1	20.312	19.398	0.9	4.6
182.023	182.087	0.1	0.0	21.673	20.507	1.2	5.5
187.695	187.889	0.2	0.1	23.003	21.942	1.1	4.7
193.386	194.005	0.7	0.4	24.015	23.397	0.6	2.7
199.769	200.294	1.5	0.9	24.293	24.327	0.0	0.1
203.800	205.995	2.2	1.1	24.410	24.806	0.4	1.6
208.155	213.444	2.3	1.1	24.073	24.564	0.5	2.0
211.741	213.159	1.5	0.7	23.940	23.518	0.4	1.8
214.181	214.985	0.8	0.4	22.610	22.508	1.0	4.5
215.052	215.698	0.7	0.3	22.140	22.229	0.9	4 1

214.393	215.447	1.1	0.5				8.8
213.118	214.122	1.0	0.5	22.355	22.545	0.2	3.9
212.473	213.032	0.6	0.3	22.243	23.131	0.9	2.9
211.934	212.117	0.8	0.4	21.645	23.722	0.7	2.4
211.054	212.515	1.5	0.7	23.471	24.044	0.5	3.8
210.545	212.635	2.1	1.0	23.944	24.875	0.9	3.8
209.612	211.512	1.9	0.9	24.592	25.517	0.9	0.9
208.825	[illegible]	1.7	0.8	25.542	25.324	0.2	4.4
197.277	195.431	2.1	1.1	25.248	24.558	1.1	3.4
187.408	182.921	2.5	1.4	25.527	24.674	0.9	0.1
177.134	180.175	2.8	1.6	24.979	24.335	0.0	1.3
168.378	171.033	2.7	1.5	21.493	23.733	0.3	2.1
160.097	163.143	2.6	1.5	22.618	23.058	0.5	2.6
153.754	155.337	2.5	1.7	21.923	22.495	0.7	3.4
145.033	153.027	2.6	1.7	21.244	21.977	1.0	4.5
[illegible]	145.503	2.5	1.8	20.603	21.619	1.1	5.3
[illegible].494	142.072	2.5	1.8	20.127	21.418	1.2	6.0
135.369	139.024	2.6	1.9	20.052	21.299	1.4	6.7
134.100	135.718	2.6	1.9	19.515	21.286	1.4	6.9
132.480	135.079	2.6	1.9	19.847 / 19.815	21.258 / 21.382	1.5	7.2

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EVENT NO. 24

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
90.472	89.515	1.0	1.1	17.366	16.544	0.8	4.8
126.751	126.085	0.7	0.6	19.122	18.274	0.8	4.5
132.360	133.673	1.3	1.0	13.665	14.161	0.5	3.6
135.022	134.424	0.6	0.4	13.311	14.297	1.0	7.1
144.518	144.815	0.3	0.2	18.533	19.085	0.5	2.5
146.291	147.736	1.4	1.0	25.392	24.275	1.1	4.5
124.612	124.910	0.3	0.2	23.885	23.944	0.1	0.2
132.284	130.915	1.4	1.1	18.256	19.254	1.0	5.3
143.333	144.158	0.8	0.6	18.692	18.301	0.4	2.1
128.619	131.827	3.2	2.5	24.464	25.215	0.8	3.0
103.918	103.595	0.3	0.3	19.748	19.988	0.2	1.2
101.654	99.626	2.0	2.0	17.340	18.036	0.7	3.9
116.104	116.220	0.1	0.1	13.477	14.519	1.0	7.4
175.442	175.748	0.3	0.2	16.779	17.895	1.1	6.4
192.276	192.933	0.7	0.3	17.854	19.705	1.9	9.9
122.225	120.487	1.7	1.4	11.072	11.876	0.8	7.0
101.289	101.199	0.1	0.1	22.119	21.340	0.8	3.6
135.165	132.039	3.1	2.3	18.970	19.509	0.5	2.8
178.317	176.979	1.3	0.8	20.211	21.839	1.6	7.6
117.047	114.810	2.2	1.9	21.459	20.429	1.0	4.9
100.988	98.800	2.2	2.2	19.392	17.638	1.8	9.5
132.855	131.427	1.4	1.1	10.255	9.481	0.8	7.8
71.361	69.079	2.3	3.2	21.321	19.595	1.7	8.4
182.817	185.359	2.5	1.4	22.422	24.055	1.6	7.0
131.505	128.473	3.0	2.3	22.620	22.409	0.2	1.0
107.119	106.621	0.5	0.3	23.393	21.923	1.6	7.7

90.848	89.306	1.5	1.7	18.262	17.167	1.1	6.2
119.352	121.112	1.8	1.5	17.338	15.963	1.4	8.3
99.114	97.262	1.9	1.9	19.305	18.031	1.3	6.8
140.016	145.847	3.2	2.1	23.196	24.231	1.0	4.4
108.377	108.231	0.1	0.1	18.138	17.958	0.2	1.0
154.464	158.321	4.1	2.7	110.195	110.723	0.5	0.5
59.719	60.756	1.0	1.7	13.016	11.760	1.3	10.1
85.010	85.350	0.3	0.4	3.023	2.732	0.3	10.4
149.754	155.572	5.8	3.8	37.777	34.143	3.6	10.1
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
95.520	95.584	0.0	0.0	13.175	13.205	0.0	0.2
79.806	81.069	1.3	1.6	17.952	16.652	1.3	7.5
59.052	58.039	1.0	1.6	19.496	19.133	0.4	1.9
57.062	54.656	2.4	4.3	16.618	16.908	0.3	1.7
58.814	57.104	1.7	2.9	18.269	18.221	0.0	0.2
62.647	62.127	0.5	0.8	19.236	19.025	0.2	1.1
64.173	63.777	0.4	0.6	18.520	19.173	0.7	3.5
66.913	66.117	0.8	1.2	18.613	19.124	0.5	2.7
72.195	71.211	1.0	1.4	19.245	19.784	0.5	2.8
79.163	78.525	0.6	0.8	20.819	20.883	0.1	0.3
89.714	89.026	0.7	0.8	23.189	23.464	0.3	1.2
101.546	101.057	0.5	0.5	23.312	23.443	0.1	0.6
109.004	109.762	0.8	0.7	23.092	22.494	0.6	2.6
109.646	111.275	1.6	1.5	22.984	23.252	0.3	1.2
106.616	107.672	1.1	1.0	21.957	22.431	0.5	2.1
105.236	105.834	0.4	0.3	21.196	20.352	0.8	4.1
111.800	111.407	0.4	0.3	21.725	20.558	1.2	5.5
118.027	117.357	0.7	0.6	22.412	22.227	0.2	0.8
128.183	128.645	0.5	0.4	23.105	22.714	0.4	1.7
130.748	132.848	2.1	1.6	23.626	22.271	1.4	5.9
129.794	133.482	3.7	2.8	24.152	22.852	1.3	5.5
117.858	122.144	4.3	3.5	23.732	23.366	0.4	1.6
106.711	110.077	3.4	3.1	22.691	22.016	0.7	3.0
89.913	92.086	2.2	2.4	21.228	19.941	1.3	6.3
81.365	82.713	1.3	1.6	20.398	19.363	1.0	5.2
74.485	75.549	1.1	1.4	20.326	20.180	0.1	0.7
70.549	72.033	1.5	2.1	20.585	21.065	0.5	2.3
61.020	62.155	1.1	1.9	21.101	21.910	0.8	3.8
111.264	112.117	0.8	0.7	20.410	20.390	0.0	0.1
129.987	130.805	0.9	0.7	20.420	19.543	0.9	4.4
107.971	112.039	4.1	3.7	22.119	21.479	0.6	2.9
91.466	91.374	0.1	0.1	17.795	17.772	0.0	0.1
119.352	121.112	1.8	1.5	17.338	15.963	1.4	8.3
86.590	86.365	0.2	0.3	13.046	13.085	0.0	0.3
122.743	124.059	1.3	1.1	15.157	15.279	0.9	5.6
121.342	121.997	0.7	0.5	19.473	18.895	0.6	3.0
116.807	120.524	3.7	3.1	22.371	20.700	1.5	7.4
79.121	79.877	0.3	0.4	13.193	13.131	0.0	0.2
[illegible]	137.799	2.0	1.5	18.255	16.805	1.4	8.3
127.172	128.714	1.6	1.2	17.703	16.363	1.4	8.2
121.317	124.303	3.0	2.4	20.616	18.941	1.7	8.5
99.808	99.599	0.2	0.2	12.285	12.125	0.2	1.3
126.978	126.800	0.1	0.1	21.561	21.329	0.2	1.1
75.500	75.921	1.3	1.7	19.597	19.333	0.3	1.4
119.713	121.701	3.0	2.5	20.910	19.298	1.6	8.1
[illegible]	[illegible]	0.1	0.1	20.773	20.122	0.7	3.2

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126.075	127.887	1.8	1.4	17.892	16.298	1.6	9.3
126.259	128.039	1.8	1.4	17.925	16.352	1.6	9.2
122.312	125.172	2.4	1.8	19.531	18.133	1.4	7.2
73.271	75.432	2.1	2.4	19.716	18.759	0.9	4.9
83.932	83.739	0.2	0.2	11.024	11.117	0.0	0.2
133.169	134.740	1.6	1.2	13.873	15.795	1.1	6.5
111.113	111.474	0.6	0.5	15.452	15.155	0.3	1.9
113.171	113.114	3.0	2.3	23.078	19.211	1.7	8.3
75.031	74.102	1.1	1.5	19.002	19.917	0.0	0.2
120.947	122.505	1.6	1.3	18.619	17.318	1.3	7.3
95.699	98.759	3.1	3.2	20.857	20.135	0.7	3.6
118.543	120.740	2.2	1.8	17.415	17.156	0.1	0.8
73.421	69.528	5.8	5.8	29.344	28.757	1.1	2.8
91.803	88.619	3.2	3.5	43.183	42.203	2.2	4.9
71.113	71.601	1.5	4.7	11.319	12.453	1.4	10.7
151.612	152.915	1.4	0.9	12.503	12.530	0.4	3.2
164.302	166.241	1.9	1.2	24.745	21.470	3.3	14.2
104.707	105.427	0.7	0.7	9.158	8.622	0.7	8.3
65.003	65.073	0.0	0.0	0.003	0.000	0.0	0.0
180.267	178.858	1.4	0.8	12.472	11.954	0.5	4.2
181.016	179.621	1.4	0.8	12.459	11.948	0.5	4.2
183.277	181.875	1.4	0.8	12.487	12.029	0.5	3.8
187.266	185.832	1.4	0.8	12.548	12.129	0.4	3.4
190.420	191.065	1.6	0.8	12.744	12.397	0.3	2.8
222.459	220.750	1.7	0.9	13.234	13.016	0.3	2.0
216.272	214.211	2.1	1.0	15.017	14.630	0.4	2.6
226.255	224.565	1.7	0.7	16.335	16.792	0.5	2.8
246.449	247.119	0.7	0.3	12.262	11.787	0.5	4.0
272.724	274.071	1.3	0.6	15.744	15.230	0.5	3.3
216.698	216.729	0.1	0.0	15.302	14.285	1.0	6.9
225.744	225.306	0.4	0.2	13.804	12.723	1.1	8.1
198.516	197.890	0.6	0.3	12.607	12.002	0.6	4.9
191.788	192.952	0.8	0.4	12.037	11.688	0.3	2.9
190.603	189.628	1.0	0.5	11.885	11.778	0.1	0.9
188.387	187.221	1.2	0.6	12.089	12.126	0.0	0.3
186.543	185.226	1.3	0.7	12.431	12.559	0.1	1.0
184.608	183.287	1.3	0.7	12.653	12.853	0.2	1.6
182.390	181.225	1.2	0.6	12.650	13.063	0.4	3.2
179.991	179.071	0.9	0.5	12.604	13.252	0.6	5.0
177.705	177.018	0.7	0.4	12.619	13.442	0.8	6.3
175.769	175.275	0.5	0.3	12.795	13.662	0.9	6.6
174.428	174.029	0.4	0.2	13.092	13.916	0.8	6.1
173.831	173.499	0.3	0.2	13.644	14.330	0.7	4.9
174.238	173.843	0.4	0.2	14.586	15.013	0.4	2.9
175.729	175.208	0.5	0.3	16.001	15.975	0.0	0.2
178.339	177.656	0.7	0.4	17.625	17.158	0.5	2.7
182.059	181.225	0.8	0.5	19.392	18.602	0.8	4.2
186.542	185.745	0.8	0.4	20.969	19.870	1.1	5.4
190.892	190.666	0.2	0.1	21.451	20.901	0.6	2.6
194.588	194.788	0.2	0.1	21.587	21.134	0.5	2.2
196.656	197.309	0.7	0.3	21.401	21.126	0.3	1.5
196.964	197.965	1.0	0.5	22.038	21.582	0.5	2.2
195.115	196.662	1.5	0.8	22.759	22.551	0.2	0.9
191.842	193.644	1.8	0.9	22.185	22.916	0.7	3.2
188.292	189.882	1.6	0.9	21.592	22.609	1.0	4.6
185.039	186.328	1.2	0.7	20.823	21.799	1.0	4.5

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182.947	183.670	0.7	0.4	20.294	20.818	0.5	2.6
181.986	182.150	0.2	0.1	19.973	19.958	0.0	0.1
182.036	181.987	0.0	0.0	19.996	19.516	0.5	2.4
183.467	183.212	0.3	0.1	20.580	19.820	0.8	3.8
185.994	185.702	0.3	0.2	21.732	20.907	0.8	3.9
189.121	189.028	0.1	0.0	22.978	22.444	0.5	2.4
192.443	192.533	0.1	0.0	24.272	23.692	0.6	2.4
195.185	195.697	0.5	0.3	25.297	24.674	0.6	2.5
197.108	197.945	0.8	0.4	26.398	25.307	1.1	4.2
197.286	198.655	1.4	0.7	27.207	25.696	1.5	5.7
194.852	197.709	2.9	1.5	27.152	26.309	0.8	3.2
190.628	194.753	4.1	2.1	27.415	27.005	0.4	1.5
184.441	188.888	4.4	2.4	27.242	27.235	0.0	0.0
177.163	180.667	3.5	2.0	25.945	26.159	0.8	2.9
168.937	171.858	2.9	1.7	25.763	24.584	1.2	4.7
160.815	163.254	2.4	1.5	24.604	22.931	1.7	7.0
153.262	155.510	2.2	1.5	23.255	21.818	1.4	6.4
146.553	148.595	2.0	1.4	22.287	20.997	1.3	6.0
140.669	142.532	1.9	1.3	21.610	20.466	1.1	5.4
135.542	137.282	1.7	1.3	21.101	20.167	0.9	4.5
131.032	132.741	1.7	1.3	20.699	19.976	0.7	3.6
127.302	128.901	1.6	1.2	20.416	19.793	0.6	3.1
124.191	125.705	1.5	1.2	20.198	19.669	0.5	2.7
121.674	123.129	1.5	1.2	20.048	19.534	0.5	2.3
119.739	121.180	1.4	1.2	19.955	19.565	0.4	2.0
118.359	119.767	1.4	1.2	19.905	19.537	0.4	1.9

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EVENT NO. 25

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
138.349	140.267	1.9	1.4	20.964	22.011	1.0	4.9
95.978	96.322	0.6	0.7	15.223	14.576	0.7	4.4
131.594	132.018	0.4	0.3	15.144	15.328	0.2	1.2
140.134	140.146	0.0	0.0	16.099	15.781	0.3	1.9
154.281	155.001	0.7	0.5	18.168	17.399	0.8	4.3
118.799	121.609	2.8	2.3	22.569	23.714	1.1	4.9
119.648	117.269	2.4	2.0	17.605	18.965	1.4	7.4
140.218	139.761	0.5	0.3	15.983	16.938	0.0	0.2
138.946	140.531	1.6	1.1	20.679	21.421	0.7	3.5
122.389	123.029	0.7	0.6	23.245	24.073	0.8	3.5
105.533	106.153	0.6	0.5	19.183	18.665	0.6	3.0
103.904	105.774	2.2	2.1	15.063	16.025	1.0	6.3
117.903	116.725	1.2	1.0	11.185	11.659	0.5	4.1
174.127	175.337	1.0	0.5	17.593	19.383	1.7	9.9
192.412	190.909	2.5	1.3	18.515	18.728	0.2	1.0
125.661	124.847	0.8	0.7	9.329	10.212	0.9	9.0
95.779	92.205	3.6	3.8	23.155	24.777	1.6	6.8
141.706	143.024	1.4	1.0	18.209	18.728	0.5	2.7
178.945	180.201	1.3	0.7	20.126	21.373	1.3	6.5
113.151	113.625	1.5	1.3	24.129	25.089	0.8	3.9

116.587	114.815	2.6	2.3	19.445	19.413	0.0	0.2
[illegible]	125.7?5	0.8	0.7	12.251	12.649	0.4	2.2
87.193	84.910	3.0	3.4	22.??2	22.532	0.1	0.1
104.144	177.404	1.?	1.9	22.256	22.877	0.8	3.7
[illegible]	1?5.712	1.5	1.1	22.534	24.012	1.4	6.0
[illegible]	117.215	1.6	0.9	19.571	20.269	0.6	2.9
[illegible]	1??.455	3.1	2.0	[illegible]	[illegible]	0.0	0.1
119.204	1??.402	1.2	1.0	15.2??	15.031	0.4	2.5
[illegible]	145.2?2	1.0	0.5	14.5??	11.785	0.8	5.5
[illegible]	[illegible]	1.?	0.5	[illegible]	22.5??	2.2	12.6
[illegible]	1??.162	0.2	0.2	23.?41	21.878	0.9	4.4
1??.365	1??.1?4	5.1	3.4	111.??2	110.784	1.0	0.9
[illegible]	??.837	1.5	2.5	12.479	9.765	0.7	7.1
[illegible]	85.579	0.4	0.5	2.448	2.174	0.3	11.9
[illegible]	157.585	5.0	3.2	13.455	23.2?3	1.2	[illegible]
57.003	57.?20	0.0	0.0	0.000	0.000	0.0	0.0
[illegible]	98.546	3.0	3.2	14.715	16.563	1.8	11.7
[illegible]	99.5?3	1.7	1.7	12.417	11.519	1.1	8.5
[illegible]	1??.812	1.8	1.0	15.5?0	17.010	0.4	2.2
9?.622	93.245	0.4	0.4	19.652	20.225	0.5	2.9
74.020	73.145	1.7	2.3	15.596	15.764	0.2	1.0
73.550	72.492	1.2	1.6	[illegible]	15.822	0.5	3.3
79.424	78.163	1.3	1.6	15.589	16.128	0.7	4.6
8?.513	82.294	1.2	1.5	16.157	16.877	0.5	3.1
92.5?9	91.109	1.2	1.4	18.122	18.875	0.5	2.7
107.?71	106.294	1.7	1.6	19.746	19.793	0.0	0.0
119.909	119.109	0.5	0.5	18.177	17.571	0.6	3.4
120.757	121.908	1.2	0.9	18.104	17.863	0.2	1.3
111.718	114.028	2.3	2.0	19.721	20.869	1.1	5.7
104.239	105.831	1.6	1.5	19.635	20.119	0.5	2.5
104.386	104.277	0.1	0.1	19.732	19.437	0.3	1.5
110.070	108.975	1.1	1.0	19.259	19.809	0.6	3.3
117.604	117.028	0.6	0.5	19.709	20.168	0.5	2.3
121.903	122.?31	0.4	0.3	21.029	21.130	0.1	0.5
129.590	130.569	1.0	0.8	21.627	22.498	0.9	3.9
128.550	129.936	1.4	1.1	22.247	23.208	1.0	4.2
124.859	126.607	1.8	1.4	22.925	23.417	0.5	2.1
112.963	114.883	1.9	1.7	22.118	22.754	0.6	2.8
103.384	105.770	2.4	2.3	20.507	20.890	0.4	1.9
98.445	98.770	1.3	1.5	19.062	19.210	0.1	0.8
82.769	82.544	0.2	0.2	19.010	18.881	0.1	0.7
76.000	75.943	0.1	0.2	19.480	19.521	0.0	0.2
73.270	72.270	1.0	1.4	19.777	20.095	0.3	1.6
64.820	6?.713	1.1	1.7	20.844	20.841	0.0	0.0
109.832	109.626	0.7	0.6	18.018	18.415	0.4	2.2
130.667	131.535	0.9	0.7	18.571	19.276	0.7	3.7
103.898	105.759	1.9	1.8	20.478	20.925	0.4	2.2
108.955	108.790	0.2	0.2	13.664	13.564	0.1	0.7
119.2?4	12?.462	1.2	1.0	15.479	15.0?1	0.4	2.5
102.245	100.84?	1.4	1.4	11.411	12.407	1.0	8.4
122.908	124.608	1.7	1.4	14.742	14.455	0.3	2.0
[illegible]	123.848	0.5	0.4	17.151	17.487	0.3	1.9
110.137	114.116	2.0	1.8	21.081	21.317	0.2	1.1
8?.816	84.296	1.4	1.7	11.?96	12.247	1.0	8.1
[illegible]	129.413	1.6	1.2	17.191	17.3?5	0.2	1.0
[illegible]	1?8.776	1.3	1.0	15.959	15.807	0.2	1.0

5.70

117.881	120.070	2.2	1.8	19.869	20.152	0.3	1.4
114.499	113.429	1.1	0.9	10.859	11.500	0.6	5.7
129.412	130.193	0.8	0.6	19.887	20.620	0.7	3.6
77.467	76.982	0.5	0.6	18.948	18.877	0.1	0.4
115.076	117.289	2.2	1.9	20.237	20.606	0.4	1.8
124.723	125.320	0.6	0.5	18.494	19.208	0.7	3.8
126.060	127.473	1.4	1.1	16.303	16.260	0.0	0.3
126.231	127.673	1.4	1.1	16.354	16.311	0.0	0.3
130.558	132.300	1.7	1.3	18.934	19.311	0.4	2.0
83.439	84.203	0.8	0.9	18.105	18.351	0.2	1.3
95.793	94.040	1.8	1.9	11.890	13.008	1.1	9.2
124.248	125.754	1.5	1.2	15.009	14.704	0.4	2.6
121.771	122.035	0.7	0.6	17.133	17.202	0.1	0.4
121.783	123.975	2.2	1.8	20.188	20.512	0.3	1.6
75.137	74.666	0.5	0.6	19.258	19.270	0.0	0.1
129.457	130.687	1.1	0.9	16.725	16.966	0.2	1.4
93.245	95.073	1.8	1.9	18.999	19.323	0.3	1.7
93.957	94.948	1.0	1.0	34.945	33.302	1.6	4.8
88.195	82.926	5.2	6.1	47.792	44.969	2.8	6.1
84.147	78.113	6.2	7.7	47.789	42.570	5.1	11.4
38.793	38.341	0.5	1.2	19.269	20.314	1.0	5.3
146.358	148.454	2.1	1.4	17.908	14.692	3.2	19.7
152.826	152.294	1.5	1.0	16.936	16.255	0.7	4.1
135.020	135.556	0.5	0.4	13.768	13.611	0.2	1.1
65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
172.272	170.354	1.9	1.1	15.074	14.731	0.3	2.3
172.752	170.871	1.9	1.1	15.078	14.744	0.3	2.2
174.268	172.388	1.9	1.1	15.053	14.787	0.3	1.8
176.852	174.992	1.9	1.1	15.053	14.875	0.2	1.2
180.674	178.825	1.8	1.0	15.115	15.054	0.1	0.4
185.805	184.004	1.8	1.0	15.319	15.388	0.1	0.5
192.920	191.010	1.9	1.0	15.810	16.018	0.2	1.3
202.468	200.518	1.9	1.0	17.040	17.208	0.2	1.0
215.558	213.505	2.1	1.0	19.137	19.235	0.1	0.5
230.895	229.448	1.4	0.6	17.941	19.033	1.1	5.9
243.235	241.991	1.2	0.5	13.875	14.760	0.9	6.2
240.091	240.345	0.3	0.1	15.584	15.824	0.2	1.5
225.376	226.253	0.9	0.4	16.893	17.318	0.4	2.5
212.437	212.654	0.2	0.1	15.457	15.217	0.2	1.6
201.048	201.038	0.0	0.0	14.342	13.824	0.4	3.0
195.953	195.875	0.1	0.1	13.187	12.932	0.2	1.3
190.374	190.216	0.1	0.1	12.318	12.302	0.0	0.1
185.971	185.758	0.2	0.1	11.801	11.810	0.0	0.1
182.513	182.000	0.3	0.1	11.502	11.514	0.0	0.4
179.975	179.679	0.3	0.2	11.424	11.439	0.0	0.1
178.391	178.021	0.4	0.2	11.524	11.595	0.1	0.5
177.799	177.442	0.4	0.2	11.777	12.044	0.3	2.2
178.122	177.815	0.4	0.2	12.288	12.903	0.6	4.9
1??.125	179.705	0.4	0.2	13.226	14.159	0.9	6.7
1??.297	182.753	0.5	0.1	14.355	15.385	1.0	6.7
187.827	187.102	0.7	0.4	15.512	16.429	0.9	5.6
193.610	192.??3	0.7	0.4	16.719	17.718	1.0	5.8
199.792	198.963	0.7	0.4	17.971	18.436	0.6	3.1
2??.579	205.208	0.3	0.1	18.349	18.271	0.1	0.4
212.138	211.884	1.2	0.6	18.829	19.211	0.4	2.0
1??.424	200.275	2.8	1.4	19.1??	20.267	1.1	5.6

5.71

[illegible]	[illegible]	1.5	1.1	22.??8	21.452	1.1	6.8
[illegible]	[illegible]	1.4	1.1	21.682	20.149	1.5	7.4
174.1??	175.411	1.2	0.9	21.111	19.497	1.6	7.0
[illegible]	[illegible]	1.?	0.8	20.6??	19.11?	1.6	6.3
[illegible]	[illegible]	0.9	0.7	20.14?	[illegible]	1.4	6.9
[illegible]	[illegible]	0.8	0.7	[illegible]	18.7??	1.3	6.5
11?.???	11?.???	0.7	0.6	19.213	18.??3	1.3	6.2
11?.804	11?.50?	0.7	0.6	19.765	18.571	1.2	6.2
[illegible]	1?1.0?9	0.6	0.5	19.??1	18.507	1.2	6.1
[illegible]	10?.077	0.5	0.5	1?.040	18.514	1.1	5.9
107.181	10?.716	0.5	0.5	19.61?	18.478	1.1	6.0

EVENT NO. 26

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
162.618	164.234	1.6	1.0	19.759	18.179	1.6	8.3
101.?93	103.496	0.2	0.2	18.555	18.656	0.1	0.5
117.147	116.178	1.0	0.8	18.?18	17.868	0.2	0.9
[illegible]	140.004	1.0	0.7	14.???	14.022	0.1	0.5
15?.?48	152.393	0.5	0.3	16.?82	18.0?5	1.4	7.8
1??.787	[illegible]	2.5	1.9	27.7??	27.712	0.1	0.3
[illegible]	[illegible]	0.5	0.4	[illegible]	18.641	0.5	2.8
[illegible]	114.??9	1.0	1.?	15.773	17.0?9	1.3	7.9
14?.187	142.465	0.8	0.5	16.296	16.855	0.6	3.4
1??.117	[illegible]	2.7	2.2	21.6??	22.784	1.1	4.9
10?.?07	[illegible]	0.1	0.1	17.104	18.574	1.5	8.2
10?.??3	101.007	2.2	2.1	15.?29	16.272	1.0	6.6
[illegible]	115.787	0.4	0.4	11.441	11.835	0.4	3.3
[illegible]	1??.112	1.0	0.6	15.1??	17.245	2.1	12.2

190.732	192.953	2.2	1.2	18.054	19.001	0.9	5.1
125.459	124.161	1.3	1.0	8.351	9.435	1.1	12.2
71.574	69.784	1.8	2.5	24.868	24.726	0.1	0.6
139.342	137.258	2.1	1.5	15.362	16.920	1.6	9.7
181.910	182.049	0.1	0.1	18.004	20.590	2.6	13.4
117.884	117.750	0.1	0.1	19.828	19.187	0.6	3.3
111.353	109.640	1.7	1.6	18.093	18.277	0.2	1.0
124.082	123.421	0.7	0.5	9.518	9.604	0.1	0.9
92.353	89.206	2.1	2.5	19.949	20.157	0.2	1.1
179.908	182.210	3.3	1.8	22.123	22.454	0.3	1.5
135.884	134.221	1.6	1.2	19.342	20.196	0.9	4.3
187.772	189.442	1.7	0.9	19.092	20.447	1.4	6.9
99.776	97.728	2.0	2.1	17.708	18.298	0.6	3.3
124.032	124.259	0.2	0.2	15.671	16.499	0.8	5.1
110.957	109.918	1.0	0.9	14.998	16.039	1.0	6.7
153.215	151.431	1.8	1.2	19.054	22.005	2.9	14.3
108.672	107.365	1.3	1.2	17.907	17.972	0.1	0.4
143.380	154.311	10.9	7.3	112.488	110.852	1.6	1.5
67.748	65.550	2.2	3.4	12.012	11.066	0.9	8.2
86.090	86.585	0.5	0.6	2.445	2.120	0.3	14.3
161.342	169.185	7.8	4.7	36.204	34.317	1.9	5.4
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
73.?26	79.928	3.0	4.1	18.511	18.110	0.4	2.2
93.189	91.203	2.0	2.1	15.323	16.055	0.7	4.7
109.614	108.233	1.4	1.3	12.932	12.892	0.0	0.3
110.541	109.213	1.3	1.2	16.418	15.789	0.6	4.0
86.294	84.729	1.6	1.8	17.779	18.064	0.3	1.6
73.641	71.274	2.3	3.0	14.758	15.158	0.4	2.7
76.641	74.107	2.5	3.4	13.849	14.548	0.7	5.0
79.992	78.807	1.2	1.5	14.315	15.254	0.9	6.4
88.694	87.111	1.6	1.8	15.604	15.346	0.3	1.7
102.09?	99.477	2.6	2.6	[illegible]	[illegible]	0.2	1.1
114.04?	112.504	2.0	1.8	18.413	18.834	0.4	2.3
120.073	119.805	0.9	0.7	18.033	17.910	0.1	0.7
119.249	118.717	0.5	0.4	21.778	21.205	0.6	2.7
111.1??	110.994	0.9	0.8	22.082	23.433	1.4	5.9
110.215	111.203	1.0	0.9	19.518	20.979	1.5	7.2
113.921	114.014	0.1	0.1	17.987	18.405	0.4	2.3
1??.590	119.787	0.8	0.7	18.397	18.511	0.1	0.6
[illegible]	[illegible]	1.6	1.3	[illegible]	[illegible]	0.3	1.7
1??.783	[illegible]	1.6	1.2	[illegible]	21.1?2	0.7	3.5
[illegible]	1??.470	0.2	0.1	21.745	22.667	0.9	4.2
[illegible]	1?4.006	1.1	0.8	22.8?1	24.476	1.6	6.8
[illegible]	[illegible]	1.5	1.3	22.5?2	24.5??	2.0	8.4
10?.?14	103.845	1.0	0.9	[illegible]	21.9??	2.1	10.3
[illegible]	[illegible]	0.6	0.7	[illegible]	18.?04	0.8	4.6
[illegible]	[illegible]	1.2	1.4	1?.274	17.748	0.5	2.9
[illegible]	[illegible]	1.6	2.?	[illegible]	[illegible]	0.6	3.2
[illegible]	[illegible]	1.6	2.2	[illegible]	18.?04	0.3	1.4
[illegible]	[illegible]	2.1	3.2	2?.274	[illegible]	0.0	0.1
[illegible]	[illegible]	0.6	0.5	1?.772	[illegible]	1.2	6.4
[illegible]	[illegible]	0.7	0.5	[illegible]	[illegible]	0.7	[illegible]
[illegible]	[illegible]	1.1	1.0	2?.71?	[illegible]	1.?	9.3
[illegible]	[illegible]	0.8	0.7	[illegible]	[illegible]	0.4	2.9
[illegible]	[illegible]	0.2	0.2	[illegible]	[illegible]	0.8	5.1
[illegible]	[illegible]	1.?	1.?	[illegible]	[illegible]	0.2	1.4

[illegible]	[illegible]	0.2	0.1	15.224	15.911	0.5	4.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.555	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.777	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.592	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.0	0.2	[illegible]	17.911	0.5	2.5
174.519	174.229	0.2	0.2	[illegible]	17.527	0.8	4.5
[illegible]	[illegible]	0.8	0.5	19.143	20.029	1.7	4.9
[illegible]	[illegible]	1.9	1.0	[illegible]	30.111	1.7	4.9
[illegible]	[illegible]	5.9	7.0	41.???	43.972	1.0	2.4
[illegible]	[illegible]	4.7	5.0	[illegible]	38.854	2.?	5.6
41.???	[illegible]	1.4	3.5	[illegible]	25.7??	0.4	1.5
147.973	153.282	0.3	0.2	10.811	14.925	4.1	32.0
153.715	158.285	1.6	1.0	19.554	21.167	1.6	7.7
152.592	151.813	0.4	0.3	14.121	14.162	0.0	0.1
65.093	65.000	0.0	0.0	0.000	0.000	0.0	0.0
161.351	161.271	2.1	1.3	17.314	16.953	1.0	5.5
161.792	161.679	2.1	1.3	17.??3	16.943	1.0	5.5
169.124	165.078	2.1	1.3	17.891	16.951	0.9	5.4
167.411	165.??5	2.1	1.3	17.912	16.962	0.9	5.4
170.716	168.524	2.1	1.2	17.912	17.020	0.9	5.2
173.159	173.010	2.1	1.2	17.924	17.053	0.9	5.3
180.916	178.749	2.2	1.2	18.156	17.285	1.0	5.4
183.257	185.990	2.3	1.2	18.565	17.418	1.1	5.9
197.681	195.221	2.4	1.2	18.801	17.861	1.1	6.1
219.059	217.570	2.5	1.2	19.847	18.415	1.4	7.5
229.422	231.061	1.4	0.6	19.104	18.977	0.1	0.7
240.161	240.049	0.3	0.1	15.265	15.559	0.3	1.9
241.380	241.832	0.2	0.1	15.754	14.725	1.0	6.7
229.248	228.458	0.4	0.2	18.330	18.299	0.0	0.2
215.251	214.652	0.6	0.3	17.831	18.037	0.2	1.1
204.629	204.031	0.6	0.3	16.222	16.618	0.4	2.4
[illegible]	[illegible]	0.5	0.3	14.539	14.924	0.4	3.0
[illegible]	[illegible]	0.5	0.3	13.257	13.710	0.5	3.4
184.7??	184.275	0.5	0.2	12.475	12.900	0.4	3.4
182.732	181.??3	0.4	0.2	12.127	12.497	0.4	3.0
177.092	177.517	0.4	0.2	12.024	12.400	0.4	3.0
176.146	175.725	0.4	0.2	12.213	12.627	0.4	3.3
[illegible]	175.059	0.5	0.3	[illegible]	13.141	0.5	3.5
176.031	175.50?	0.5	0.3	1?.495	14.059	0.6	4.1
177.040	177.?21	0.7	0.4	[illegible]	15.1??	0.3	2.1

5.74

181.541	180.492	1.0	0.6	16.562	16.754	0.2	1.2
186.502	185.152	1.4	0.7	18.597	18.671	0.1	0.4
191.946	190.630	1.3	0.7	19.551	19.932	0.4	1.9
196.627	195.812	0.8	0.4	19.724	20.320	0.6	3.0
199.102	199.302	0.1	0.1	19.745	20.480	0.7	3.7
199.165	199.352	0.2	0.1	20.418	20.326	0.1	0.5
196.201	196.900	0.7	0.3	21.652	20.982	0.7	3.1
191.328	193.001	1.7	0.9	22.368	22.495	0.1	0.6
185.964	188.342	2.4	1.3	22.174	23.316	1.1	5.0
181.070	183.663	2.6	1.4	21.155	22.946	1.8	8.1
177.412	179.669	2.3	1.3	20.128	21.634	1.5	7.2
175.147	177.025	1.9	1.1	19.175	20.418	1.2	6.3
174.168	175.719	1.6	0.9	18.267	19.398	1.1	6.1
174.520	175.779	1.3	0.7	17.704	18.813	1.1	6.1
176.043	177.061	1.0	0.6	17.603	18.572	1.0	5.4
178.714	179.391	0.7	0.4	18.112	18.869	0.8	4.1
182.202	182.505	0.2	0.1	19.508	19.795	0.3	1.5
186.193	185.914	0.3	0.1	21.409	21.280	0.1	0.6
189.428	188.903	0.5	0.3	23.017	23.071	0.1	0.2
191.107	190.588	0.5	0.3	24.366	24.255	0.1	0.5
190.632	190.700	0.1	0.1	24.830	24.824	0.0	0.0
188.524	189.769	1.2	0.6	25.207	25.877	0.7	2.6
185.444	187.279	1.8	1.0	25.962	25.640	0.7	2.6
180.826	183.029	2.1	1.2	26.409	27.213	0.8	3.0
174.549	176.908	2.4	1.4	25.997	27.372	1.4	5.2
165.875	168.152	2.3	1.4	24.545	26.213	1.7	6.6
158.665	160.629	2.0	1.2	22.708	24.521	1.8	7.7
150.824	152.143	1.3	0.8	21.373	22.403	1.0	4.8
143.702	144.433	0.7	0.5	20.615	20.908	0.3	1.4
137.333	137.556	0.2	0.2	20.227	19.977	0.3	1.2
131.505	131.506	0.1	0.0	19.593	19.427	0.6	2.9
126.513	126.716	0.2	0.2	19.800	19.125	0.7	3.5
122.003	121.837	0.3	0.2	19.678	18.978	0.7	3.6
118.218	117.979	0.3	0.3	19.500	18.897	0.7	3.6
115.168	114.832	0.4	0.3	19.526	18.832	0.7	3.6
112.614	112.254	0.4	0.3	19.504	18.825	0.7	3.5
110.659	110.335	0.4	0.3	19.484	18.812	0.7	3.5
109.273	108.833	0.4	0.4	19.490	18.814	0.7	3.5

EVENT NO. 27

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
171.129	171.452	0.3	0.2	14.693	14.913	0.2	1.5
183.545	183.841	0.3	0.2	18.527	19.091	0.5	2.6
[illegible]	[illegible]	1.4	1.1	[illegible]	20.049	0.1	0.7
[illegible]	[illegible]	0.5	0.4	[illegible]	21.264	0.2	0.7
[illegible]	155.610	0.1	0.1	19.519	20.119	0.8	4.1
[illegible]	[illegible]	1.0	[illegible]	17.407	[illegible]	0.2	1.0
[illegible]	[illegible]	2.2	1.6	13.691	[illegible]	0.3	2.4
[illegible]	[illegible]	0.5	0.4	[illegible]	[illegible]	0.5	3.1

5.75

5.76

[illegible]	175.249	0.4	0.3	[illegible]	18.949	0.0	0.2
[illegible]	[illegible]	2.8	2.2	21.579	21.827	[illegible]	1.2
[illegible]	[illegible]	0.0	0.0	[illegible]	[illegible]	2.1	[illegible]
[illegible]	[illegible]	1.5	1.4	19.459	[illegible]	1.2	[illegible]
[illegible]	[illegible]	0.1	0.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.2	[illegible]	[illegible]	[illegible]	1.6	[illegible]
[illegible]	[illegible]	0.4	0.2	[illegible]	[illegible]	0.1	[illegible]
[illegible]	[illegible]	1.5	[illegible]	[illegible]	[illegible]	1.0	[illegible]
[illegible]	[illegible]	0.9	[illegible]	[illegible]	[illegible]	0.6	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.9	2.5
[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]	1.0	[illegible]
[illegible]	[illegible]	1.0	0.5	[illegible]	[illegible]	0.8	4.0
[illegible]	[illegible]	[illegible]	1.4	[illegible]	[illegible]	0.7	[illegible]
[illegible]	[illegible]	1.5	1.1	[illegible]	[illegible]	0.2	[illegible]
[illegible]	[illegible]	2.1	2.1	[illegible]	[illegible]	1.1	[illegible]
[illegible]	[illegible]	2.2	[illegible]	[illegible]	[illegible]	0.2	0.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	0.9
[illegible]	[illegible]	1.3	0.7	[illegible]	[illegible]	0.3	1.5
[illegible]	[illegible]	2.0	1.7	[illegible]	16.524	1.4	9.1
[illegible]	108.479	0.5	0.4	14.249	14.922	0.1	0.4
[illegible]	114.797	0.1	0.1	13.594	[illegible]	0.1	0.4
[illegible]	149.132	2.4	1.6	18.009	[illegible]	1.9	9.9
[illegible]	108.415	1.1	1.0	18.293	18.904	0.6	3.4
[illegible]	145.865	0.5	0.3	[illegible]	112.655	1.0	0.9
[illegible]	61.092	1.5	2.6	[illegible]	11.124	0.2	2.1
[illegible]	[illegible]	0.4	0.4	[illegible]	2.435	0.1	3.3
[illegible]	[illegible]	4.9	3.2	[illegible]	[illegible]	1.1	3.4
[illegible]	[illegible]	0.0	0.0	0.000	0.000	0.0	0.0
[illegible]	61.502	1.6	2.5	14.272	15.122	1.1	7.4
81.149	82.259	1.0	1.3	17.078	18.170	1.3	7.3
109.223	107.951	1.3	1.2	15.329	16.042	0.7	4.5
122.170	123.918	1.3	1.0	15.643	15.519	0.1	0.7
111.773	110.754	1.0	0.9	[illegible]	17.597	0.6	4.3
[illegible]	[illegible]	0.1	0.0	18.822	18.101	0.7	4.0
[illegible]	[illegible]	0.4	0.3	19.183	19.295	0.1	0.4
[illegible]	[illegible]	0.1	0.1	17.445	18.162	0.7	4.0
[illegible]	112.907	0.1	0.1	16.611	18.609	0.6	3.3
[illegible]	108.832	0.2	0.2	19.762	19.930	0.2	1.1
92.762	92.516	0.2	0.2	18.155	17.526	0.6	3.1
[illegible]	92.457	0.1	0.2	16.828	16.495	0.3	2.0
92.579	[illegible]	0.8	0.3	17.146	16.741	0.4	2.6
[illegible]	95.505	0.4	0.5	17.613	16.790	0.8	4.8
[illegible]	98.770	1.4	1.4	17.170	16.192	0.8	4.6
[illegible]	102.828	1.2	1.2	16.604	16.119	0.5	3.1
[illegible]	[illegible]	0.9	0.8	17.659	17.701	0.2	0.9
111.002	110.600	1.0	0.9	19.999	20.116	0.1	0.6
[illegible]	116.503	0.4	0.4	21.691	21.894	0.2	0.9
[illegible]	115.931	1.0	0.8	22.289	23.057	0.8	3.4
[illegible]	[illegible]	2.3	2.0	22.704	23.691	0.9	4.1
[illegible]	[illegible]	2.7	2.6	21.366	23.059	1.8	7.9
[illegible]	[illegible]	2.3	2.4	[illegible]	20.956	1.4	6.9
[illegible]	88.094	1.7	2.0	[illegible]	18.797	0.5	2.7
83.177	81.009	0.8	1.0	17.816	17.718	0.1	0.6
72.849	73.854	1.8	1.4	17.794	17.866	0.1	0.5
[illegible]	70.578	0.8	1.1	19.053	18.656	0.4	2.0
[illegible]	62.815	0.4	0.7	21.062	20.932	1.0	4.8

5.77

101.514	100.619	0.9	0.9	15.594	15.034	0.6	3.7
117.961	118.184	0.2	0.2	19.073	19.529	0.5	2.4
97.278	99.892	2.6	2.6	19.100	20.599	1.5	7.6
116.935	117.276	0.3	0.3	13.404	13.172	0.2	1.8
108.906	109.479	0.5	0.4	14.949	14.882	0.1	0.4
99.268	97.964	1.3	1.3	14.346	15.241	0.9	6.1
119.296	119.875	0.6	0.6	14.474	14.043	0.4	3.0
111.626	112.706	0.9	0.8	15.769	15.407	0.4	2.3
102.754	105.438	2.7	2.5	20.166	21.015	0.8	4.1
93.229	93.278	1.0	1.1	12.815	13.133	0.3	2.4
113.204	114.406	1.2	1.0	17.703	18.003	0.3	1.7
116.430	116.939	0.6	0.5	15.303	15.045	0.1	0.7
106.765	108.637	2.1	1.9	19.504	20.015	0.5	2.7
119.527	118.809	0.6	0.5	11.555	11.528	0.0	0.1
117.168	116.683	0.5	0.4	19.773	19.774	0.0	0.0
74.762	75.511	0.7	1.0	17.709	17.330	0.4	2.2
103.599	105.677	2.1	2.0	20.008	20.609	0.6	2.9
112.410	112.703	0.6	0.6	17.909	17.803	0.1	0.6
114.709	115.673	0.9	0.9	16.501	16.874	0.3	1.7
114.891	115.761	0.9	0.8	16.600	15.998	0.3	1.8
118.409	119.715	1.3	1.1	19.560	20.206	0.6	3.1
80.477	81.583	1.5	1.8	17.069	17.291	0.2	1.4
78.182	77.019	1.2	1.5	16.078	17.417	1.3	8.0
113.601	114.165	0.6	0.5	14.652	14.392	0.2	1.8
112.242	111.349	0.9	0.9	15.329	14.951	0.4	2.6
[illegible]	113.403	2.1	1.9	19.299	20.590	0.6	2.0
72.163	72.009	0.9	1.2	18.042	17.689	0.4	2.0
117.912	117.502	0.4	0.3	17.152	17.731	0.6	3.3
89.822	91.802	2.0	2.3	17.714	18.811	1.1	6.0
70.916	72.187	1.4	1.9	27.105	30.271	3.0	10.3
113.651	106.364	6.7	6.1	58.222	57.478	0.7	1.3
95.170	97.097	2.2	2.2	47.400	47.550	0.1	0.3
50.000	52.022	1.8	2.4	32.643	31.032	1.6	5.0
[illegible]	142.159	1.8	1.2	21.020	20.815	0.2	1.2
101.254	101.982	0.7	0.6	23.510	23.777	0.3	1.1
164.902	164.962	0.0	0.0	18.572	18.398	0.2	0.9
[illegible]	[illegible]	0.0	0.0	0.000	0.000	0.0	0.0
165.073	162.131	1.8	1.1	17.320	16.145	0.9	5.2
[illegible]	162.601	1.7	1.1	17.004	16.182	0.9	5.4
[illegible]	164.724	1.7	1.0	17.171	15.222	0.9	5.4
[illegible]	165.692	1.7	1.9	17.014	16.125	0.9	5.5
[illegible]	[illegible]	1.7	1.0	[illegible]	16.007	0.9	5.6
174.614	171.012	1.6	0.9	16.874	15.912	1.0	5.9
179.279	177.725	1.6	0.9	[illegible]	15.873	1.0	6.1
[illegible]	[illegible]	1.5	0.9	[illegible]	15.815	1.0	6.1
[illegible]	[illegible]	1.4	0.7	15.703	15.825	0.9	5.7
[illegible]	[illegible]	1.2	0.6	16.074	[illegible]	0.7	4.4
[illegible]	[illegible]	0.9	0.4	[illegible]	15.171	0.2	1.3
[illegible]	[illegible]	0.7	[illegible]	[illegible]	[illegible]	0.3	2.0
[illegible]	[illegible]	0.8	[illegible]	[illegible]	[illegible]	0.4	2.2
[illegible]	[illegible]	0.7	0.3	[illegible]	[illegible]	0.1	0.8
[illegible]	[illegible]	0.0	[illegible]	[illegible]	[illegible]	0.5	3.9
[illegible]	[illegible]	0.2	0.1	[illegible]	[illegible]	0.3	1.9
[illegible]	[illegible]	0.0	0.0	[illegible]	[illegible]	0.6	3.7
[illegible]	[illegible]	0.1	0.0	[illegible]	[illegible]	1.0	5.9
[illegible]	[illegible]	0.4	[illegible]	[illegible]	[illegible]	0.9	5.1

213.291	214.108	0.8	0.4	18.140	17.582	0.6	3.1
214.025	215.059	1.0	0.5	18.641	18.294	0.3	1.9
214.758	215.751	1.0	0.5	18.905	18.650	0.3	1.4
214.295	215.003	0.8	0.4	19.019	18.821	0.2	1.2
211.711	212.291	0.6	0.3	19.451	19.354	0.1	0.5
207.124	207.517	0.5	0.2	20.010	20.334	0.3	1.6
[illegible]	201.500	0.7	0.3	20.127	21.124	1.0	4.8
[illegible]	194.611	0.5	0.3	19.848	20.959	1.1	5.5
187.004	187.572	0.6	0.3	18.875	20.146	1.3	6.5
180.605	181.523	0.9	0.5	17.559	19.224	1.7	9.1
175.442	176.341	0.9	0.5	16.627	18.274	1.6	9.4
171.419	172.185	0.8	0.4	16.131	17.603	1.5	9.1
168.155	168.875	0.7	0.4	16.027	17.405	1.4	8.2
166.312	166.850	0.5	0.3	16.187	17.394	1.2	7.2
164.903	165.403	0.4	0.3	16.240	17.495	1.2	7.4
164.367	164.609	0.2	0.1	16.256	17.490	1.2	7.3
164.312	164.399	0.1	0.1	16.265	17.294	1.0	6.1
164.700	164.693	0.1	0.0	16.013	16.997	1.0	5.9
[illegible]	165.402	0.2	0.1	15.788	16.620	0.8	5.1
[illegible]	166.408	0.4	0.3	15.877	16.459	0.6	3.6
[illegible]	167.787	0.6	0.4	16.333	16.731	0.4	2.4
169.804	169.138	0.7	0.4	17.305	17.546	0.2	1.4
170.015	170.171	0.6	0.4	18.514	18.552	0.0	0.2
171.156	170.703	0.5	0.3	19.550	19.486	0.1	0.3
170.818	170.700	0.1	0.1	20.207	20.017	0.2	[illegible]
170.088	170.511	0.4	0.2	20.723	20.607	0.1	0.6
169.187	170.273	1.1	0.6	21.382	21.462	0.1	0.4
167.863	169.605	1.8	1.1	21.617	22.219	0.6	2.7
166.048	168.537	2.5	1.5	21.763	22.825	1.1	4.8
163.405	166.266	2.9	1.7	22.034	23.223	1.2	5.3
159.442	162.557	3.1	1.9	21.872	23.222	1.4	6.0
154.270	157.516	3.2	2.1	21.704	23.133	1.4	6.4
148.228	151.215	3.0	2.0	21.045	22.180	1.1	5.3
141.833	144.509	2.7	1.9	20.002	21.195	1.2	5.8
135.694	138.003	2.3	1.7	19.470	20.492	1.0	5.1
130.019	132.032	2.0	1.5	19.179	20.165	1.0	5.0
124.920	126.620	1.7	1.4	18.906	19.854	0.9	4.5
120.397	121.872	1.5	1.2	18.934	19.635	0.7	3.6
116.484	117.789	1.3	1.1	18.957	19.554	0.6	3.1
113.182	114.339	1.2	1.0	19.023	19.571	0.5	2.8
110.421	111.508	1.1	1.0	19.148	19.649	0.5	2.6
108.228	109.223	1.0	0.9	19.260	19.727	0.5	2.4
106.539	107.406	0.9	0.9	19.394	19.837	0.4	2.3
105.385	106.271	0.9	0.8	19.509	19.939	0.4	2.2

EVENT NO. 28

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
159.139	160.206	1.1	0.7	18.279	18.389	0.1	0.6
121.326	121.582	0.3	0.2	18.424	18.783	0.4	1.[illegible]

139.829	141.773	1.9	1.4	20.799	20.856	0.1	0.3
103.168	102.318	0.8	0.8	20.847	21.568	0.7	3.5
113.949	115.353	0.6	0.5	18.194	19.137	0.9	5.1
131.094	130.322	0.8	0.6	12.895	13.819	0.9	6.9
132.602	132.408	0.7	0.6	14.097	14.055	0.0	0.3
137.998	137.598	0.4	0.3	15.813	16.045	0.2	1.5
130.973	130.915	0.1	0.0	19.510	19.511	0.0	0.0
120.687	123.030	2.3	1.9	22.160	22.969	0.8	3.6
115.084	116.030	0.9	0.8	20.339	20.879	0.5	2.6
110.601	109.712	0.9	0.8	15.937	17.228	1.3	7.8
118.545	118.093	0.5	0.4	13.165	13.881	0.7	5.3
161.900	160.729	1.2	0.7	18.904	19.871	1.0	5.0
176.186	175.953	0.2	0.1	20.292	20.402	0.1	0.5
126.154	124.778	1.4	1.1	9.132	10.325	1.2	12.3
99.382	98.067	1.3	1.3	24.134	23.883	0.3	1.0
143.131	140.796	2.3	1.6	17.697	18.977	1.4	7.5
168.059	165.809	2.3	1.3	21.658	23.510	1.9	8.2
124.786	122.645	2.1	1.7	20.826	21.632	0.8	3.8
140.372	139.058	1.3	0.9	15.527	15.967	0.4	2.8
138.166	136.947	1.2	0.9	11.569	11.610	0.0	0.4
113.501	111.931	1.6	1.4	16.201	16.630	0.4	2.6
161.643	163.024	1.4	0.9	22.357	22.374	0.0	0.1
140.668	137.931	2.7	2.0	20.145	21.753	1.6	7.7
175.314	173.955	1.4	0.8	21.006	21.857	0.9	4.0
126.540	125.146	1.4	1.1	13.229	13.826	0.6	4.3
99.980	99.846	0.1	0.1	16.450	16.699	0.2	1.5
127.743	128.443	0.7	0.5	15.482	16.298	0.8	5.1
148.469	145.640	2.8	1.9	20.097	22.479	1.9	8.7
112.490	112.317	0.2	0.2	18.788	19.169	0.4	2.0
155.402	160.445	5.0	3.2	110.709	108.654	2.1	1.9
61.524	63.191	1.7	2.7	11.039	9.928	1.2	11.1
85.565	86.066	0.5	0.6	2.508	2.103	0.4	17.5
156.534	163.391	6.8	4.3	33.590	30.621	3.0	9.2
57.999	57.999	0.0	0.0	0.000	0.000	0.0	0.0
77.400	74.615	2.8	3.7	14.699	15.244	0.5	3.6
93.734	90.944	2.8	3.0	14.834	16.015	1.2	7.7
105.539	107.821	1.7	1.6	15.123	15.567	0.4	2.9
113.443	112.719	0.7	0.6	17.738	17.480	0.3	1.5
100.865	102.403	1.5	1.4	17.842	18.404	0.6	3.1
110.747	110.245	0.5	0.4	17.157	[illegible]	1.0	5.9
116.694	117.176	0.5	0.4	18.067	18.979	0.9	4.9
107.157	108.271	1.1	1.0	22.143	22.557	0.4	2.0
92.862	92.494	0.4	0.4	20.863	21.651	0.8	3.7
84.123	83.100	1.0	1.2	17.747	18.446	0.7	3.9
81.811	80.047	1.8	1.2	17.568	17.982	0.4	2.3
83.366	81.891	1.5	1.8	17.923	18.141	0.2	1.2
85.906	84.169	1.7	2.0	17.671	17.883	0.2	1.2
88.457	87.297	1.2	1.3	17.725	17.947	0.2	1.2
91.557	90.577	1.0	1.1	17.979	18.076	0.1	0.8
[illegible]	[illegible]	1.2	1.3	18.751	18.370	0.4	2.1
[illegible]	101.175	1.4	1.4	20.753	[illegible]	0.5	2.2
103.909	102.315	1.6	1.5	22.841	[illegible]	0.6	2.5
103.538	105.098	1.4	1.4	24.527	24.416	0.1	0.5
102.572	102.253	0.3	0.3	24.943	25.659	0.7	2.8
102.225	101.123	0.9	0.9	24.322	25.834	1.5	6.0
93.032	94.770	1.7	1.8	22.721	25.040	2.3	9.7

[illegible]

5.80

5.81

232.016	232.047	0.0	0.0	15.828	15.659	0.2	1.1
224.805	224.655	0.1	0.1	16.577	16.249	0.3	2.0
221.303	220.860	0.4	0.2	17.385	16.818	0.6	3.3
220.177	219.657	0.5	0.2	17.877	17.359	0.5	2.9
220.241	220.085	0.2	0.1	18.198	18.053	0.1	0.8
219.998	220.712	0.7	0.3	18.249	18.715	0.5	2.5
217.980	219.569	1.6	0.7	18.091	19.091	1.0	5.4
213.618	215.451	1.8	0.9	18.319	19.370	1.1	5.6
208.294	209.604	1.6	0.8	18.596	19.479	0.9	4.6
198.859	200.268	1.4	0.7	18.185	18.949	0.8	4.1
190.800	191.998	1.2	0.6	17.285	18.107	0.8	4.6
183.648	184.462	0.8	0.4	16.120	16.669	0.5	3.3
177.645	178.108	0.5	0.3	15.172	15.461	0.3	1.9
172.757	172.982	0.2	0.1	14.652	14.754	0.1	0.6
168.852	168.858	0.0	0.0	14.467	14.436	0.0	0.2
165.791	165.677	0.1	0.1	14.441	14.379	0.1	0.4
163.414	163.222	0.2	0.1	14.461	14.436	0.0	0.2
161.677	161.425	0.2	0.1	14.491	14.549	0.1	0.5
160.590	160.255	0.3	0.2	14.552	14.786	0.2	1.6
159.864	159.529	0.2	0.1	14.657	15.034	0.4	2.5
159.640	159.459	0.2	0.1	14.768	15.296	0.5	3.5
159.720	159.624	0.1	0.1	14.840	15.523	0.7	4.5
159.961	160.027	0.1	0.0	14.526	15.554	1.0	6.8
160.459	160.599	0.1	0.1	14.576	15.559	1.0	6.5
161.122	161.171	0.0	0.0	14.962	15.577	0.6	4.0
161.846	161.792	0.1	0.0	15.651	15.748	0.1	0.6
162.496	162.340	0.2	0.1	16.445	16.220	0.2	1.4
162.967	162.849	0.2	0.1	17.469	17.069	0.4	2.3
163.220	163.087	0.2	0.1	18.592	18.109	0.5	2.6
163.098	162.754	0.3	0.2	19.499	18.884	0.6	3.2
162.445	162.057	0.4	0.2	19.921	19.374	0.5	2.8
161.491	161.121	0.4	0.2	20.180	19.915	0.2	1.2
160.179	159.977	0.2	0.1	20.523	20.505	0.0	0.1
158.326	158.731	0.4	0.3	20.841	21.524	0.7	3.2
155.750	156.913	1.2	0.7	21.191	22.521	1.3	6.1
152.525	154.245	1.7	1.1	21.918	23.277	1.4	6.0
148.443	150.645	2.2	1.5	22.267	23.806	1.5	6.7
143.723	146.273	2.5	1.8	22.441	24.009	1.6	6.9
138.623	141.441	2.8	2.0	22.652	24.398	1.7	7.4
133.256	136.024	2.8	2.1	22.148	23.617	1.5	6.4
127.941	130.578	2.6	2.0	21.597	22.581	1.0	4.5
122.924	125.412	2.5	2.0	20.692	21.585	0.9	4.2
118.181	120.503	2.3	1.9	19.998	20.719	0.8	3.7
114.305	116.409	2.1	1.8	19.417	20.093	0.7	3.4
110.967	112.905	1.9	1.7	19.129	19.622	0.5	2.6
108.142	109.895	1.7	1.5	19.014	19.374	0.4	1.9
105.839	107.346	1.5	1.4	19.015	19.260	0.2	1.3
103.967	105.377	1.4	1.4	19.095	19.239	0.1	0.7
[illegible]	103.742	1.3	1.3	19.215	19.290	0.1	0.4
[illegible]	[illegible]	1.3	1.2	19.340	19.340	0.0	0.0

EVENT NO. 29

5.82

[illegible]	[illegible]	DIFF	% DIFF	[illegible]	[illegible]	DIFF	% DIFF
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111.171	111.134	2.0	1.8	19.878	20.503	0.9	4.5
[illegible]	[illegible]	1.5	1.1	[illegible]	19.145	0.5	2.4
[illegible]	[illegible]	0.1	0.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	112.313	2.3	1.9	[illegible]	21.415	0.5	2.2
[illegible]	117.313	2.3	1.9	19.770	[illegible]	0.7	[illegible]
[illegible]	149.517	1.2	0.9	[illegible]	14.155	0.4	2.9
[illegible]	[illegible]	2.4	2.7	[illegible]	[illegible]	0.6	[illegible]
[illegible]	[illegible]	0.5	0.3	[illegible]	[illegible]	2.4	10.8
[illegible]	[illegible]	1.1	0.8	21.111	[illegible]	0.2	0.8
[illegible]	[illegible]	0.5	0.3	19.714	[illegible]	1.1	5.4
[illegible]	[illegible]	2.3	2.0	[illegible]	[illegible]	0.1	0.8
[illegible]	[illegible]	1.9	1.7	[illegible]	[illegible]	0.7	4.1
[illegible]	[illegible]	2.1	1.8	15.917	15.189	0.7	4.8
[illegible]	[illegible]	0.4	0.3	[illegible]	19.046	1.7	9.2
[illegible]	[illegible]	0.8	0.8	[illegible]	[illegible]	1.4	7.4
[illegible]	145.245	6.2	4.3	112.101	111.809	0.3	0.3
[illegible]	[illegible]	1.0	1.9	9.590	9.829	0.7	7.8
[illegible]	84.510	0.4	0.4	[illegible]	2.229	0.4	16.2
[illegible]	[illegible]	2.8	1.9	[illegible]	25.715	2.5	9.2
[illegible]	[illegible]	0.0	0.0	[illegible]	0.000	0.0	0.0
[illegible]	[illegible]	0.5	0.5	11.761	11.922	0.2	1.4
89.702	89.602	0.1	0.1	16.290	16.004	0.3	1.8
[illegible]	[illegible]	0.5	0.7	19.169	19.259	0.1	0.5
[illegible]	67.170	1.1	1.6	14.461	15.815	1.4	8.9
[illegible]	68.141	1.4	2.0	15.087	[illegible]	0.3	1.7
75.216	74.295	0.9	1.2	16.716	17.084	0.4	2.2
[illegible]	[illegible]	0.4	0.5	19.417	20.412	1.0	5.0
[illegible]	[illegible]	0.8	0.9	21.572	22.433	0.9	4.2
[illegible]	[illegible]	1.0	1.0	21.625	21.690	0.1	0.3
[illegible]	97.795	1.2	1.2	[illegible]	23.228	0.7	3.4
96.779	96.563	0.2	0.2	21.245	20.826	0.4	2.0
[illegible]	95.318	0.5	0.6	21.165	22.199	0.8	3.8
[illegible]	[illegible]	0.5	0.6	20.079	21.761	1.7	8.0
[illegible]	[illegible]	0.9	1.1	[illegible]	[illegible]	0.9	4.9
[illegible]	92.497	0.9	1.0	[illegible]	18.877	0.8	4.4
[illegible]	[illegible]	0.4	0.4	19.559	[illegible]	0.8	4.1

5.83

111.135	111.861	0.7	0.7	21.092	22.074	1.0	4.5
116.917	117.389	0.5	0.4	21.290	22.595	1.3	5.9
120.328	121.691	1.4	1.1	22.037	23.771	1.7	7.6
112.251	115.234	3.0	2.6	23.886	25.277	1.4	5.7
105.936	108.937	3.0	2.8	23.753	24.735	1.0	4.0
96.029	98.044	2.0	2.1	21.991	22.035	0.0	0.2
90.007	91.864	1.1	1.2	20.884	19.916	1.0	4.7
78.425	79.047	0.6	0.8	21.147	19.624	1.5	7.5
74.057	74.632	0.6	0.8	20.410	20.822	0.4	2.0
69.258	70.368	1.1	1.6	20.580	21.627	1.0	5.0
66.315	67.980	1.7	2.5	20.796	22.209	1.4	6.5
56.480	58.608	2.2	3.8	21.683	22.032	0.3	1.6
96.057	96.776	0.7	0.7	17.528	18.479	1.0	5.3
121.129	122.665	1.5	1.3	18.799	20.221	1.4	7.3
96.872	98.826	2.0	2.2	20.869	20.380	0.4	1.8
99.778	99.479	0.3	0.3	13.981	14.185	0.2	1.4
107.776	109.614	1.8	1.7	16.128	16.838	0.7	4.1
94.981	94.426	0.6	0.6	11.383	11.544	0.2	1.4
108.903	110.621	1.7	1.6	15.770	16.710	0.9	5.7
114.078	115.667	1.6	1.4	17.200	18.178	1.0	5.5
94.997	97.720	2.7	2.8	21.754	22.043	0.3	1.3
78.788	78.224	0.6	0.7	11.332	11.486	0.2	1.3
113.908	115.864	1.9	1.6	18.082	18.730	0.6	3.5
116.567	118.375	1.8	1.5	16.517	17.263	0.7	4.4
101.833	104.858	3.0	2.9	21.441	21.981	0.5	2.5
107.118	106.704	0.4	0.4	10.693	10.722	0.0	0.3
131.964	133.317	1.4	1.1	19.792	21.275	1.5	7.2
69.961	71.178	1.2	1.7	19.876	20.743	0.9	4.3
98.572	101.510	2.9	2.9	21.930	22.662	0.7	3.3
117.185	118.651	1.5	1.2	18.429	19.629	1.2	6.5
115.520	117.394	1.9	1.6	17.009	17.608	0.6	3.5
115.678	117.530	1.9	1.6	17.045	17.673	0.6	3.6
117.659	119.500	1.9	1.6	20.219	21.324	1.1	5.3
73.704	74.819	1.1	1.5	19.877	19.182	0.7	3.6
91.205	90.641	0.5	0.5	11.499	11.591	0.1	0.8
112.035	113.782	1.7	1.5	15.900	16.625	0.7	4.5
111.521	112.580	1.0	0.9	17.520	18.271	0.8	4.2
105.369	108.290	2.9	2.7	21.862	22.531	0.7	3.0
68.017	69.413	1.4	2.0	20.116	20.985	0.9	4.2
119.168	120.965	1.8	1.5	17.197	18.126	0.9	5.3
81.471	82.834	1.4	1.7	19.553	18.920	0.6	3.3
91.180	93.314	2.1	2.3	38.754	38.651	0.1	0.3
86.155	79.532	6.6	7.9	48.416	44.043	4.4	9.5
94.208	93.399	0.8	0.9	46.821	47.557	0.7	1.5
36.247	34.215	2.0	5.8	16.555	13.129	3.4	23.1
143.071	143.669	0.6	0.4	13.146	16.172	3.0	20.6
175.042	175.312	0.3	0.2	23.653	24.725	1.1	4.4
[illegible]	128.177	0.8	0.7	11.413	10.772	0.6	5.8
[illegible]	[illegible]	0.0	0.0	[illegible]	[illegible]	0.0	0.0
[illegible]	[illegible]	1.8	1.0	11.701	11.902	0.2	[illegible]
[illegible]	192.546	1.8	1.0	11.721	11.835	0.1	1.4
185.529	184.542	1.9	1.0	11.709	11.934	0.2	1.5
[illegible]	188.234	2.0	1.0	11.652	11.939	0.3	2.4
193.577	191.083	2.1	1.1	11.702	12.160	0.5	3.8
204.401	202.170	2.3	1.1	12.151	12.737	0.6	5.1
212.047	214.410	2.6	1.2	13.649	14.534	0.9	6.4

EVENT NO. 30

75-SPKR AVGS	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
81.564	79.514	2.0	2.5	12.854	12.542	0.3	2.5
139.925	139.214	1.4	1.0	14.437	15.109	0.7	4.5
139.112	137.732	1.4	1.0	20.799	20.831	0.1	0.4
130.875	128.022	2.2	1.7	27.243	26.842	0.4	1.5
[illegible]	128.928	0.2	0.2	25.333	26.192	0.9	3.3
124.575	125.758	1.2	0.9	18.384	19.083	0.7	3.7
173.080	173.279	0.2	0.1	14.340	15.274	0.9	6.3
146.792	147.172	0.4	0.3	17.917	18.517	0.7	3.9
142.979	141.204	1.8	1.2	23.778	25.709	1.9	7.8
112.606	111.458	0.8	0.7	22.136	24.653	2.5	10.8
113.797	112.420	1.4	1.3	17.595	18.278	0.7	3.8
112.818	111.220	1.6	1.4	15.315	16.599	1.3	8.1
121.198	120.375	0.8	0.7	14.341	15.246	0.9	6.1
160.453	160.492	0.0	0.0	19.629	19.398	0.8	4.0
172.472	181.425	2.0	1.1	20.010	20.987	1.0	4.8
128.019	127.229	0.8	0.6	7.778	9.172	1.6	18.7
118.429	116.978	1.5	1.3	27.592	27.328	0.3	1.0
147.950	147.843	0.1	0.1	17.703	20.631	2.9	15.3
174.789	175.296	0.5	0.3	20.823	21.968	1.1	5.3
113.261	112.822	0.6	0.5	21.693	23.558	2.5	11.4
121.171	119.059	2.1	1.7	24.813	24.897	0.1	0.3
117.419	118.552	1.1	0.8	12.212	14.235	2.0	15.3
33.975	31.726	2.2	2.4	26.273	26.354	0.1	0.3
161.783	162.644	1.3	0.8	21.965	23.144	1.2	5.1
142.220	142.219	0.0	0.0	19.795	22.707	3.0	14.2
176.536	177.992	1.4	0.8	21.495	23.028	1.5	6.9
117.515	115.040	2.4	2.1	24.153	24.163	0.0	0.0
88.037	89.655	1.6	1.8	25.723	26.195	0.5	1.8
111.722	109.765	1.9	1.7	18.823	17.832	1.0	5.6
157.365	156.995	0.8	0.5	17.115	19.958	2.6	13.8
96.503	96.072	0.4	0.4	15.827	17.599	1.8	10.5
147.819	[illegible]	3.4	2.3	111.329	111.229	0.6	0.5
59.849	61.199	1.4	2.3	11.574	11.041	0.5	4.7
[illegible]	[illegible]	0.4	0.5	2.979	2.559	0.4	14.9
[illegible]	[illegible]	4.9	3.1	34.360	32.024	2.3	6.9
[illegible]	57.000	0.0	0.0	0.000	0.000	0.0	0.0
[illegible]	88.[illegible]	0.7	0.8	16.192	16.481	0.3	1.8
[illegible]	[illegible]	0.7	1.2	20.626	21.087	0.5	2.2
[illegible]	[illegible]	0.7	1.5	17.912	17.813	0.1	0.7
[illegible]	[illegible]	2.3	4.3	[illegible]	19.147	0.0	0.2
57.498	[illegible]	1.4	2.6	[illegible]	21.315	0.5	2.3
[illegible]	[illegible]	2.3	4.0	24.413	24.045	0.4	1.5
[illegible]	[illegible]	2.7	4.3	26.045	25.372	0.7	2.6
[illegible]	64.215	1.5	2.4	24.775	23.947	0.7	2.9
[illegible]	64.039	0.6	0.9	[illegible]	25.423	0.5	2.0
[illegible]	65.471	0.4	0.5	25.889	25.365	0.5	2.0

[illegible]	[illegible]	1.6	1.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.0	1.2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.7	1.8	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.6	0.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	84.442	0.8	0.9	15.514	15.812	[illegible]	[illegible]
181.604	104.0[illegible]	0.4	0.4	28.385	[illegible]	1.4	4.9
[illegible]	56.729	0.1	0.2	26.518	[illegible]	1.4	4.9
[illegible]	[illegible]	0.5	0.7	28.170	[illegible]	1.4	4.5
[illegible]	[illegible]	0.8	0.8	27.006	[illegible]	0.7	2.6
[illegible]	90.003	1.6	1.6	26.160	26.763	0.6	2.3
[illegible]	93.157	1.6	1.6	26.270	26.825	0.6	2.1
103.409	101.220	0.7	0.7	28.109	29.402	1.4	4.8
59.079	98.722	0.7	1.2	28.673	27.382	0.7	2.6
[illegible]	74.214	0.0	1.0	16.119	16.188	0.2	1.5
[illegible]	91.615	1.6	1.7	28.915	26.043	0.5	2.0
[illegible]	91.479	1.0	1.1	27.112	27.589	0.4	1.4
81.426	83.909	0.6	0.5	29.665	30.476	1.4	4.7
54.152	92.948	0.2	0.4	26.878	28.389	1.5	5.6
93.756	101.152	1.4	1.4	26.652	27.274	0.6	2.3
85.540	67.070	1.4	2.1	26.580	27.629	1.0	2.9
75.705	79.009	2.3	3.0	42.211	43.184	1.0	2.3
[illegible]	74.850	9.2	11.6	50.752	44.203	6.0	12.8
101.174	[illegible]	1.9	1.8	51.500	52.272	0.8	1.5
[illegible]	[illegible]	1.4	4.8	12.618	12.566	0.1	0.6
149.829	[illegible]	0.2	0.2	15.014	15.267	0.2	1.5
187.219	[illegible]	2.8	2.2	15.421	34.838	0.8	2.2
53.049	[illegible]	0.3	0.1	7.587	8.121	0.8	10.0
65.033	65.000	0.0	0.0	0.000	0.000	0.0	0.0
187.472	186.001	1.4	0.8	11.892	11.817	0.0	0.1

188.420	186.954	1.5	0.8	11.822	11.833	0.0	0.1
191.319	189.942	1.5	0.8	11.819	11.896	0.0	0.1
195.557	195.015	1.5	0.8	11.806	11.810	0.0	0.0
204.951	201.193	1.6	0.8	12.021	12.026	0.0	0.0
218.482	216.709	1.7	0.8	12.553	12.937	0.0	0.3
243.026	238.619	1.4	0.6	14.173	14.689	0.5	3.6
243.154	243.496	0.1	0.1	11.173	11.036	0.1	1.2
229.273	229.304	0.0	0.0	15.245	15.951	0.7	4.5
212.324	211.608	0.6	0.3	14.165	14.510	0.3	2.4
201.416	200.452	1.0	0.5	12.926	13.212	0.3	2.2
194.042	193.321	1.1	0.6	12.464	12.726	0.3	2.1
190.053	189.811	1.2	0.7	12.457	12.731	0.3	2.6
187.503	186.235	1.3	0.7	12.859	13.267	0.4	3.1
186.295	185.061	1.2	0.7	13.576	14.220	0.7	5.3
185.908	184.844	1.1	0.6	14.344	15.739	1.4	9.3
[illegible]	184.953	1.1	0.6	15.644	16.858	1.2	7.5
[illegible]	184.855	1.6	0.8	17.021	17.438	0.4	2.4
[illegible]	184.292	2.1	1.1	18.319	17.748	0.6	3.3
[illegible]	182.598	2.2	1.2	19.594	18.292	1.3	6.9
[illegible]	182.418	1.6	0.9	19.748	19.159	0.6	3.1
181.409	181.542	0.9	0.5	19.352	19.149	0.2	1.1
178.911	178.595	0.4	0.2	19.173	19.244	0.1	0.4
175.504	175.751	0.1	0.0	19.442	19.727	0.3	1.5
174.054	175.003	0.2	0.1	20.225	20.207	0.1	0.3
173.197	173.524	0.1	0.1	21.524	21.159	0.4	1.7
172.072	172.170	0.1	0.1	22.024	22.455	0.4	1.8
170.655	170.742	0.1	0.1	24.350	23.746	0.6	2.5
165.831	168.119	0.3	0.2	25.805	25.151	0.5	1.9
155.180	157.835	1.0	0.6	26.017	26.117	0.3	1.1
162.785	164.445	1.7	1.0	25.417	26.784	1.4	5.2
159.465	161.423	2.0	1.2	24.605	26.504	1.9	7.4
157.594	159.297	1.7	1.1	23.921	25.495	1.6	6.3
154.218	155.646	1.4	0.9	22.215	24.305	1.1	4.5
152.512	152.072	1.4	0.9	22.647	23.183	0.7	2.1
151.723	[illegible]	1.4	0.9	22.327	22.778	0.6	2.5
151.874	150.128	1.5	1.0	22.122	22.557	0.4	2.0
152.105	154.847	1.7	1.1	22.528	22.838	0.4	1.6
155.782	157.672	1.9	1.2	21.524	23.971	0.4	1.6
158.769	161.718	1.9	1.2	25.264	25.546	0.3	1.1
164.841	165.515	2.1	1.3	27.283	27.935	0.7	2.6
[illegible]	171.976	1.9	1.1	28.849	28.632	0.8	2.8
174.147	175.415	1.1	0.5	[illegible]	30.216	0.2	0.7
[illegible]	176.469	0.0	0.0	30.715	30.743	0.4	1.3
[illegible]	[illegible]	0.4	0.2	30.221	30.372	0.1	0.3
171.717	171.256	0.5	0.2	29.715	29.756	0.0	0.1
168.485	166.823	0.7	0.2	28.675	29.455	0.8	2.7
162.682	161.851	1.1	0.7	28.049	28.954	0.9	3.2
[illegible]	[illegible]	1.8	1.2	[illegible]	28.457	1.1	3.9
[illegible]	[illegible]	2.4	1.5	[illegible]	[illegible]	1.1	3.9
[illegible]	[illegible]	2.7	1.6	[illegible]	[illegible]	0.3	1.1
[illegible]	[illegible]	2.1	1.3	27.143	[illegible]	0.4	1.4
[illegible]	[illegible]	1.8	1.1	27.417	[illegible]	0.9	3.2
[illegible]	[illegible]	1.6	1.2	27.124	[illegible]	0.8	3.0
[illegible]	[illegible]	1.6	1.2	[illegible]	[illegible]	0.4	1.3
[illegible]	[illegible]	1.4	1.1	[illegible]	[illegible]	0.0	0.0
[illegible]	151.991	1.2	[illegible]	[illegible]	25.577	0.1	0.6

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EVENT NO 21

[illegible] FREQ	[illegible] FREQ	DIFF	% DIFF	[illegible] STD DEV	[illegible] STD DEV	DIFF	% DIFF
142.421	142.691	[illegible]	[illegible]	22.827	21.117	[illegible]	[illegible]
131.427	185.[illegible]	[illegible]	[illegible]	22.000	22.824	0.9	4.0
12[illegible]	[illegible]	1.2	[illegible]	18.148	17.957	0.2	1.1
111.969	[illegible]	2.5	[illegible]	10.859	11.011	0.2	1.4
97.167	90.5[illegible]	[illegible]	2.5	19.[illegible]07	19.107	0.1	0.5
171.5[illegible]	175.125	0.6	0.4	21.874	21.931	0.1	0.4
11[illegible]	11[illegible]72	2.0	0.8	22.851	23.422	0.6	2.5
-177.243	173.957	1.6	2.1	19.1[illegible]	20.268	1.0	5.2
11[illegible]	115.[illegible]	1.3	1.5	15.49[illegible]	15.992	0.5	[illegible]
111.174	113.467	2.3	0.9	15.795	14.498	0.9	[illegible]
[illegible]	[illegible]	1.5	2.0	14.553	13.866	0.7	4.8
140.8[illegible]	[illegible]	1.4	2.0	21.878	23.214	1.3	5.9
101.197	[illegible]	0.9	1.2	17.771	18.816	1.0	5.7
161.1[illegible]	155.1[illegible]	5.4	0.9	108.841	109.558	0.8	0.7
[illegible]	91.4[illegible]	1.7	3.4	[illegible]	[illegible]	0.4	3.6
[illegible]	85.7[illegible]	1.5	2.5	2.1[illegible]	2.169	0.3	12.9
15[illegible]	10[illegible]	4.6	2.9	2[illegible]	28.877	0.5	1.6
[illegible]	57.0[illegible]	0.0	0.0	0.000	0.000	0.0	0.0
[illegible]	91.0[illegible]	3.1	[illegible]	13.850	15.405	1.6	10.6
104.1[illegible]	102.0[illegible]	2.3	2.2	11.074	12.268	1.2	10.2
[illegible]	107.5[illegible]	0.0	0.8	15.9[illegible]	15.715	0.7	4.6
[illegible]	[illegible]	0.5	0.9	19.101	20.960	1.9	[illegible]

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77.952	77.529	0.4	0.5	16.813	17.888	1.1	6.2
78.840	78.612	0.2	0.3	15.968	17.891	1.9	11.4
88.215	88.650	0.7	0.7	17.889	20.498	2.6	13.6
98.603	97.192	1.5	1.5	21.101	22.570	1.5	6.7
107.216	106.129	1.1	1.0	19.439	20.969	1.5	7.6
109.721	110.688	1.0	0.9	17.515	18.213	0.7	3.9
104.737	107.268	2.5	2.4	21.073	20.243	0.8	3.8
98.792	99.955	1.2	1.2	20.952	21.425	0.5	2.2
94.318	93.871	0.5	0.6	18.627	19.143	0.5	2.7
92.365	92.149	0.2	0.2	16.971	17.824	0.9	4.9
93.634	94.498	0.9	0.9	16.457	15.931	0.5	2.8
98.190	100.179	2.0	2.0	17.427	17.525	0.1	0.6
107.175	108.700	1.4	1.3	19.060	19.131	0.7	3.8
111.607	114.698	1.1	0.9	21.014	20.129	0.8	4.1
121.813	120.806	1.0	0.8	20.668	21.058	0.4	1.9
121.162	123.192	2.0	1.7	21.270	21.724	0.5	2.1
119.510	122.939	3.4	2.8	22.677	22.245	0.4	1.9
109.091	112.121	3.0	3.0	22.577	22.932	0.6	2.8
100.752	104.155	3.4	3.3	22.880	21.403	1.5	6.6
86.738	89.119	2.4	2.7	20.918	19.650	1.3	6.2
80.181	81.082	0.9	1.1	19.886	18.527	1.4	7.1
74.334	74.507	0.2	0.3	19.598	18.814	0.8	4.1
71.130	71.276	0.1	0.2	19.446	19.592	0.1	0.7
62.036	62.965	0.1	0.2	20.042	20.192	0.1	0.7
56.952	57.805	0.9	0.9	15.519	16.034	0.5	3.4
122.799	124.476	1.7	1.4	18.352	18.201	0.2	0.8
100.872	104.050	3.2	3.1	21.944	21.064	0.9	4.1
102.047	103.811	0.8	0.7	12.397	13.092	0.7	5.4
111.174	113.457	2.3	2.0	15.195	14.402	0.9	6.0
108.802	107.685	1.5	1.4	10.249	11.245	1.0	9.3
112.952	114.738	1.8	1.6	14.291	13.797	0.5	3.5
113.319	114.822	1.5	1.3	16.688	16.983	0.1	0.5
107.659	111.159	3.5	3.2	21.137	20.198	0.9	4.4
88.715	87.408	1.3	1.5	10.265	11.226	1.0	8.9
119.549	120.819	2.3	1.9	17.009	15.259	0.8	4.9
119.454	121.854	2.4	2.0	16.307	15.234	1.0	6.2
112.515	115.414	2.9	2.6	19.513	18.945	0.5	3.1
112.573	113.585	0.9	0.8	9.710	10.432	0.8	7.7
121.153	122.352	1.2	1.0	19.494	19.414	0.1	0.4
75.414	75.815	0.4	0.5	19.185	18.325	0.9	4.6
109.848	112.856	3.0	2.7	19.912	19.459	0.5	2.7
115.475	117.045	1.6	1.4	18.553	18.220	0.3	1.8
118.878	121.380	2.5	2.0	16.529	15.467	1.1	6.7
118.940	121.319	2.4	2.0	16.592	15.530	1.1	6.7
124.524	126.903	2.4	1.9	18.420	17.905	0.5	2.9
80.137	82.010	1.8	2.2	19.514	18.415	1.1	5.9
[illegible]	[illegible]	2.3	2.4	[illegible]	11.855	1.3	11.3
[illegible]	[illegible]	1.1	1.0	14.829	14.072	0.8	5.2
[illegible]	[illegible]	1.1	1.0	16.112	[illegible]	0.3	1.8
[illegible]	[illegible]	1.0	[illegible]	18.817	[illegible]	0.5	2.7
71.[illegible]	71.472	0.2	0.2	19.161	19.508	0.6	3.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7	4.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	7.1
[illegible]	[illegible]	[illegible]	4.[illegible]	[illegible]	[illegible]	1.0	3.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53.4[illegible]	1.4	2.7
91.[illegible]	[illegible]	[illegible]	9.9	[illegible]	43.125	5.5	10.8

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

147.243	151.707	4.5	3.0	25.456	24.361	1.1	4.4
140.253	144.224	4.0	2.8	24.157	22.984	1.2	5.0
[illegible]	136.979	3.4	2.5	22.896	21.341	1.6	7.2
127.556	130.471	2.9	2.3	21.820	20.141	1.7	8.0
122.209	124.771	2.6	2.1	21.078	19.510	1.6	7.7
117.549	119.811	2.3	1.9	20.543	19.157	1.4	7.0
113.505	115.513	2.0	1.8	20.153	18.910	1.2	6.4
110.083	111.911	1.8	1.7	19.907	18.779	1.1	5.8
107.249	108.918	1.7	1.5	19.705	18.702	1.0	5.2
104.849	106.506	1.6	1.5	19.597	18.684	0.9	4.8
102.892	104.605	1.4	1.4	19.542	18.639	0.9	4.5
102.006	103.408	1.4	1.4	19.517	18.726	0.8	4.1

EVENT NO. 32

75-SPKR AVGE	118/SPKR AVGS	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
95.881	96.355	0.5	0.5	15.845	16.820	1.0	6.0
123.866	124.133	0.3	0.2	17.645	17.705	0.1	0.3
[illegible]	[illegible]	1.1	0.8	15.682	16.507	0.8	5.1
[illegible]	[illegible]	[illegible]	0.6	[illegible]	[illegible]	1.1	5.9
[illegible]	[illegible]	0.9	0.7	[illegible]	[illegible]	1.7	7.3
[illegible]	[illegible]	0.0	0.0	[illegible]	[illegible]	0.9	5.5
[illegible]	[illegible]	0.2	0.2	21.132	[illegible]	0.5	2.4
[illegible]	[illegible]	2.1	1.8	15.821	[illegible]	0.0	0.1
121.157	[illegible]	0.2	0.2	[illegible]	14.449	0.2	1.5
[illegible]	[illegible]	0.3	0.2	14.187	[illegible]	1.3	5.6
[illegible]	[illegible]	0.4	0.4	11.673	[illegible]	0.1	0.5
[illegible]	[illegible]	[illegible]	0.2	14.176	[illegible]	0.3	1.8
[illegible]	[illegible]	0.9	0.7	14.460	[illegible]	1.0	7.0
[illegible]	[illegible]	1.2	0.8	[illegible]	15.278	0.8	5.0
[illegible]	[illegible]	1.0	1.1	[illegible]	19.176	0.1	0.5
[illegible]	[illegible]	0.0	0.0	[illegible]	5.514	0.2	2.9
[illegible]	[illegible]	0.1	0.1	18.144	18.240	0.2	1.1
[illegible]	[illegible]	0.3	0.2	[illegible]	11.442	0.9	7.5
[illegible]	[illegible]	1.0	0.6	[illegible]	[illegible]	1.2	6.1
[illegible]	[illegible]	1.9	1.2	[illegible]	[illegible]	0.8	4.3
[illegible]	[illegible]	1.4	0.9	15.624	[illegible]	0.6	4.0
[illegible]	[illegible]	0.1	0.1	[illegible]	[illegible]	0.1	0.7
[illegible]	[illegible]	[illegible]	0.5	[illegible]	[illegible]	[illegible]	2.0
[illegible]	[illegible]	1.4	1.0	[illegible]	[illegible]	[illegible]	1.8
[illegible]	[illegible]	1.0	[illegible]	[illegible]	16.145	0.1	0.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	2.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1	7.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.714	[illegible]	1.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	111.171	1.4	1.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	16.2

5.92

158.985	163.785	4.8	3.0	35.028	33.442	2.6	7.5
57.030	57.028	0.0	0.0	0.022	0.020	0.0	0.0
54.417	51.820	0.6	0.5	14.924	15.235	0.3	2.0
61.202	61.229	0.0	0.1	18.035	17.455	0.5	3.0
61.229	61.175	0.1	0.2	19.478	19.019	0.5	2.4
61.769	61.109	0.3	0.5	17.755	17.774	0.0	0.1
60.155	60.287	0.2	0.3	18.097	18.375	0.4	2.0
64.513	64.990	0.5	0.7	18.122	18.525	0.4	2.2
71.228	72.434	1.2	1.7	19.691	20.613	0.9	4.5
85.134	85.967	0.8	1.0	24.408	24.554	0.1	0.5
103.844	104.123	0.3	0.3	24.569	23.910	0.7	2.7
114.983	115.742	0.9	0.7	21.999	20.287	0.8	3.8
115.008	116.220	1.2	1.0	20.168	19.947	0.2	1.1
110.915	111.205	1.4	1.2	20.658	22.740	0.1	0.4
105.001	105.209	1.2	1.1	21.093	21.943	0.1	0.2
99.070	100.391	1.3	1.3	23.539	23.526	0.1	0.5
90.822	92.098	1.4	1.6	24.212	24.406	0.3	1.1
84.511	84.525	0.1	0.1	22.699	23.477	0.8	3.4
82.851	82.142	0.7	0.9	22.462	22.230	0.2	1.0
78.428	77.243	1.2	1.5	23.820	22.305	1.5	6.6
77.000	76.103	0.9	1.2	24.603	22.817	1.8	7.5
71.802	71.210	0.6	0.8	23.988	22.705	1.3	5.5
72.254	71.629	0.6	0.9	23.441	22.694	0.7	3.2
69.449	68.690	0.8	1.2	23.158	23.216	0.1	0.2
68.399	68.223	0.2	0.3	23.439	23.578	0.1	0.6
61.000	61.134	0.1	0.2	22.701	23.316	0.4	1.6
58.979	58.521	0.5	0.8	23.403	22.968	0.4	1.9
54.653	54.776	0.1	0.2	23.169	22.921	0.2	1.1
52.463	52.879	0.4	0.8	23.008	22.631	0.4	1.7
44.279	45.252	1.0	2.2	22.898	22.725	0.2	0.8
97.507	98.806	1.3	1.3	21.730	21.631	0.1	0.5
79.010	78.075	0.9	1.2	23.069	21.633	1.4	6.2
65.058	65.576	0.5	0.7	22.100	21.910	0.2	0.9
107.639	109.042	1.4	1.3	17.782	16.722	1.1	6.1
82.909	83.370	0.4	0.5	21.426	21.292	0.1	0.6
85.972	85.585	0.4	0.5	14.585	14.459	0.1	0.9
99.294	100.360	1.1	1.1	19.418	19.104	0.3	1.6
90.804	91.366	0.6	0.6	22.458	22.217	0.3	1.1
66.554	66.032	0.5	0.7	22.097	21.592	0.5	2.3
69.707	69.415	0.3	0.4	14.370	14.313	0.1	0.4
75.477	75.537	0.9	1.2	21.409	20.735	0.8	3.6
83.782	83.299	0.5	0.6	21.502	21.479	0.0	0.1
68.227	68.653	0.6	0.8	21.749	21.161	0.6	2.7
102.338	102.848	0.5	0.5	14.102	13.185	0.9	6.7
83.594	79.662	0.9	1.2	23.536	22.053	1.5	6.5
55.985	56.022	0.0	0.1	22.497	22.196	0.3	1.3
63.857	63.214	0.7	1.0	22.345	21.675	0.7	3.0
79.992	79.165	0.7	0.9	22.345	21.697	0.7	3.4
79.974	79.227	0.7	0.9	21.047	20.618	0.4	2.1
79.642	78.839	0.8	1.0	21.208	20.795	0.4	2.0
77.457	76.399	1.1	1.4	22.729	21.827	0.9	4.0
58.165	58.279	0.2	0.3	22.350	21.927	0.4	1.9
82.094	81.612	0.5	0.6	14.577	14.560	0.0	0.0
95.367	96.251	0.9	0.9	20.625	20.252	0.4	1.8
101.208	102.217	1.0	1.0	21.279	21.060	0.3	1.5
71.001	70.362	0.7	1.0	22.201	21.097	0.6	2.7

5.93

54.162	54.541	0.4	0.7	22.500	22.297	0.2	0.9
80.924	80.111	0.8	1.0	21.916	21.250	0.7	3.1
62.921	62.790	0.1	0.2	22.012	21.913	0.1	0.5
71.388	69.334	2.1	2.9	30.393	28.171	2.2	7.6
140.717	136.929	3.8	2.7	69.828	65.665	3.4	5.0
98.112	95.702	2.4	2.5	50.965	46.257	4.7	9.7
33.228	34.694	0.5	1.5	13.023	13.211	0.2	1.4
123.508	121.746	1.8	1.4	41.715	38.820	2.9	7.2
135.959	137.282	1.3	1.0	20.575	17.499	3.1	16.2
108.511	110.045	1.5	1.4	14.594	11.103	3.5	27.2
65.000	65.000	0.0	0.0	0.000	0.000	0.0	0.0
184.381	182.715	1.7	0.9	11.827	11.568	0.3	2.2
185.017	183.323	1.7	0.9	11.848	11.558	0.3	2.5
185.967	185.256	1.7	0.9	11.809	11.528	0.3	2.4
190.419	188.643	1.8	0.9	11.849	11.528	0.3	2.7
195.606	193.816	1.8	0.9	12.009	11.649	0.4	3.0
203.355	201.353	2.0	1.0	12.555	12.106	0.4	3.6
214.732	212.567	2.2	1.0	14.018	13.372	0.6	4.7
231.617	229.423	2.2	1.0	16.126	15.869	0.3	1.6
246.552	245.907	0.6	0.3	11.965	12.279	0.3	2.6
241.134	241.522	0.4	0.2	13.075	13.612	0.5	4.0
223.974	223.870	0.1	0.0	14.053	14.591	0.5	3.8
210.373	210.159	0.2	0.1	12.008	12.853	0.8	6.8
201.471	201.145	0.3	0.2	11.279	12.144	0.9	7.4
195.482	195.119	0.4	0.2	11.129	11.963	0.8	7.2
191.452	191.020	0.4	0.2	11.311	11.989	0.7	5.8
188.877	188.436	0.4	0.2	11.509	12.106	0.5	4.4
197.405	197.014	0.4	0.2	11.850	12.282	0.4	3.6
186.898	186.629	0.3	0.1	12.028	12.569	0.5	4.4
187.225	187.198	0.0	0.0	12.252	13.100	0.8	6.7
188.918	188.737	0.2	0.1	12.772	13.900	1.2	9.0
190.822	191.346	0.5	0.3	13.792	15.282	1.5	10.2
194.327	195.010	0.7	0.4	15.265	16.678	1.4	8.6
199.095	199.715	0.7	0.4	17.004	18.002	1.0	5.7
204.641	205.431	0.8	0.4	18.620	19.584	1.0	5.0
210.272	211.043	0.8	0.4	19.312	20.288	1.0	4.9
214.641	213.192	0.6	0.3	19.103	20.158	1.1	5.4
216.692	216.913	0.2	0.1	18.618	19.827	1.2	6.3
213.905	216.243	0.3	0.2	18.614	20.174	1.6	8.0
212.557	213.554	1.0	0.5	19.220	21.281	2.1	10.2
207.624	209.113	1.5	0.7	19.658	21.939	2.3	11.0
202.318	203.820	1.5	0.7	19.921	22.026	2.1	10.0
197.175	198.554	1.4	0.7	20.000	21.788	1.8	8.6
192.178	193.534	1.3	0.7	20.024	21.519	1.5	7.2
187.200	188.603	1.3	0.7	19.761	21.164	1.4	7.0
182.628	183.836	1.2	0.7	19.769	20.949	1.2	5.8
178.160	179.129	1.0	0.5	19.762	20.762	1.0	4.9
173.765	174.414	0.6	0.4	19.762	20.589	0.8	4.1
169.380	169.741	0.4	0.2	19.615	20.451	0.8	4.1
165.004	165.023	0.1	0.0	19.309	20.141	0.8	4.2
160.822	160.517	0.3	0.2	19.070	19.652	0.6	3.0
155.952	155.245	0.7	0.5	19.159	19.149	0.0	0.1
151.454	152.349	1.1	0.7	19.212	18.695	0.5	2.8
150.722	148.950	1.4	0.9	19.193	18.237	0.9	4.8
147.544	145.183	1.4	1.0	18.941	17.941	1.0	5.4
145.200	142.735	1.4	1.0	18.593	17.721	0.9	4.8

142.295	141.993	1.3	0.9	18.437	17.662	0.8	4.3
141.791	140.595	1.2	0.9	18.538	17.775	0.8	4.2
140.548	139.474	1.1	0.8	18.709	18.086	0.7	3.9
139.[illegible]	138.449	0.9	0.6	19.094	18.582	0.5	2.7
137.918	137.[illegible]	0.6	0.5	19.522	19.181	0.3	1.8
135.[illegible]	135.[illegible]	0.4	0.3	20.145	19.916	0.2	1.1
134.[illegible]	133.845	0.4	0.3	21.021	20.622	0.4	1.9
131.[illegible]	131.293	0.4	0.3	21.952	21.485	0.4	2.1
[illegible].405	128.114	0.4	0.2	22.285	21.774	0.5	2.3
124.918	124.483	0.4	0.3	22.389	21.697	0.7	3.1
121.178	120.783	0.4	0.3	22.341	21.522	0.8	3.7
117.573	117.230	0.3	0.3	22.137	21.400	0.7	3.4
114.256	113.957	0.3	0.3	21.879	21.255	0.6	2.7
111.369	111.194	0.3	0.2	21.696	21.227	0.5	2.2
108.941	108.694	0.3	0.2	21.568	21.217	0.4	1.5
106.959	106.727	0.2	0.2	21.542	21.254	0.3	1.3
105.483	105.210	0.3	0.3	21.542	21.322	0.2	1.0
104.417	104.148	0.3	0.3	21.581	21.367	0.2	1.0

EVENT NO. 33

[illegible]	118/5PKR	DIFF	% DIFF	75-SPKR STD DEV	118-SPKR STD DEV	DIFF	% DIFF
			[illegible]4	16.024	13.579	2.5	16.6
			[illegible]1	16.586	15.635	1.0	5.9
			[illegible]8	13.761	13.193	0.6	4.2
			[illegible]4	18.130	18.181	0.1	0.3
			[illegible]3	27.649	26.695	1.0	3.5
			[illegible]3	26.238	26.859	0.6	2.3
			[illegible]4	17.092	18.244	1.2	6.5
			[illegible]8	13.548	15.569	2.0	13.9
			[illegible]4	17.360	17.682	0.3	1.8
			[illegible]	26.716	28.493	1.8	6.4
			[illegible]3	25.139	24.910	0.2	0.9
			[illegible]1	19.892	18.797	1.1	5.7
			[illegible]	12.610	13.272	0.7	5.1
			[illegible]	19.051	20.584	1.5	7.3
			[illegible]3	18.281	19.717	1.4	7.6
			[illegible]3	15.103	15.487	0.3	2.0
			[illegible]3	20.098	21.546	1.4	7.0
			[illegible]3	19.819	20.954	1.1	5.6
			[illegible]1	22.892	25.195	2.3	9.6
			[illegible].1	18.709	18.265	0.4	2.4
			3.9	18.086	18.252	0.6	3.4
[illegible]	[illegible]	6.3	0.2	6.282	7.026	0.7	11.2
79.509	74.603	4.9	6.4	20.164	19.791	0.4	1.9
193.289	191.032	0.7	0.4	21.957	23.561	1.6	7.0
110.216	111.904	1.8	1.6	24.376	25.709	1.3	5.3
173.504	176.026	2.5	1.4	21.549	23.124	1.6	7.1
104.914	100.198	4.7	4.6	18.459	18.759	0.3	1.7
90.819	95.672	4.9	5.2	20.907	20.670	0.2	1.1

107.358	106.718	0.6	0.6	16.635	15.690	0.9	5.8
133.047	135.690	2.6	2.0	28.861	30.300	1.4	4.9
95.099	93.181	1.9	2.0	19.370	20.424	1.1	5.2
145.629	154.534	8.9	5.9	112.421	111.272	1.1	1.0
65.810	67.175	1.4	2.1	11.258	9.867	1.4	13.2
86.677	86.802	0.2	0.2	2.445	2.044	0.4	17.8
170.224	176.158	5.9	3.4	35.836	31.311	4.5	13.5
57.000	57.000	0.0	0.0	0.000	0.000	0.0	0.0
79.004	79.406	0.5	0.6	15.724	17.133	1.4	8.6
61.280	61.164	0.1	0.2	19.625	20.729	1.1	5.5
38.651	38.773	0.1	0.3	21.011	20.267	0.8	3.7
40.453	40.820	0.4	0.9	17.979	18.918	0.9	5.1
42.185	42.434	0.2	0.6	17.774	18.834	1.1	5.8
45.002	44.621	0.5	1.0	18.971	19.733	0.8	3.9
48.078	47.319	0.6	1.6	20.650	21.087	0.4	2.1
55.293	55.004	0.3	0.5	22.448	23.396	0.9	4.1
64.746	66.020	1.3	1.9	25.237	25.085	0.2	0.6
71.065	75.342	4.3	5.8	25.288	24.674	0.6	2.5
71.345	78.449	7.1	9.5	25.619	24.699	0.9	3.7
68.047	75.124	7.1	9.9	26.914	28.093	1.2	4.3
65.534	71.072	5.5	8.1	25.716	28.457	2.7	10.1
63.573	67.374	3.8	5.8	22.336	25.413	3.1	12.9
62.138	65.989	3.9	6.0	20.038	21.504	1.5	7.1
64.858	68.319	3.5	5.2	20.365	19.911	0.5	2.3
71.371	76.345	5.0	6.7	20.597	21.199	0.6	2.9
78.573	83.954	5.4	6.6	21.238	24.243	3.0	13.2
93.241	98.862	5.6	5.9	23.587	26.445	2.9	11.4
103.539	108.879	5.3	5.0	23.819	26.028	2.2	8.9
110.806	114.624	3.8	3.4	26.508	27.680	1.2	4.3
102.888	105.730	2.8	2.7	31.595	30.774	0.8	2.6
88.569	92.670	4.1	4.5	32.365	29.728	2.6	8.5
68.566	71.986	3.4	4.9	28.899	26.722	2.2	7.8
55.638	59.825	4.2	7.3	23.569	23.258	0.3	1.3
47.543	51.049	3.5	7.1	22.354	22.807	0.5	2.0
43.716	47.072	3.4	7.4	21.690	23.159	1.5	6.7
35.595	38.624	3.0	8.2	20.919	22.573	1.7	7.6
66.103	69.761	3.7	5.4	20.723	22.624	1.9	8.8
98.004	103.500	5.6	5.5	21.664	24.092	2.4	10.6
91.957	94.891	2.9	3.1	29.329	29.080	0.8	2.9
71.177	75.391	4.2	5.8	18.664	19.161	0.5	2.6
90.819	95.672	4.9	5.2	20.907	20.670	0.2	1.1
69.565	69.664	0.1	0.1	15.451	17.047	1.6	9.8
91.601	96.465	4.8	5.1	20.635	20.950	0.3	1.5
82.009	87.649	5.6	6.5	20.377	22.250	1.9	8.8
98.804	102.655	3.8	3.7	26.454	26.376	0.1	0.3
53.108	53.233	0.1	0.2	15.189	16.971	1.8	11.1
100.509	105.629	5.0	4.9	21.653	21.274	0.4	1.8
99.582	104.586	4.9	4.8	21.162	21.076	0.1	0.4
104.500	109.102	4.6	4.5	23.409	22.795	0.6	2.8
80.828	81.747	0.9	1.1	15.518	16.453	0.9	5.9
90.444	96.161	5.7	6.1	22.366	24.830	2.5	10.4
48.628	52.409	3.9	7.5	22.271	22.274	0.0	0.0
98.181	102.721	4.5	4.5	22.599	22.003	0.6	2.6
84.237	89.796	5.6	6.4	21.493	23.611	2.1	9.4
99.097	104.953	5.9	4.8	21.417	20.980	0.4	2.1
103.095	108.055	5.0	4.8	21.504	21.078	0.4	2.0

5.95

109.151	114.124	5.0	4.5	22.152	22.897	0.1	0.3
93.547	94.577	1.4	5.5	25.917	25.192	1.7	5.7
[illegible]	65.133	0.1	0.2	19.412	17.136	1.7	10.6
94.951	99.637	4.7	4.9	20.764	20.744	0.0	0.1
77.808	82.629	4.8	6.0	19.783	22.272	2.2	[illegible]
104.758	109.152	4.5	4.3	21.593	[illegible]	[illegible]	[illegible]
45.292	43.503	3.4	7.1	21.754	22.593	0.8	[illegible]
100.625	105.649	5.0	4.9	22.853	22.042	[illegible]	[illegible]
75.133	83.126	4.8	5.1	[illegible]	27.952	1.2	[illegible]
89.112	95.971	7.9	0.4	[illegible]	[illegible]	1.1	[illegible]
54.612	51.073	1.5	2.0	31.397	25.552	1.1	[illegible]
83.500	75.451	14.1	17.1	48.954	35.659	[illegible]	31.4
21.849	22.139	0.5	1.7	10.918	11.687	0.9	7.8
155.970	156.575	0.6	0.4	15.715	9.888	6.8	51.[illegible]
142.608	144.802	2.2	1.6	22.681	19.241	4.4	20.7
101.871	101.713	0.2	0.2	11.150	8.144	3.2	12.9
65.093	65.093	0.0	0.0	8.913	8.929	0.0	9.9
181.962	181.951	0.0	0.0	12.013	10.974	1.0	9.0
182.681	182.701	0.0	0.0	12.029	10.979	1.0	9.1
185.066	185.030	0.0	0.0	12.083	10.971	1.0	9.0
189.138	189.302	0.2	0.1	11.928	11.020	0.9	7.9
195.534	195.756	0.2	0.1	11.922	11.281	0.7	6.2
205.842	205.271	0.3	0.2	12.343	11.789	0.6	4.6
219.823	220.385	0.6	0.3	14.055	13.672	0.4	3.0
241.029	241.687	0.5	0.3	15.591	14.783	1.2	7.8
244.455	245.845	1.4	0.6	13.183	11.799	1.3	10.5
229.192	228.733	0.7	0.3	15.977	15.068	0.9	5.9
214.943	213.011	1.0	0.5	14.644	13.536	1.1	7.9
203.526	202.625	0.9	0.4	12.898	12.059	0.8	6.7
195.495	195.754	0.7	0.4	11.976	11.488	0.5	4.2
191.780	191.069	0.7	0.4	11.842	11.421	0.4	3.6
188.461	187.739	0.7	0.4	12.056	11.749	0.3	2.9
185.909	185.198	0.7	0.4	12.563	12.174	0.4	3.1
182.763	183.115	0.6	0.4	13.028	12.612	0.4	3.2
181.901	181.333	0.6	0.3	13.554	13.194	0.4	3.4
180.435	179.954	0.5	0.3	14.260	13.777	0.5	3.4
179.539	179.092	0.4	0.2	15.356	14.941	0.4	2.7
179.397	178.853	0.5	0.3	16.953	16.100	0.9	5.2
180.034	179.379	0.7	0.4	18.621	17.525	1.1	6.1
181.336	180.845	0.5	0.3	20.138	19.418	0.7	3.7
183.104	182.937	0.2	0.1	21.546	20.853	0.7	3.3
185.026	185.540	0.5	0.3	22.527	21.694	0.8	3.8
186.341	188.207	1.9	1.0	22.843	22.272	0.6	2.5
186.504	190.208	3.0	2.0	22.457	22.431	0.0	0.1
185.245	190.695	5.4	2.8	21.717	21.812	0.1	0.4
182.582	189.385	5.8	3.1	21.739	21.254	0.5	2.3
181.047	187.000	6.0	3.2	22.193	22.124	0.1	0.3
177.803	183.572	5.7	3.2	23.279	23.645	0.4	1.6
173.823	178.819	5.0	2.8	23.545	24.217	0.7	2.8
169.227	173.102	4.2	2.4	22.873	23.431	0.6	2.4
164.440	168.259	3.8	2.3	20.946	21.821	0.9	4.1
160.422	164.019	3.6	2.2	18.847	20.021	1.2	6.0
157.578	159.994	3.4	2.1	17.341	18.291	0.9	5.3
155.909	159.147	3.2	2.1	16.287	16.904	0.6	3.7
155.341	158.572	3.2	2.1	15.651	15.965	0.3	2.0
156.793	159.181	2.4	2.2	15.389	15.574	0.2	1.2

157.319	160.876	3.6	2.2	15.560	15.643	0.1	0.5
159.901	163.776	3.9	2.4	16.088	16.377	0.3	1.8
163.440	167.816	4.4	2.6	17.114	17.933	0.8	4.7
168.022	172.989	5.0	2.9	18.778	20.360	1.6	8.1
173.272	178.448	5.2	2.9	20.909	22.059	1.1	5.4
178.591	183.963	5.4	3.0	22.711	24.135	1.4	6.1
183.547	188.649	5.1	2.7	23.707	25.826	2.1	8.6
187.052	191.279	4.2	2.2	23.952	26.289	2.3	9.3
189.319	192.351	3.0	1.6	25.183	26.949	1.8	6.8
189.039	191.690	2.7	1.4	26.331	28.002	1.7	6.1
185.603	187.974	2.4	1.3	28.717	29.002	0.3	1.0
178.793	181.397	2.6	1.4	31.246	30.342	0.9	2.9
168.595	171.741	3.1	1.8	31.297	29.963	1.3	4.4
157.302	160.511	3.2	2.0	28.700	26.907	1.8	6.4
146.944	150.592	3.6	2.5	25.508	24.562	0.9	3.8
138.323	142.017	3.7	2.6	23.457	22.683	0.8	3.4
131.246	134.862	3.6	2.7	22.304	21.506	0.8	3.6
125.302	128.868	3.6	2.8	21.710	20.802	0.9	4.3
120.384	123.790	3.4	2.8	21.352	20.340	1.0	4.9
116.263	119.556	3.3	2.8	21.211	20.001	1.2	5.9
112.905	116.135	3.2	2.8	21.126	19.844	1.3	6.3
110.220	113.408	3.2	2.9	21.143	19.717	1.4	7.0
108.228	111.299	3.1	2.8	21.164	19.644	1.5	7.4
106.823	109.887	3.0	2.8	21.212	19.585	1.6	8.0

It is understood that γ_t and $\gamma_{tt'}$ depend implicitly upon the indicies e and f.

These correlation coefficients, aside from having general interest, are important in the discriminant analysis for the case of multiple samples and triads.

Since γ_t depends upon e, t, and f, it is unfeasible to list their estimates for all values of these indicies. Instead we present averages of these quantities on certain indicies and combinations of indices. The estimates have been obtained from Data Base I using standard estimators.

In Tables 5-11 and 5-12, we present estimates of certain averages of γ_t and $\gamma_{tt'}$ for phonetic event #20, a typical case. In sub-table 5-11a we give estimates of the triad average and standard deviation of γ_t listed as functions of the feature f. In 5-11b on the other hand, we present the feature average and standard deviation of γ_t listed as functions of the triad t. In Table 5-12 subtable 5-12a gives estimates of the triad average and standard deviation of the inter-triad correlation coefficient $\gamma_{tt'}$ listed as functions of the feature f. In 5-12b, the feature average and standard deviation of the same quantity are listed as functions of the triad pair t and t', t≠t'.

In Table 5-13 we present estimates of the inter-utterance and inter-triad correlation coefficients γ_t and $\gamma_{tt'}$ for all phonetic events. However, for the sake of brevity, we present only grand averages of these quantities, i.e., averages on <u>both</u> features and triads (actually, triad pairs in the case of $\gamma_{tt'}$). In Table 5-14, we present rank orderings of the grand averages of γ_t and $\gamma_{tt'}$.

It is to be noted that the grand average of γ_t has a maximum of .493 and a minimum of .357, corresponding to phonetic events 29 and 32, respectively. The grand average of $\gamma_{tt'}$ has a maximum of .361 and a minimum of .193, corresponding to events 23 and 32, respectively. It is worthy of note that event 20 is not far from the middle of each rank ordering. The ratios of grand averages of γ_t and $\gamma_{tt'}$ has a minimum of 1.16 and a maximum of 2.20, corresponding to events 27 and 29, respectively.

TABLE 5-11

Estimates of the Inter-Utterance Correlation Coefficient γ_t for Phonetic Event #20

Feature No.	AVG.	STDEV
291	0.573	0.186
560	0.652	0.347
220	0.556	0.323
250	0.756	0.153
279	0.514	0.269
225	0.629	0.312
526	0.595	0.228
210	0.472	0.432
219	0.440	0.283
541	0.535	0.355
245	0.374	0.266
529	0.472	0.139
252	0.738	0.207
254	0.351	0.290
272	0.432	0.254
296	0.415	0.201
514	0.548	0.440
566	0.424	0.219
261	0.399	0.220
221	0.335	0.303
512	0.403	0.413
303	0.600	0.306
222	0.220	0.278
216	0.118	0.227
535	0.197	0.354
215	-0.007	0.294
227	0.345	0.352
249	0.198	0.248
211	-0.064	0.306
229	0.316	0.201

a) Avg. on triads

TRIAD NO.	AVG	STDEV
28	0.437	0.304
54	0.321	0.427
77	0.477	0.260
86	0.387	0.303
103	0.528	0.328
137	0.451	0.322
185	0.494	0.369
219	0.222	0.345
249	0.428	0.246
253	0.497	0.450

b) Avg. on features

TABLE 5-12

Estimates of the Inter-Triad Correlation Coefficient $\gamma_{tt'}$ for Phonetic Event #20

Feature No.	AVG	STDEV
291	0.512	0.101
560	0.449	0.186
220	0.445	0.218
250	0.603	0.129
279	0.421	0.157
225	0.312	0.179
526	0.421	0.127
210	0.293	0.205
219	0.247	0.223
541	0.459	0.200
245	0.241	0.152
529	0.216	0.299
252	0.467	0.294
254	0.261	0.163
272	0.308	0.139
296	0.287	0.145
514	0.311	0.230
556	0.299	0.183
261	0.284	0.135
221	0.303	0.190
512	0.172	0.247
103	0.281	0.218
222	0.177	0.177
216	0.093	0.194
535	0.177	0.162
215	0.044	0.128
227	0.078	0.294
249	0.041	0.175
211	0.052	0.144
229	0.110	0.211

a) Avg. on triads

TABLE 5-12 (contd)

TRIAD PAIR		AVG	STDEV
28	54	0.264	0.208
28	77	0.272	0.263
28	86	0.215	0.227
28	108	0.254	0.288
28	137	0.259	0.246
28	185	0.260	0.224
28	219	0.226	0.203
28	249	0.265	0.223
28	253	0.265	0.216
54	77	0.348	0.218
54	86	0.206	0.253
54	108	0.254	0.262
54	137	0.228	0.240
54	185	0.336	0.191
54	219	0.239	0.193
54	249	0.178	0.247
54	253	0.361	0.242
77	86	0.306	0.182
77	108	0.342	0.240
77	137	0.256	0.217
77	185	0.379	0.233
77	219	0.240	0.228
77	249	0.285	0.225
77	253	0.369	0.271
86	108	0.266	0.219
86	137	0.308	0.166
86	185	0.229	0.157
86	219	0.269	0.189
86	249	0.253	0.237
86	253	0.248	0.235
108	137	0.343	0.270
108	185	0.338	0.269
108	219	0.242	0.312
108	249	0.346	0.204
108	253	0.366	0.248
137	185	0.235	0.198
137	219	0.287	0.252
137	249	0.335	0.200
137	253	0.298	0.237
185	219	0.284	0.256
185	249	0.223	0.221
185	253	0.349	0.267
219	249	0.224	0.244
219	253	0.232	0.323
249	253	0.278	0.233

b) Avg. on features

TABLE 5-13

Grand Averages of Inter-Utterance and Inter-Triad Correlation Coefficients

Phonetic Event	Inter-Utterance $\overline{\gamma}_t$	Inter-Triad $\overline{\gamma}_{tt'}$
20	.424	.287
21	.429	.333
22	.415	.271
23	.491	.361
24	.468	.290
25	.455	.258
26	.361	.309
27	.409	.354
28	.460	.334
29	.493	.224
30	.441	.291
31	.423	.296
32	.357	.193
33	.359	.287

TABLE 5-14

Rank Orderings of Grand Averages of Inter-Utterance and Inter-Triad Correlations Coefficients

Rank	Phonetic Event	Inter-Utterance $\overline{\gamma}_t$	Phonetic Event	Inter-Triad $\overline{\gamma}_{tt'}$
1	29	.493	23	.361
2	23	.491	27	.354
3	24	.468	28	.334
4	28	.460	21	.333
5	25	.455	26	.309
6	30	.441	31	.296
7	21	.429	30	.291
8	20	.424	24	.290
9	31	.423	33*	.287
10	22	.415	20*	.237
11	27	.409	22	.271
12	26	.361	25	.258
13	33	.359	29	.224
14	32	.357	32	.193

*Tie

6.0 MERGING: REDUCTION OF SYSTEM COMPLEXITY WITHOUT LOSS OF SIGNIFICANT PHONETIC EVENTS

6.1 The Combinatorial Problem

As discussed above 14 phonetic events have been labelled in the various data bases. Operationally, it is desirable to be able to use the system if any subset of these is present. Various notions for extracting and clustering the statistical information contained in the data bases were conceptually explored before the determination was made that the most reasonable match, to both the forensic application of SASIS and the schedule of data availability, was to tabulate the performance for all possible subsets. Table 6-1 gives the detailed numbers for the combinatorial problem for the range of interest to SASIS. Part 2 of the table illustrates the reduction which is achieved by either reducing the number of phonetic events (column 1) or by restricting the system to be used for I or more events of the N available. Determination of an I for any particular N is not reasonable before both further operational situation scenarios and the statistical significance of the results are obtained. Consideration of disc storage and table computational time suggests a set of 10 events yielding 1023 subsets as a reasonable tabulation goal. The sections below describe the analysis carried out to determine if this is indeed a reasonable goal and, if so, specifically how it can be attained without discarding any useful phonetic events. The solution presented is to discard one phonetic event and to merge 3 pairs of events. This merging process enables the system to retain the information in these phonetic events but to suppress their effect on the combinatorial explosion. The pairs are chosen to minimize the degradation in performance, and, as shown below, the degradation which does result is very small. The discussion below first outlines criteria for selecting 4 pairs of the original 14 events to be merged, presents arguments for discarding one event, defines the specific experiments performed, and presents the results for the two best sets of three pairs of events.

The analysis of section 6.2 below was carried out on Data Base I; the final results of section 6.4 were obtained on the 75 speaker training portion of Data Base II.

CONTINUED

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$_N C_M$

N \ M	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1													
2	2	1												
3	3	3	1											
4	4	6	4	1										
5	5	10	10	5	1									
6	6	15	20	15	6	1								
7	7	21	35	35	21	7	1							
8	8	28	56	70	56	28	8	1						
9	9	36	84	126	126	84	36	9	1					
10	10	45	120	210	252	210	120	45	10	1				
11	11	55	165	330	462	462	330	165	55	11	1			
12	12	66	220	495	792	924	792	495	220	66	12	1		
13	13	78	286	715	1287	1716	1716	1287	715	286	78	13	1	
14	14	91	364	1001	2002	3003	3432	3003	2002	1001	364	91	14	1

$\sum_{M=I}^{N} {_N C_M}$

N \ I	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1													
2	[illegible]	1												
3	[illegible]	4	1											
4	15	11	5	1										
5	31	26	16	6	1									
6	63	57	42	22	7	1								
7	127	120	99	64	29	8	1							
8	255	247	219	163	93	37	9	1						
9	511	502	466	382	256	130	46	10	1					
10	1023	1013	968	848	638	386	176	56	11	1				
11	2047	2036	1981	1816	1486	1024	562	232	67	12	1			
12	4095	4083	4017	3797	3302	2510	1586	794	299	79	13	1		
13	8191	8178	8100	7814	7099	5812	4096	2380	1093	378	92	14	1	
14	16383	16369	16278	15914	14913	12911	9908	6176	3473	1471	470	106	15	1

$$_N C_M = \binom{N}{M}$$

TABLE 6-1. The Combination of N Taken at a Time for the Region of Interest to SASIS

6.2 Criteria for Determining Merge Candidates

The decision to use a table look up procedure on combinations of 1 or more events has necessitated a reduction in the 14 basic events. Experimental results have indicated that the dimensionality is less than 14, so the effort appears reasonable. The basic assumption for the analysis below is that it is desirable to merge 4 pairs of events. Since this may be done

$$\binom{14}{2}\cdot\binom{12}{2}\cdot\binom{10}{2}\cdot\binom{8}{2} = 91 \cdot 66 \cdot 45 \cdot 28$$
$$= 7{,}567{,}560$$

ways, no attempt at an optimal solution is made. Rather, several forms of "reasonableness" criteria are used to obtain candidates for merge. Approximately 20 sets of candidates are obtained by this procedure. The choice among them is made by comparing the resulting statistics, as described more fully below.

The most likely phonetic confusion pairs are shown in Table 6-2. The grouping represents subjective judgments based on similarity in terms of the SASIS display and in terms of the vowel quadrangle. These conjectured confusion pairs are shown linked on Table 6-3, which presents the SOC and F-ratio* rank ordered events. The intent is to examine which phonetically similar pairs are also similar with respect to the statistics represented by the SOC and F-ratio measures. Table 6-4 tabulates subjective evaluation of the confusion pairs based on a SOC F-ratio measure which is the number of intervening events between a candidate pair on the SOC and F-ratio rank orderings. Only the (30,29) or /ʊ/ - /u/ pair receives a good rating.

Tables 6-5 and 6-6 show the correlation coefficients computed on the intra and interspeaker data, respectively, from Data Base I using an edited weighted Euclidean metric Event pairs with correlation coefficients greater than or equal to 0.50 are circled. The intra case is plotted in Table 6-5c together with the average correlation per event. The phonetic confusion pairs are circled.

*As defined in the discussion on distance measure.

TABLE 6-2

Phonetic Confusion Groups

20	/m/	MX
21	/n/	NX
22	/ŋ/	HG
23	/i/	EE
24	/I/	IX
25	/ɛ/	EH
26	/ɑ/	AH
27	/ɒ/	AA
28	/ɔ/	AW
29	/ʊ/	UX
30	/u/	UU
31	/ʌ/	UH
32	/ɝ/	ER
33	/ə/	SW

TABLE 6-3

Phonetic Confusion Pairs

SOC	F2
20	33
30	23
29*	30
23	29*
24	20
33	21
22	24
28	27
27	22
32	28
31	32
21	26
25	31
26	25

TABLE 6-4

Evaluation of the phonetic confusion pairs' mergeability based on the rank ordered SOC and F2 measures

Phonetic Confusion Pair from Table I	$d_{SOC,F2}$	Result of Suitability for Merge based on SOC/F2 Ranking
(30, 29)	0, 0	Good
(23, 24)	0, 4	Poor
(21, 22)	4, 2	Fair
(28, 26)	5, 1	Poor
(27, 25)	3, 5	Fair

TABLE 6-5a

Intraspeaker Correlation Coefficients
(From Data Base 1 using the edited weighted Euclidean metric)

ENTS	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Σ||	AVG	EVENT
20	1.00	0.26	0.38	0.41	0.01	0.08	0.15	0.38	0.34	0.23	0.25	0.35	0.05	-0.26	3.15	.24	20
21		1.00	0.27	0.18	0.19	-0.03	0.01	0.25	0.20	-0.11	0.22	0.08	0.32	0.24	2.36	.18	21
22			1.00	0.27	0.40	0.27	0.23	0.24	0.13	0.35	0.34	0.21	0.22	0.04	3.35	.26	22
23				1.00	0.26	0.29	0.30	0.48	0.26	0.21	0.36	[illegible]	0.33	0.21	4.16	.32	23
24					1.00	[illegible]	0.23	0.45	0.21	[illegible]	0.32	[illegible]	0.39	0.47	4.41	.34	24
25						1.00	0.46	[illegible]	0.43	[illegible]	0.30	[illegible]	0.43	0.11	4.93	.38	25
26							1.00	[illegible]	[illegible]	[illegible]	0.39	[illegible]	[illegible]	-0.14	4.58	.35	26
27								1.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	5.92	.46	27
28									1.00	0.25	[illegible]	[illegible]	[illegible]	-0.27	5.32	.41	28
29										1.00	[illegible]	[illegible]	0.19	0.17	4.09	.31	29
30											1.00	0.26	[illegible]	0.04	4.35	.33	30
31												1.00	[illegible]	-0.14	5.50	.42	31
32													1.00	-0.04	5.18	.40	32
33														1.00	2.19	.17	33

TABLE 6-5b

Events Ordered by Avg. Corr.

27 - .46
31 - .42
28 - .41
32 - .40
[illegible] - .38
[illegible] - .35
24 - .34
[illegible] - .33
[illegible] - .32
[illegible] - .31
[illegible] - .26
20 - .24
[illegible] - .18
33 - .17

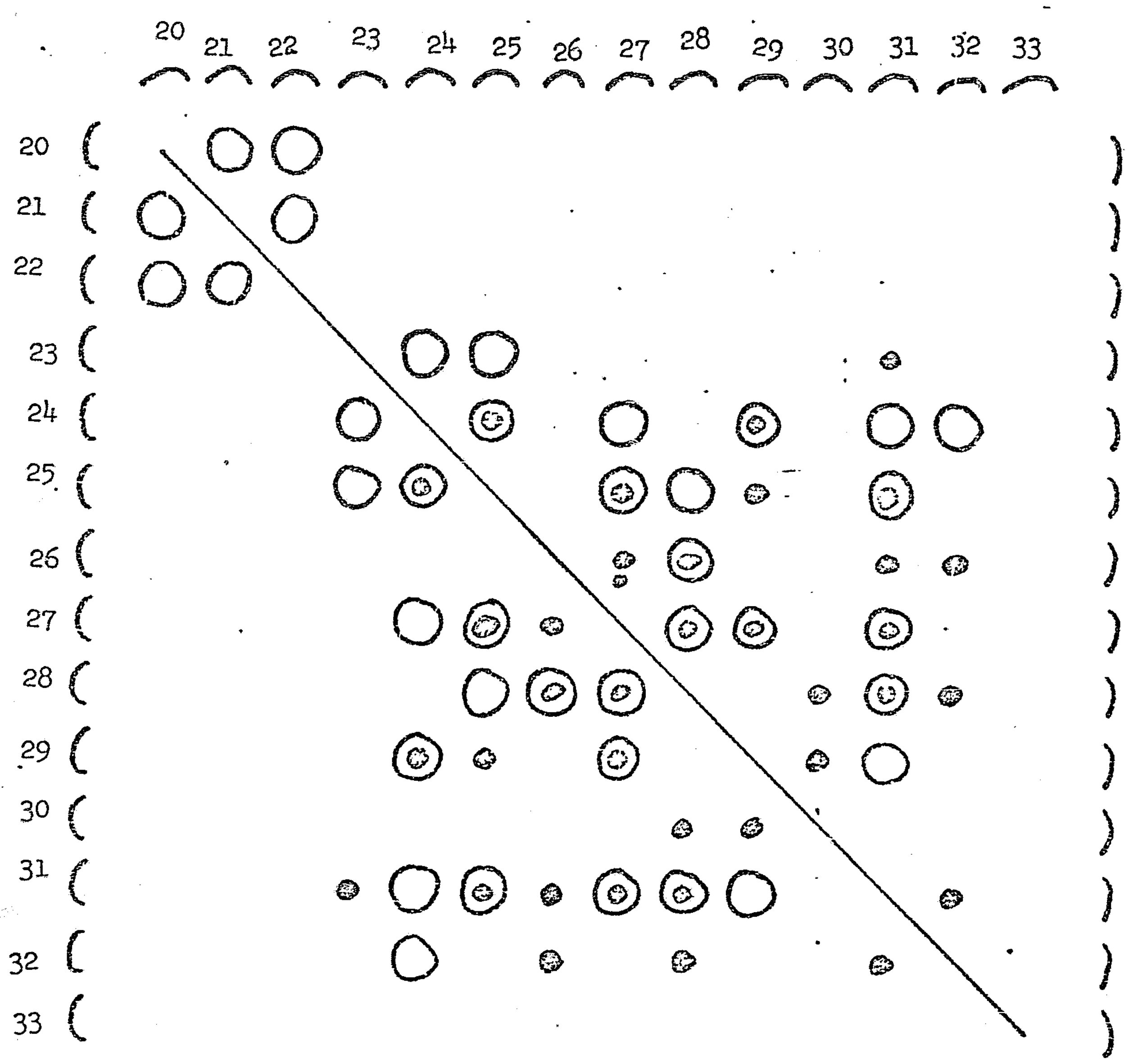
TABLE 6-6

Interspeaker Correlation Coefficients
(from Data Base 1 using the edited
weighted Euclidean metric)

	20	21	22	23	24	25	26	27	28	29	30	31	32	33
20	1.00	0.58	0.58	0.38	0.33	0.31	0.01	0.26	0.25	0.12	0.23	0.19	0.31	0.29
21		1.00	[illegible]	0.45	0.34	0.38	0.09	0.41	0.36	0.22	0.32	0.31	0.38	0.30
22			1.00	0.42	[illegible]	0.23	-0.03	-0.20	0.18	0.21	0.35	0.10	0.39	0.36
23				1.00	[illegible]	0.50	0.09	-0.48	0.26	0.31	0.42	0.45	0.44	0.30
24					1.00	[illegible]	0.16	[illegible]	0.44	[illegible]	0.45	[illegible]	[illegible]	0.35
25						1.00	0.40	[illegible]	[illegible]	0.47	0.36	[illegible]	0.28	0.22
26							1.00	[illegible]	[illegible]	[illegible]	0.03	[illegible]	0.09	0.02
27								1.00	[illegible]	[illegible]	0.32	[illegible]	0.40	0.20
28									1.00	[illegible]	0.28	[illegible]	0.33	0.20
29										1.00	0.40	[illegible]	0.39	0.23
30											1.00	[illegible]	0.46	0.43
31												1.00	0.33	0.15
32													1.00	0.38
33														1.00

A number of tables have been constructed, based on these statistics, for the purpose of producing interpretations suitable for defining event merge candidates. Table 6-5b shows the events rank ordered by the average inter event correlation coefficients derived from the intraspeaker data. Table 6-7 shows the correlation rank ordered event pairs having intraspeaker correlations ≥0.50. Table 6-8 is a 14x14 event matrix showing those event pairs having high intra and interspeaker correlations. The marginal tabulation gives the number of high correlations per event for the intraspeaker and interspeaker cases. Table 6-9 presents a rating of the phonetic confusion pairs based on the intraspeaker and interspeaker correlations.

Table 6-10 shows the 14 events rank ordered from most favorable for merging to least favorable for merging, based on the third column of the marginal tabulation in Table 6-8 (the total number of high correlations). The phonetic confusion pairs and the subjective evaluations from Tables 6-4 and 6-9 are also shown. Table 6-11 lists the nine event pairs from Table 6-8 which had high correlation for both the intra and the interspeaker data. The event pairs are rank ordered on the sum of the intra and interspeaker correlations. The events themselves are then grouped as shown and rank ordered using a figure of merit based on the event pair rank ordering (this is essentially equivalent to rank ordering the events based on the average correlation for the intra and interspeaker data, as shown). Table 6-12 presents a comparison of the event rank orderings from Tables 6-10 and 6-11. The correspondence is quite good, indicating the reasonableness of this procedure for evaluation of the "mergeableness" of the events. Table 6-11b indicates which events to merge. Table 6-13 shows nine sets of events, seven of which are unique, chosen from the structure of Table 6-11. For the first group, the event pair ranking most likely to be reasonable mergeable was selected first from Table 6-11a, then the next ranked event pair for which both events were available was selected. This process is continued until either the events are exhausted or 4 pairs are selected. For the second group the initial event pair chosen is that ranked 2nd in Table 6-11a; the rest of the pairs are chosen as above. The event groupings of Table 6-13 result. Where the list is incomplete a reasonable final event pair was chosen based on a subjective inclusion of previous results.



Event	No. of high intra corr. ⊙	No. of high inter corr. O	Σ
20	0	2	2
21	0	2	2
22	0	2	2
23	1	2	3
24	2	6	8
25	4	5	9
26	4	1	5
27	5	5	10
28	5	4	9
29	4	3	7
30	2	0	2
31	6	5	11
32	3	1	4
33	0	0	0
	Σ = 36/2= 18 intra	Σ = 38/2 = 19 inter	

TABLE 6-8

Matrix representation of event pairs having high intraspeaker correlation ⊙ and high interspeaker correlation O

TABLE 6-9

Rating of the phonetic confusion pairs based on intra and inter-speaker correlations.

Phonetic Confusion Pairs	Rating	Intra Corr.	Inter Corr.
30, 29	Fair/poor	.50,	.40
23, 24	Fair	.26,	.57
21, 22	Fair	.27,	.57
28, 26	Good	.61,	.55
27, 25	Good	.65,	.78

Key:

High corr. inter and intra = Good

or = Fair

not hi corr = Poor

TABLE 6-10

Order of events by total # of correlations (intra & inter) ≥ .50

"Worst Event" (most correlated)

	Event	# Intra # Inter
	31 - 11	6.5 (most favorable candidate for merge)
SOC: fair Corr: good	27 - 10	5.5
	28 - 9	5.4
	25 - 9	4.5
	24 - 8	2,6
SOC: poor Corr: fair	29 - 7	4,3
SOC: poor Corr: good	26 - 5	4,1
	32 - 4	3,1
	23 - 3	1,2
	20 - 2	0,2
SOC: fair Corr: fair	21 - 2	0,2
	22 - 2	0,2
SOC: good Corr: fair-poor	30 - 2	2,0
	33 - 0	0,0

"Best Event" least correlated

TABLE 6-11a

9-Event Pairs with High Corr
inter & intra (from Table VII)

	Intra	Inter	Σ	Ranked
24-25	.61,	.74	1.35	4
25-27	.65,	.78	1.43	2
26-28	.61,	.55	1.16	7
27-38	.64,	.64	1.28	5
24-29	.56,	.50	1.08	8
27-29	.50,	.50	1.00	9
25-31	.51,	.73	1.24	6
27-31	.78,	.77	1.55	1 ← best merge candidate
28-31	.71,	.69	1.40	3

TABLE 6-11b

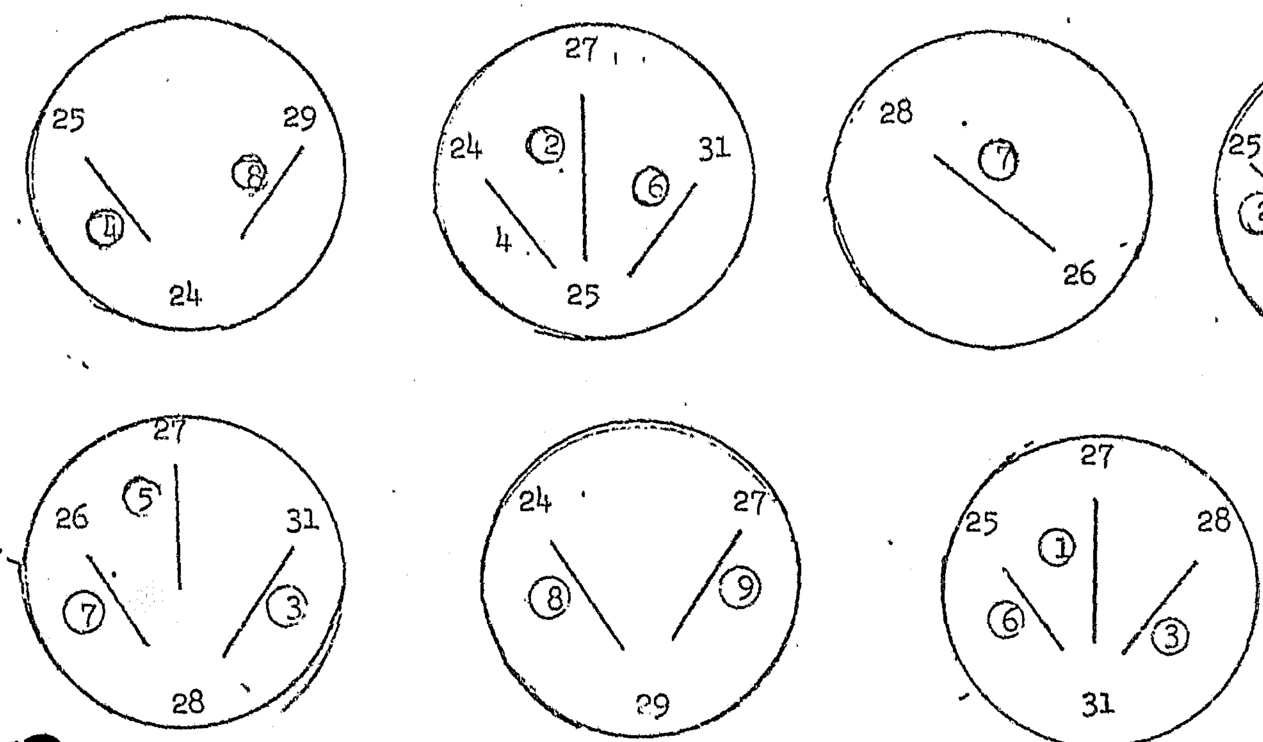


TABLE 6-11b (Cont)

These 7 events

ranked: low to hi

↗ best merge candidate

31	$3\frac{1}{3}$	.67
25	4	.67
27	$4\frac{1}{4}$	.65
28	5	.64
24	6	.60
26	7	.58
29	$8\frac{1}{2}$	.51

TABLE 6-12

Comparison of Rank Orderings from Tables IX and X

Table X's from Ranking		ranked by avg corr. coef for intra and inter corr. Both ≥.50	Table IX's from Ranking
31	$3\frac{1}{3}$	.67	31 - 11 - 6,5
25	4	.67	27 - 10 - 5,5
27	$4\frac{1}{4}$	.65	28 - 9 - 5,4
28	5	.64	25 - 9 - 4,5
24	6	.60	24 - 8 - 2,6
26	7	.58	29 - 7 - 4,3
29	$8\frac{1}{2}$	.51	26 - 5 - 4,1
			32 - 4 - 3,1
			23 - 3 - 1,2
			20 - 2 - 0,2
			22 - 2 - 0,2
			30 - 2 - 2,0
			33 - 0 - 0,0

Left: ranking from overlap of high corr. intra & inter entries only (not considering other events)

Right: ranking from # of other events for which sig. corr. exists in both intra & inter corr. matrices

TABLE 6-13

Selection of Sets of Event Pairs for Merging Based on Table X

1	2	3	4	5
31-27	• 27-25	31-28	25-24	28-27
25-24	31-28	25-24	28-27	31-25
• 28-26	29-24	29-27	26-31	29-24
• 29-30	26-32	26-32	• 29-30	26-32

6	7	8	9
31-25	• 28-26	29-24	29-27
• 28-26	29-24	31-27	31-28
29-24	31-27	• 28-26	25-24
27-32	25-23	25-23	26-32

• = a phonetic confusion pair

The process described above for the 9 event pairs having high intra and interspeaker correlations is repeated for the nine event pairs for which the intra correlation but not the inter correlation is high, and for the 10 event pairs for which the intercorrelation but not the intra-correlation is high. Tables 6-14 and 6-15 repeat the form of Table 6-11 for these two cases. Tables 6-16 and 6-17 list the selected sets from Tables 6-14 and 6-15.

Table 6-18 presents 3 sets of 4 event pairs chosen from the phonetic confusion pairs conjectured above.

Tables 6-13, 6-16, 6-17, and 6-18 present 20 sets of 4 event pairs each as candidates for merging, chosen with the aid of the criteria discussed above.

6.3 Definition of a Specific Set of Experiments

6.3.1 Relative Frequency of Phonetic Events

Table 6-19 presents the relative frequency of occurrence of the SASIS phonetic events, based on the data of Denes and Dewey. These data have been extracted to prevent the possible merging of two phonetic events, each of which have a very high percentage of occurrence. If this were to occur the resultant event class would be too large a fraction of the total and the results of SASIS would be excessively sensitive to the presence of this event class.

Table 6-19 shows that the results of Denes on English spoken in the Received Pronunciation (a dialect of Southern England) and Dewey on written General American English are surprisingly similar (except for event 25: /a/) despite the rather extreme differences in the details of their respective data. Only the merge of the unlikely pair of events /ŋ/-/I/ based on Denes or any of /n/-/I/, /n/-/a/ /I/-/a/ would create an event class which represents too large a fraction of speech. Accordingly, these are avoided below.

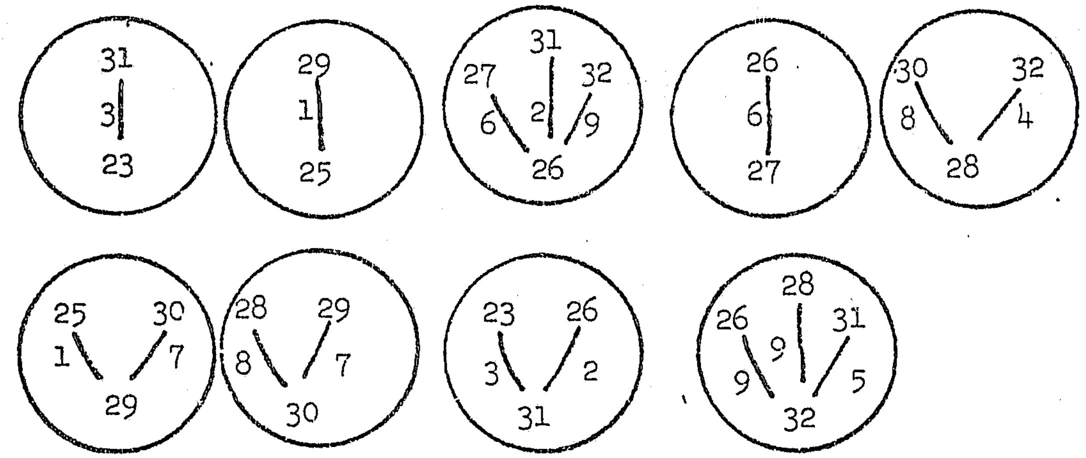
TABLE 6-14

Nine Event Pairs with High Intra and Low Interspeaker Correlations

(A)

Event Pairs	Intra Corr.	Inter Corr.	Σ	Rank
23-31	.60,	.45	1.05	3
25-29	.71,	.47	1.18	1
26-27	.52,	.44	.96	6
26-31	.67,	.45	1.12	2
26-32	.73,	.00(!)	.73	9
28-30	.50,	.28	.78	8
28-32	.72,	.33	1.05	4
29-30	.50,	.40	.90	7
31-32	.68,	.33	1.01	5

(B)



(C) Rank ordered events

Event	Score
25	1
31	$2\frac{1}{2}$
23	3
29	4
26	$5\frac{2}{3}$
27	6
32	6
28	6
30	$7\frac{1}{2}$

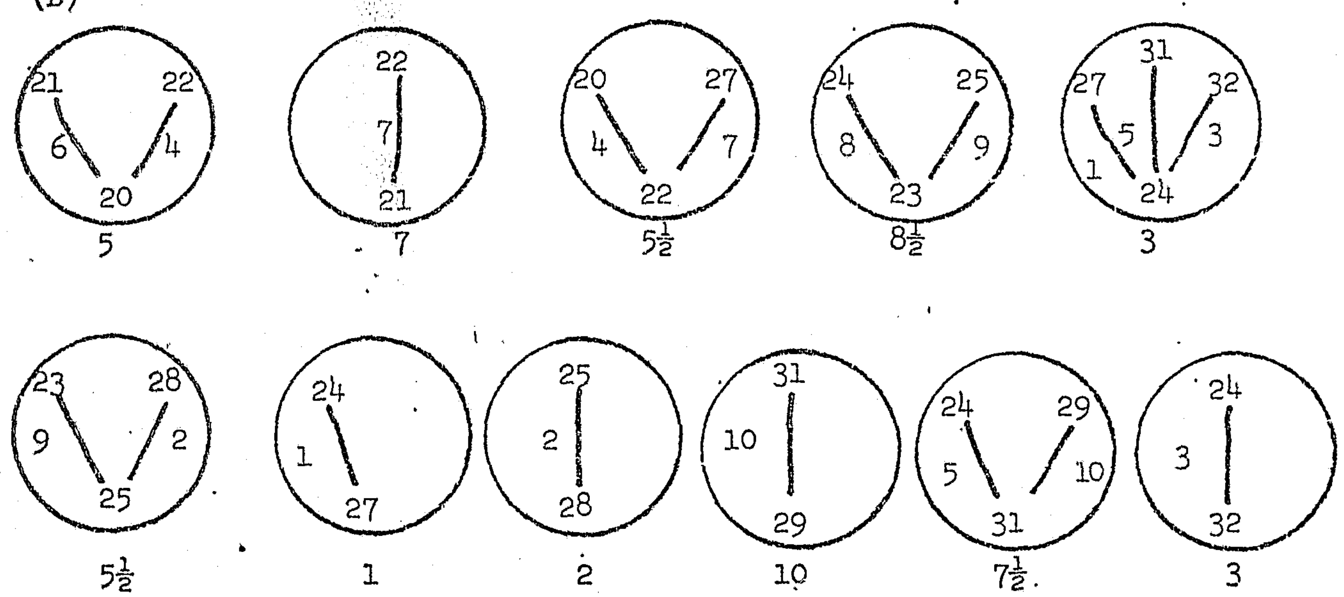
TABLE 6-15

Ten Event Pairs with High Inter and Low Intraspeaker Correlations

(A)

Event Pairs	Intra Corr.	Inter Corr.	Σ	Rank
20-21	.26,	.58	.84	6
20-22	.38,	.58	.96	4
21-22	.27,	.57	.84	7
23-24	.26,	.57	.83	8
23-25	.29,	.50	.79	9
24-27	.45,	.64	1.09	1
24-31	.31,	.64	.95	5
24-32	.39,	.51	1.00	3
25-28	.48,	.53	1.01	2
29-31	.20,	.56	.76	10

(B)



(C) Rank Ordered Events

Event	Score
27	1
28	2
32	3
24	3
20	5
22	5½
25	5½
21	7
31	7½
23	8½
29	10

TABLE 6-16

Selection* of Sets of Events Pairs for Merging Based on Table XIII

1	2	3	4	5
25-29	26-31	23-31	28-32	31-23
26-31	28-32	28-32	26-27	26-27
28-32	• 29-30	26-27	• 29-30	• 29-30
**21-22	**23-24	• 29-30	23-31	**21-22

*(the 6 to 9 initialization is not pursued)

• phonetic confusion pair

** phonetic confusion pair added to obtain a set of 4 event pairs

TABLE 6-17

Selection* of Sets of Event Pairs for Merging
Based on Table XIV

1	2	3	4	5
24-27	25-28	24-32	20-22	24-31
25-28	24-32	20-22	24-31	20-21
20-22	20-22	23-25	23-25	23-25
29-31	29-31	29-31	**26-28	**26-28

*Phonetic confusion pair added to obtain 4 event pairs

**(the 6 to 10 initialization is not pursued)

TABLE 6-18

Selection of 3 Sets of Event Pairs from the
Phonetic Confusion Conjectured Pairs

1	2	3
29-30	21-22	21-22
26-28	23-24	25-27
25-27	25-27	26-28
23-24	26-28	29-30

TABLE 6-19

Relative[++] Frequency of Occurrence of the Phonetic Events of SASIS (expressed in %)

		Denes[+]	Dewey	Denes Stressed	Denes Unstressed
20	/m/	3.2890	2.78	3.80	2.89
21	/n/	7.0849	7.24	7.42	6.82
22	/ŋ/	1.2436	.96	.75	1.62
23	/i/	1.7878	2.12	1.78	1.79
24	/ɪ/	8.2537	8.53	3.11	12.23
25	/ɛ/	2.8126	3.44	4.79	1.29
*26	/ɑ/	2.3085	3.30	3.78	1.18
**27	/a/	1.5261	8.58	2.73	.60
28	/ɔ/	1.2007	1.26	1.89	.67
29	/ʊ/	.7672	.69	.80	.74
30	/u/	1.4222	1.60	1.44	1.41
31	/ʌ/	1.6701	2.33	2.80	.80
32	/ɝ/	.6661	-	.83	.54
33	/ə/	9.0445	-	.04	16.01

+ ± .3% at 99% confidence level.

++ Relative to the data base of the two authors quoted.

* 26=a: + ɑ of Denes; ɑ + ɑ of Dewey.

** a + ae of Dewey.

6.3.2 Discard of Event 33: /ə/ (the)

Event 33 has been eliminated from further consideration for the following reasons:

1) If the data of the first and second sessions of Data Base II is tabulated to yield the number of appropriate triad pairs available per speaker comparision per event, the result is a set of numbers between 0 and 9. An approximate tabulation is given in Table 6-20. Event 33 is the single event with the least number of tokens available.

2) Event 33 is not well represented in the Data Base (labeled only in "the").

3) As shown in Table 6-19, although /ə/ occurs with a total relative frequency of over 9%, this is actually a lopsided average of over 16% unstressed and 0.04% stressed. Its unstressed, aperiodic structure makes it difficult to label and, as implied by (1) above, it frequently is unlabelable.

4) As a frequently occurring unstressed neutral, it is very likely to result in confusions with many other unstressed events, resulting in a large variation in performance.

Hence, for the purposes of SASIS, there are 13 phonetic events considered.

6.3.3 Rules for Merge Experiments

The following rules for conducting the merge experiments were used:

1) IGNORE event 33 so there are only 13 events.
2) The following merge sets are to be considered for a 13 → 10 merge:

	①	②	③	④	⑤	
Phonetic Confusion Pairs:	25-26 27-28 29-30	25-26 27-28 21-22	25-26 27-28 23-24	21-22 23-24 29-30	26-28 23-24 29-30	Set I
	⑥	⑦	⑧	⑨	⑩	
High Intra & Inter Corr	31-26 25-24 28-27	26-25 31-28 29-24	31-28 25-24 29-26	25-24 28-26 27-31	28-25 31-25 29-24	

\- -

TABLE 6-20

Approximate Number of Triad Pairs Available* From Data Base II
(From the Training Portion Consisting of 75 Randomly Selected Speakers)

20	21	22	23	24	25	26	27	28	29	30	31	32	33
1-3	1-3	1-3	1-4	4-7	4-6	4-6	5-7	5-7	4-5	4-5	4-5	4-5	0-2

* per speaker comparison using "matching" triads.

High Intra	25-29	27-31	23-31	28-32	31-32
Low Inter	27-31	28-32	28-32	27-2	27-26
Corr	28-32	29-30	27-26	29-30	29-30
High Inter	24-26*	25-28	24-32	20-22	24-31
Low Intra	25-28	24-32	20-22	24-31	20-21
Corr	20-22	20-22	23-25	23-25	23-25

Set II

3) The merge of two events is performed on the expanded data (where the expansion is by averaging over triad triplets, so there are 10 "distances" for each speaker comparision) if event i and j are to be merged, then there exist already $\bar{d}_i \underline{\Delta} \frac{d_{i\ intra} + d_{i\ inter}}{2}$ and also $\bar{d}_j$, then the merged event ij's distances are defined as

$$d'_{ij} \ \underline{\Delta} \ \frac{\frac{d_i}{\bar{d}_i} + \frac{d_j}{\bar{d}_j}}{2} \left(\frac{\bar{d}_i + \bar{d}_j}{2} \right)$$

There are 10 distances for each speaker pair comparison for the "event class "i j".

4) The similarty measure is then run on the 10 event classes to yield 10 SOC curves via the following procedure:

1 2 3 4 5 6 7 8 9 10

1 $\underline{\Delta}$ drop event class 1

2 $\underline{\Delta}$ drop event class 2

.

.

.

10 $\underline{\Delta}$ drop event class 10

and plot the SOC curve for the remaining 9 event classes.

5) This process yields 10 SOC curves for each three pairs listed above.

*One of the merges to be avoided.

The 100 SOC curves on Set I were obtained first. The results, described below, were satisfactory and Set II was not examined.

6.4 Results: Final Set of Phonetic Events

Table 6-21 lists in detail the events dropped for computing the 9 event-class SOC curves discussed above. The pairwise decision tree is shown in Figure 6-1. It is based on comparing those cases in pairs which have the largest number of comparable SOC curves (i.e., for which the same event or event class was dropped). Table 6-22 presents the detailed scores used to determine the branches of Figure 6.1.

Case										
1	20	21	22	23	24	31	32	(25-26)	(27-28)	(29-30)
2	20	23	24	29	30	31	32	(25-26)	(27-28)	(21-22)
3	20	21	22	29	30	31	32	(25-26)	(27-28)	(23-24)
4	20	25	26	27	28	31	32	(21-22)	(23-24)	(29-30)
5	20	21	22	25	26	31	32	(27-28)	(23-24)	(29-30)
6	20	21	22	23	29	30	32	(31-26)	(25-24)	(28-27)
7	20	21	22	23	27	30	32	(26-25)	(31-28)	(29-24)
8	20	21	22	23	27	30	32	(31-28)	(25-24)	(29-26)
9	20	21	22	23	29	30	32	(25-24)	(28-26)	(27-31)
10	20	21	22	23	27	30	32	(28-26)	(31-25)	(29-24)

TABLE 6-21

Set I 13 → 10 Event Comparison -
SOC with 9 event curves - events dropped

Winners:
Step A ○
Step B □
Step C ◇
Step D •

TABLE 6-22

STEP A

Case	Merges			Score*	Win
1	(25-26)	(27-28)	(29-30)	1.00	*
2	(25-26)	(27-28)	(21-22)	0.14	
3	(25-26)	(27-28)	(23-24)	1.00	*
6	(31-26)	(23-24)	(28-27)	0.00	
4	(21-22)	(23-24)	(29-30)	0.57	
5	(27-28)	(23-24)	(29-30)	0.57	*
7	(26-25)	(31-28)	(29-24)	0.86	*
8	(31-28)	(25-24)	(29-26)	0.43	
9	(25-24)	(28-26)	(27-31)	0.43	
10	(28-26)	(31-25)	(29-24)	1.00	

STEP B

Case	Merges			Score*	Win
3	(25-26)	(27-28)	(23-24)	1.00	*
5	(27-28)	(23-24)	(29-30)	0.14	
7	(26-25)	(31-28)	(29-24)	0.83	*
9	(25-24)	(28-26)	(27-31)	0.17	

STEP C

Case	Merges			Score*	Win
1	(25-26)	(27-28)	(29-30)	0.71	*
3	(25-26)	(27-28)	(23-24)	0.43	

STEP D

Case	Merges			Score*	Win
1	(25-26)	(27-28)	(29-30)	1.00	*
7	(26-25)	(31-28)	(29-24)	0.33	

CASE 1 WINS

*SCORE: By comparing SOC curves consisting of dropping the same event class out of the 10 possible, the score is the percent of wins and ties over the total number of comparisons.

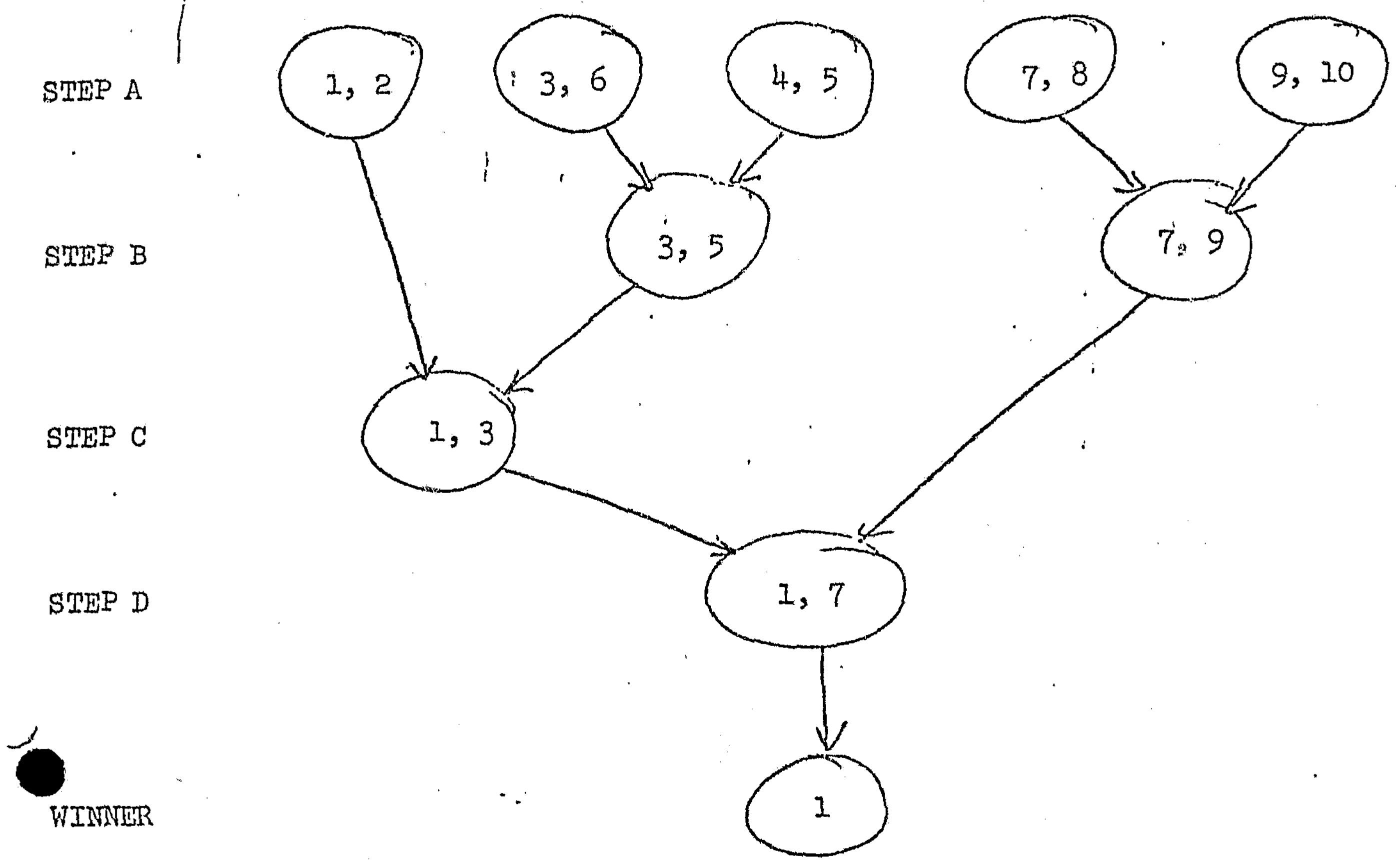


FIGURE 6.11

Binary Elimination Process for Case Selection

7.0 DISTANCE AND SIMILARITY MEASURES

7.1 OVERVIEW: A TWO-STEP APPROACH

Many structures are feasible to map features into a similarity measure. The following structure describes the architecture within which this investigation has been conducted:

- Any one of 10 phonetic event groups may be present in the base (or reference) sentence(s) (or utterance(s)).
- For each event to be used in the base sentence (in the form of one or more triads), the query (or suspect) sentence(s) have one or more triads.
- For each event present in the base sentence a single distance measure is obtained by comparison of allowable triad pairs or tokens (those having the same sentence position).
- Complete or partial sentence repetitions are explicitly handled by the distance measure.
- The similarity measure explicitly allows any combination of the 10 events to be present and produces a likelihood ratio whose reliability is, of course, a function of the data upon which it is based (number of distances, which distances, number of tokens upon which the distances were based).
- Guidelines for interpretation of the likelihood ratio are presented which may be used to make a same, different, or insufficient data decision (a "two choice open decision": TCOD).

Figure 7.1 shows the two-step structure. Figure 7.2 illustrates the input data structure.

The analyses described below made use of Data Base I for the determination of the distance form and of Data Base II for the final results on the similarity measure. Where time and schedule permitted, consistency checks on conclusions drawn on Data Base I were made using Data Base II. The areas in which this was not done are explicitly stated below.

7.2 DISTANCE MEASURE DEVELOPMENT

7.2.1 Basic Considerations

1) What is Distance?

The formal definition of a metric space is:

> An arbitrary set X is a metric space if there exists a function d: $X \times X \to R$ such that (1) $d(x,y) \geq 0$, with $=0$ IFF $x \equiv y$; (2) $d(x,y) = d(y,x)$ (symmetry); (3) $d(x,z) \leq d(x,y) + d(y,z)$ (triangle inequality), for any $x,y,z \in X$. d is the metric.

Any inner product generates a norm which may, itself, be taken as a metric.

While the formal properties must be kept in mind, engineering applications in the pattern classification context have generalized the intuition behind this structure to include a wide variety of measures to compare pattern points (elements of the basic set X). The two-step process described above was chosen for SASIS because it provides enough degrees of freedom to permit obtaining a reasonable solution given the time and schedule constraints and the a priori unknown nature of the data. The overall similarity measure certainly may be viewed as a metric. We choose to apply this terminology only to the first step for the discussion and development described immediately below.

The distance being sought is to be a measure of the separation between the feature representation of the steady state portion of identical triads in identical sentence position. Since a phonetic event is expected to be found in several such triad pairs, for a given operational comparison of

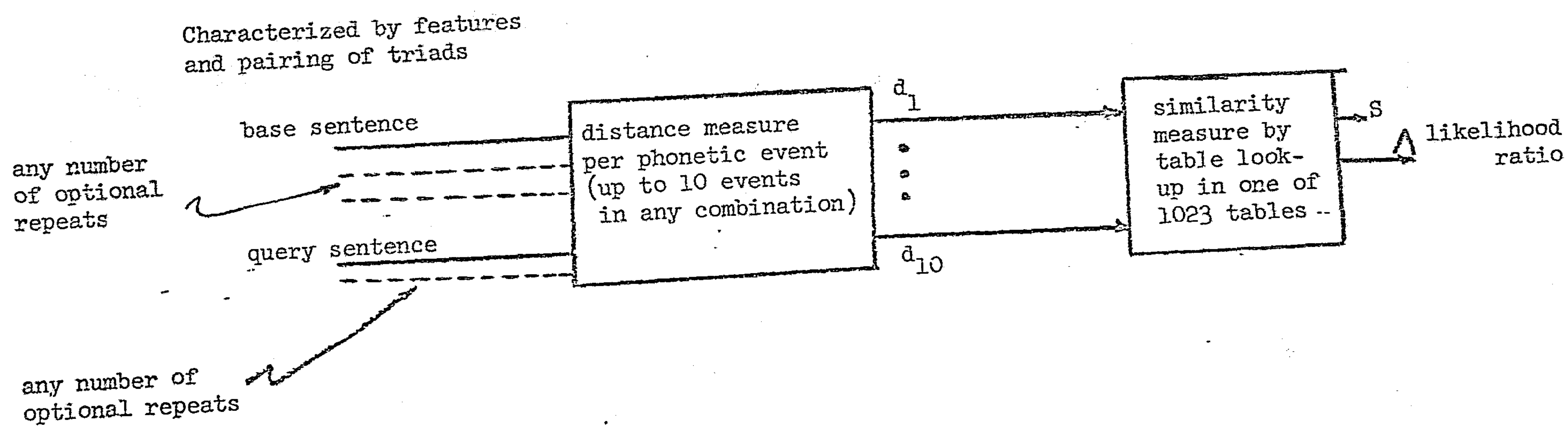


Figure 7-1. Two-step distance and similarity structure

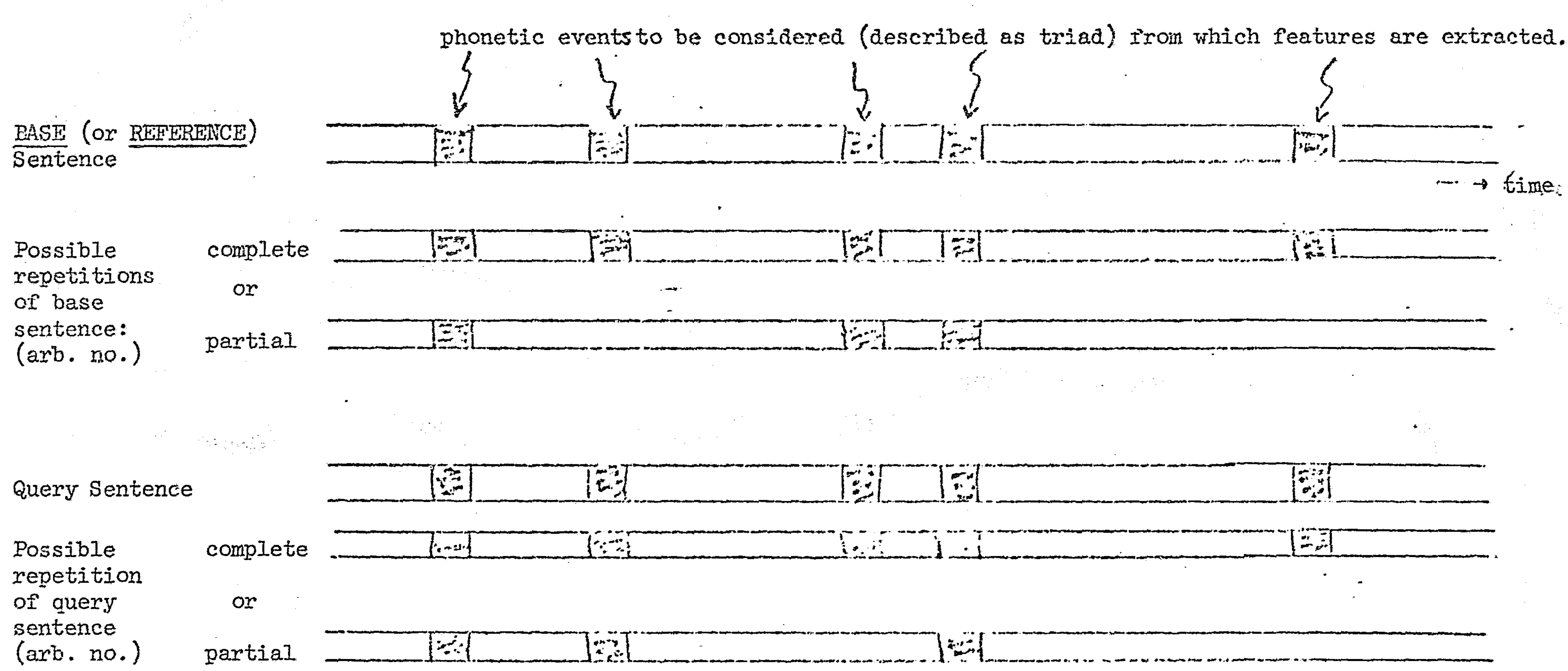


Figure 7-2 Input Structure

a base and query sentence, the distance measure must specifically take this into account. Since repetition of the query sentence has not been part of the data bases collected, the operational form remains to be defined and the distance measure results given below do not consider this aspect of the operation.

A frequently-used, geometrically based, measure of distance is the Euclidean form, which may be interpreted as motivated by an energy criterion and second order statistics. For classification purposes, a large distance between any pair of components (features) tends to dominate the result. This suggests that alternate forms, such as a weighted sum, a saturating "local" distance, or powers other than the square, may be less sensitive to individual features and, consequently, may more suitably reflect the separation of the triads in question.

Before proceeding with a description of the forms which were examined and why, the problem definition is represented from two different viewpoints.

7.2.1.2 Problem Definition

7.2.1.2.1 First Viewpoint

Let us restrict attention, for the purposes of the discussion in this section, to a single phonetic event characterized by M features. The event is represented by one or more triads in the base sentence(s) and in the query sentence(s). For illustrative purposes let M = 2 so that simple figures may be drawn--e.g. Figure 7.3 represents a case with three triads in the base and query sentences, with a single repetition of query 1. Although distance between two sets is, in general, an ill defined concept, certain "natural" interpretations are suggested by a priori knowledge of what the data represents. For example, if the samples shown in Figure 7.3 are viewed as observations produced by 3 processes with unknown statistics on the (f_1, f_2) space, then in a qualitative sense, it seems "natural" to regard a measure

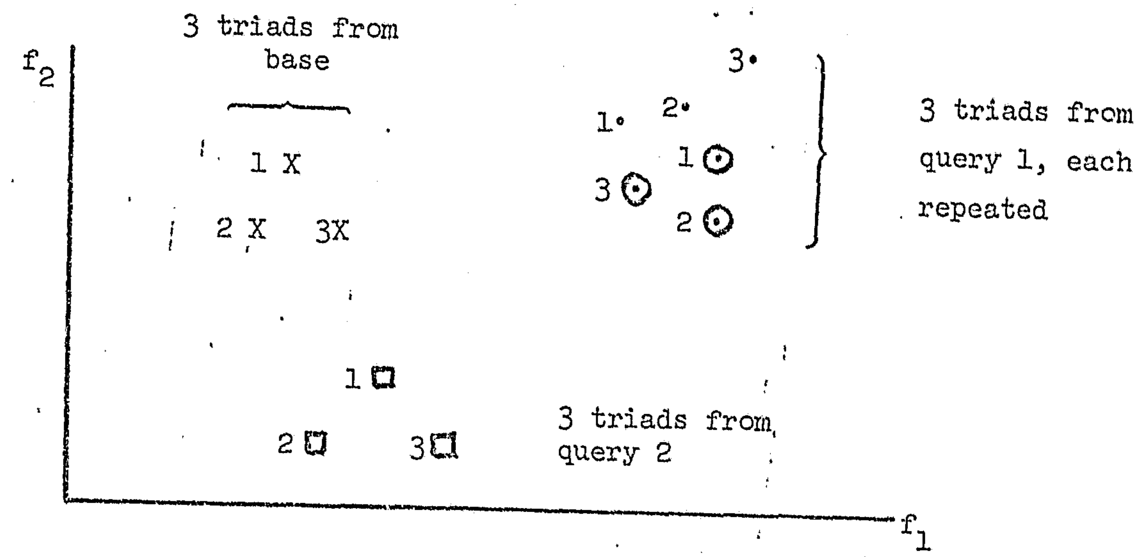


Figure 7.3

which compares estimates of those statistics as a valid distance between those processes -- i.e. between the clusters shown. These estimates

$$\hat{p}(f_1, f_2)\Big|_{base}$$

$$\hat{p}(f_1, f_2)\Big|_{query\ 1}$$

$$\hat{p}(f_1, f_2)\Big|_{query\ 2}$$

may be constructed from the samples in a number of ways, e.g.,

a) by using potential functions (over the entire space or, preferably, only in the vicinity of actual samples),

b) parametrically (by assuming a functional form for the true pdf's),

c) indirectly, by expanding the estimates into a weighed linear sum of functions drawn from a complete set and determining the coefficients.

Direct application of these formulations, and a host of others equivalent to them, is not appropriate for SASIS for the following reason. The overall distance between two clusters for the given phonetic event must be constructed from pairwise measures and not from some averaged cluster properties as shown in Figure 7.4.

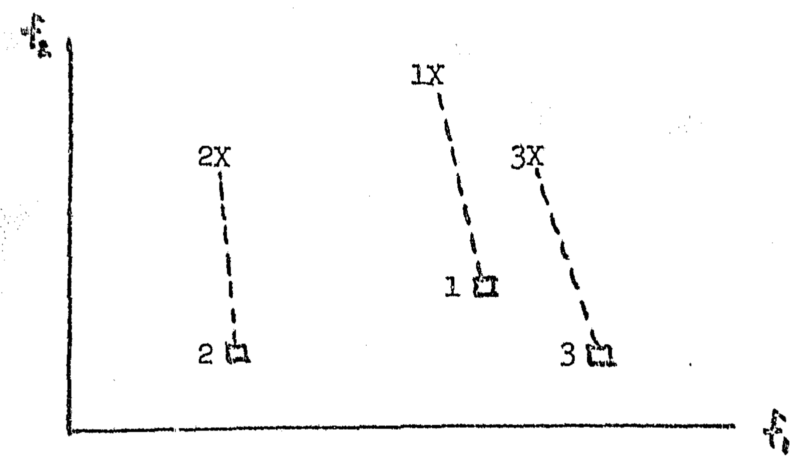


Figure 7.4

This is essential because the events are only partially characterized by the features and the additional characterization is implicit in the pairing. (The specific question concerning whether the points shown are necessarily triads, as stated above, or some higher grouping based on hub positions, say, is of no consequence for this discussion; the pairwise comparison described is still essential.) Hence, the structure dictated by the problem is to construct a distance per event based on one or more specified pairwise comparisons and to perform averaging, if any, after this step. The specification of the pairing for repeated equivalent points (triads in the example above) may be either parallel

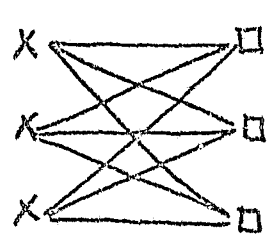


Figure 7-5a

or concatenated

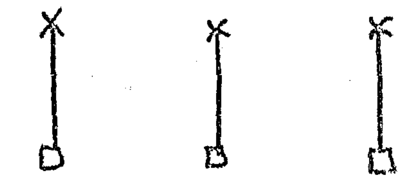


Figure 7.5b

The choice between the two must be empirically determined. Either viewpoint is acceptable; the algorithm for the distance measure remains unchanged.

Within this structure a large number of approaches are reasonable. The best approach is dependent, of course, on the type and complexity of the distributions encountered. Two such approaches were selected on an intuitive basis for comparison with each other and with the weighted Euclidean distance. They are described in section 7.2.1.3 below.

7.2.1.2.2 Second Viewpoint

The primary feature vector is x_{setnf} where the subscripts

- s - speaker lable (s = 1, ..., S)
- e - phonetic event lable (e = 1, ..., E) (E = 10 below)
- t - triad label (t = 1, ..., T_e)
- n - ordinary number of samples for a given speaker (n = 1, ..., N_{set})
- f - feature index $f \epsilon F_e$ where F_e is a subset of 30 of the 165 available features.

In approaching the problem of distance or pseudo-distance measures we consider first the situation in which there is only one sample for each speaker assuming a given phonetic event e and triad t. We then define the F_e-dimensional vector

$$
(1) \qquad X_s = \begin{matrix} X_{setl1} \\ X_{setl2} \\ \vdots \\ X_{setlf} \\ \vdots \\ X_{setlF} \end{matrix}
$$

In X_s, the subscripts e,t and n(=1) are understood to have assigned values and the feature index f labels the components of X_s. We next define the 2F-dimensional vector

$$
(2) \qquad X = \begin{pmatrix} X_1 \\ --- \\ X_2 \end{pmatrix},
$$

i.e., X is the direct sum of X_1 and X_2. This would be the feature vector to be used in the speaker comparison problem, if there were only one phonetic event e, one triad t and one sample for each speaker.

As stated before, in order to obtain a significant measure we focus on obtaining one with optimal performance in the role of a discriminant function. Thus it is appropriate to recast the problem in a pattern classification form. Here we define two classes: (a) one in which the two speakers are different people and (b) another in which the two speakers are the same person. The index c will label the classes with c = 0 corresponding to (a) above and c=1 corresponding to (b).

The classes are described by probability densities in the 2F-dimensional X-space, namely,

$$
(3) \qquad P(x|c), \quad c = 0,1.
$$

The *a priori* probabilities of the existence of the classes are

$$
(4) \qquad P(c), \quad c=0,1.
$$

Since, in the c=0 class the speakers are different people, it follows that here x_1 and x_2 are statistically independent, i.e.,

$$
(5) \qquad P(x|0) = P(x_1)P(x_2)
$$

where $P(x_s)$ is the probability density of x_s, s = 1,2. The functional form of $P(x_s)$ is independent of the value of s.

On the other hand, in the case of the c=1 class the two speakers are the same person; thus, their utterances are not statistically independent. Thus we must now write

(6) $\quad P(x|1) = P(x_1)P(x_2)Q(x_1,x_2)$ where the function $Q(x_1\ x_2)$ expresses the statistical dependendence effects. If we had Q = 1, then the case of statistical independence would be regained.

It is clear that integrating either class probability density on x_1 gives the following result

$$
(7) \qquad \int dx_1 P(x|c) = P(x_2|c) = P(x_2)
$$

where dx_1 is the appropriate differential volume element in x_1-space. In the case of c = 0, the above relation follows directly from (5). In the case of c = 1, this relation follows from the fact that in the case of an isolated speaker the meaning of class disappears. The relation (7) is also valid when x_1 and x_2 are interchanged. From (7) it follows that the mean of a function $f(x_2)$ in class 0 or 1 reduces to

$$
(8) \qquad \begin{aligned} E(f(x_2)|c) &= \int dx_1 \int dx_2\, f(x_2)P(x|c) \\ \int dx_2\, f(x_2)P(x_2) &= Ef(x_2). \end{aligned}
$$

In particular, the two classes have the same mean in x-space, i.e., Ex. In fact any function that is composed of a sum of functions of x_1 or x_2 will have the same mean value in each class. It is only functions not decomposable in this way (e.g., x_1x_2) that have mean values dependent on c.

7.2.1.3 A Plethora of Distance Forms

Since the distance between two sets, in general, is an ill-defined concept, a plethora of forms and terminologies have arisen to describe such measures. For example, Meisel (Meisel, 1972) describes 13 forms in a decidely non-exhaustive survey under the title "quality measures." The facts are clear: at the present state-of-the-art, selection of an appropriate metric is a subjective and highly intuitive process which requires careful examination of the data and iterative evaluation. The pairwise structure of SASIS must be kept at the forefront during the metric design process. To complicate matters further, not only the metric form but the methods of comparing the success of various forms are subjective. Accordingly, any solution is definitely suboptimal in the sense that lower error rates are attainable. These facts imply that conservative decisions made with the aid of the SASIS system may, in fact, be very conservative interpretations of the data.

The discussion below outlines the rationale used to select the distance forms which were investigated.

7.2.1.3.1 Local Distance Forms

Figure 7-6 shows two hypothesized sheet-like distributions and their pairwise comparisons.

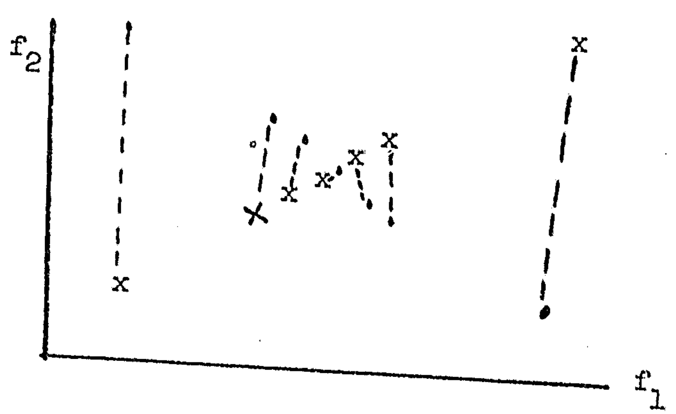


Figure 7-6
Sheet Distributions

Five of the pairwise Euclidean distance are clustered in a low range and two are considerably higher. For this structure it is clear that a local distance measure is of more interest than a global distance measure which would allow the two large distances to dominate. The use of such local distance measures which concentrate attention on local properties at the expense of global properties is well supported in the literature (see, e.g., Andrews, 1972). The local form is also obtained by measuring the distance between two sets as a function of the difference of the potential functions (or probability density functions) induced by those sets. For example, consider using the points in each set of Figure 7-6 to obtain the estimates $p(\bar{f}/\text{class 1})$ and $p(\bar{f}/\text{class 2})$ in the Parzen sense (e.g., by superimposing the effects of Gaussian puffballs, of an appropriate size, around each point). One measure of the difference between the classes is* (Patrick-Fischer, 1969)

$$d^2(\text{class 1, class 2}) = \int \left[p(\text{class 1})\hat{p}(\bar{f}/\text{class 1}) - p(\text{class 2})\hat{p}(\bar{f}/\text{class 2}) \right]^2 d\bar{f}$$

By substituting Parzen estimates for the probability densities (Parzen, 1962; Murthy, 1966) and specifically using the normal form, this may be rewritten as

$$d^2\,(\text{class 1, class 2}) = \sum_{r=1}^{n_1}\sum_{s=1}^{n_1} C_{rs}^{1,1} + \sum_{r=1}^{n_2}\sum_{s=1}^{n_2} C_{rs}^{2,2} - 2\sum_{r=1}^{n_1}\sum_{s=1}^{n_2} C_{rs}^{1,2}$$

*To avoid numerical difficulties in high dimensional spaces Meisel (Meisel, 1971) points out the integration should be performed only over regions of $\bar{f}$ space where data points from each class exist.

where n_1 = no. of points in class 1

n_2 = no. of points in class 2

and

$$C_{r\ s}^{\alpha,K} = \frac{P_\alpha P_K}{n_\alpha n_K} \frac{1}{\sqrt{2\pi}\sigma} \exp\left[\frac{-1}{4\sigma^2} |W (X_r^\alpha - X_s^K)|^2\right]$$

p_1 = apriori probability of class 1

p_2 = apriori probability of class 2

σ = a 'choice' parameter useful for smoothing the result (e.g. to 'tune' how large a distance can be before it is called 'large enough'

W = is a weight matrix

This form gives a measure of the distance between two classes each consisting of 1 or more points. All 'large' (with respect to the 'choice' parameter, or 'time constnat', σ) Euclidean distances give approximately the same effect because of the exponential form, subject, of course, to the weighting (i.e. insignificant components don't effect the result at all). The asymptotic behavior is interesting: if σ becomes large, d becomes a difference between inter and intra class distances; if σ becomes small, an optimum W exists which maximizes the minimum inter-class distances while minimizing the minimum intra-class distances.* The form may be viewed as saturating with respect to the Euclidean:

---

*The distance between any two points in the form suggested by Meisel (See Footnote page (7-10) is influenced by all other points in each class - i.e. for this case, the distance is not only a property of points and space but also of the distribution of the population of samples in that space. The desirability of this property is questionable.

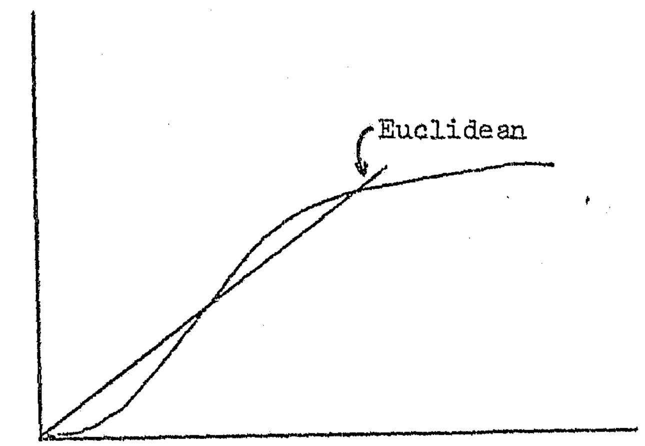


Figure 7-7

This structure was originally derived to perform a dimensionality reduction for feature selection under certain constraints. The discussion above is presented simply to show that the local distance form is suggested by several avenues of thought. In fact, the argument based on measuring distances between two sets is not appropriate for SASIS because it explicitly allows and takes into account cross comparisons, i.e., instead of considering the <u>paired</u> points as shown in Figure (7-4) above, it considers the primary observations as each belonging to a class. This viewpoint tacitly assumes that the feature data of SASIS is to be interpreted as performing a speaker <u>identification</u> (i.e., a standard M class categorization problem, where M is the number of speakers), rather than a verification/rejection of speakers considered in pairs. The former viewpoint leads to consideration of confusion matrices which, though they provide interesting and useful characterization of the data, are <u>not appropriate</u> for the SASIS system. Of course, the fact that a local distance measure form may be derived using an inappropriate line of reasoning does not, in itself, imply the local distance form is not appropriate. In fact, we judged the arguments in favor of the local distance form sufficient to include it in the investigation described below.

7.2.1.3.2 Discriminant Function Forms

Consider

$$R = \sum_{i \varepsilon I} d^2 \left(\overline{F}\,(\overline{x}_i,\ \overline{y}_i)\right)$$

where $\sum_{i \varepsilon I}$ is a normalized summation over the allowable pairs of points $(\overline{x}_i, \overline{y}_i)$, d^2 an arbitrary distance measure, $\overline{F}$ a functional on $(\overline{x}, \overline{y})$ to be tabulated on intraclass and interclass data yielding Ro and Rl respectively. (Intraclass: $\overline{x}_i$ and $\overline{y}_i$ known to be from the same speaker
Interclass: $\overline{x}_i$ and $\overline{y}_i$ known to be from different speakers).

Suppose F is chosen to minimize $\frac{R_o}{R_1}$. This is a well posed, though computationally prohibitive, problem in the calculus of variations framework. Further, suppose $\overline{F}$ to be restricted to be linear, say a matrix W, d to be the Euclidean distance and consider the formulation

$$\max R_1 = \sum_{i \varepsilon I} \left|\,\left|\, W\,\overline{x}_i - W\,\overline{y}_i \right|\,\right|^2$$

subject to $R_o + R_1$ = constant.

The solution, via Lagrangian multipliers, is of the form

$$\overline{W}_j\ [M] = \lambda_j\ \overline{W}_j$$

where M is a matrix defined from the data. The optimum is found to occur when all λ_j correspond to the maximum eigenvalue and all $\overline{W}_j$ correspond to the same eigenvector. This corresponds to a transformation into a one-dimensional space and this one dimensional line is usually viewed as a discriminant function. (Fisher, Maholanóbis) Clearly, if the symmetric

intersecting sheet distributions shown in Figure 7-6 are representative, this optimization procedure is relatively worthless. However, for a large set of distributions this structure has found wide use and it was chosen as the second form to be examined.

7.2.1.3.2.1 Derivation from a Likelihood Ratio

For the sake of simplicity, we first consider the case in which only one feature is available, i.e., F = 1. Now x_1 and x_2 are scalars and x is a 2-dimensional vector.

To get a better insight into the nature of the problem, let us first investigate the ideal situation in which the probability densities P(x/o) and P(x/1) are Gaussian. From the relation (8) of Section 7.2.1.2.2 we deduce

(1) $E(x_1/d) = E(x_2/c) = \mu$

(2) $E\left((\Delta x_1)^2/c\right) = E\left((\Delta x_2)^2/c\right) = \sigma^2$

in which

(3) $\Delta(\cdot) = (\cdot) - E(\cdot)$.

In the case of cross-correlations, we get

(4) $E(\Delta x_1\ \Delta x_2/0) = 0$

(5) $E(\Delta x_1\ \Delta x_2/1) = \sigma^2\gamma$

where γ is the correlation coefficient associated with different utterances from the same person. Based upon the above results, the Gaussian probability densities are

$$(6) \qquad P(x/0) = \frac{1}{2\pi\sigma^2} \exp\left[-\frac{1}{2\sigma^2}\left((x_1-\mu)^2 + (x_2-\mu)^2\right)\right]$$

$$(7) \qquad \begin{cases} P(x/1) = \dfrac{1}{2\pi\sigma^2 (1-\gamma^2)^{1/2}} \\ \cdot \exp\left[-\dfrac{1}{2\sigma^2(1-\gamma^2)}\left((x_1-\mu)^2 + (x_2-\mu)^2 - 2\gamma(x_1-\mu)(x_2-\mu)\right)\right] \end{cases}$$

It can be easily verified that integration on x_1 yields Gaussian densities on x_2 that are independent of c, namely,

$$(8) \qquad P(x_2/c) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{1}{2\sigma^2}(x_2-\mu)^2\right].$$

Clearly, x_1 and x_2 can be interchanged in the last result.

It is perhaps easier to visualize the geometrical nature of P(x/1) and P(x/0) if the coordinate axes are rotated 45° after translation to a new origin at (μ,μ). To this end we define the new coordinates

$$(9) \qquad \begin{cases} \mu = \dfrac{1}{\sqrt{2}}(\Delta x_1 + \Delta x_2) = \dfrac{1}{\sqrt{2}}(x_1 + x_2 - 2\mu) \\ v = \dfrac{1}{\sqrt{2}}(\Delta x_1 - \Delta x_2) = \dfrac{1}{\sqrt{2}}(x_1 - x_2). \end{cases}$$

The μ axis is the line $x_1 = x_2$ and v axis is the line $x_1 + x_2 = 2\mu$. The inverse relations are

$$(10) \qquad \begin{cases} \Delta x_1 = x_1 - \mu = \dfrac{1}{\sqrt{2}}(u + v) \\ \Delta x_2 = x_2 - \mu = \dfrac{1}{\sqrt{2}}(u - v). \end{cases}$$

The Jacobian of the transformation from the coordinates system $(\Delta x_1, \Delta x_2)$ to the system (u, v) is equal to unity.

In the new coordinate system

$$(11) \qquad P(x/0) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{u^2+v^2}{2\sigma^2}\right)$$

$$(12) \qquad \begin{cases} P(x/1) \\ = \dfrac{1}{2\pi\sigma^2(1-\gamma^2)^{1/2}} \exp\left(-\dfrac{u^2}{2\sigma^2(1+\gamma)} - \dfrac{v^2}{2\sigma^2(1-\gamma)}\right) \end{cases}$$

The probability isodensity contours for P(x/0) are circles centered at (0,0) in the (u, v) coordinate system or at (μ,μ) in the (x_1, x_2) coordinate system. The circle corresponding to $P(x/0)/P_{max}(x/0) = \exp(-\frac{1}{2})$ has a radius equal to σ. On the other hand, the probability isodensity contours for P(x/1) are similar ellipses centered at (0,0) in the (u, v) coordinate system as was the case with the circular contours. The common major axis coincides with the u-axis (i.e., the line $x_1 = x_2$) and the common minor axis coincides with the v-axis (i.e., the line $x_1 + x_2 = 2\mu$). The ellipse corresponding to $P(x/1)/P_{max}(x/1) = \exp(-\frac{1}{2})$ has a semi-major axis of length $\sigma(1+\gamma)^{1/2}$ and a semi-minor axis of length $\sigma(1-\gamma)^{1/2}$. The geometry is illustrated in Figure 7-8.

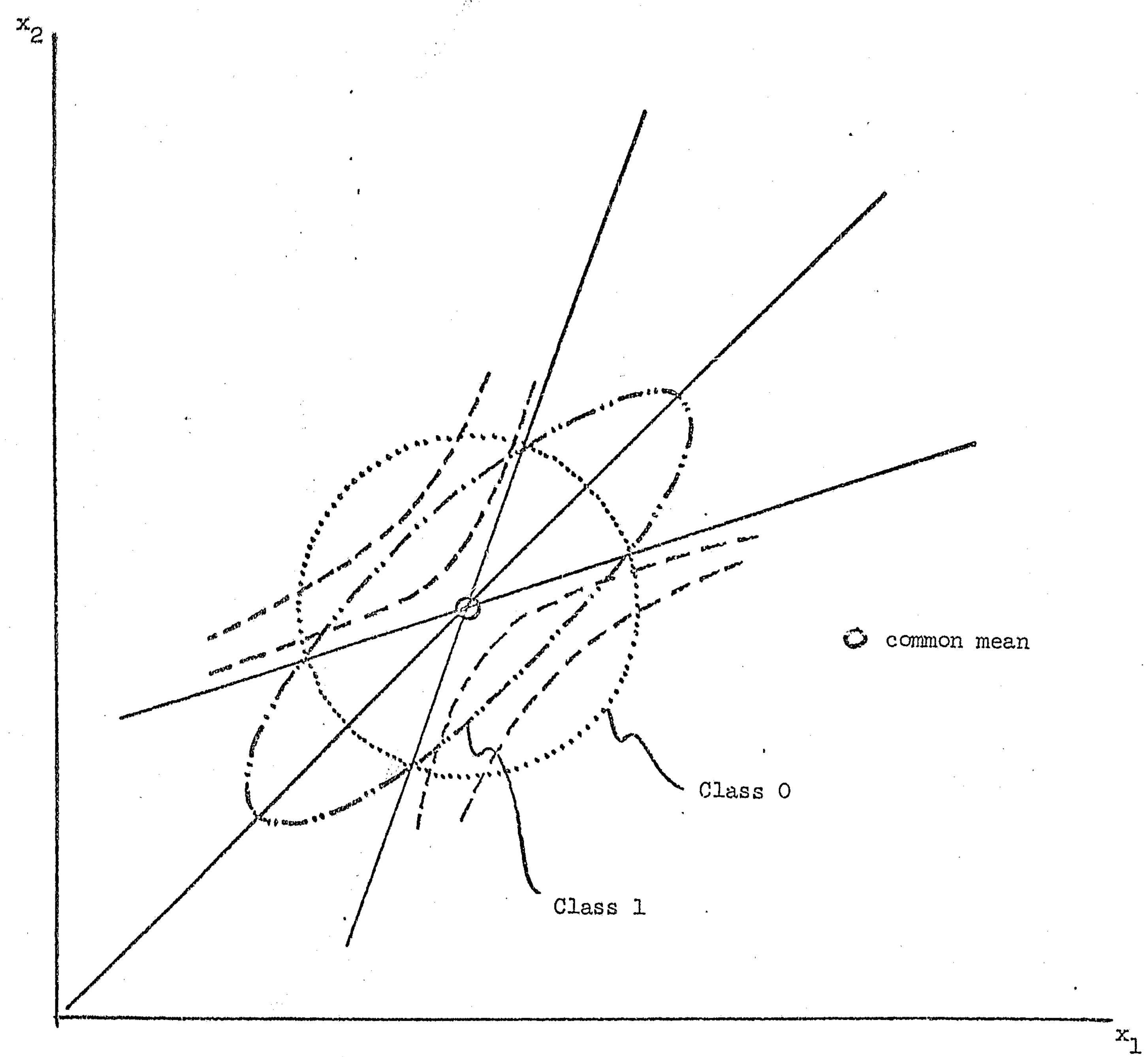


Figure 7-8 Classes in Pair Space

The likelihood function now takes the form

$$\Omega(x) = \frac{P(x/1)}{P(x/0)}$$

(13)
$$= \frac{1}{(1 - \gamma^2)^{1/2}} \exp\left(- \frac{\gamma}{2\sigma^2 (1 - \gamma^2)} D(x)\right)$$

where D(x) is the discriminant function defined by

(14)
$$D(x) = \gamma(x_1 - \mu)^2 + \gamma(x_2 - \mu)^2 - 2(x_1 - \mu)(x_2 - \mu).$$

The optimal classification decision using any of a certain wide class of loss functions is given by the rule that

(15) $\Omega > \theta \Rightarrow$ class 1

and

(16) $\Omega < \theta \Rightarrow$ class 0

where θ is a threshold value dependent upon the loss function and the a priori probabilities P(c), c = 0, 1. Since an equivalent rule can be obtained in terms of similar inequalities involving the discriminantfunction D(x), it follows that D(x) is optimal. Thus, it is an optimally significant distance or pseudo-distance measure.

The constant D contours are a family of hyperbolas with the asymptotes given by the relations

(17) $(x_2 - \mu) = \alpha(x_1 - \mu)$

and

(18) $(x_1 - \mu) = \alpha(x_2 - \mu)$

where

$$(19)\quad \begin{cases} \alpha = \gamma^{-1} + \sqrt{\gamma^{-2} - 1} \\ \quad = \gamma^{-1}\left(1 + \sqrt{1 - \gamma^2}\right). \end{cases}$$

The value D = 0, corresponds, of course, to the asymptotes themselves. The contours for which D > 0 lie to the northwest and southeast of the asymptotes corresponding to $\Omega < (1 - \gamma^2)^{-1/2}$, i.e. corresponding to increased probability that x belongs to class 0. The contours for which D < 0 lie to the northeast and southwest of the asymptotes corresponding to $\Omega > (1 - \gamma^2)^{-1/2}$, i.e. corresponding to increased probability that x belongs to class 1. (see Figure 7-9).

In the limit in which the utterances of the same person are perfectly correlated, i.e., $\gamma = 1$, we obtain

$$(20)\quad \begin{cases} D(x) = (x_1 - \mu)^2 + (x_2 - \mu)^2 - 2(x_1 - \mu)(x_2 - \mu) \\ \quad = (x_1 - x_2)^2 \end{cases}$$

in which case D(x) is the square of the distance between x_1 and x_2. Here the asymptotes are degenerate, i.e., they are coincident with the line $x_1 = x_2$.

In the opposite limit in which the different utterances of the same person are completely uncorrelated we obtain

$$(21)\quad D(x) = -2(x_1 - \mu)(x_2 - \mu)$$

Here the asymptotes are coincident with the x_1 and x_2 axes if the origin were translated to the common mean $Ex_1 = Ex_2 = \mu$.

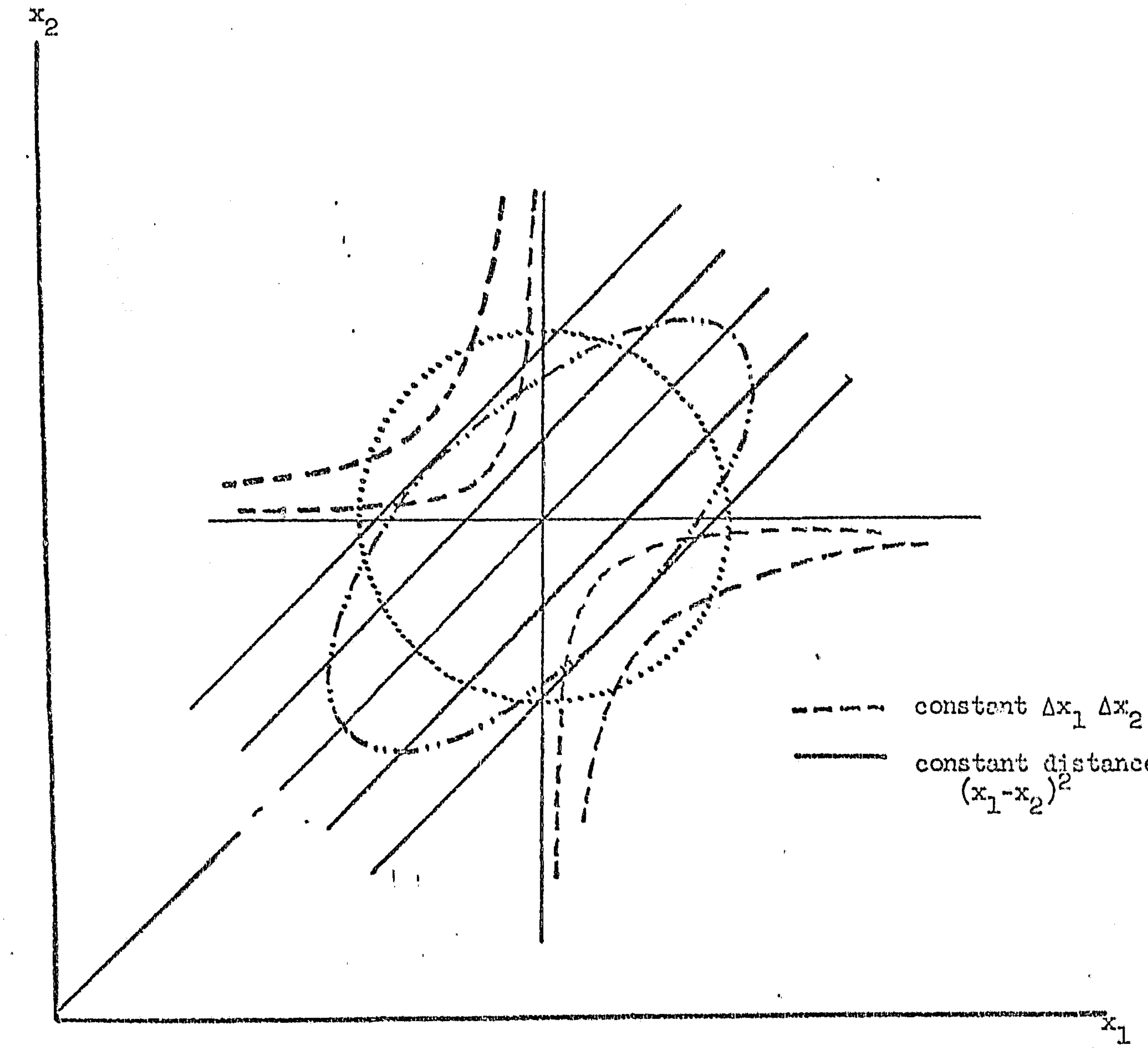


Figure 7-9 Comparison of Distance Measure with Alternative

7.2.1.3.2.2 Fisher Discriminant

We turn now to the consideration of another type of discriminant not requiring prior knowledge of probability densities in x-space. This is the Fisher (or Mahalanóbis) discriminant function which is defined as follows. Let us consider a vector z whose components are linearly independent functions of x. Let us introduce the operator

(1) $$\delta E(\cdot) = E(\cdot/0) - E(\cdot/0),$$

giving the difference of the class means, and the matrix

(2) $$C = P(0)\ \mathrm{Cov}\ (z/0) + P(1)\ \mathrm{Cov}(z/1).$$

The Fisher discriminant is defined by

(3) $$\phi = \delta E_z^T\ C^{-1}\ z,$$

A measure of the separability performance of is the following ratio of interclass to intraclass variations.

(4) $$F = \frac{(\delta E\phi)^2}{P(0)\ \mathrm{Var}(\phi/0) + P(1)\ \mathrm{Var}(\phi/1)}$$

i.e., the so-called F-ratio. A straightforward calculation yields the reduced form

(5) $$F = \delta E_z^T\ C^{-1}\ \delta E_z$$

which is the Mahalanóbis distance.

It will be useful to decompose z in the following manner

(6) $$z = \begin{pmatrix} z^{(+)} \\ \cdots \\ z^{(-)} \end{pmatrix}$$

where the components of the subvector $z^{(+)}$ are functions of

(7) $$x = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

that are invariant to the interchange $x_1 \rightleftarrows x_2$ and where the components of the subvector $z^{(-)}$ are functions that reverse sign with this interchange. It is easily established that

(8) $$\delta E_z^{(-)} = 0$$

and

(9) $$C = \begin{pmatrix} C^{(++)} & 0 \\ 0 & C^{(--)} \end{pmatrix}.$$

Thus, the Fisher discriminant reduces to

(10) $$\phi = \begin{pmatrix} \delta E_z^{(+)} \\ 0 \end{pmatrix}^T \begin{pmatrix} C^{(++)^{-1}} & 0 \\ 0 & C^{(--)^{-1}} \end{pmatrix} \begin{pmatrix} z^{(+)} \\ z^{(-)} \end{pmatrix}$$

$$= \delta E_z^{(+)^T}\ C^{(++)^{-1}}\ z^{(+)}.$$

which is the discriminant function we would have obtained if we had started out with $z^{(+)}$ in place of z. This result is independent of the dimensionality of z and the functions of x comprising its components.

Since the probability densities P(x/0) and P(x/1), determined by empirical means, are Gaussian to a good degree of approximation, it follows that limiting the components of z to quadratic functions of

$$\text{(11)}\qquad \begin{aligned} \Delta x_1 &= x_1 - \mu \\ \Delta x_2 &= x_2 - \mu \end{aligned}$$

will not lead to a significant degradation of performance of the Fisher discriminant.

Based upon the above considerations it follows that in the present case (i.e., two speakers but a given triad, given phonetic event, given feature and, finally, only one sample per speaker) the vector z must be three-dimensional with the two-dimensional

$$\text{(12)}\qquad z^{(+)} = \begin{pmatrix} (\Delta x_1)^2 + (\Delta x_2)^2 \\ \Delta x_1 \, \Delta x_2 \end{pmatrix}$$

and the scalar

$$\text{(13)}\qquad z^{(-)} = (\Delta x_1)^2 - (\Delta x_2)^2$$

as subvectors. It is clear that an equivalent form of $z^{(+)}$ may be obtained by multiplying the r.h. side of (12) by a nonsingular constant matrix. Obviously,

an equivalent form of $z^{(-)}$ can be obtained trivially by multiplying the r.h. side of (13) by a constant factor.

We now obtain

$$\text{(14)}\qquad \delta E_z^{(+)} = \begin{pmatrix} 0 \\ \delta E \Delta x_1 \Delta x_2 \end{pmatrix} = \begin{pmatrix} 0 \\ -\sigma^2 \gamma \end{pmatrix}$$

defining (now without the Gaussian assumption)

$$\text{(15)}\qquad \sigma^2 = \text{Var}\ (x_1/c) = \text{Var}\ (x_2/c)$$

and

$$\text{(16)}\qquad \sigma^2\gamma = E(\Delta x_1 \Delta x_2/1).$$

The matrix $C^{(++)}$ is given by

$$\text{(17)}\qquad C^{(++)} = P(0)\ \text{cov}(z^{(+)}/0) + P(1)\ \text{Cov}\ (z^{(+)}/1)$$

where in the Gaussian approximation

$$\text{(18)}\qquad \text{Cov}\ (z^{+}/0) = \begin{pmatrix} 4\sigma^4 & 0 \\ 0 & \sigma^4 \end{pmatrix}$$

$$\text{(19)}\qquad \text{Cov}\ (z^{+}/1) = \begin{pmatrix} 4\sigma^4\ (1 + \gamma^2) & 4\sigma^4\gamma \\ 4\sigma^4\gamma & \sigma^4\ (1 + \gamma^2) \end{pmatrix}$$

The Gaussian approximation for C will not cause significant error in the Fisher discriminant. We now obtain

(20) $$C^{-1} = (\mathrm{Det}C)^{-1}\sigma^4 \begin{pmatrix} (1 + P(1)\gamma^2) & -4P(1)\gamma \\ -4P(1)\gamma & 4(1 + P(1)\gamma^2) \end{pmatrix}$$

where

(21) $$\mathrm{Det}C = 4\sigma^8 [P(0) + P(1)(1 - \gamma^2)^2 + 4P(0)P(1)\gamma^2].$$

The discriminant is then

(22) $$\phi = -(\mathrm{Det}C)^{-1} 4\sigma^6\gamma \left[(1 + D(1)\gamma^2)\Delta x_1 \Delta x_2 - P(1)\gamma\left((\Delta x_1)^2 + (\Delta x_2)^2\right)\right]$$

The following limiting cases are of interest:

<u>(a) $P(0) = 1,\ P(1) = 0$</u>

(23) $$\phi = -\sigma^{-2}\gamma\,\Delta x_1 \Delta x_2$$

<u>(b) $P(0) = 0\ P(1) = 1$</u>

(24) $$\phi = \frac{\gamma^2}{\sigma^2(1-\gamma^2)^2}\left[(\Delta x_1)^2 + (\Delta x_2)^2 - \frac{1+\gamma^2}{\gamma}\Delta x_1 \Delta x_2\right]$$

<u>(c) $\gamma = 1$</u>

(25) $$\phi = \frac{1}{\sigma^2 P(0)(1 + 4P(1)}\left[P(1)\left((\Delta x_1)^2 + (\Delta x_2)^2\right) - \left(1 + P(1)\right)\Delta x_1 \Delta x_2\right]$$

<u>(d) $\gamma = 0$</u>

(26) $$\lim_{\gamma \to 0} \gamma^{-1}\phi = -\sigma^{-2}\Delta x_1 \Delta x_2 .$$

<u>(e) $P(0) = 0,\ P(1) = 1,\ \gamma = 1$</u>

(27) $$\lim_{P(0) \to 0} P(0)\,\phi = \sigma^{-2}(\Delta x_1 - \Delta x_2)^2 = \sigma^{-2}(x_1 - x_2)^2.$$

Thus, we see that a low correlation coefficient and/or a low probability $P(1)$ favors a discriminant proportional to $\Delta x_1\ \Delta x_2$. On the other hand, a high probability $P(1)$ (~ 1) <u>and</u> a high correlation coefficient ($\gamma \sim 1$) favor a discriminant proportional to $(x_1 - x_2)^2$, the Euclidean distance.

These results are to be contrasted with those in Section (7.2.1.3.2.1) associated with the likelihood ratio under the assumption that $D(x/0)$ and $D(x/1)$ are Gaussian. There we obtained the discriminant

(28) $$D(x) = \gamma\left((\Delta x_1)^2 + (\Delta x_2)^2\right) - 2\Delta x_1\ \Delta x_2.$$

In this treatment the <u>a priori</u> probabilities do not enter into the dicriminant itself but only into the threshold value used in the decision process, assuming that this is to be carried out. This is an important difference between the Fisher discriminant ϕ and the discriminant $D(x)$ based upon the likelihood ratio. However, the dependence on γ in ϕ and D are somewhat similar except that for ϕ to behave like D as γ approaches 1, $P(1)$ must also approach 1.

We can show that ϕ and D are identical, except for a constant factor, if we set

(29) $$P(1) = \frac{1}{2 - \gamma^2},$$

a relation that summarizes in quantitative form the qualitative remarks above.

7.2.2 Distance Measure Forms Investigated

Table 7-1 shows nine distance forms investigated. The global/local forms were chosen in the form 1 - exp ( ), which may be approximated by the curves shown in Figure 7-13. Only curve (1) was used.

Table 7-1

Distance Forms Considered Per Triad Pair

$$d_1^2 = \sum_{i \varepsilon I} W_i^2 (x_i - y_i)^2$$ weighted Euclidean

$$d_2^2 = \sum_{i \varepsilon I} (x_i - y_i)^2$$ uniform Euclidean

$$d_3^2 = \sum_{i \varepsilon I} g_i \left|(x_i - y_i)^2\right|$$ local

$$\text{where } g_i\left|Z\right| = \begin{cases} g_i\ (2.5\ \sigma_i), & Z \geq 2.5\ \sigma_i \\ Z, & Z < 2.5\ \sigma_i \end{cases}$$

$$d_4^2 = \sum_{i \varepsilon I} g_i \left|(x_i - y_i)^2\right|$$ global

$$\text{where } g_i(Z) = \begin{cases} Z, & Z \geq 2.5\ \sigma_i \\ g_i(2.5\ \sigma_i), & Z < 2.5\ \sigma_i \end{cases}$$

<u>data edited forms</u>

$d_5^{\,2} \sim d_1^{\,2}$ except drop minimum per speaker comparison

$d_6^{\,2} \sim d_1^{\,2}$ except drop maximum per speaker comparison

$d_7^{\,2} \sim d_1^{\,2}$ except drop minimum & maximum per speaker comparison

<u>discriminant forms</u>

$d_8 = \Sigma\, W_i\, \bar{d}_i$

where $d_i = (x_i - y_i)^2$; $\bar{d}_i$ = Aver. d_i over matching triad pairs

and $W_i = [E(\bar{d}_i/\text{intra}) - E(\bar{d}_i/\text{inter})]\ \text{Var}(\bar{d}_i/\text{inter})^{-1}$

$d_9 = \Sigma\, W_i\, Z_i$

where $Z_i = (x_i - \mu_i)(y_i - \mu_i)$; $\mu_i = \frac{1}{2} \underset{\text{triads speakers}}{\text{Aver}} (x_i + y_i)$

$\bar{Z}_i$ = Aver. Z_i over matching triad pairs

$W_i = [E(\bar{Z}_i/\text{intra}) - E(Z_i/\text{inter})]\ \text{Var}(\bar{Z}_i/\text{inter})^{-1}$

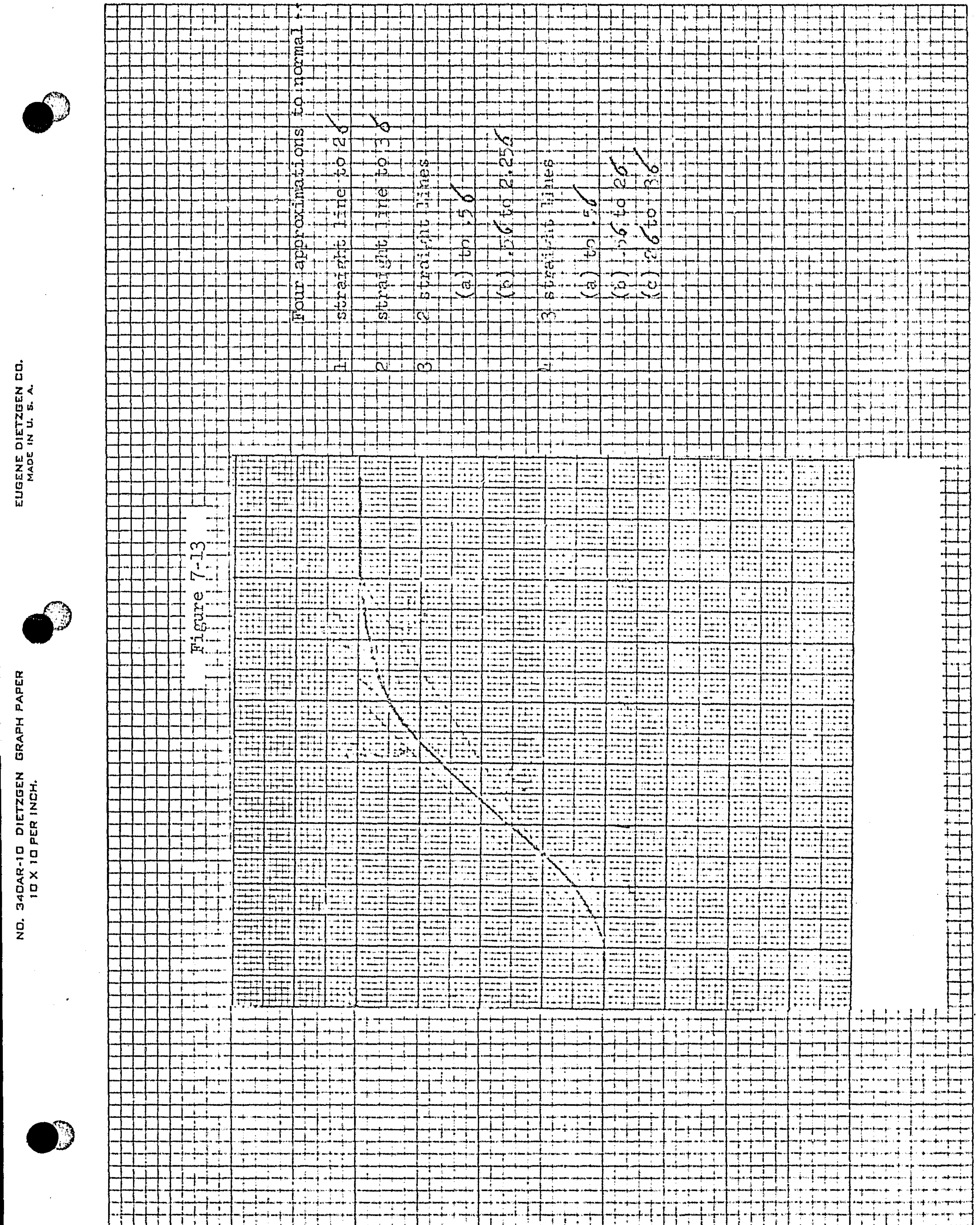
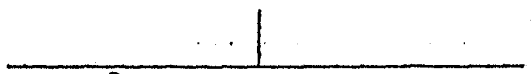


Figure 7-13

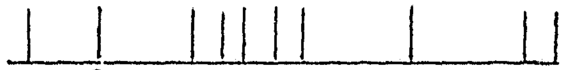
Effect of Number of Tokens (Triad Pairs) per Event

The distance per event is determined from the total number of triad pair distances per event. No distinction is made between the parallel and the concatenated viewpoint for handling the additional data which results from sentence repetitions or event repetitions. Hence, the data upon which a distance per event is based is illustrated in Figure 7-14.



(a) d^2 from a single triad pair

Figure 7-14



(b) d^2 from 10 triad pairs

The viewpoint taken is one which regards Figure 7-14b as data from which to form an estimate of the "true" distance, d, which is regarded as a random variable.

Forms considered for making the results of (a) and (b) comparable are:

(1) Since an average is an unbiased, consistent estimate, average the entries in (b) and associate three additional parameters with the result:

(a) number of triads averaged

(b) max d^2 - min d^2 (range)

(c) s. d. of the d^2 entries.

This triplet may be appended to the distance measure.

(2) select the min and max d^2 to characterize the event distance (worst case bounds).

(3) use (1) if σ^2 is sufficiently low, or (2) if σ^2 is sifficiently high.

These forms were examined initially to avoid conjecture on whether stray large token distances from the same speaker pairs or stray small token distances from different speakers pairs are more likely to occur. The latter is the case. Form (1) is used in the following without the appended triplet. The statistical justification for this structure has been discussed in Section 4.3.2.

7.2.3 Evaluation and Comparison--Methods and Results

In order to compare various metric forms, it is necessary to define one or more figures of merit or "measures of the measure." Although these figures of merit may be, and are, made quantitatively, they must be interpreted qualitatively. For example, a specific measure of error probability for a specific decision rule certainly is quantitative, but since (1) the desired goal is the minimization of the final error probability, and (2) minimization of an intermediate error probability does not guarantee this goal, even this specific measure must be broadly interpreted, with the aid of as much auxiliary data as is reasonable. The concepts discussed below were applied with these facts in mind.

7.2.3.1 F-Ratios

Figure 7-15 depicts distances between comparable triad pairs, within a single phonetic event, which results from a hypothetical comparison of three pairs of speakers. For example, for the first speaker pair comparison there are five triad pair distances whose average is shown as A_1 and whose variance is V_1. Similarly the six triad pair distances for the second speaker pair comparison yield A_2, V_2 and the five from the third yield A_3, V_3. The mnemonic terms average of the averages, the variance of the averages, and the average of the variances are defined as shown in Figure 7-15. These definitions may be computed separately for speaker pairs known to be the same people (the intraspeaker case), and for speaker pairs known to be different people (the interspeaker case), as is shown schematically in Figure 7-16. Two intuitively attractive F-ratios are also defined in Figure 7-16. Their use to explore various values for a thresholded distance measure is also shown in Figure 7-17. Two additional F-like ratios are also defined in Figure 7-17.

These auxiliary definitions attempt to relate the distribution of the variance to the F-ratio's attempt to measure spread. They are not properly normalized and were not pursued. The peaking of both F2 and F4 in Figure 7-19 as a function of the threshold parameter illustrates the use of these ratios to optimize a local distance measure. A refinement of the peak is shown in Figure 7-18. This technique, also, was not pursued for the following reason. While the F-ratio does give a quantitative measure of the spread between the intraspeaker and interspeaker distribution, the variances on which it depends are heavily influenced by points in the widely separated tails of the distributions. Hence, "optimal" peaks, like the one shown in Figure 3, are most likely the result of changes made to the tails and these are not of any particular interest for the SASIS application. Hence, metric comparison based solely on F-ratio type* figures of merit is likely to be misleading. However, given either similar variances or few points in the tails of the distributions, the F-ratio comparisons are useful. Table 7-2 shows F-ratios for the last three distance measures of the preceding section. The differences are not large. They will be discussed further in the next section. Tables 7-3 and 7-4 present the average of the averages (AA) and the average standard deviation (ASD), defined in Figure 7-16 for all 14 events for metric d_1 and d_7, respectively. Consider the histogram of the number of speaker pairs having a given number of valid triad pairs per event. These speaker pairs in the lower and upper half of this distribution are averaged and listed separately. Table 7-5 summarizes both halves for d_7.

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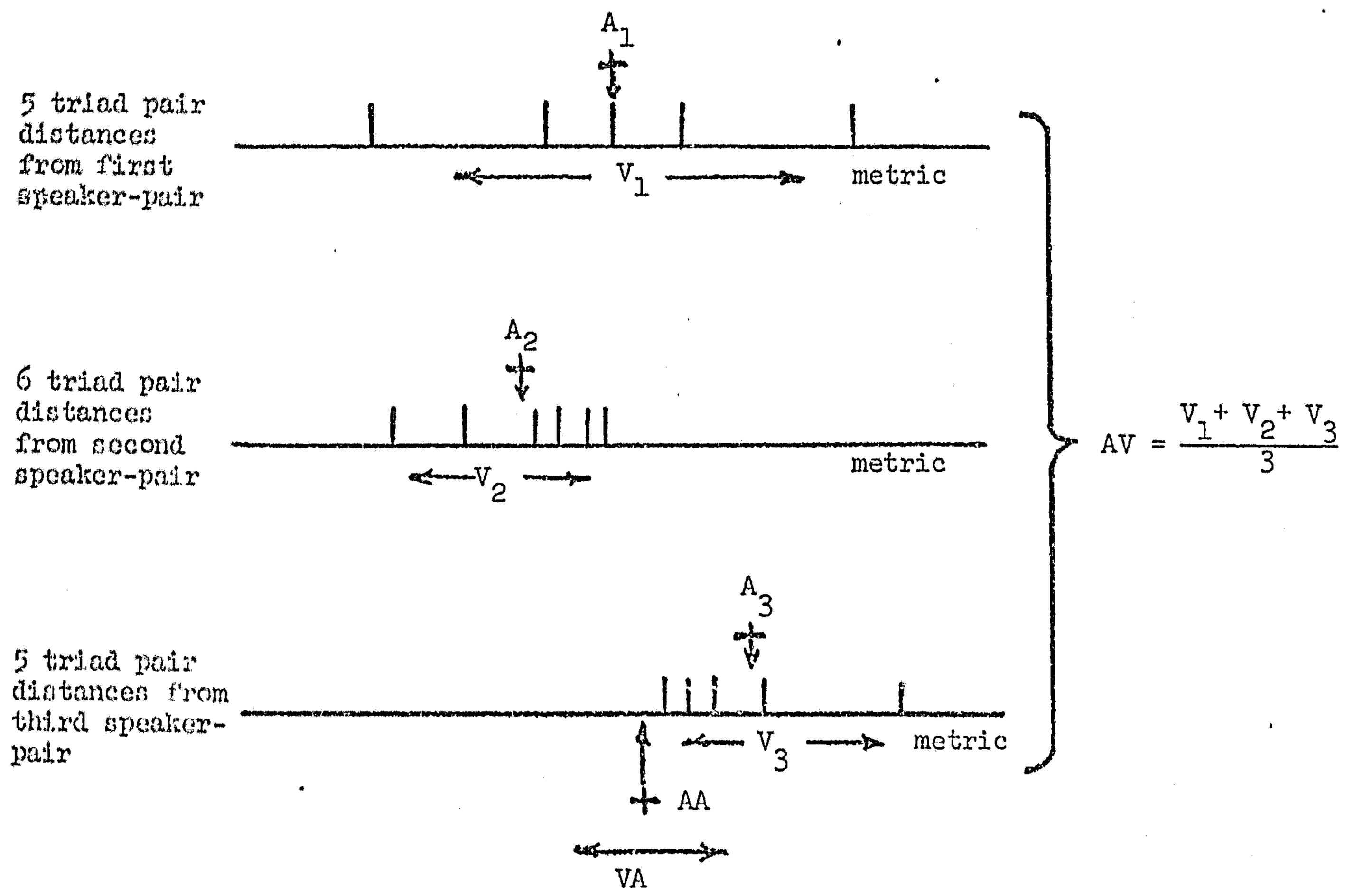
* The F-ratio may be modified, of course, so that, for example, a "pseudo-variance" is defined which is insensitive to outlying points. Certain such modifications were examined. They seem to introduce as many difficulties as they solve and they were abandoned in favor of the approach outlined in the next section.



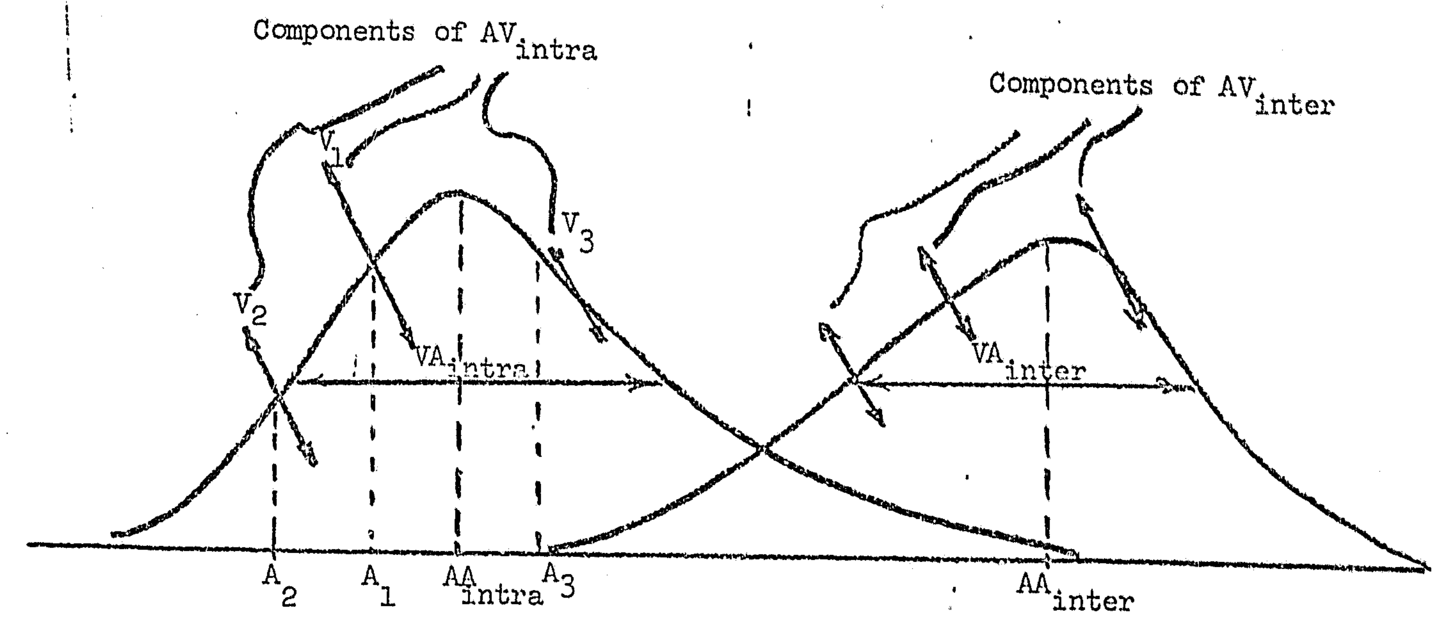
Definition of terms:

AA - ave. ave. = average (A_1, A_2, A_3)

VA - var. ave. = var. (A_1, A_2, A_3)

AV - ave. var. = average (V_1, V_2, V_3)

Figure 7-15



Schematic interpretation of the F-ratios:

$$F_2 = \frac{(AA\ intra - AA\ inter)^2}{(AV\ intra + AV\ inter)}$$

$$F_4 = \frac{(AA\ intra - AA\ inter)^2}{(VA\ intra + VA\ inter)}$$

Figure 7-16

EVT NO. 23 ×10^7 INTRA FA	INTRA √FA	INTER FA	INTER √FA	×10^14 INTRA AV	INTRA √VV	INTER AV	INTER √VV	a	b	c	d	F1	F2	F3	F4	threshold ×10^7
8.223	4.311	23.726	11.898	44.389	70.270	155.025	127.259	0.1	0.9	0.2	0.8	0.3	1.2	0.6	1.5	60
8.159	4.181	22.247	9.753	37.993	45.256	109.748	78.115	0.2	0.8	0.3	0.7	0.2	1.3	0.4	1.8	45
7.739	3.849	19.197	6.568	31.155	29.112	56.455	38.469	0.3	0.7	0.4	0.6	0.0	1.4	0.1	2.2	30
7.550	3.237	15.232	3.776	23.036	17.159	23.121	18.520	0.4	0.6	0.5	0.5	0.2	1.3	0.4	2.4	20
7.171	2.695	12.575	2.367	15.691	9.507	10.638	10.509	0.6	0.4	0.5	0.5	1.2	1.1	2.3	2.3	15
6.195	1.863	9.110	1.099	7.416	3.869	3.257	4.128	0.7	0.3	0.5	0.5	5.0	0.8	5.6	1.8	10
4.152	0.676	4.871	0.236	1.374	1.124	0.274	0.596	0.9	0.1	0.8	0.2	29.4	0.3	64.9	0.9	5

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$$F_2 = \frac{(AA_{intra} - AA_{inter})^2}{AV_{intra} + AV_{inter}}$$

$$F_4 = \frac{(AA_{intra} - AA_{inter})^2}{VA_{intra} + VA_{inter}}$$

$$F_1 = \frac{(b\ AA_{intra} - a\ AA_{inter})^2}{d\ AV_{intra} + c\ AV_{inter}}$$

$$F_3 = \frac{(b\ AA_{intra} - a\ AA_{inter})^2}{d^2\ AV_{intra} + c^2 AV_{inter}}$$

where $a = \frac{VA_{intra}}{VA_{intra} + VA_{inter}}$

$b = 1-a$

$c = \frac{VV_{intra}}{VV_{intra} + VV_{inter}}$

$d = 1-c$

Figure 7-17. Use of F-Ratios to Optimize a Local Distance Measure

F4 for Event 23 /1/

B \ A	5	10	15	20	25	30	35	40	45	50	55	60
35						1.9	2.0	2.1	2.1	2.1		1.9
30					2.0	2.2	2.2	2.1	2.1	2.1		1.9
25				2.2	2.3	2.4	2.2	2.0	2.0			1.9
20	1.3	2.2	2.4	2.4	2.2	2.0	1.8	1.6				1.9
15		2.2	2.3	1.7	1.1	1.2	1.3					1.8
10		1.8										
5	1.9											

Figure 7-18

Event	D_7		D_8	
	F2	F4	F4	F4
20	2.8	1.9	1.9	1.7
21	2.8	1.9	1.9	1.3
22	2.5	1.6	.1	.1
23	4.4	2.3	2.9	2.5
24	2.8	2.8	1.4	1.9
25	2.0	2.6	2.4	3.3
26	2.2	2.1	1.9	2.4
27	2.7	2.2	1.7	2.1
28	2.5	1.8	1.0	2.2
29	4.0	1.9	.05	.1
30	4.2	3.9	.3	.5
31	2.2	2.1	2.2	2.8
32	2.3	3.1	1.9	2.2
33*	4.8	.9	-	-

Table 7-2

F-Ratios for Selected Distance Measures

*insufficient data (Data Base I)

TABLE 7-3

	D_1 Intra AA lower ½	D_1 Intra AA upper ½	D_1 Int[illegible] AA lower ½	D_1 Int[illegible] AA upper ½	D_1 INTRA ASD lower ½	D_1 INTRA ASD upper ½	D_1 INTE[illegible] D lower ½	D_1 INTE[illegible] D upper ½
20	55.3	47.1	105.2	104.7	32.6	25.2	30.2	36.7
21	61.7	59.3	120.5	119.3	29.7	25.7	38.6	39.6
22	58.9	54.0	109.9	114.7	25.7	27.5	37.4	43.1
23	65.0	74.0	163.7	172.7	32.5	33.6	53.7	60.0
24	52.2	45.0	112.5	104.0	19.4	23.5	41.4	39.6
25	39.2	43.8	89.8	76.7	22.5	22.3	32.7	28.5
26	46.5	48.0	98.6	93.7	25.7	23.3	37.1	35.7
27	60.8	50.3	128.4	111.0	33.4	31.3	46.2	42.3
28	73.9	81.3	170.2	155.0	40.2	44.5	59.3	58.3
29	60.0	48.5	144.4	109.2	16.2	19.0	30.8	39.5
30	49.3	46.3	118.3	107.6	19.7	22.8	38.7	37.9
31	48.4	43.0	99.1	93.6	27.1	21.5	38.8	36.9
32	34.1	32.3	66.3	60.6	13.7	14.1	24.6	22.7
33	95.9	79.4	259.5	165.6	17.8	32.3	37.5	54.1

TABLE 7-4

D_7

EVENT	INTRA AA Lower ½	INTRA AA Upper ½	INTER AA Lower ½	INTER AA Upper ½	INTRA $\sqrt{AV}$ Lower ½	INTRA $\sqrt{AV}$ Upper ½	INTER ASD Lower ½	INTER ASD Upper ½
20	59.0	42.4	106.5	102.9	19.0	10.6	15.2	21.8
21	61.6	52.3	121.1	117.1	18.2	19.7	23.8	25.5
22	57.0	51.1	109.0	111.8	12.7	16.8	24.2	26.9
23	62.4	69.8	169.8	169.4	20.4	18.4	33.7	41.9
24	51.5	42.9	110.0	101.9	12.4	17.4	28.9	30.0
25	36.9	42.4	88.1	75.3	15.7	16.7	22.8	21.1
26	43.8	46.4	97.0	90.8	17.6	15.9	25.4	25.0
27	56.0	46.7	125.4	108.4	19.8	20.4	32.0	31.0
28	67.9	75.9	168.9	151.2	23.7	30.5	35.9	39.8
29	59.4	57.3	145.4	118.1	11.0	19.0	24.3	24.9
30	47.3	43.6	116.2	105.7	12.3	19.6	24.7	27.9
31	45.5	40.9	96.9	91.3	18.2	14.8	27.1	26.6
32	33.0	31.5	64.5	59.2	7.8	10.6	15.1	16.0
33	106.3	69.7	260.8	176.1	7.4	11.5	37.9	35.0

TABLE 7-5

D_7

EVENT	INTRA AA	INTRA $\sqrt{VA}$	INTRA AV	INTER AA	INTER $\sqrt{VA}$	INTER AV
20	50.4	20.4	447.9	104.7	34.2	619.0
21	56.8	24.5	536.4	119.1	38.2	835.8
22	53.9	14.8	296.5	110.4	41.7	955.1
23	66.3	20.7	459.6	167.1	63.9	1838.6
24	47.0	12.7	263.5	105.9	32.9	991.1
25	39.8	10.7	319.9	81.7	23.4	542.4
26	45.1	15.6	391.1	93.9	29.4	760.6
27	51.1	16.3	481.7	116.9	40.7	1119.9
28	72.1	26.9	1065.1	160.1	59.5	1993.4
29	55.2	24.2	277.2	128.7	48.0	1067.2
30	45.4	10.5	222.1	110.9	31.3	797.8
31	43.1	14.3	391.6	99.1	32.1	828.2
32	32.3	8.2	102.6	61.9	14.6	277.2
33	87.2	51.6	175.9	216.6	130.1	3397.2

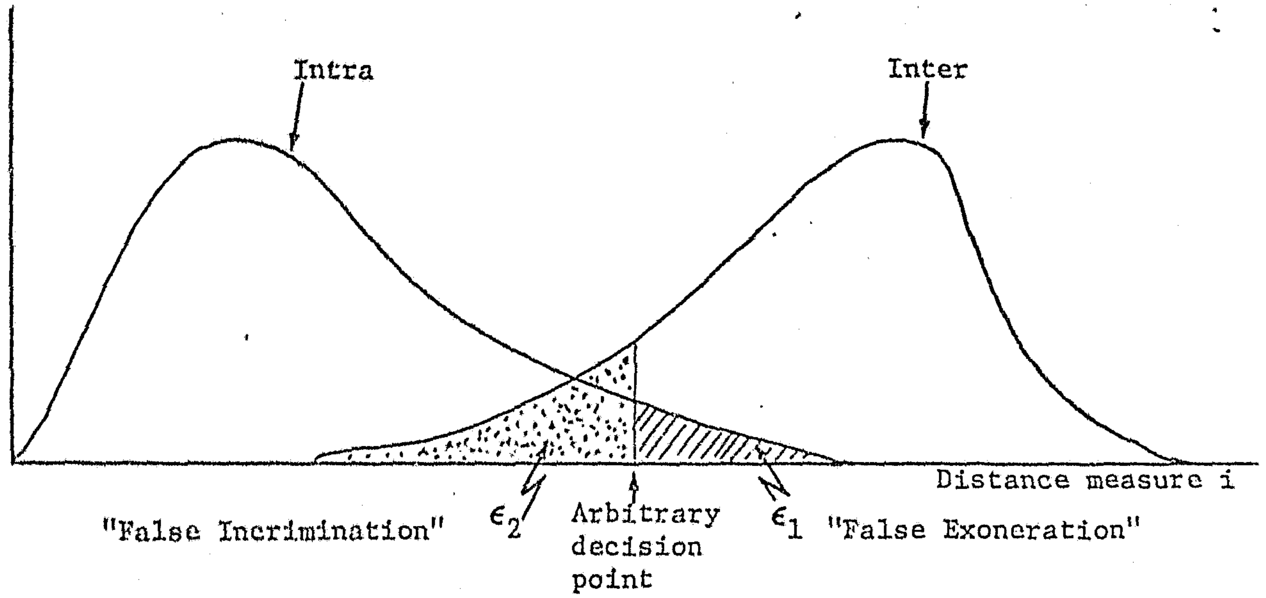


FIGURE 7-19(a). INTRASPEAKER AND INTERSPEAKER NORMALIZED HISTOGRAMS

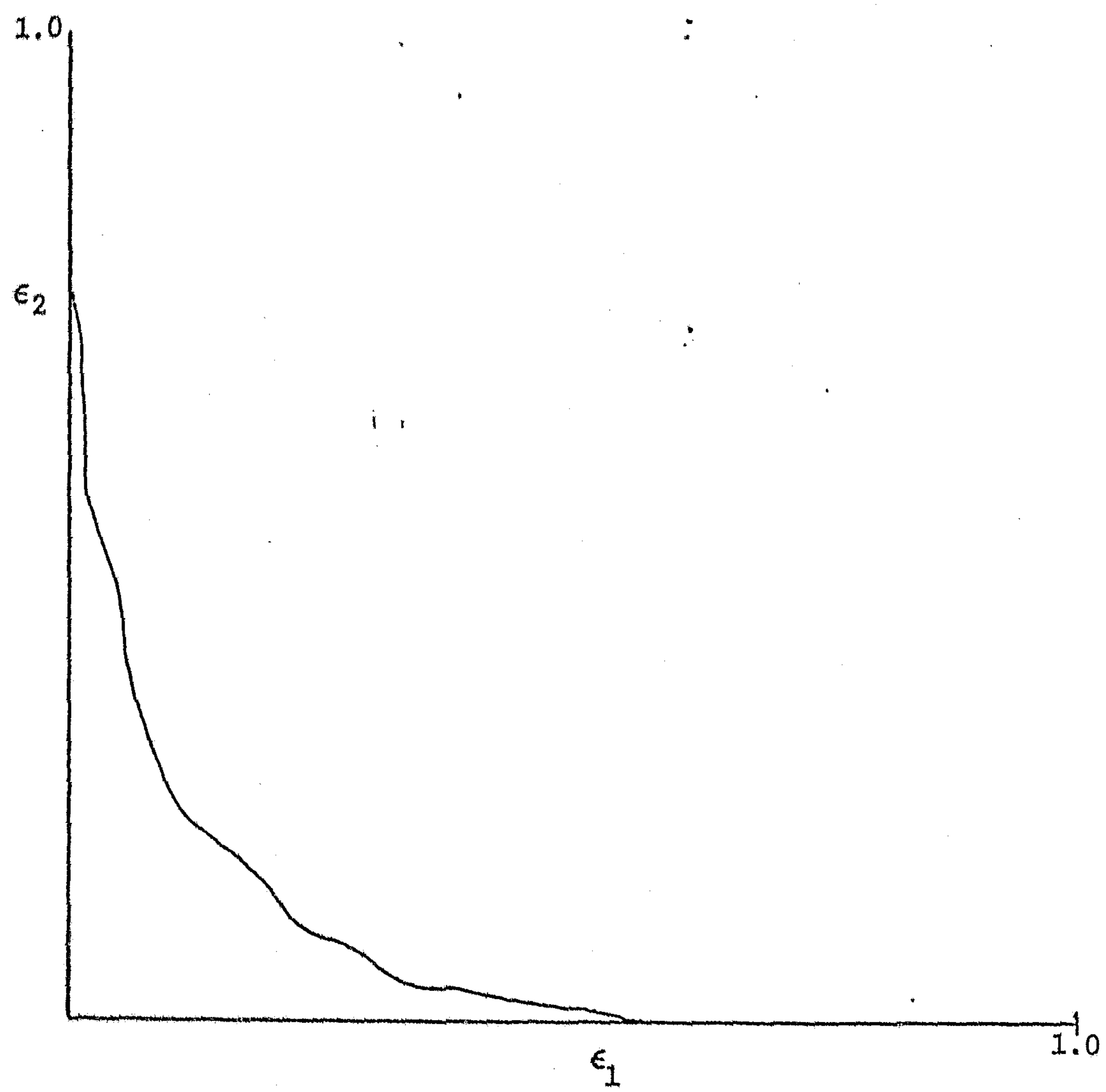


FIGURE 7-19(b). SOC (SASIS OPERATING CHARACTERISTIC)

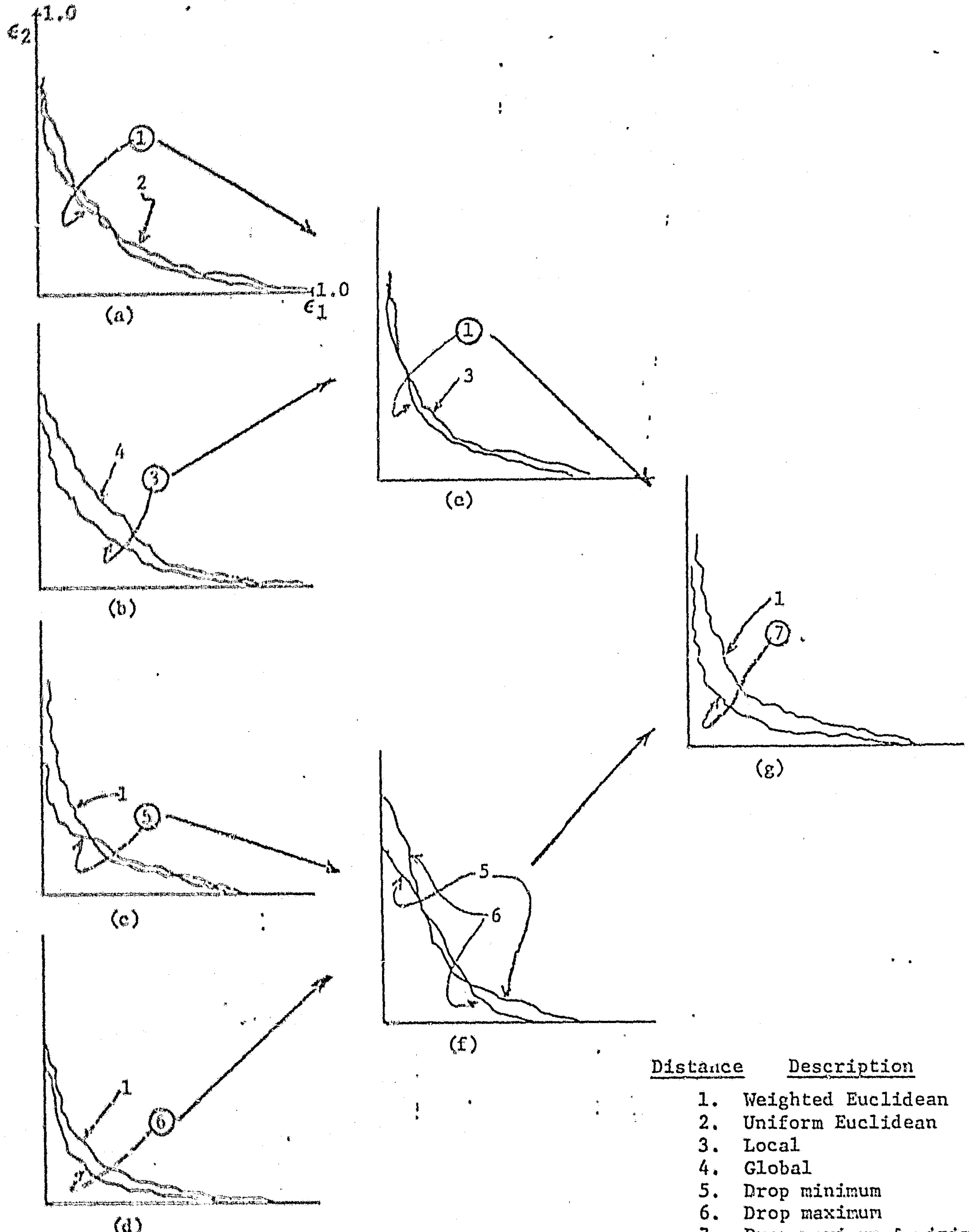
7.2.3.2 Operating Characteristic Curves for SASIS (SOC)

Figure 7-19(a) shows hypothetical intraspeaker and interspeaker normalized histograms for one event. If an arbitrary decision point were chosen, the resulting false exoneration probability E_1 and false incrimnation probably E_2 is shown graphically. The result of plotting E_1 versus E_2 as the arbitrary decision point traverses the entire range of the distance measure is a "characteristic" function or curve which describes the overlap region of the histograms. An example is shown in Figure 7-19(b). The term SOC (SASIS Operating Characteristic) has been coined to denote this curve. It describes precisely that information which is of most use to SASIS. Since it is self normalizing and invariant to arbitrary non-linear distortions of the distance axis, it permits a ready comparison of the effects of the various distance measures on the overlap of the intraspeaker and interspeaker histograms. Its use for comparing various metrics is, of course, subject to the qualification that the overlap of interest is not that shown on Figure 7-19(a), i.e., for a *single* event, but that for a concatenation of events viewed through a yet-to-be-defined similarity measure. Hence, selection of a distance measure which is optimal by SOC comparison criteria is not necessarily the optimal overall solution. We maintain, however, that it is an eminently reasonable solution.

Figure 7-20 presents a summary of SOC comparisons made for all 14 phonetic events for the first seven distance measures listed in Table 7-1 above.+ The ideal no-overlap condition is represented by the two axes. If the curves cross, a subjective judgment must be made*. Part (a) of Figure 7-20

+The complete set of curves is given in Appendix 7-A.

*Of course, this may be made quantitatively, for example, defining as an auxiliary figure of merit, e.g., the area under the SOC curve. This has not been done since the use of the SOC curve is already a qualitative comparison.



Distance	Description
1.	Weighted Euclidean
2.	Uniform Euclidean
3.	Local
4.	Global
5.	Drop minimum
6.	Drop maximum
7.	Drop maximum & minimum

FIGURE 7-20. SUMMARY OF COMPARISON OF DISTANCE MEASURES d_1, ..., d_7

shows that a properly weighted Euclidean measure is, in general, superior to a uniformly weighted measure, as would be expected. Part (b) of the figure shows that the local measure d_3 is always significantly better than the global measure d_4, while part (e) shows that the weighted Euclidean form is superior to the local measure d_3. Hence, the conjectures of section 7.2.1.3.1 above are not supported by this data and the non-local form of distance measure is preferable when the SOC curves are used as a figure of merit. The motivation for the data-editing forms d_5, d_6, and d_7 is the intuitive reasoning that outliers,, on any statistical distribution which may be viewed as a superposition of a "true" population and additive noise with a larger variance, may significantly distort the sample and may be eliminated by a non-linear data discarding process.

Parts (c) and (d) of Figure 7-20 show the effects of dropping the maximum and minimum triad-pair distance per speaker comparison. In general, dropping the minimum decreases E_2 (which may be interpreted as the false incrimination rate) without affecting E_1 (the analygous false exoneration rate); while dropping the maximum decreases the E_1 without appreciably affecting E_2. These effects are plausible since the largest percentage effect occurs in the overlapping tails of the distributions illustrated in Figure 7-19(a). The combined effect of dropping the maximum and minimum is shown by d_7 in Figure 7-20(g). It is not as intuitively clear, but apparently is true, that these effects are approximately additive, so that d_7 is appreciably better than d_1. The data edited weighted Euclidean form d_7 emerges as the metric chosen from these first seven measures. For these plots, the histograms were compiled from the triad pair distances without averaging over the distances available within a speaker pair comparison. Hence, the overlap between the interspeaker and intraspeaker histograms is a worst-case upper bound on the overlap to be expected when averaging is included. The overlap obtained represents the case where only single triad-pair distances are typically available for a phonetic event. Foldout sheet Figure 7-21 repeats the curves summarized by Figure 7-20(a) and gives the same curves for the case where the histograms are computed by averaging over-all triad-pairs available in data base I. The separation decreases in all cases, as expected, but the superiority of d_7 over d_1 is no longer as clear. This point is discussed further below in section 7.2.4 after consideration of metrics d_8 and d_9. Foldout sheet Figure 7-22 shows the SOC curves for all the events* for distance measures d_8, d_9 and d_7. For these plots, the histograms associated with the distance measure d_7 were obtained by first averaging over all triad-pair distances within each speaker-pair comparison. The small triangles indicate a choice of the best of the three. As may be seen, the differences are frequently small. If only one form is to be selected, however, the choice must go to d_7 because of the rather erratic behavior of d_8 and d_9 for certain events (which may indicate a sensitivity to the data). If the unaveraged curves for d_1 are substituted for the d_7 in the figure, the conclusions drawn are not changed.

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*Event 33 was not sufficiently represented for curves for d_8 and d_9 to be obtained.

7.2.4 Summary of Functional Form Selected

As discussed above, distance form d_1, the weighted Euclidean metric, is not the optimum measure when the SOC curves are used as the figure of merit. However, the differences between this measure and the best of the above alternatives are slight. The data editing forms have the subjectively annoying characteristics of being inapplicable when the data is sparse. The discriminant function forms are apparently erratic over the data examined. The global/local thresholding conjectures actually made the SOC curves worse. Hence, the upshot of this investigation is to confirm the utility of the generally used properly weighted Euclidean sum. There is no doubt that superior measures are attainable, but none has been found which are significantly and consistently better from the viewpoint of the figures of merit employed. Hence, we are lead to the following summary.

For each event, there is a set of 30 features, weights and normalizing factors of interest:

A. Each feature value F_i is normalized to fall within a byte

$$F_i' = \left[\left(\frac{64.0}{SD_i}\right) * (F_i - \overline{F}_i)\right] + 127.0$$

where SD_i and $\overline{F}_i$ are calculated from the training data and known a priori for each feature.

B. The distance between two corresponding triads is the weighted Euclidean sum

$$\sum_{i=1}^{30} W_i^2 \quad (F_{i1}' - F_{i2}')^2$$

where the W_i are known a priori and the F_{i1}' and F_{i2}' are the normalized feature values from triads 1 and 2, respectively.

C. All such distances available within an event class are averaged to produce a distance for that event between speaker 1 and speaker two.

7.3 SIMILARITY MEASURE

7.3.1 Introduction

For a given phonetic event class, e, the distance between two speakers (who may or may not be the same person) is denoted by d_e. For a particular operational speaker comparison, there are one or more phonetic event classes and their corresponding distances, yielding a vector

$$\bar{d} = \{ d_e | e \in \mathscr{S}_e \}$$

whose components are the individual phonetic event distances which are present (this set is denoted by $\mathscr{S}_e$). The similarity measure must accept this vector $\bar{d}$, of dimension 1 to 10, and produce a quantitative measure of similarity, between the two speakers, which has (a) statistical significance, and (b) an understandable interpretation.

An ideal similarity measure would satisfy the following criteria:

(a) It must be insensitive to sampling fluctuations in the training set, i.e., it must have almost the same value when computed for two different random samplings of the same parent population.

(b) It must converge to a definite limit as the size of the training set increases.

(c) It must be a good measure in the case of low false incrimination probabilities. (If it is used as an investigative tool, this is less important.)

(d) It must be as free of subjective elements as possible.

(e) Whatever subjective elements exist must be of a kind that is widely accepted by workers in information sciences, in particular, mathematical statistics.

(f) The measure must be of such a nature that it can be used by the law enforcement community.

(g) It must be easy to compute for a multiplicity of sets $\mathscr{S}_e$ of phonetic events available for comparison purposes.

7.3.2 Discussion of the Relative Merits of the Direct and Indirect Approaches

7.3.2.1 Definitions

For a specific vector $\bar{d}$, of any given dimension from 1 to 10, there exists an exact probability density function which describes its distribution over the two possible hypotheses:

(1) The two speakers are, in fact, the same -- an <u>intra</u>-class distribution.

(2) The two speakers are, in fact, different -- an <u>inter</u>-class distribution.

For a given dimensionality i of $\bar{d}$, there are $\binom{10}{i}$ subsets of phonetic events of which $\bar{d}$ may be comprised. The following table gives the number of probability density functions which, in principle, exist as a function of the number of dimensions.

For 10 distances based on phonetic event groups, there are 1023 joint probability density functions, as shown in Table 7-6.

Table 7-6

# Dimensions	# Probability Density Functions	Example
1	10	$p(d_1)$
2	45	$p(d_1,d_2)$
3	120	$p(d_1,d_2,d_3)$
4	210	$p(d_4,d_5,d_7,d_{10})$
5	252	$p(d_2,d_4,d_6,d_8,d_{10})$
6	210	$p(d_1,d_2,d_3,d_4,d_5,d_5)$
7	120	$p(d_1,d_2,d_3,d_5,d_7,d_8,d_9)$
8	45	$p(d_1,d_2,d_3,d_4,d_5,d_6,d_9,d_{10})$
9	10	$p(d_1,d_2,d_3,d_4,d_6,d_7,d_3,d_9,d_{10})$
10	1	$p(d_1,d_2,d_3,d_4,d_5,d_6,d_7,d_8,d_9,d_{10})$

7.3.3 Forms Investigated

Given the distance vector $\overline{d}$ of dimension K between 1 and 10 (i.e., there are K particular events present for a particular speaker pair comparison), mappings or transformations of $\overline{d}$, into a scalar S, of the following form have been investigated:

$$S = \overline{a}^T \overline{d} + \overline{d}^T B \overline{d}$$

where $\overline{a}$ is a constant vector of dimension K and B is a constant K x K matrix. The motivations for consideration of this class of transformations comes from several directions:

(a) they are readily amenable to analysis

(b) they are optional with respect to figures of merit and functional forms which are widely used in mathematical statistics.

(c) they reasonably satisfy the criteria of Section A above

(d) they represent a logical extension of previous work

Discussion

Given a comparison between two speakers, which may or may not be the same person, the presence of K phonetic event classes results in a distance vector $\overline{d}$ of dimension K. If the labelled data are from the same speaker, this point is included within the intra-speaker distribution; if they are not, the point is included within the inter-speaker distribution class. Hence, we have a classical two-class problem. The F-ratio of Fisher has frequently been used as a figure of merit or quality to judge the optimality of various members of the class of transformation given above. Maximization of this ratio, which is the square of the separation of the two class means, divided by the sum of the variances about each class mean, yields a projection of the vector $\overline{d}$ into one dimension, i.e.,

$$B = 0$$

and $\overline{a} = [E(\overline{d}^T/\text{same speaker class}) - E(\overline{d}^T/\text{different speaker class})]C^{-1}$

where C^{-1} is the inverse of a weighted sum of the covariance matrices for each class.

In addition to being optional with respect to this intuitively reasonable F-ratio criteria, this Fisher discriminant is optimal in the decision theoretic sense if the distribution functions of the two classes are Gaussian (either with identical covariance matrices or with a suitable normalization before the discriminant is applied).

A comparable justification of the complete quadratic form requires either a figure of merit or a distribution functional form for which it is optimal. Since neither has been widely used, we simply defer to the results below to indicate the reasonableness of the consideration of the additional terms from the point of view of improved performance.

Interpretation of the Statistics of Scalar S

Appendix 7-2 discusses five possible quantities which are relatable to whatever scalar similarity measure S is selected. The one chosen is the likelihood ratio based on the probability distribution functions

$$\Lambda = \frac{\epsilon_1}{\epsilon_2} = \frac{1 - \text{p.d.f.}(\overline{d}/\text{intraclass})}{\text{p.d.f.}(\overline{d}/\text{interclass})}$$

7.3.4 Presentation and Discussion of Experimental Results

7.3.4.1 Linear Forms

A series of experiments was conducted for the purpose of comparing the levels of performance of various candidate similarity measures. The data employed in this experimentation consisted of the extended edited weighted Euclidean distance data described in Section 8.0 below.

Three metric forms were empirically examined:

(1) The Fisher linear discriminant

$$S = \overline{a}^T \overline{d}$$

where $\overline{a} = [E(\overline{d}^T/\text{same speaker class}) - E(\overline{d}^T)\text{ different speaker class})]C^{-1}$

(2) The linear discriminant for the case of the separating plane perpendicular to the vector connecting the class means (C=I)

$$S = \overline{a}^{T} \overline{d}$$

where $\overline{a} = E(\overline{d}^{T}$/same speaker class) $- E(\overline{d}^{T}$/different speaker class)

(3) The uniform linear discriminant

$$S = \overline{a}^{T} \overline{d}$$

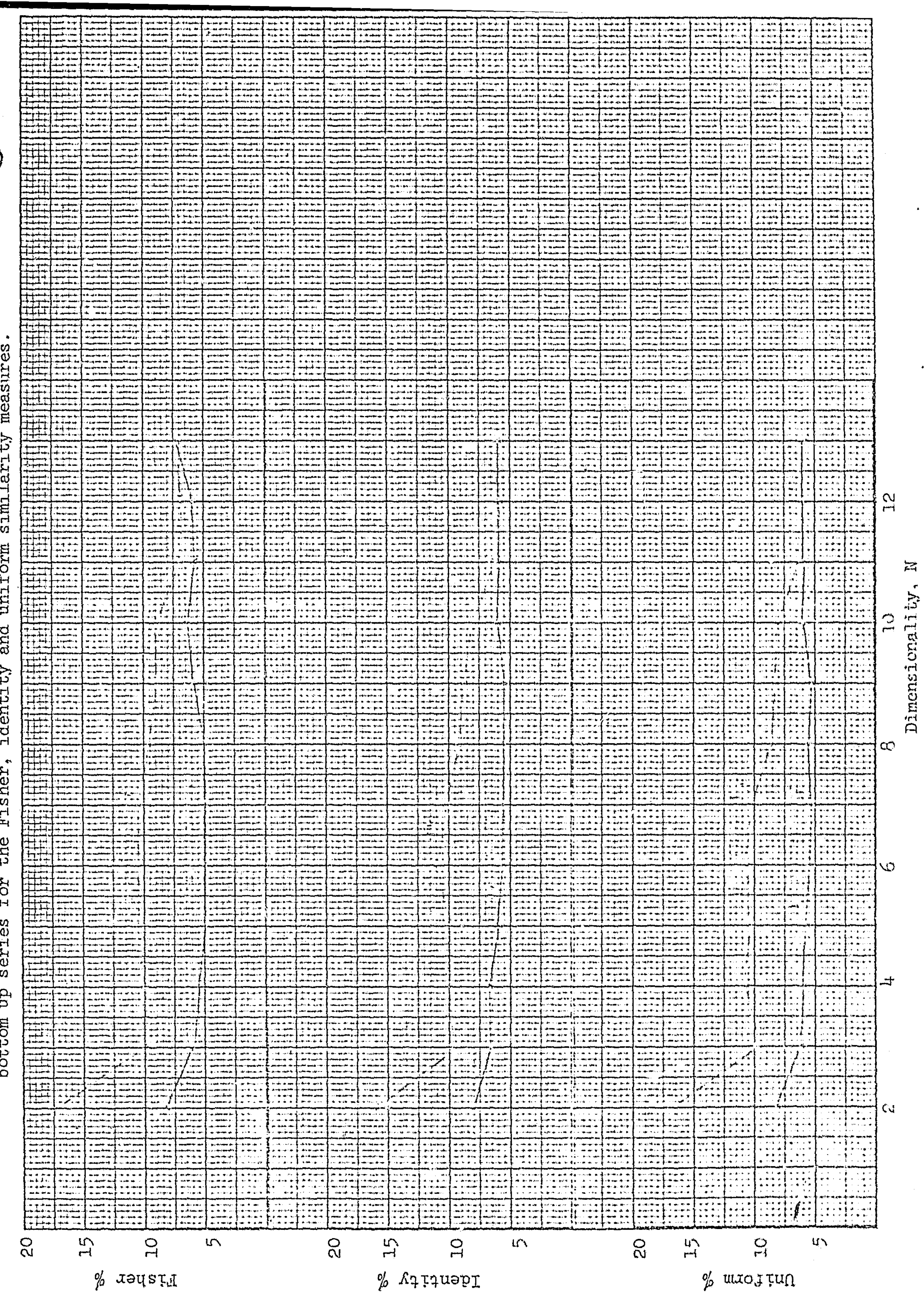
where $\overline{a}^{T} = [1\ 1\ \ldots\ 1]$.

The primary criterion of performance used was total area of the SOC curve. For each of the three metrics above, 24 SOC curves were developed. Twelve plots were generated by repeatedly defining the metric to be a function of the N highest ranked types of the SOC ranking, based on the distances of single phonetic events. The parameter N, therefore, ranged from 2 to 13 and the weight vector $\overline{a}$ recomputed for each value of N. In a similar manner, the remaining 12 curves resulted from the N lowest ranked types. The resulting three sets of SOC curves (Figures 7-23 and 7-24) and plots of the error rate as a function of dimensionality at $\epsilon_1 = \epsilon_2$ (Figure 7-25) were qualitatively compared.

It is apparent from the error rate plot that the rate of error at a given threshold is not necessarily a monotonically decreasing function of dimensionality. In the case of the Fisher discriminant taken top down, the inclusion of events ranked below eight on an independent SOC basis combined with the effects of a non-Gaussian distribution caused an eventual degradation of slightly over 2%. The decrease in performance was not as significant in the case of the identity covariance matrix and uniform linear metrics for the top down series.

Each of the bottom up series exhibited a very significant drop in error rate as dimensionality was increased from 2 to 3 (inclusion of the /n/). Inclusion of /Λ/ resulting in a dimensionality of 11 effected a 3 to 5% decrease in error rate across metrics. It is important to note that the error rate at $\epsilon_1 = \epsilon_2$ is a strong function of N for low dimensionality, regardless of the metric utilized. For N = 2, the difference in performance between the lowest and highest ranked types is 8 to 9%. For N = 6, the difference is 5 to 6% and for N = 10, 2 to 3%.

Figure 7-25. Error rate at $\epsilon_1 = \epsilon_2$ in percent as a function of dimensionality in the top down and bottom up series for the Fisher, identity and uniform similarity measures.



As judged by both the SOC curves and error rate curves, the performance of the identity matrix and linear uniform metrics is essentially identical. This result is expected since little inter-type variation in distance exists on either an intra- or inter-speaker basis. In comparing the Fisher with the identity and uniform metrics on the basis of the SOC curves alone, the former possesses a slight superiority for dimensionalities less than eight, particularly in the top down case. For $N > 8$, the identity and uniform metrics exhibit considerable advantage over the Fisher for both the top down and bottom up series. At $\epsilon_1 = \epsilon_2$, the identity and uniform metrics displayed a trend of superiority for $N > 8$ and at $N = 2$ in the bottom up case. In the top down series, the Fisher was superior for $3 \leq N \leq 8$ and inferior for $N = 9$ and 13. As there are several crossover points in error rate between the three metrics as the threshold is varied, error rates at $\epsilon_1 = \epsilon_2$ are not as useful for comparing the metrics as are SOC curves.

Two factors are of interest in comparing the performance of the Fisher with respect to the identity and uniform forms. These are (1) the shape of the distributions, and (2) the positions of their means. As dimensionality increases, the means of the intra- and inter-distributions will fall closer to the 45° axis in hyperspace; thus, the identity matrix and uniform linear form will tend to improve in performance. On the other hand, the increasingly non-Gaussian nature of the distributions as dimensionality is increased will tend to twist the Fisher vector to a position away from the 45° axis vector to a more sub-optimum orientation. At low dimensionality, the degradation from non-Gaussian distributions is outweighed by the shift of the distributions from the 45° axis.

These statements concerning performance of the Fisher approach should be regarded only as hypotheses. Certainly, a more explicit statement of the properties of the intra- and inter-distributions in 13 dimensions would be appropriate if readily available. Based on the results of this section, a decision was made to use the Fisher metric, but with a suitable desensitization of the covariance matrix to reduce the degradation experienced at higher dimensionality and dependency on the intrinsic characteristics of Data Base II. Experimentation involving desensitization is discussed in the following section.

7.3.4.2 Desensitization Study

For the purposes of (1) reducing the sensitivity and dependency of the coefficients on pecularities or imbalances that may exist in the data base (II) used for coefficient generation, and (2) reducing the degradation in performance of the Fisher metric relative to the identity and uniform metrics at greater dimensionality, the use of a desensitized version of the covariance matrix in the calculation of the Fisher coefficients was examined. Specifically, desensitization was introduced by modification of the diagonal terms C_{ii}, $i = 1, \ldots, N$, through the following function:

$$C'_{ii} = C_{ii} + k \cdot \hat{C}$$

where C_{ii} is the autocovariance term from the original matrix for the ith event and $\hat{C}$ is either the minimum or maximum of the diagonal terms of the original matrix. It should be noted that as k is increased, effectively the case of $C = I$ is approached.

A series of experiments was performed on the extended Euclidean distance data of Data Base I with the intent of selecting an appropriate degree of desensitization. The three phonetic sets utilized were (1) the highest 5 types of the single event SOC ranking, (2) the highest 9 types of the ranking, and (3) the full set of 13 types. For each set, five SOC curves were generated (Figure 7-26). The first was the case of $\hat{C} = C_{ii(min)}$ and $k = 1.0$. The remaining four were for $\hat{C} = C_{ii(max)}$ and $k = 0.1$, 0.5, 1.0, and 10.0.

Performance was found to be quite compatible with the experimental results of the previous section. For $N = 5$, the SOC curves deteriorated somewhat with increasing desensitization. In the case of $N = 9$, little change was observed and for $N = 13$, gradual improvement was achieved excluding the result for $k = 10.0$. Using the overall performance, as judged by the SOC curves, of the three phonetic sets for each of the five cases, the desensitization function was selected to be

$$C'_{ii} = C_{ii} + 0.5 \ C_{ii(max)}.$$

7.3.4.3 Nonlinear Forms

For the situation of Gaussian distributional forms for $\overline{d}$ in both the intra- and inter-speaker cases, the linear form of S given by

$$S = \overline{a}^T \overline{d}$$

is optimum with regard to the criterion of Fisher F-ratio. As a limited means of gaining knowledge of the form of p.d.f.$\overline{d}$, d_{e_i} was plotted, in a density representation, as a function of d_{e_j} for several phonetic types e_i and e_j on both an intra- and inter-speaker basis. The extended weighted Euclidean distance data described in Section 7.2 was used for these scatter plots (Figure 7-27). Visual observations suggest that the inter distributions are vaguely though probably not exactly Gaussian. Data for the intra situation was too limited to be conclusive.

It is of interest to determine the gain in speaker discrimination performance that may be achieved, by the utilization of nonlinear forms as given by Equation 7.1 (excluding forms of a quotient nature). Thus, a limited empirical study was performed to determine the value of some simple nonlinear functions. Two phases of experimentation were undertaken. The first involved computation of the F-ratios[1] for all products, quotients, and sums of the distances for two events. The distances employed were the edited weighted Euclidean (extended) data of various triad tokens of the same phoneme type taken between the 25 speakers of Data Base I.

Results, as initially judged by F-ratio, were found to be quite poor for quotients; therefore, SOC curves were not generated for this form. Products, however, indicated greater speaker separability on a global basis. Those products involving the events /u/ and /ʒ/ consistently achieved F-ratios greater than found for combinations not containing either of these two types. The F-ratios of uniform sums of two events were also computed and found to be invariably higher than those of the product for the same event pair. As a means of making a valid comparison of the two on the basis of the local properties of inter- and intra-distributions in the overlap region, SOC curves

1 This F-ratio, as distinguished from the Fisher F-ratio, has the traditional definition of the quotient of the variance of means and the mean of variances.

were plotted for the products and sums of the 12 event pairs which yielded the highest F-ratio for products. The product was judged to be superior for five pairs while, in the remaining seven cases, the curves were too similar for a definitive decision[1].

No significant correspondence was found between F-ratio (global) and SOC curve (local) performance, i.e., those pairs possessing a higher F-ratio did not necessarily yield a more minimal SOC curve.

The second phase of experimentation involved overall distance functions consisting of the sum of linear and nonlinear terms. Two cases were considered. The first metric is given as

$$S = \overline{a}^T \overline{d} + d_2 d_{10} + d_2 d_{11} + d_7 d_{11} + d_{10} d_{11} + d_{10} d_{13} + d_{11} d_{13}.$$

The nonlinear terms included are the six greatest of the F-ratio ranking for products. This metric was exercised on the extended weighted Euclidean data. With SOC curves as the criterion (Figure 7-28), performance was found to be improved over that achieved by

$$S = \overline{a}^T \overline{d}$$

where $\overline{a}$ possesses all unity elements (Fig. 7.29). The second metric processed was

$$S = \overline{a}^T \overline{d} + d_1 d_{11} + d_2 d_{11} + d_7 d_{11} + d_{11} d_{13}.$$

The four nonlinear terms appended are those ranking seven through ten in the product F-ratio ranking. Performance for this metric was somewhat degraded from that of the uniform linear sum.

The results above indicate that the inclusion of appropriate nonlinear terms can provide additional speaker separation beyond that attainable by a linear sum of distances. However, because of the highly subjective nature of performing a suitable nonlinear form through empirical study, this task is

1 SOC curves were compared qualitatively on the basis of area.

beyond the scope of this work. Although the linear form selected is certainly suboptimal, it is quite well matched to the problem structure, in view of the limited analytical exploration described above. The fact that the data became available largely at the end of this examination played a significant role in the posing of the hypotheses and the resulting procedure described above.

7.3.5 Summary of Similarity Measure Calculation for SASIS

For each speaker comparison for which a similarity measure is to be obtained, there are K event distances available, K = 1..., 10. The similarity measure is a two step computation:

1) $S = \sum_{j=1}^{K} a_j(d_j^2)$

where d_j^2 are the K distances and the a_j are known a priori. The a_j depend on both K and which K events are present; hence, there are $\sum_{e=1}^{10}\binom{K}{e} = 2^K-1$ or for K = 10, 1023 sets of a_j's, each set having K coefficients, so the total number of a_j's is

$\sum_{j=1}^{K}\left[\binom{K}{j}\cdot j\right] = 2^{K-1}$, so for K = 10, there are 5120 coefficients.

2) Once an S has been obtained, a likelihood ratio Λ is found by table look up on one of the 1023 sets of curves tabulated from the training data.

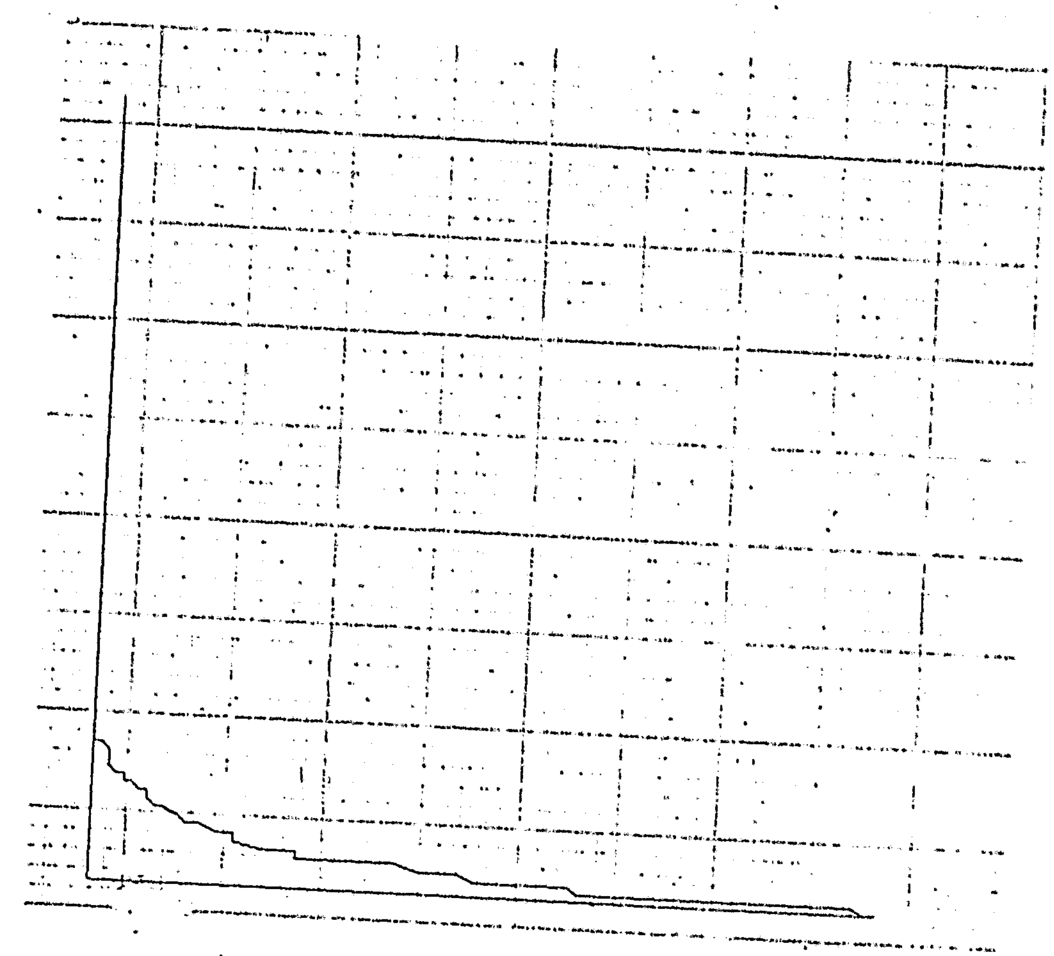


Figure 7.28 SOC curve for uniform similarity measure with six nonlinear terms appended. All data used are the extended weighted Euclidean distances of Data Base I. Note that the range of the abscissa is [0.0, 0.4360] and that of the ordinate is [0.0, 0.5723].

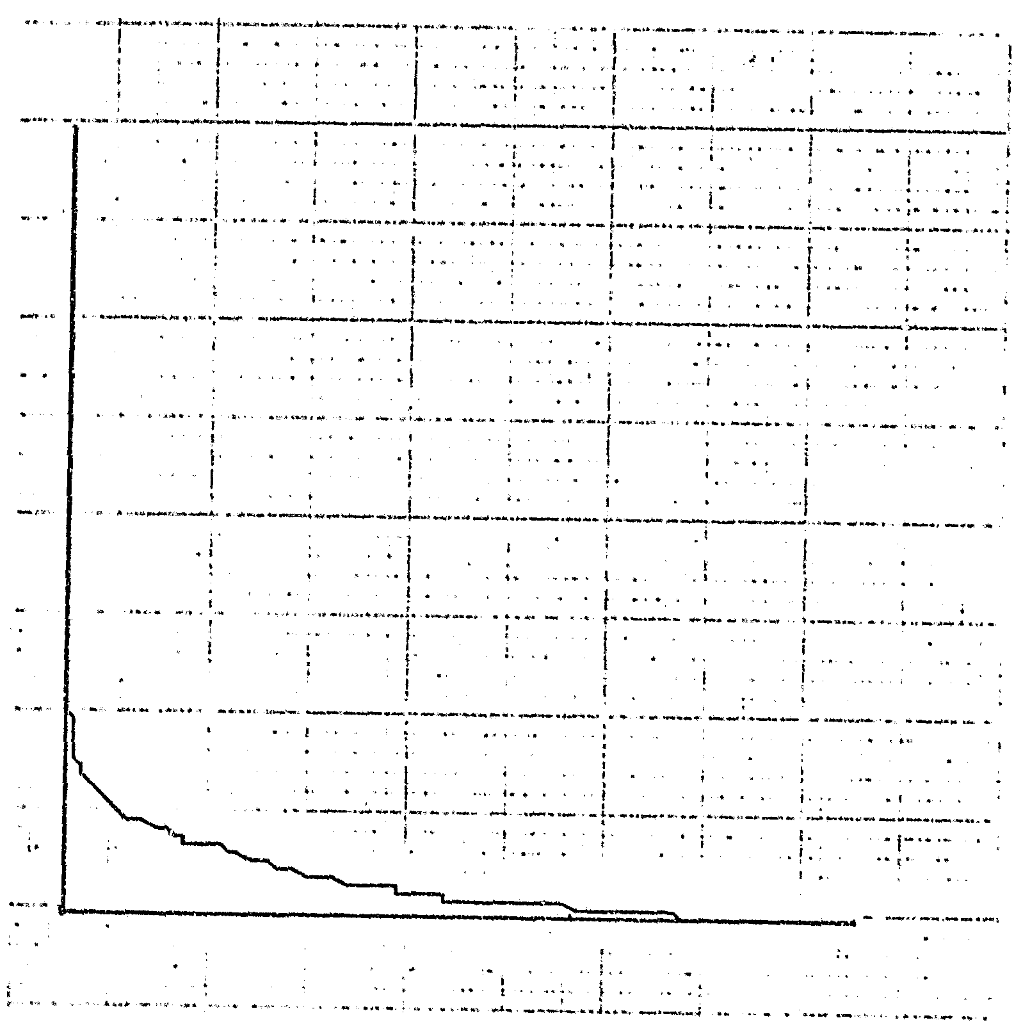


Figure 7.29 SOC curve for uniform linear similarity measure over thirteen types. All data used are the extended weighted Euclidean distances of Data Base I. Note that the range of the abscissa is [0.0, 0.4760] and that of the ordinate is [0.0, 0.5287].

8.0 SYSTEM EVALUATION

8.1 Introduction

The design, collection, labelling, editing and final content of Data Bases I, II, and III have been discussed in detail above. The development of the two-step distance and similarity measure whose function is to generate a single random variable under a wide variety of conditions and upon which the SASIS system is based has been carried out using Data Base I for formulation and a random 75 speakers (of the 193 available) from Data Base II for training (or parameter optimization) of this formulation.* It remains, then, to employ the remainder of Data Base II and all of Data Base III to evaluate the formulation and to tabulate the results to permit further evaluations beyond the scope of the currently available data bases.

A basic philosophy employed during the development of this system has been to avoid restrictive assumptions whenever possible and to explicitly state all assumptions which must be made, accompanied, where it is reasonable to do so, by demonstration or illustration of their validity. This must especially be true for the evaluation below and the associated statistical interpretations.

8.2 Data Organization

The General American English (GAE) portion of Data Base II consists of 193 speakers in two sessions numbered non-consecutively from 1 to 233. Since the method used to record and number speakers has some possibility of producing groups of similar speakers (because of similar backgrounds, jobs, ...), the speaker numbers were randomized. The data from the first 75 speakers from this randomized list are selected for the training portion of the system evaluation procedure; the remaining 118 are selected for the testing portion. The speakers are renumbered from this randomized list to run consecutively from 1 to 193.

*The partition of Data Base II in this manner is discussed in section 2.4.

The data on the labelled tape is, of course, found in the order it was spoken. This is reorganized and ordered by event to permit easier manipulation of the tape units for the calculations described below.*

The data organization is shown in Figure 8-1. Intraspeaker comparisons are found on the main diagonal. Only those interspeaker comparisons shown shaded are used. This data editing procedure allows manipulation of 25x25 matrix subportions within the core limitations of the FRD system at no significant sacrifice in statistical significance because: (1) all the intraspeaker comparisons are fully utilized; (2) an order of magnitude more interspeaker comparison than intraspeaker comparison data is considered (considerably more are available- - all the unshaded regions of Figure 8-1 - but their use is costly and cumbersome and adds very little to the significance of the results); (3) the prerandomization of the speaker selection order assures that the data in the shaded regions are taken from throughout an original matrix which might have been constructed from the unrandomized list of speakers. The reasonableness of this procedure may be demonstrated by examining Figure 8-2a which shows SOC curves for the 10 phonetic event classes taken singly. The top portion of Figure 8-2a shows the curves which result by using only the data in the first 25x25 block shown in Figure 8-1; the bottom gives the results when all three 25x25 blocks are used. Figure 8-2b shows the same results for 1, 2, 3 & 5 block portions from the 118 speaker testing portion of Data Base II. Since there is no consistent degradation or improvement as a function of the number of blocks, the variations present in 8-2a, e.g., must be taken as representing the variation of a 25 speaker SOC curve about a 75 speaker SOC curve. Inclusion of additional interspeaker data from the unused portions of the matrix in Figure 8-1 would give similar results. Table 8-1 shows the percent variation in the intra- and interspeaker averages for three events selected to cover the range of the number of tokens available. The interspeaker variation is always less than the intraspeaker variation and is within ~2% of the average.

*Because of its length the complete tabulation of the data has been omitted from this report. It is found in an auxiliary manual "Summary Tabulation of Labelled Data for SASIS," TM-74-521-010-008.

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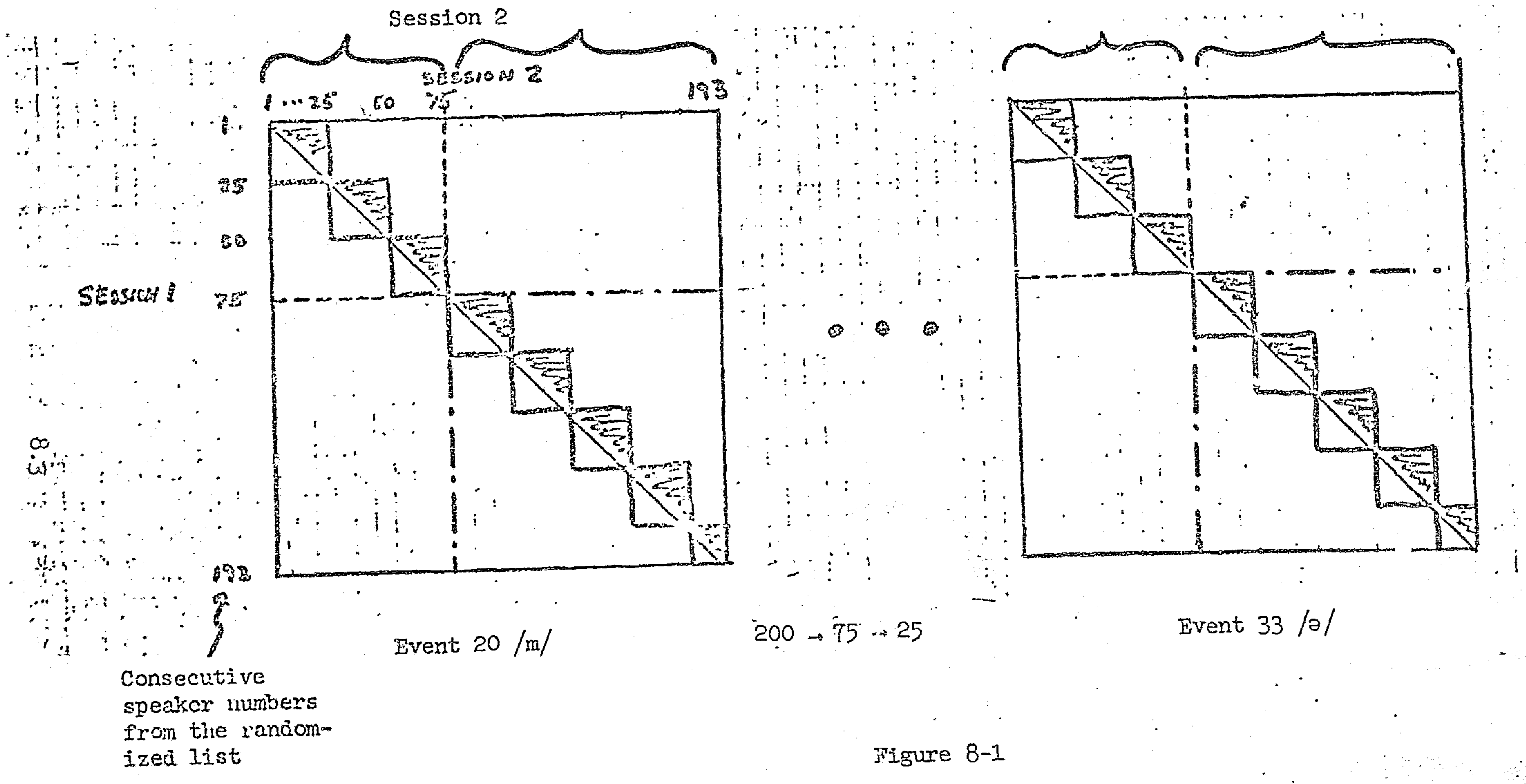

Figure 8-1

SASIS Data Base II Organization for System Evaluation

TABLE 8-1

Percent Change in Intraspeaker and Interspeaker Averages Over 1st, 2nd & 3rd 25x25 Blocks of Figure 8-1 for Events 27 (~ 5-7 Tokens), 23 (~ 2-4 Tokens) and 20 (~ 1-3 Tokens).

	Event 27				Event 23				Event 20			
	Intra	%	Inter	%	Intra	%	Inter	%	Intra	%	Inter	%
1st 25x25 Block	139.4	-.5	254.3	-0.2	145.1	-4.2	320.6	0	147.7	-2.2	326.1	+2.0
2nd 25x25 Block	148.7	6.5	250.7	-1.7	142.4	-5.9	315.4	-1.6	150.4	-0.5	315.8	-1.2
3rd 25x25 Block	132.1	-7.0	259.9	1.9	167.9	+11.0	325.8	+1.6	155.1	+2.6	317.2	-0.8
Average	140.1		255.0		151.4		320.6		151.1		319.7	

Use of all the interspeaker data available could reduce this by a factor of ~ 2 but the effect on the accuracy of the SASIS results is not significant because of the inability to reduce the intraspeaker variation. The structure shown in Figure 8-1 is claimed to represent a judicious engineering compromise in the use of the data available.

A detailed tabulation of the number of distance tokens that are available in the forty-two (3x14 events) 25x25 matrices of the training portion of the data base has been omitted from this report.* This tabulation takes into account the criteria by which a triad from speaker i of session 1 and speaker j of session 2 are appropriate for use in obtaining a distance (these criteria are, in essence, common triad forms and position within the sentence). The number of tokens available per speaker comparison ranges from 0 to 9 and is clustered between 4 and 6 for most events. It is desirable to so structure this data that the statistics obtained are representative of those which will be found operationally. To this end, the following assumption has been made:

- a realistic number of triad pairs from which a distance is calculated, per phonetic event available, is three.

Since the distance used for a phonetic event is an average over the number available, the available tokens have been grouped in three's for the calculations made on this base. A further structure has been imposed to simplify the computational and, especially, the manipulational tasks. The tokens described above have been grouped in three's, by rule, so that there are always ten numbers which result, regardless of the number of tokens which are present (except for 0 tokens which is a special case). The following table lists the combination of n items taken 3 at a time for n=0, ..., 9.

n	0	1	2	3	4	5	6	7	8	9
$_nC_3$	-	-	-	1	4	10	20	35	56	84

Table 8-2

*See footnote, page 8-2.

As discussed above, the number of tokens is clustered between 4 and 6 for most events. Ten was chosen from the center of this range ($_5C_3 = 10$). The extract rules which are used are tabulated in Table 8-3. For n=5, the rules simply tabulate all combinations of 3 distances. For other than n=5 there is some arbitrariness in the definition. The structure was chosen based on the form shown in Figure 8-3. The event distances are arranged in increasing order and the three symmetries shown are used to generate the distance triplets. Some distortion is introduced for those events for which the available number of tokens is generally less than 4 (primarily the nasals, once the /ə/ has been omitted).

The rationale used to merge the 14 initial phonetic events into 10 phonetic event classes has been discussed in section 6.0 above. Given that there are 10 phonetic event classes defined, the data structuring described above is further described in Figure 8-4. The block of 100 numbers is available for any speaker comparison of the form: speaker i session 1 vs speaker j session 2, with i and j arbitrary and each in the range 1, ..., 193.

From any one block such as that shown in Figure 8-4 a large number of "pseudo comparison sessions" may be generated. Based on the assumptions above, each of the 10 numbers on each of the 10 lines represents a realistic distance between the two speakers i and j for the particular phonetic class indicated by the line. A "pseudo comparison session" is defined by:

1) selecting n of the 10 phonetic event classes, for any value of n = 1, ..., 10

   (this may be done, of course, $_{10}C_n$ ways)

2) selecting one value from each of the n phonetic event classes chosen in (1) above

   (this may be done 10^n ways)

$\underline{n}$										
≥ 14	(1,7,14)	(2,8,13)	(3,7,11)	(4,6,8)	(1,2,10)	(5,7,9)	(2,12,13)	(5,6,8)	(4,8,9)	(10,11,12)
13	(1,7,11)	"	"	"	"	"	"	"	"	"
12	"	(2,8,12)	"	"	"	"	(2,11,12)	"	"	"
11	"	(2,8,10)	(3,7,9)	"	"	"	(2,10,11)	"	"	(9,10,11)
10	(1,6,10)	(2,5,9)	(3,7,8)	"	"	"	(2,9,10)	"	"	(8,9,10)
9	(1,5,9)	(2,4,8)	(3,5,7)	"	(1,2,9)	"	(2,8,9)	"	"	(7,8,9)
8	(1,5,8)	(2,4,7)	"	"	(1,2,8)	(5,7,8)	(2,7,8)	"	(3,7,8)	(6,7,8)
7	(1,4,7)	(2,3,6)	(2,4,6)	(4,6,7)	(1,2,7)	(3,5,7)	(2,6,7)	(3,4,5)	(3,5,6)	(5,6,7)
6	(1,3,6)	(2,4,5)	(2,3,4)	(2,5,6)	(1,2,6)	(2,4,6)	(2,3,4)	(3,4,5)	(3,5,6)	(4,5,6)
5	(1,2,3)	(1,2,4)	(1,2,5)	(1,3,4)	(1,3,5)	(2,3,4)	(2,3,5)	(1,4,5)	(2,4,5)	(3,4,5)
4	(1,2,3)	(1,2,4)	(2,3,4)	(1,3,4)	(1,2,3)	(1,2,4)	(2,3,4)	(1,3,4)	(1,2,3)	(2,3,4)
3	1	2	3	(1,3)	(1,2)	(2,3)	(1,2,3)	(1,3)	(1,2)	(2,3)
2	1	2	$(d_1+i\Delta)$, i= 1,8) where $\Delta = (d_2-d_1)/9$							
1	1	1	1	1	1	1	1	1	1	1

TABLE 8-3

Rules used to form triplets of distances to produce 10 numbers per speaker comparison per event

Evaluation (1,7,14) means $(d_1+d_7+d_{14})/3$; (1,2) means $(d_1+d_2)/2$ etc.

n	0	1	2	3	4	5	6	7	8	9	10	11	12	13
$_nC_3$	-	-	-	1	4	10	20	35	56	84	120	165	220	286

event distances arranged in increasing order 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Symmetries:

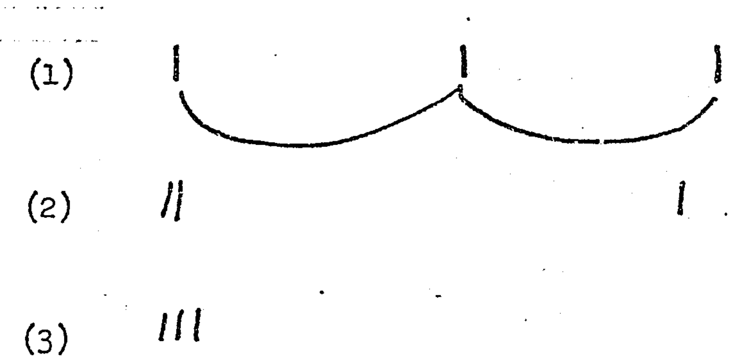

Figure 8-3

Structure from which the rules of Table 8-2 were designed

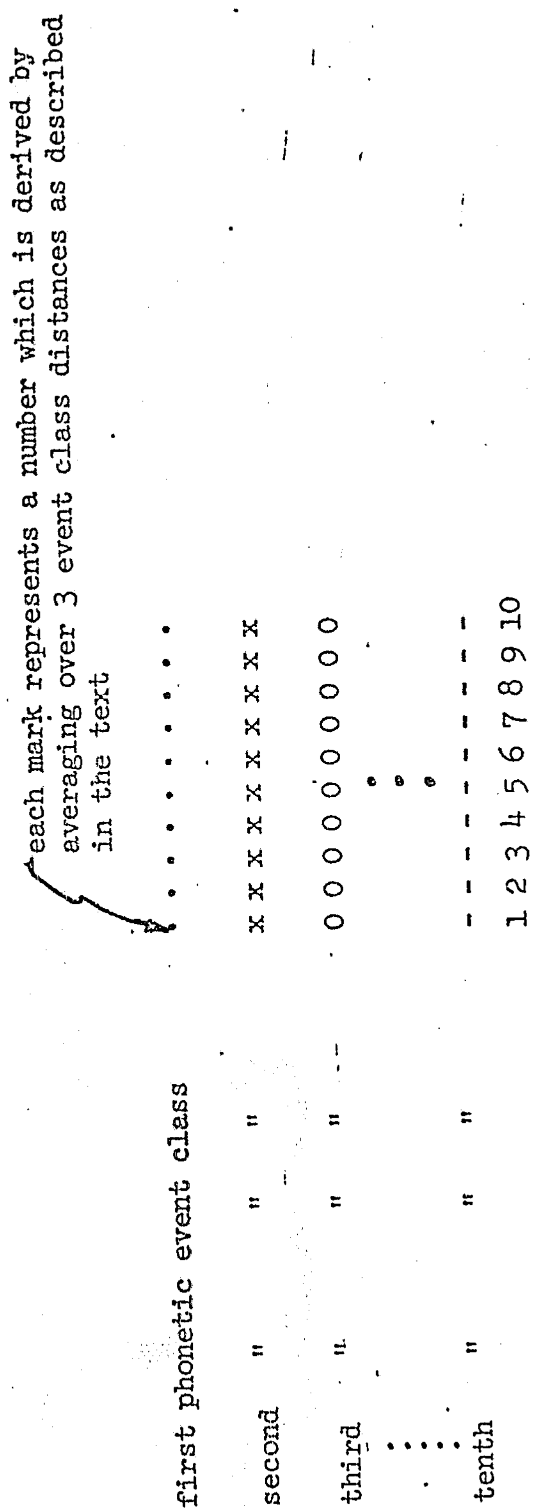

Figure 8-4

Data structure for any speaker pair comparison of the form: speaker i session 1
speaker j session 2

The total number of such "pseudo comparison sessions" which may be generated from a single speaker comparison block of the form shown in Figure 8-4 is then:

$$\sum_{n=1}^{10} {}_{10}C_n \cdot 10^n$$

or

$$10\cdot 10+45\cdot 10^2+120\cdot 10^3+210\cdot 10^4+252\cdot 10^5+210\cdot 10^6+120\cdot 10^7+45\cdot 10^8+10\cdot 10^9+1.10^{10}$$
$$\approx 2.6\cdot 10^{10} .$$

Clearly, this is not computable. The following subset is selected by replacing rule (2) by

3) Select any arbitrary one of the 10 numbers from the first phonetic event class; then select the corresponding value (e.g., the 5th) from each of the other phoentic event classes. (this may be done 10 ways)

The total number of "pseudo comparison sessions" for a single comparison block is now:

$$\sum_{n=1}^{10} {}_{10}C_n \cdot 10 = 10 \cdot (1023) = 10230 \approx 10^4$$

The exact distribution of these by n is shown in Table 8-4.

n	1	2	3	4	5	6	7	8	9	10
no. of "pseudo comparison sessions"	100	450	1200	2100	2520	2100	1200	450	100	10

Table 8-4

Since there are 118 speakers in the training portion of the data base, as indicated in Figure 8-1, and 1353 interspeaker comparisons (the shaded areas of Figure 8-1), there are then a total of

$$118 \cdot 10230 = 1.20714 \cdot 10^6 \approx 10^6$$

"intraspeaker pseudo comparison sessions" and

$$1353 \cdot 10230 = 1.384119 \cdot 10^7 \approx 10^7$$

"interspeaker pseudo comparison sessions." The approximate number of speaker "pseudo comparison sessions" using the data structuring described above is shown in Tables 8-5 and 8-6. Because of the procedure followed for expanding the data and producing 10 distances for each speaker comparison per phonetic event class and the rules (1) and (2)' which define a "pseudo comparison session," the number of sessions which are used to tabulate the statistics for a given specific set of n phonetic events is not a function of n, as is indicated in Table 8-5. Hence, each such tabulation has the same validity (effected only by the reasonableness of the assumptions delineated above).

TABLE 8-5

Approximate number of speaker comparison sessions using the data structuring presented in the text and the testing portion of data base II

	intraspeaker	interspeaker
Total No. of Sessions	1.2×10^6	$1.4\ \ 10^7$
No. of sessions per phonetic event class	1.2×10^5	$1.4\ \ 10^6$
No. of sessions for a non specific set of n events n = 1, ..., 10	function of n (see Table VI)	function of n (see Table VI)
No. of sessions for a specific set of n events	(not a function of n) 1180	(not a function of n) 13530

TABLE 8-6

Numbers of Comparison Session for a non-specific set of n events

n	1	2	3	4	5	6	7	8	9	10
intraspeaker $x10^5$	.118	.531	1.416	2.478	2.9736	2.478	1.416	.531	.118	.0118
interspeaker $x10^6$	.1353	.60885	1.6236	2.8413	3.40956	2,8413	1.6236	.60885	.1353	.01353

This permits selection of a single resolution for which all the 1023 inter-speaker/intraspeaker statistical distributions are tabulated. The intra-speaker statistical distributions consist of 1180 "pseudo comparison sessions;" The interspeaker distributions consist of 13530 such points. These points themselves are recorded and constitute the primary output of the system procedures. From this data, histograms are constructed on 200 bins* distributed between the minimum and maximum values. The histograms are area-normalized to 1000. Although this procedure might be sensitive to the presence of points in the tails, no such results have been observed.

The data manipulations using the 75 speakers from the training portion are:

1) obtain a set of 30 features, of the possible 165, for each phonetic event j

$$\{f_i,\ i \epsilon I_j\} \quad j=1, \ldots, 13$$

where I_j = a set of 30 of the 165 features and the corresponding weights

$$\{w_i,\ i \epsilon I_j\} \quad j=1, \ldots, 13$$

for use in the distance measure calculations.

These are given in Appendix 5E.

2) obtain the normalizing factors for event j and feature i

$$\overline{f_i},\ \sigma_i \quad i=1, \ldots, 30 \quad j=1, \ldots, 13$$

where $\overline{f}_i$ is a feature average overall data in class j; σ_i is the corresponding feature standard deviation.

These are presented and discussed in Section 4.3.1 above.

*Empirical examination of 100, 200, and 1000 bin histograms and a consideration of the disc storage requirements lead to this choice.

3) obtain a set of coefficients for use in the similarity measure: for each n events ($n=1, \ldots, 10$) there are ${}_{10}C_n$ sets, of n coefficients each, obtained. Hence, a total of

$$\sum_{n=1}^{10} {}_{10}C_n = 2^9 \cdot 10 = 5120$$

coefficients are determined from the data base.

The coefficients are tabulated in Table 8-7. Table 8-8 illustrates the behavior of the coefficients for the subset of cases listed. As expected, the merged events are consistently more heavily weighted than the non-merged events and the nasals are the least heavily weighted.

8.3 Considerations for Presenting the Results

The 118 speakers in the testing portion of Data Base II are used to calculate the system performance. The results may be tabulated in one (or more) of the forms shown in Figure 8-5. Λ is a form of likelihood ratio

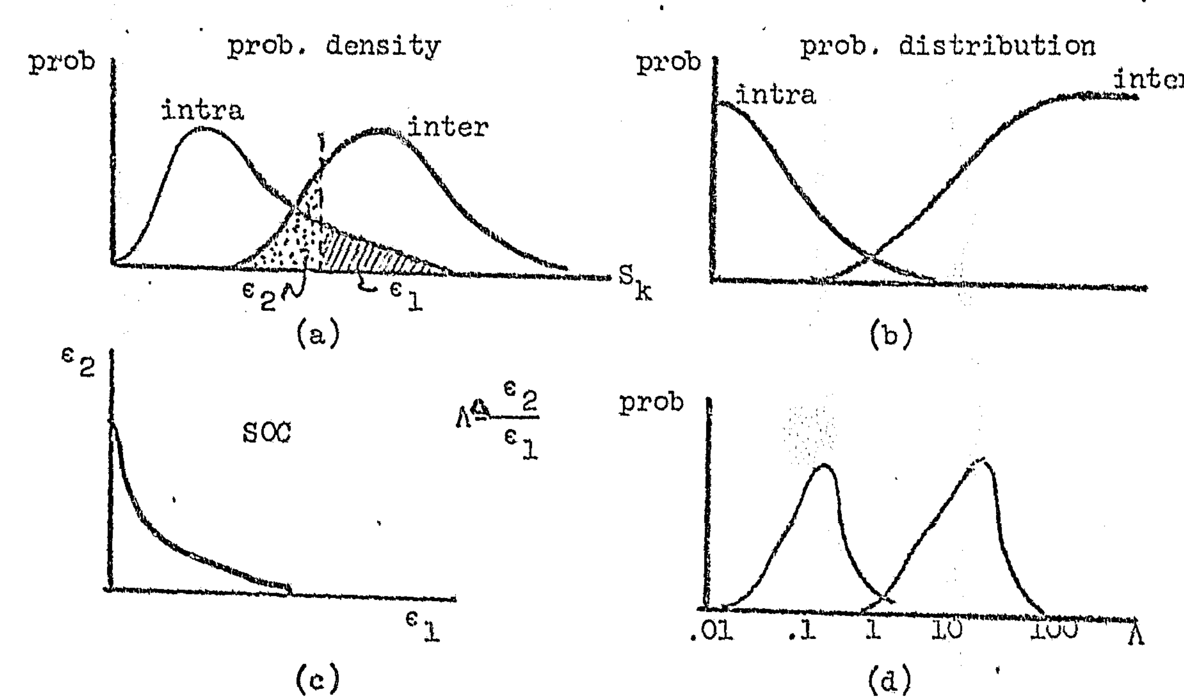

Figure 8-5

TABLE 8-7

Coefficients for Similarity Measure Calculated from the Training Portion of Data Base II
(Events present indicated by a 1; order 20, 21, 22, 23, 24, 31, 32, (25-26),(27-28),(29-30)

Coefficients										Events Present									
0.0079	0.0032	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	0	0	0
0.0091	0.0074	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	0	0	0
0.0094	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	0	0	0
0.0092	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	0	0	0
0.0093	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	0	0	0
0.0093	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	0	0	0
0.0087	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	1	0	0
0.0095	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	0	1	0
0.0097	0.0168	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	0	0	1
0.0055	0.0365	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	0	0	0
0.0060	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	0	0	0
0.0059	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	0	0	0
0.0061	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	0	0	0
0.0061	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	0	0	0
0.0059	0.0130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	1	0	0
0.0063	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	0	1	0
0.0065	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	0	0	1
0.0092	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	0	0	0
0.0087	0.0152	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	0	0	0
0.0090	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	0	0	0
0.0091	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	0	0	0
0.0089	0.0178	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	1	0	0
0.0090	0.0159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	0	1	0
0.0092	0.0190	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	0	0	1
0.0103	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	0	0	0
0.0111	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	0	0	0
0.0111	0.0129	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	0	0	0

0.0104	0.0164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	1	0	0
0.0114	0.0153	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	0	1	0
0.0109	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	0	0	1
0.0152	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	0	0
0.0158	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	0	0	0
0.0116	0.0170	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	1	0	0
0.0161	0.0173	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	0	1	0
0.0153	0.0202	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	0	0	1
0.0146	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	0	0	0
0.0122	0.0187	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	1	0	0
0.0144	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	0	1	0
0.0147	0.0226	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	0	0	1
0.0111	0.0195	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	1	0	0
0.0148	0.0193	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	0	1	0
0.0138	0.0222	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	0	0	1
0.0204	0.0178	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	1	1	0
0.0205	0.0233	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	1	0	1
0.0229	0.0288	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1	1

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0.0073	0.0045	0.0057	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	0	0	0
0.0074	0.0049	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	0	0	0
0.0072	0.0048	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	0	0	0
0.0072	0.0049	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	0	0	0
0.0073	0.0058	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	0	0	0
0.0069	0.0048	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	1	0	0
0.0074	0.0051	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	0	1	0
0.0075	0.0053	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	0	0	1
0.0083	0.0074	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	0	0	0
0.0082	0.0080	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	0	0	0

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0.0082	0.0071	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	0	0	0
0.0082	0.0073	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	0	0	0
0.0077	0.0071	0.0152	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	1	0	0
0.0084	0.0071	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	0	1	0
0.0086	0.0073	0.0166	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	0	0	1
0.0086	0.0093	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	0	0	0
0.0085	0.0100	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	0	0	0
0.0086	0.0100	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	0	0	0
0.0081	0.0095	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	1	0	0
0.0087	0.0103	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	0	1	0
0.0090	0.0098	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	0	0	1
0.0085	0.0121	0.0101	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	0	0	0
0.0085	0.0125	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	0	0	0
0.0081	0.0112	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	1	0	0
0.0086	0.0127	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	0	1	0
0.0089	0.0122	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	0	0	1
0.0086	0.0107	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	0	0	0
0.0082	0.0095	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	1	0	0
0.0087	0.0107	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	0	1	0
0.0089	0.0108	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	0	0	1
0.0081	0.0100	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	1	0	0
0.0087	0.0109	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	0	1	0
0.0090	0.0104	0.0152	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	0	0	1
0.0082	0.0137	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	1	1	0
0.0084	0.0138	0.0150	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	1	0	1
0.0091	0.0125	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	0	1	1
0.0050	0.0065	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	0	0	0
0.0050	0.0061	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	0	0	0

8.20

0.0051	0.0063	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	0	0	0
0.0051	0.0064	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	0	0	0
0.0049	0.0063	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	1	0	0
0.0053	0.0063	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	0	1	0
0.0055	0.0063	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	0	0	1
0.0055	0.0084	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	0	0	0	0
0.0056	0.0089	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	0	0	0
0.0057	0.0089	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	0	0	0
0.0055	0.0085	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	1	0	0
0.0050	0.0091	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	0	1	0
0.0061	0.0088	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	0	0	1
0.0056	0.0105	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	0	0	0
0.0056	0.0108	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	0	0	0
0.0055	0.0098	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	1	0	0
0.0057	0.0110	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	0	1	0
0.0060	0.0106	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	0	0	1
0.0058	0.0094	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	0	0	0
0.0056	0.0085	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	1	0	0
0.0059	0.0094	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	0	1	0
0.0061	0.0095	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	0	0	1
0.0056	0.0088	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	1	0	0
0.0059	0.0096	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	0	1	0
0.0062	0.0092	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	0	0	1
0.0057	0.0118	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	1	1	0
0.0059	0.0119	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	1	0	1
0.0063	0.0103	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	0	1	1
0.0065	0.0102	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	0	0	0
0.0067	0.0110	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	0	0	0

8.21

0.0089	0.0110	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	0	0	0
0.0086	0.0103	0.0159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	1	0	0
0.0087	0.0113	0.0148	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	0	1	0
0.0090	0.0107	0.0173	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	0	0	1
0.0083	0.0131	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	0	0	0
0.0084	0.0136	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	0	0	0
0.0083	0.0119	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	1	0	0
0.0082	0.0139	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	0	1	0
0.0085	0.0133	0.0168	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	0	0	1
0.0087	0.0120	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	0	0	0
0.0085	0.0104	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	1	0	0
0.0006	0.0120	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	0	1	0
0.0088	0.0122	0.0173	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	0	0	1
0.0086	0.0112	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	1	0	0
0.0087	0.0124	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	0	1	0
0.0089	0.0118	0.0171	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	0	0	1
0.0085	0.0157	0.0129	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	1	1	0
0.0087	0.0158	0.0167	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	1	0	1
0.0088	0.0142	0.0176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	0	1	1
0.0097	0.0120	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	0	0	0
0.0096	0.0125	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	0	0	0
0.0093	0.0110	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	1	0	0
0.0099	0.0127	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	0	1	0
0.0095	0.0123	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	0	0	1
0.0104	0.0114	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	0	0	0
0.0099	0.0100	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	1	0	0
0.0107	0.0113	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	0	1	0
0.0102	0.0116	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	0	0	1

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0.0098	0.0106	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	1	0	0
0.0107	0.0116	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	0	1	0
0.0102	0.0111	0.0158	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	0	0	1
0.0101	0.0144	0.0127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	1	1	0
0.0096	0.0147	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	1	0	1
0.0104	0.0138	0.0162	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	0	0	1	1
0.0138	0.0112	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	0	0	0
0.0122	0.0099	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	1	0	0
0.0141	0.0109	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	1	0
0.0131	0.0114	0.0188	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	0	1
0.0123	0.0112	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	1	0	0
0.0144	0.0120	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	0	1	0
0.0138	0.0113	0.0182	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	0	0	1
0.0127	0.0146	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	1	1	0
0.0117	0.0150	0.0183	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	1	0	1
0.0139	0.0154	0.0186	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	0	1	1
0.0104	0.0116	0.0164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	1	0	0
0.0121	0.0127	0.0161	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	0	1	0
0.0126	0.0116	0.0204	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	0	0	1
0.0102	0.0164	0.0148	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	1	1	0
0.0103	0.0163	0.0203	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	1	0	1
0.0122	0.0157	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	0	1	1
0.0118	0.0168	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	1	1	0
0.0107	0.0172	0.0195	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	1	0	1
0.0121	0.0167	0.0203	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	0	1	1
0.0174	0.0156	0.0217	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	1	1	1

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0.0068	0.0041	0.0057	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	0	0	0

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0.0067	0.0041	0.0053	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	0	0	0
0.0067	0.0042	0.0055	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	0	0	0
0.0067	0.0042	0.0056	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	0	0	0
0.0063	0.0041	0.0055	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	1	0	0
0.0068	0.0043	0.0055	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	0	1	0
0.0069	0.0046	0.0035	0.0130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	0	0	1
0.0068	0.0045	0.0080	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	0	0	0
0.0068	0.0046	0.0085	0.0093	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	0	0	0
0.0068	0.0046	0.0085	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	0	0	0
0.0065	0.0045	0.0082	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	1	0	0
0.0069	0.0047	0.0087	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	0	1	0
0.0071	0.0050	0.0084	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	0	0	1
0.0067	0.0046	0.0100	0.0084	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	0	0	0
0.0067	0.0046	0.0103	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	0	0	0
0.0055	0.0045	0.0094	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	1	0	0
0.0068	0.0047	0.0105	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	0	1	0
0.0070	0.0049	0.0101	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	0	0	1
0.0068	0.0047	0.0088	0.0087	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	0	0	0
0.0065	0.0046	0.0080	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	1	0	0
0.0069	0.0048	0.0089	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	0	1	0
0.0070	0.0050	0.0089	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	0	0	1
0.0065	0.0046	0.0084	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	1	0	0
0.0069	0.0049	0.0090	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	0	1	0
0.0070	0.0051	0.0086	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	0	0	1
0.0066	0.0047	0.0111	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	1	1	0
0.0067	0.0049	0.0111	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	1	0	1
0.0071	0.0052	0.0098	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	0	1	1
0.0076	0.0053	0.0093	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	0	0	0

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0.0075	0.0071	0.0100	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	0	0	0
0.0075	0.0072	0.0100	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	0	0	0
0.0071	0.0071	0.0095	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	1	0	0
0.0077	0.0071	0.0102	0.0130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	0	1	0
0.0079	0.0072	0.0097	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	0	0	1
0.0075	0.0067	0.0118	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	0	0	0
0.0075	0.0068	0.0121	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	0	0	0
0.0071	0.0067	0.0109	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	1	0	0
0.0076	0.0066	0.0124	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	0	1	0
0.0078	0.0068	0.0118	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	0	0	1
0.0075	0.0070	0.0105	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	0	0	0
0.0071	0.0069	0.0093	0.0130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	1	0	0
0.0077	0.0069	0.0105	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	0	1	0
0.0078	0.0070	0.0106	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	0	0	1
0.0071	0.0070	0.0099	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	1	0	0
0.0076	0.0070	0.0108	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	0	1	0
0.0079	0.0071	0.0102	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	0	0	1
0.0072	0.0069	0.0136	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	1	1	0
0.0074	0.0070	0.0136	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	1	0	1
0.0080	0.0070	0.0122	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	0	1	1
0.0079	0.0089	0.0109	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	0	0	0
0.0079	0.0088	0.0113	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	0	0	0
0.0077	0.0085	0.0101	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	1	0	0
0.0080	0.0090	0.0115	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	0	1	0
0.0083	0.0086	0.0110	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	0	0	1
0.0079	0.0095	0.0100	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	0	0	0
0.0076	0.0091	0.0090	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	1	0	0
0.0080	0.0097	0.0100	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	0	1	0

0.0083	0.0092	0.0102	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	0	0	1
0.0076	0.0090	0.0094	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	1	0	0
0.0080	0.0097	0.0102	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	0	1	0
0.0084	0.0092	0.0097	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	0	0	1
0.0077	0.0092	0.0126	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	1	1	0
0.0079	0.0087	0.0127	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	1	0	1
0.0084	0.0094	0.0120	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	0	1	1
0.0079	0.0112	0.0089	0.0093	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	0	0	0
0.0077	0.0102	0.0081	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	1	0	0
0.0080	0.0114	0.0088	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	0	1	0
0.0082	0.0108	0.0090	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	0	0	1
0.0076	0.0103	0.0090	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	1	0	0
0.0080	0.0117	0.0095	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	0	1	0
0.0083	0.0112	0.0091	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	0	0	1
0.0077	0.0106	0.0113	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	1	1	0
0.0079	0.0100	0.0115	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	1	0	1
0.0083	0.0113	0.0113	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	0	1	1
0.0077	0.0084	0.0090	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	1	0	0
0.0081	0.0094	0.0097	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	0	1	0
0.0083	0.0096	0.0091	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	0	0	1
0.0078	0.0084	0.0119	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	1	1	0
0.0079	0.0084	0.0119	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	1	0	1
0.0084	0.0095	0.0110	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	0	1	1
0.0077	0.0093	0.0123	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	1	1	0
0.0079	0.0087	0.0124	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	1	0	1
0.0084	0.0094	0.0115	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	0	1	1
0.0080	0.0124	0.0105	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	0	1	1	1
0.0046	0.0061	0.0084	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	0	0	0

0.0047	0.0062	0.0089	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	0	0	0
0.0047	0.0063	0.0089	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	1	0	0	0
0.0045	0.0062	0.0085	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	1	0	0
0.0048	0.0062	0.0091	0.0106	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	0	1	0
0.0051	0.0063	0.0088	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	0	0	1
0.0047	0.0059	0.0102	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	0	0	0
0.0047	0.0060	0.0105	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	0	0	0
0.0046	0.0059	0.0096	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	1	0	0
0.0048	0.0059	0.0103	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	0	1	0
0.0050	0.0060	0.0104	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	0	0	1
0.0048	0.0062	0.0092	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	0	0	0
0.0047	0.0061	0.0083	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	1	0	0
0.0049	0.0061	0.0093	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	0	1	0
0.0052	0.0061	0.0094	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	0	0	1
0.0047	0.0061	0.0088	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	1	0	0
0.0050	0.0061	0.0095	0.0101	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	0	1	0
0.0052	0.0062	0.0091	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	0	0	1
0.0048	0.0061	0.0117	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	1	1	0
0.0050	0.0061	0.0117	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	1	0	1
0.0053	0.0061	0.0101	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	0	1	1
0.0052	0.0080	0.0096	0.0085	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	0	0	0	0
0.0052	0.0080	0.0098	0.0087	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	0	0	0
0.0051	0.0077	0.0090	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	0	1	0	0
0.0053	0.0081	0.0100	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	0	0	1	0
0.0056	0.0079	0.0097	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	0	0	0	1
0.0054	0.0085	0.0088	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	0	0	0
0.0052	0.0082	0.0081	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	1	0	0
0.0055	0.0087	0.0088	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	0	1	0

8.27

0.0057	0.0083	0.0090	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	0	0	1
0.0052	0.0081	0.0084	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	1	0	0
0.0055	0.0086	0.0090	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	0	1	0
0.0057	0.0083	0.0087	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	0	0	1
0.0053	0.0083	0.0110	0.0093	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	1	1	0
0.0056	0.0080	0.0111	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	1	0	1
0.0058	0.0085	0.0100	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	0	1	1
0.0053	0.0097	0.0080	0.0083	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	0	0	0
0.0052	0.0090	0.0074	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	1	0	0
0.0054	0.0099	0.0080	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	0	1	0
0.0056	0.0095	0.0082	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	0	0	1
0.0052	0.0091	0.0081	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	1	0	0
0.0054	0.0102	0.0085	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	0	1	0
0.0057	0.0098	0.0082	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	0	0	1
0.0053	0.0093	0.0101	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	1	1	0
0.0055	0.0089	0.0102	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	1	0	1
0.0058	0.0100	0.0095	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	0	1	1
0.0054	0.0076	0.0081	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	1	0	0
0.0056	0.0084	0.0086	0.0093	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	0	1	0
0.0050	0.0086	0.0082	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	0	0	1
0.0055	0.0077	0.0105	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	1	1	0
0.0057	0.0077	0.0105	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	1	0	1
0.0059	0.0056	0.0092	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	0	1	1
0.0055	0.0083	0.0108	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	1	1	0
0.0057	0.0079	0.0109	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	1	0	1
0.0060	0.0085	0.0096	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	0	1	1
0.0058	0.0109	0.0090	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	0	1	1	1
0.0081	0.0097	0.0115	0.0106	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	0	0	0

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0.0082	0.0096	0.0120	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	0	0	0
0.0082	0.0092	0.0106	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	1	0	0
0.0081	0.0098	0.0122	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	0	1	0
0.0083	0.0094	0.0117	0.0155	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	0	0	1
0.0085	0.0103	0.0110	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	0	0	0
0.0083	0.0099	0.0097	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	1	0	0
0.0083	0.0106	0.0109	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	0	1	0
0.0085	0.0101	0.0112	0.0159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	0	0	1
0.0084	0.0097	0.0103	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	1	0	0
0.0085	0.0105	0.0113	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	0	1	0
0.0087	0.0101	0.0108	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	0	0	1
0.0083	0.0100	0.0141	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	1	1	0
0.0085	0.0095	0.0143	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	1	0	1
0.0085	0.0103	0.0133	0.0161	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	0	1	1
0.0081	0.0120	0.0099	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	0	0	0
0.0081	0.0107	0.0089	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	1	0	0
0.0080	0.0123	0.0098	0.0124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	0	1	0
0.0082	0.0116	0.0101	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	0	0	1
0.0081	0.0109	0.0100	0.0129	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	1	0	0
0.0081	0.0126	0.0107	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	0	1	0
0.0083	0.0121	0.0102	0.0153	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	0	0	1
0.0080	0.0112	0.0128	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	1	1	0
0.0082	0.0105	0.0131	0.0153	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	1	0	1
0.0082	0.0122	0.0128	0.0157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	0	1	1
0.0084	0.0091	0.0109	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	1	0	0
0.0084	0.0104	0.0109	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	0	1	0
0.0086	0.0107	0.0101	0.0159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	0	0	1
0.0082	0.0091	0.0136	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	1	1	0

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0.0084	0.0092	0.0135	0.0158	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	1	0	1
0.0094	0.0106	0.0123	0.0163	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	0	1	1
0.0083	0.0103	0.0139	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	1	1	0
0.0085	0.0096	0.0141	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	1	0	1
0.0085	0.0106	0.0129	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	0	1	1
0.0084	0.0140	0.0117	0.0158	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	0	1	1	1
0.0093	0.0110	0.0095	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	0	0	0
0.0090	0.0099	0.0087	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	1	0	0
0.0095	0.0112	0.0094	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	0	1	0
0.0090	0.0107	0.0098	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	0	0	1
0.0089	0.0101	0.0096	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	1	0	0
0.0094	0.0116	0.0101	0.0126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	0	1	0
0.0090	0.0112	0.0097	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	0	0	1
0.0091	0.0104	0.0119	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	1	1	0
0.0086	0.0098	0.0123	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	1	0	1
0.0092	0.0113	0.0125	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	0	1	1
0.0095	0.0098	0.0095	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	1	0	0
0.0101	0.0098	0.0101	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	0	1	0
0.0097	0.0102	0.0096	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	0	0	1
0.0097	0.0088	0.0124	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	1	1	0
0.0092	0.0089	0.0125	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	1	0	1
0.0099	0.0100	0.0120	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	0	1	1
0.0096	0.0097	0.0128	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	1	1	0
0.0091	0.0091	0.0132	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	1	0	1
0.0099	0.0100	0.0127	0.0148	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0	0	0	1	0	0	1	0	1	1
0.0093	0.0120	0.0116	0.0147	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0	0	0	1	0	0	0	1	1	1
0.0112	0.0086	0.0102	0.0128	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0	0	0	0	1	1	1	1	0	0
0.0129	0.0093	0.0107	0.0139	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0	0	0	0	1	1	1	0	1	0

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0.0121	0.0099	0.0099	0.0172	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	0	0	1
0.0116	0.0083	0.0126	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	1	1	0
0.0105	0.0086	0.0129	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	1	0	1
0.0122	0.0095	0.0136	0.0176	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	1	1
0.0116	0.0102	0.0128	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	1	1	0
0.0108	0.0094	0.0134	0.0169	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	1	0	1
0.0126	0.0101	0.0142	0.0170	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	0	1	1
0.0110	0.0120	0.0130	0.0172	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	0	1	1	1
0.0097	0.0107	0.0145	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	1	1	0
0.0090	0.0095	0.0146	0.0186	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	1	0	1
0.0105	0.0104	0.0145	0.0191	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	0	1	1
0.0087	0.0143	0.0132	0.0192	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	0	1	1	1
0.0097	0.0149	0.0136	0.0184	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	1	1	1	1

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0.0063	0.0037	0.0054	0.0090	0.0100	0.0000	0.0000	0.0000	0.0003	0.0000	1	1	1	1	1	0	0	0	0	0
0.0062	0.0038	0.0055	0.0086	0.0092	0.0000	0.0000	0.0000	0.0003	0.0000	1	1	1	1	0	1	0	0	0	0
0.0062	0.0039	0.0056	0.0085	0.0091	0.0000	0.0000	0.0000	0.0003	0.0000	1	1	1	1	0	0	1	0	0	0
0.0059	0.0037	0.0056	0.0082	0.0112	0.0000	0.0000	0.0000	0.0003	0.0000	1	1	1	1	0	0	0	1	0	0
0.0063	0.0040	0.0055	0.0087	0.0101	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	0	1	0
0.0065	0.0042	0.0056	0.0094	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	0	0	1
0.0062	0.0038	0.0052	0.0099	0.0083	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	0	0	0
0.0062	0.0038	0.0053	0.0101	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	0	0	0
0.0060	0.0038	0.0053	0.0093	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	1	0	0
0.0063	0.0039	0.0052	0.0104	0.0096	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	0	1	0
0.0064	0.0041	0.0053	0.0100	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	0	0	1
0.0062	0.0040	0.0055	0.0087	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	0	0	0
0.0060	0.0039	0.0054	0.0079	0.0106	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	1	0	0
0.0062	0.0041	0.0053	0.0089	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	0	1	0
0.0064	0.0042	0.0054	0.0088	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	0	0	1

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0.0059	0.0039	0.0055	0.0093	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	1	0	0
0.0063	0.0041	0.0054	0.0090	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	0	1	0
0.0064	0.0042	0.0055	0.0086	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	0	0	1
0.0060	0.0040	0.0054	0.0111	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	1	1	0
0.0061	0.0042	0.0054	0.0111	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	1	0	1
0.0065	0.0044	0.0054	0.0097	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	0	1	1
0.0054	0.0043	0.0077	0.0092	0.0080	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	0	0	0
0.0054	0.0043	0.0077	0.0095	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	0	0	0
0.0062	0.0042	0.0074	0.0087	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	1	0	0
0.0064	0.0044	0.0078	0.0096	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	0	1	0
0.0066	0.0046	0.0075	0.0093	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	0	0	1
0.0064	0.0044	0.0082	0.0083	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	0	0	0
0.0061	0.0043	0.0079	0.0076	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	1	0	0
0.0064	0.0045	0.0083	0.0084	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	0	1	0
0.0065	0.0047	0.0080	0.0085	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	0	0	1
0.0061	0.0043	0.0078	0.0089	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	1	0	0
0.0064	0.0045	0.0083	0.0085	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	0	1	0
0.0066	0.0047	0.0080	0.0082	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	0	0	1
0.0062	0.0044	0.0080	0.0103	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	1	1	0
0.0063	0.0046	0.0077	0.0104	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	1	0	1
0.0065	0.0048	0.0081	0.0095	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	0	1	1
0.0063	0.0044	0.0094	0.0076	0.0078	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	0	0	0
0.0062	0.0043	0.0087	0.0070	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	1	0	0
0.0064	0.0045	0.0096	0.0076	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	0	1	0
0.0065	0.0047	0.0091	0.0077	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	0	0	1
0.0061	0.0043	0.0088	0.0076	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	1	0	0
0.0064	0.0045	0.0098	0.0080	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	0	1	0
0.0065	0.0047	0.0094	0.0077	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	0	0	1

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0.0062	0.0044	0.0090	0.0094	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	1	1	0
0.0063	0.0046	0.0086	0.0095	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	1	0	1
0.0066	0.0048	0.0096	0.0090	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	0	1	1
0.0062	0.0044	0.0073	0.0077	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	1	0	0
0.0064	0.0046	0.0080	0.0081	0.0089	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	0	1	0
0.0066	0.0048	0.0081	0.0077	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	0	0	1
0.0062	0.0045	0.0073	0.0099	0.0084	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	1	1	0
0.0063	0.0047	0.0073	0.0098	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	1	0	1
0.0066	0.0049	0.0081	0.0088	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	0	1	1
0.0062	0.0045	0.0079	0.0101	0.0087	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	1	1	0
0.0063	0.0047	0.0075	0.0102	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	1	0	1
0.0066	0.0049	0.0080	0.0092	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	0	1	1
0.0064	0.0048	0.0102	0.0086	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	0	1	1	1
0.0070	0.0067	0.0089	0.0106	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	0	0	0
0.0069	0.0068	0.0088	0.0109	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	0	0	0
0.0067	0.0068	0.0085	0.0098	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	1	0	0
0.0070	0.0066	0.0090	0.0111	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	0	1	0
0.0073	0.0068	0.0086	0.0107	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	0	0	1
0.0069	0.0070	0.0095	0.0098	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	0	0	0
0.0066	0.0069	0.0091	0.0088	0.0120	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	1	0	0
0.0070	0.0069	0.0097	0.0098	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	0	1	0
0.0072	0.0070	0.0092	0.0099	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	0	0	1
0.0065	0.0070	0.0090	0.0093	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	1	0	0
0.0070	0.0070	0.0097	0.0101	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	0	1	0
0.0072	0.0071	0.0092	0.0096	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	0	0	1
0.0066	0.0069	0.0092	0.0124	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	1	1	0
0.0068	0.0070	0.0097	0.0125	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	1	0	1
0.0074	0.0070	0.0094	0.0117	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	0	1	1

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0.0073	0.0066	0.0115	0.0087	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	0	0	0
0.0067	0.0066	0.0099	0.0080	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	1	0	0
0.0071	0.0065	0.0111	0.0087	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	0	1	0
0.0073	0.0066	0.0105	0.0089	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	0	0	1
0.0066	0.0057	0.0100	0.0089	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	1	0	0
0.0070	0.0066	0.0113	0.0095	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	0	1	0
0.0073	0.0067	0.0109	0.0090	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	0	0	1
0.0068	0.0065	0.0103	0.0112	0.0105	0.0000	0.0000	-0.0000	0.0000	0.0000	1	0	1	0	1	0	0	1	1	0
0.0069	0.0067	0.0096	0.0114	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	1	0	1
0.0073	0.0066	0.0110	0.0111	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	0	1	1
0.0067	0.0069	0.0082	0.0090	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	1	0	0
0.0071	0.0068	0.0092	0.0096	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	0	1	0
0.0073	0.0069	0.0094	0.0090	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	0	0	1
0.0068	0.0068	0.0082	0.0118	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	1	1	0
0.0069	0.0069	0.0083	0.0118	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	1	0	1
0.0074	0.0068	0.0093	0.0107	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	0	1	1
0.0067	0.0068	0.0092	0.0122	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	1	1	0
0.0069	0.0069	0.0086	0.0123	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	1	0	1
0.0074	0.0069	0.0094	0.0112	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	0	1	1
0.0070	0.0068	0.0122	0.0103	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	0	1	1	1
0.0074	0.0085	0.0101	0.0085	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	0	0	0
0.0073	0.0083	0.0092	0.0078	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	1	0	0
0.0075	0.0087	0.0102	0.0083	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	0	1	0
0.0077	0.0083	0.0097	0.0086	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	0	0	1
0.0072	0.0082	0.0094	0.0086	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	1	0	0
0.0075	0.0086	0.0105	0.0090	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	0	1	0
0.0078	0.0082	0.0101	0.0086	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	0	0	1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]										

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0.0075	0.0079	0.0090	0.0107	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	1	0	1
0.0078	0.0084	0.0102	0.0110	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	0	1	1
0.0072	0.0087	0.0080	0.0085	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	1	0	0
0.0075	0.0092	0.0088	0.0090	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	0	1	0
0.0078	0.0088	0.0090	0.0085	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	0	0	1
0.0073	0.0089	0.0079	0.0109	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	1	1	[illegible]
0.0074	0.0085	0.0080	0.0110	3.0135	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	1	0	[illegible]
0.0078	0.0090	0.0089	0.0106	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	0	1	1
0.0072	0.0088	0.0087	0.0113	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	1	1	0
0.0074	0.0084	0.0082	0.0115	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	1	0	1
0.0078	0.0090	0.0088	0.0111	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	0	1	1
0.0075	0.0086	0.0114	0.0103	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	0	1	1	1
0.0073	0.0095	0.0072	0.0082	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	1	0	0
0.0075	0.0106	0.0078	0.0086	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	0	1	0
0.0078	0.0101	0.0081	0.0081	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	0	0	1
0.0074	0.0097	0.0072	0.0099	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	1	1	0
0.0075	0.0091	0.9073	0.0100	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	1	0	1
0.0078	0.0102	0.0079	0.0102	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	0	1	1
0.0073	0.0098	0.0084	0.0102	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	1	1	0
0.0075	0.0093	0.0078	0.0104	0.0129	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	1	0	1
0.0078	0.0105	0.0083	0.0105	0.0130	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	0	1	1
0.0075	0.0095	0.0103	0.0099	0.0132	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	0	1	1	1
0.0074	0.0075	0.0085	0.0109	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	1	1	0
0.0075	0.0076	0.0078	0.0109	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	1	0	1
0.0079	0.0084	0.0084	0.0103	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	0	1	1
0.0076	0.0075	0.0108	0.0096	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	0	1	1	1
0.0076	0.0080	0.0112	0.0099	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	0	1	1	1	1
0.0043	0.0059	0.0000	0.0093	0.0084	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	0	0	0

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0.0043	0.0060	0.0080	0.0096	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	0	0	0
0.0042	0.0060	0.0078	0.0088	0.0102	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	1	0	0
0.0044	0.0059	0.0082	0.0098	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	0	1	0
0.0047	0.0060	0.0079	0.0095	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	0	0	1
0.0044	0.0061	0.0085	0.0086	0.0085	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	0	0	0
0.0043	0.0061	0.0082	0.0079	0.0104	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	1	0	0
0.0045	0.0060	0.0087	0.0087	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	0	1	0
0.0047	0.0061	0.0083	0.0088	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	0	0	1
0.0043	0.0061	0.0081	0.0083	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	1	1	0	0
0.0045	0.0061	0.0086	0.0089	0.0098	0.0000	0.0000	0.0000	0.0030	0.0000	0	1	1	1	0	0	1	0	1	0
0.0048	0.0062	0.0083	0.0086	0.0116	0.0000	0.0000	0.0000	0.0030	0.0000	0	1	1	1	0	0	1	0	0	1
0.0044	0.0061	0.0083	0.0108	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	1	1	0
0.0046	0.0061	0.0080	0.0109	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	1	0	1
0.0049	0.0061	0.0085	0.0098	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	0	1	1
0.0044	0.0059	0.0095	0.0079	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	1	0	0	0
0.0044	0.0058	0.0088	0.0073	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	1	0	0
0.0046	0.0058	0.0097	0.0079	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	0	1	0
0.0048	0.0058	0.0093	0.0081	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	0	0	1
0.0043	0.0059	0.0089	0.0080	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	1	0	0
0.0045	0.0058	0.0099	0.0084	0.0093	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	0	1	0
0.0048	0.0059	0.0096	0.0081	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	0	0	1
0.0044	0.0058	0.0091	0.0100	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	1	1	0
0.0046	0.0059	0.0087	0.0101	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	1	0	1
0.0049	0.0058	0.0098	0.0093	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	0	1	1
0.0044	0.0060	0.0075	0.0080	0.0103	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	1	0	0
0.0047	0.0060	0.0083	0.0085	0.0091	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	0	1	0
0.0049	0.0060	0.0084	0.0081	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	0	0	1
0.0046	0.0059	0.0076	0.0103	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	1	1	0

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0.0047	0.0060	0.0076	0.0103	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	1	0	1
0.0050	0.0059	0.0084	0.0091	0.0119	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	0	1	1
0.0045	0.0060	0.0082	0.0106	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	1	1	0
0.0047	0.0060	0.0078	0.0107	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	1	0	1
0.0050	0.0060	0.0084	0.0094	0.0117	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	0	1	1
0.0049	0.0059	0.0107	0.0088	0.0116	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	0	1	1	1
0.0050	0.0077	0.0089	0.0077	0.0078	0.0000	0.0000	0.0000	0.0300	0.0000	0	1	0	1	1	1	1	0	0	0
0.0049	0.0075	0.0082	0.0071	0.0091	0.0000	0.0000	0.0000	0.0300	0.0000	0	1	0	1	1	1	0	1	0	0
0.0051	0.0079	0.0091	0.0076	0.0090	0.0000	0.0000	0.0000	0.0300	0.0000	0	1	0	1	1	1	0	0	1	0
0.0053	0.0076	0.0087	0.0078	0.0110	0.0000	0.0000	0.0000	0.0300	0.0000	0	1	0	1	1	1	0	0	0	1
0.0049	0.0074	0.0084	0.0077	0.0094	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	1	0	0
0.0051	0.0078	0.0093	0.0081	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	0	1	0
0.0053	0.0075	0.0090	0.0078	0.0108	0.0000	0.0000	0.0000	0.0003	0.0000	0	1	0	1	1	0	1	0	0	1
0.0050	0.0076	0.0085	0.0094	0.0088	0.0000	0.0000	0.0000	0.0003	0.0000	0	1	0	1	1	0	0	1	1	0
0.0052	0.0073	0.0082	0.0096	0.0108	0.0000	0.0000	0.0000	0.0003	0.0000	0	1	0	1	1	0	0	1	0	1
0.0054	0.0077	0.0091	0.0092	0.0110	0.0000	0.0000	0.0000	0.0003	0.0000	0	1	0	1	1	0	0	0	1	1
0.0050	0.0079	0.0073	0.0076	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	1	0	0
0.0052	0.0083	0.0079	0.0081	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	0	1	0
0.0054	0.0080	0.0081	0.0077	0.0110	0.0000	0.0000	0.0000	0.0003	0.0000	0	1	0	1	0	1	1	0	0	1
0.0051	0.0080	0.0073	0.0097	0.0086	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	1	1	0
0.0053	0.0077	0.0074	0.0097	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	1	0	1
0.0055	0.0081	0.0081	0.0090	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	0	1	1
0.0051	0.0080	0.0078	0.0100	0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	1	1	0
0.0053	0.0077	0.0075	0.0101	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	1	0	1
0.0056	0.0081	0.0080	0.0093	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	0	1	1
0.0054	0.0078	0.0101	0.0087	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	0	1	1	1
0.0050	0.0085	0.0067	0.0074	0.0090	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	1	0	0
0.0052	0.0093	0.0072	0.0078	0.0087	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	0	1	0

0.0054	0.0089	0.0074	0.0074	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	0	0	1
0.0051	0.0086	0.0067	0.0090	0.0083	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	1	1	0
0.0053	0.0082	0.0068	0.0091	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	1	0	1
0.0055	0.0091	0.0074	0.0086	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	0	1	1
0.0051	0.0087	0.0076	0.0092	0.0085	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	1	1	0
0.0053	0.0084	0.0072	0.0094	0.0106	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	1	0	1
0.0055	0.0093	0.0076	0.0089	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	0	1	1
0.0054	0.0085	0.0093	0.0084	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	0	1	1	1
0.0053	0.0069	0.0076	0.0096	0.0083	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	1	1	0
0.0054	0.0070	0.0072	0.0097	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	1	0	1
0.0057	0.0077	0.0077	0.0087	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	0	1	1
0.0055	0.0070	0.0097	0.0082	0.0112	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	0	1	1	1
0.0055	0.0074	0.0100	0.0084	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	0	1	1	1	1
0.0080	0.0092	0.0106	0.0092	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	0	0	0
0.0079	0.0090	0.0095	0.0084	0.0114	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	1	0	0
0.0079	0.0094	0.0108	0.0091	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	0	1	0
0.0081	0.0090	0.0102	0.0095	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	0	0	1
0.0080	0.0088	0.0097	0.0094	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	1	0	0
0.0079	0.0093	0.0111	0.0099	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	0	1	0
0.0082	0.0089	0.0107	0.0095	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	0	0	1
0.0079	0.0090	0.0099	0.0117	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	1	1	0
0.0081	0.0086	0.0093	0.0120	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	1	0	1
0.0080	0.0091	0.0108	0.0121	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	0	1	1
0.0082	0.0094	0.0085	0.0093	0.0122	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	1	0	0
0.0082	0.0100	0.0095	0.0099	0.0118	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	0	1	0
0.0084	0.0096	0.0098	0.0093	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	0	0	1
0.0081	0.0097	0.0085	0.0121	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	1	1	0
0.0082	0.0091	0.0086	0.0122	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	1	0	1

8.37

0.0082	0.0098	0.0097	0.0116	0.0150	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	0	1	1
0.0081	0.0095	0.0095	0.0125	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	1	1	0
0.0083	0.0091	0.0089	0.0128	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	1	0	1
0.0083	0.0098	0.0097	0.0122	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	0	1	1
0.0082	0.0092	0.0126	0.0112	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	0	1	1	1
0.0079	0.0100	0.0078	0.0091	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	1	0	0
0.0079	0.0113	0.0085	0.0096	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	0	1	0
0.0081	0.0107	0.0089	0.0090	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	0	0	1
0.0078	0.0103	0.0077	0.0112	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	1	1	0
0.0080	0.0095	0.0079	0.0114	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	1	0	1
0.0079	0.0109	0.0087	0.0114	0.0148	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	0	1	1
0.0079	0.0103	0.0092	0.0115	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	1	1	0
0.0081	0.0097	0.0086	0.0118	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	1	0	1
0.0080	0.0112	0.0092	0.0118	0.0144	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	0	1	1
0.0079	0.0099	0.0116	0.0109	0.0145	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	0	1	1	1
0.0081	0.0080	0.0093	0.0122	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	1	1	0
0.0083	0.0081	0.0086	0.0123	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	1	0	1
0.0083	0.0092	0.0093	0.0114	0.0150	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	0	1	1
0.0082	0.0080	0.0122	0.0106	0.0151	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	0	1	1	1
0.0082	0.0088	0.0126	0.0109	0.0146	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	0	1	1	1	1
0.0087	0.0093	0.0077	0.0087	0.0105	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	1	0	0
0.0090	0.0104	0.0082	0.0091	0.0113	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	0	1	0
0.0087	0.0099	0.0087	0.0086	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	0	0	1
0.0088	0.0095	0.0075	0.0104	0.0108	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	1	1	0
0.0084	0.0089	0.0078	0.0107	0.0138	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	1	0	1
0.0088	0.0100	0.0084	0.0112	0.0139	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	0	1	1
0.0087	0.0096	0.0088	0.0107	0.0110	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	1	1	0
0.0083	0.0091	0.0083	0.0111	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	1	0	1

8.38

0.0088	0.0104	0.0088	0.0116	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	0	1	1
0.0085	0.0092	0.0109	0.0109	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	0	1	1	1
0.0093	0.0077	0.0088	0.0112	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	1	1	0
0.0089	0.0080	0.0082	0.0114	0.0137	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	1	0	1
0.0094	0.0089	0.0088	0.0112	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	0	1	1
0.0090	0.0078	0.0113	0.0105	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	0	1	1	1
0.0090	0.0084	0.0117	0.0108	0.0136	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	0	1	1	1	1
0.0108	0.0072	0.0094	0.0113	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	1	1	0
0.0099	0.0076	0.0085	0.0117	0.0162	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	1	0	1
0.0113	0.0082	0.0090	0.0127	0.0163	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	0	1	1
0.0101	0.0073	0.0113	0.0119	0.0166	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	1	1	1
0.0102	0.0086	0.0116	0.0122	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	0	1	1	1	1
8.39 0.0076	0.0088	0.0129	0.0124	0.0178	0.0000	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	1	1	1	1	1
210																			
0.0095	0.0064	0.0079	0.0103	0.0113	0.0155	0.0000	0.0000	0.0000	0.0000	0	0	0	0	1	1	1	1	1	1
0.0087	0.0070	0.0076	0.0103	0.0099	0.0131	0.0000	0.0000	0.0000	0.0000	0	0	0	1	0	1	1	1	1	1
0.0082	0.0086	0.0077	0.0098	0.0103	0.0127	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	0	1	1	1	1
0.0083	0.0085	0.0068	0.0096	0.0100	0.0131	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	0	1	1	1
0.0085	0.0094	0.0074	0.0079	0.0105	0.0129	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	0	1	1
0.0081	0.0083	0.0070	0.0076	0.0098	0.0129	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	1	0	1
0.0085	0.0088	0.0067	0.0081	0.0094	0.0102	0.0000	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	1	1	0
0.0080	0.0071	0.0080	0.0111	0.0100	0.0141	0.0000	0.0000	0.0000	0.0000	0	0	1	0	0	1	1	1	1	1
0.0078	0.0092	0.0080	0.0105	0.0103	0.0136	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	0	1	1	1	1
0.0078	0.0091	0.0069	0.0102	0.0100	0.0140	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	0	1	1	1
0.0078	0.0101	0.0077	0.0083	0.0106	0.0138	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	0	1	1
0.0079	0.0089	0.0070	0.0079	0.0104	0.0137	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	1	0	1
0.0077	0.0096	0.0068	0.0085	0.0102	0.0103	0.0000	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	1	1	0
0.0080	0.0089	0.0082	0.0114	0.0104	0.0135	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	0	1	1	1	1

0.0080	0.0090	0.0075	0.0110	0.0101	0.0139	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	0	1	1	1
0.0081	0.0093	0.0085	0.0086	0.0109	0.0139	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	0	1	1
0.0081	0.0088	0.0076	0.0080	0.0111	0.0136	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	1	0	1
0.0079	0.0093	0.0074	0.0086	0.0110	0.0103	0.0000	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	1	1	0
0.0078	0.0084	0.0088	0.0106	0.0105	0.0136	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	0	1	1	1
0.0079	0.0087	0.0099	0.0086	0.0113	0.0134	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	0	1	1
0.0079	0.0083	0.0086	0.0081	0.0109	0.0133	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	1	0	1
0.0077	0.0087	0.0091	0.0086	0.0105	0.0107	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	1	1	0
0.0078	0.0088	0.0096	0.0081	0.0109	0.0138	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	0	1	1
0.0079	0.0084	0.0094	0.0075	0.0104	0.0137	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	1	0	1
0.0077	0.0088	0.0090	0.0073	0.0102	0.0105	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	1	1	0
0.0079	0.0086	0.0094	0.0084	0.0084	0.0135	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	0	0	1
0.0077	0.0090	0.0099	0.0079	0.0089	0.0110	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	0	1	0
8.40 0.0078	0.0086	0.0088	0.0074	0.0085	0.0103	0.0000	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	1	0	0
0.0053	0.0064	0.0068	0.0089	0.0078	0.0105	0.0000	0.0000	0.0000	0.0000	0	1	0	0	0	1	1	1	1	1
0.0052	0.0080	0.0068	0.0086	0.0080	0.0102	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	0	1	1	1	1
0.0052	0.0079	0.0062	0.0084	0.0078	0.0105	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	0	1	1	1
0.0053	0.0086	0.0067	0.0070	0.0082	0.0104	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	0	1	1
0.0051	0.0078	0.0062	0.0067	0.0084	0.0102	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	1	0	1
0.0050	0.0081	0.0061	0.0070	0.0083	0.0079	0.0000	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	1	1	0
0.0052	0.0075	0.0070	0.0093	0.0082	0.0104	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	0	1	1	1	1
0.0052	0.0076	0.0067	0.0090	0.0080	0.0106	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	0	1	1	1
0.0053	0.0078	0.0073	0.0072	0.0085	0.0106	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	0	1	1
0.0051	0.0074	0.0067	0.0069	0.0090	0.0104	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	1	0	1
0.0049	0.0077	0.0066	0.0072	0.0099	0.0081	0.0000	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	1	1	0
0.0051	0.0072	0.0078	0.0087	0.0093	0.0104	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	0	1	1	1
0.0052	0.0074	0.0085	0.0073	0.0087	0.0103	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	0	1	1
0.0050	0.0071	0.0077	0.0069	0.0088	0.0102	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	1	0	1

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0.0048	0.0073	0.0080	0.0072	0.0086	0.0083	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	1	1	0
0.0052	0.0074	0.0083	0.0070	0.0084	0.0105	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	0	0	1	1
0.0050	0.0071	0.0075	0.0066	0.0085	0.0104	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	0	1	0	1
0.0048	0.0074	0.0079	0.0064	0.0084	0.0081	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	0	1	1	0
0.0051	0.0073	0.0082	0.0071	0.0071	0.0103	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	0	0	1
0.0049	0.0076	0.0085	0.0069	0.0074	0.0085	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	0	1	0
0.0048	0.0073	0.0077	0.0065	0.0071	0.0084	0.0000	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	1	0	0
0.0046	0.0059	0.0073	0.0099	0.0083	0.0109	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	0	1	1	1	1
0.0046	0.0058	0.0069	0.0096	0.0080	0.0111	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	0	1	1	1
0.0048	0.0059	0.0076	0.0076	0.0085	0.0111	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	0	1	1
0.0045	0.0059	0.0069	0.0071	0.0095	0.0108	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	1	0	1
0.0044	0.0059	0.0068	0.0076	0.0095	0.0081	0.0000	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	1	1	0
0.0045	0.0057	0.0083	0.0092	0.0083	0.0108	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	0	1	1	1
0.0046	0.0057	0.0091	0.0076	0.0087	0.0107	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	0	1	1
0.0044	0.0058	0.0082	0.0072	0.0093	0.0105	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	1	0	1
0.0042	0.0057	0.0085	0.0075	0.0091	0.0083	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	1	1	0
0.0046	0.0057	0.0089	0.0072	0.0085	0.0110	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	0	1	1
0.0045	0.0057	0.0080	0.0067	0.0090	0.0108	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	1	0	1
0.0043	0.0057	0.0084	0.0066	0.0089	0.0082	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	1	1	0
0.0045	0.0058	0.0087	0.0073	0.0074	0.0107	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	1	0	0	1
0.0043	0.0057	0.0091	0.0071	0.0077	0.0085	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	1	0	1	0
0.0042	0.0059	0.0083	0.0066	0.0074	0.0089	0.0000	0.0000	0.0000	0.0000	0	1	1	0	1	1	1	1	0	0
0.0045	0.0059	0.0078	0.0100	0.0085	0.0110	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	0	1	1	1
0.0046	0.0060	0.0081	0.0079	0.0091	0.0110	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	1	0	1	1
0.0044	0.0060	0.0077	0.0074	0.0100	0.0108	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	1	1	0	1
0.0042	0.0060	0.0080	0.0078	0.0099	0.0086	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	0	1	1	1	0
0.0046	0.0059	0.0081	0.0079	0.0088	0.0112	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	0	1	1
0.0044	0.0060	0.0077	0.0072	0.0096	0.0119	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	1	0	1

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0.0042	0.0059	0.0080	0.0071	0.0096	0.0084	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	0	1	1	0
0.0045	0.0060	0.0080	0.0079	0.0076	0.0110	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	0	0	1
0.0043	0.0060	0.0083	0.0078	0.0080	0.0088	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	0	1	0
0.0041	0.0060	0.0079	0.0071	0.0076	0.0095	0.0000	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	1	0	0
0.0045	0.0058	0.0077	0.0089	0.0091	0.0110	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	0	1	1
0.0043	0.0059	0.0073	0.0080	0.0095	0.0108	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	1	0	1
0.0041	0.0058	0.0076	0.0083	0.0093	0.0086	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	1	1	0
0.0044	0.0059	0.0076	0.0088	0.0077	0.0107	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	0	0	1
0.0042	0.0058	0.0078	0.0091	0.0080	0.0091	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	0	1	0
0.0040	0.0059	0.0075	0.0082	0.0076	0.0093	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	1	0	0
0.0044	0.0059	0.0076	0.0085	0.0077	0.0109	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	0	0	1
0.0042	0.0058	0.0079	0.0089	0.0075	0.0088	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	0	1	0
0.0040	0.0058	0.0075	0.0080	0.0070	0.0091	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	1	0	0
0.0041	0.0059	0.0077	0.0087	0.0075	0.0078	0.0000	0.0000	0.0000	0.0000	0	1	1	1	1	1	1	0	0	0
0.0072	0.0067	0.0074	0.0099	0.0091	0.0128	0.0000	0.0000	0.0000	0.0000	1	0	0	0	0	1	1	1	1	1
0.0072	0.0089	0.0073	0.0094	0.0093	0.0123	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	0	1	1	1	1
0.0072	0.0098	0.0064	0.0091	0.0091	0.0127	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	0	1	1	1
0.0074	0.0096	0.0071	0.0075	0.0096	0.0125	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	0	1	1
0.0072	0.0086	0.0066	0.0072	0.0092	0.0124	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	1	0	1
0.0070	0.0091	0.0064	0.0077	0.0091	0.0093	0.0000	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	1	1	0
0.0071	0.0083	0.0076	0.0103	0.0097	0.0126	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	0	1	1	1	1
0.0071	0.0083	0.0071	0.0099	0.0094	0.0129	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	0	1	1	1
0.0074	0.0086	0.0079	0.0079	0.0100	0.0129	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	0	1	1
0.0071	0.0082	0.0072	0.0074	0.0101	0.0127	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	1	0	1
0.0069	0.0086	0.0070	0.0080	0.0099	0.0096	0.0000	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	1	1	0
0.0071	0.0078	0.0086	0.0096	0.0097	0.0126	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	0	1	1	1
0.0073	0.0080	0.0095	0.0079	0.0103	0.0124	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	0	1	1
0.0071	0.0077	0.0084	0.0075	0.0090	0.0123	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	1	0	1

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0.0068	0.0080	0.0089	0.0079	0.0095	0.0098	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	1	1	0
0.0074	0.0081	0.0092	0.0075	0.0099	0.0127	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	0	1	1
0.0071	0.0078	0.0082	0.0070	0.0094	0.0127	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	1	0	1
0.0069	0.0082	0.0088	0.0068	0.0092	0.0097	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	[illegible]	1	0
0.0073	0.0088	0.0091	0.0077	0.0077	0.0125	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	0	0	1
0.0071	0.0083	0.0095	0.0074	0.0081	0.0101	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	0	1	0
0.0069	0.0080	0.0086	0.0069	0.0078	0.0093	0.0000	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	1	0	0
0.0065	0.0068	0.0080	0.0111	0.0097	0.0132	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	0	1	1	1	1
0.0066	0.0067	0.0073	0.0107	0.0094	0.0136	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	0	1	1	1
0.0069	0.0067	0.0083	0.0083	0.0101	0.0126	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	0	1	1
0.0065	0.0068	0.0074	0.0078	0.0108	0.0132	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	1	0	1
0.0064	0.0067	0.0073	0.0084	0.0107	0.0096	0.0000	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	1	1	0
0.0066	0.0065	0.0092	0.0102	0.0097	0.0131	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	1	1	1
0.0068	0.0065	0.0102	0.0082	0.0103	0.0130	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	0	1	1
0.0065	0.0056	0.0090	0.0078	0.0103	0.0128	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	1	0	1
0.0063	0.0065	0.0095	0.0093	0.0101	0.0098	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	1	1	0
0.0069	0.0065	0.0099	0.0078	0.0100	0.0134	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	0	1	1
0.0066	0.0066	0.0088	0.0072	0.0100	0.0132	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	1	0	1
0.0064	0.0064	0.0095	0.0070	0.0099	0.0097	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	1	1	0
0.0068	0.0066	0.0098	0.0079	0.0080	0.0131	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	0	0	1
0.0066	0.0064	0.0103	0.0076	0.0086	0.0101	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	0	1	0
0.0063	0.0056	0.0092	0.0071	0.0082	0.0099	0.0000	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	1	0	0
0.0065	0.0068	0.0086	0.0112	0.0100	0.0134	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	0	1	1	1
0.0068	0.0069	0.0090	0.0087	0.0109	0.0135	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	0	1	1
0.0064	0.0069	0.0084	0.0081	0.0113	0.0131	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	1	0	1
0.0052	0.0068	0.0088	0.0086	0.0112	0.0102	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	1	1	0
0.0068	0.0068	0.0090	0.0087	0.0104	0.0137	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	0	1	1
0.0064	0.0069	0.0085	0.0078	0.0108	0.0134	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	1	0	1

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0.0063	0.0068	0.0089	0.0077	0.0108	0.0100	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	1	1	0
0.0067	0.0069	0.0088	0.0088	0.0084	0.0134	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	0	0	1
0.0065	0.0068	0.0092	0.0086	0.0090	0.0106	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	0	1	0
0.0062	0.0069	0.0087	0.0078	0.0084	0.0108	0.0000	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	1	0	0
0.0058	0.0066	0.0084	0.0099	0.0108	0.0133	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	0	1	1
0.0065	0.0067	0.0080	0.0087	0.0106	0.0131	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	1	0	1
0.0063	0.0066	0.0084	0.0092	0.0104	0.0103	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	0	1	1	0
0.0068	0.0067	0.0092	0.0098	0.0085	0.0131	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	0	0	1
0.0065	0.0066	0.0086	0.0102	0.0089	0.0109	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	0	1	0
0.0062	0.0067	0.0082	0.0091	0.0085	0.0105	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	1	0	0
0.0068	0.0067	0.0083	0.0094	0.0085	0.0133	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	0	0	1
0.0066	0.0065	0.0087	0.0100	0.0082	0.0105	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	0	1	0
0.0063	0.0066	0.0083	0.0089	0.0076	0.0102	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	1	0	0
0.0065	0.0066	0.0085	0.0098	0.0083	0.0087	0.0000	0.0000	0.0000	0.0000	1	0	1	1	1	1	1	0	0	0
0.0060	0.0046	0.0070	0.0094	0.0081	0.0108	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	0	1	1	1	1
0.0061	0.0046	0.0066	0.0091	0.0079	0.0110	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	0	1	1	1
0.0063	0.0047	0.0073	0.0073	0.0083	0.0110	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	0	1	1
0.0060	0.0046	0.0067	0.0068	0.0091	0.0109	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	1	0	1
0.0059	0.0044	0.0066	0.0073	0.0091	0.0080	0.0000	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	1	1	0
0.0060	0.0045	0.0082	0.0087	0.0081	0.0107	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	0	1	1	1
0.0062	0.0046	0.0089	0.0072	0.0085	0.0106	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	0	1	1
0.0060	0.0044	0.0081	0.0068	0.0088	0.0105	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	1	0	1
0.0059	0.0042	0.0085	0.0072	0.0087	0.0082	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	1	1	0
0.0062	0.0046	0.0097	0.0069	0.0083	0.0108	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	0	1	1
[illegible]	0.0044	0.0079	0.0065	0.0085	0.0107	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	1	0	1
0.0059	0.0043	0.0084	0.0064	0.0085	0.0080	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	1	1	0
0.0062	0.0045	0.0086	0.0070	0.0073	0.0106	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	0	0	1
0.0061	0.0043	0.0090	0.0068	0.0074	0.0083	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	0	1	0

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0.0059	0.0042	0.0082	0.0064	0.0071	0.0085	0.0000	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	1	0	0
0.0060	0.0045	0.0075	0.0095	0.0084	0.0109	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	0	1	1	1
0.0062	0.0046	0.0078	0.0075	0.0089	0.0110	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	0	1	1
0.0059	0.0044	0.0074	0.0071	0.0095	0.0107	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	1	0	1
0.0059	0.0042	0.0077	0.0075	0.0094	0.0084	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	1	1	0
0.0062	0.0046	0.0078	0.0076	0.0086	0.0111	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	0	1	1
0.0060	0.0044	0.0074	0.0070	0.0092	0.0109	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	1	0	1
0.0059	0.0042	0.0077	0.0069	0.0092	0.0082	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	1	1	0
0.0062	0.0045	0.0077	0.0077	0.0073	0.0109	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	0	0	1
0.0060	0.0043	0.0080	0.0075	0.0077	0.0086	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	0	1	0
0.0058	0.0042	0.0076	0.0069	0.0073	0.0091	0.0000	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	1	0	0
0.0062	0.0045	0.0073	0.0088	0.0088	0.0108	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	0	1	1
0.0060	0.0043	0.0070	0.0079	0.0090	0.0107	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	1	0	1
0.0059	0.0041	0.0073	0.0083	0.0089	0.0085	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	1	1	0
0.0062	0.0044	0.0072	0.0087	0.0074	0.0106	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	0	0	1
0.0060	0.0042	0.0075	0.0089	0.0076	0.0089	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	0	1	0
0.0058	0.0041	0.0072	0.0081	0.0073	0.0089	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	1	0	0
0.0062	0.0044	0.0073	0.0084	0.0074	0.0108	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	0	0	1
0.0061	0.0042	0.0075	0.0087	0.0072	0.0086	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	0	1	0
0.0059	0.0041	0.0073	0.0080	0.0069	0.0085	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	1	0	0
0.0060	0.0041	0.0074	0.0086	0.0072	0.0075	0.0000	0.0000	0.0000	0.0000	1	1	0	1	1	1	1	0	0	0
0.0058	0.0041	0.0053	0.0102	0.0084	0.0114	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	0	1	1	1
0.0061	0.0042	0.0053	0.0089	0.0090	0.0115	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	0	1	1
0.0057	0.0040	0.0054	0.0074	0.0101	0.0111	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	1	0	1
0.0055	0.0038	0.0053	0.0078	0.0101	0.0085	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	1	1	0
0.0061	0.0042	0.0053	0.0080	0.0087	0.0117	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	0	1	1
0.0058	0.0040	0.0053	0.0072	0.0098	0.0113	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	1	0	1
0.0057	0.0038	0.0053	0.0072	0.0098	0.0083	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	1	1	0

8.46

0.0060	0.0041	0.0054	0.0080	0.0077	0.0114	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	0	0	1
0.0059	0.0039	0.0053	0.0079	0.0081	0.0088	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	0	1	0
0.0056	0.0037	0.0054	0.0072	0.0076	0.0097	0.0000	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	1	0	0
0.0061	0.0040	0.0051	0.0094	0.0089	0.0113	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	0	1	1
0.0058	0.0039	0.0052	0.0084	0.0095	0.0111	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	1	0	1
0.0057	0.0037	0.0051	0.0088	0.0094	0.0085	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	1	1	0
0.0060	0.0040	0.0052	0.0093	0.0077	0.0110	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	0	0	1
0.0059	0.0038	0.0052	0.0096	0.0080	0.0090	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	0	1	0
0.0056	0.0036	0.0052	0.0087	0.0076	0.0094	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	1	0	0
0.0060	0.0039	0.0052	0.0090	0.0076	0.0112	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	0	0	1
0.0059	0.0038	0.0051	0.0094	0.0075	0.0087	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	0	1	0
0.0057	0.0035	0.0052	0.0085	0.0070	0.0091	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	1	0	0
0.0058	0.0037	0.0052	0.0092	0.0075	0.0078	0.0000	0.0000	0.0000	0.0000	1	1	1	0	1	1	1	0	0	0
0.0061	0.0041	0.0054	0.0092	0.0094	0.0117	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	0	1	1
0.0057	0.0038	0.0055	0.0077	0.0103	0.0113	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	1	0	1
0.0056	0.0037	0.0054	0.0080	0.0103	0.0088	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	1	1	0
0.0059	0.0040	0.0055	0.0080	0.0081	0.0114	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	0	0	1
0.0053	0.0038	0.0055	0.0083	0.0085	0.0094	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	0	1	0
0.0055	0.0036	0.0055	0.0079	0.0079	0.0102	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	1	0	0
0.0060	0.0039	0.0054	0.0080	0.0084	0.0115	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	0	0	1
0.0059	0.0027	0.0054	0.0083	0.0083	0.0091	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	0	1	0
0.0055	0.0026	0.0055	0.0079	0.0075	0.0099	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	1	0	0
0.0058	0.0026	0.0055	0.0082	0.0082	0.0081	0.0000	0.0000	0.0000	0.0000	1	1	1	1	0	1	1	0	0	0
0.0053	0.0019	0.0053	0.0075	0.0091	0.0113	0.0000	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	0	0	1
0.0059	0.0016	0.0052	0.0078	0.0094	0.0093	0.0000	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	0	1	0
0.0056	0.0015	0.0053	0.0075	0.0085	0.0097	0.0000	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	1	0	0
0.0058	0.0016	0.0054	0.0077	0.0093	0.0092	0.0000	0.0000	0.0000	0.0000	1	1	1	1	1	0	1	0	0	0
0.0059	0.0015	0.0053	0.0077	0.0090	0.0090	0.0000	0.0000	0.0000	0.0000	1	1	1	1	1	1	0	0	0	0

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0.0086	0.0080	0.0060	0.0071	0.0087	0.0095	0.0124	0.0000	0.0000	0.0000	0	0	0	1	1	1	1	1	1	1
0.0077	0.0086	0.0061	0.0074	0.0094	0.0095	0.0132	0.0000	0.0000	0.0000	0	0	1	0	1	1	1	1	1	1
0.0079	0.0087	0.0067	0.0075	0.0100	0.0096	0.0131	0.0000	0.0000	0.0000	0	0	1	1	0	1	1	1	1	1
0.0077	0.0082	0.0052	0.0075	0.0096	0.0099	0.0127	0.0000	0.0000	0.0000	0	0	1	1	1	0	1	1	1	1
0.0077	0.0083	0.0081	0.0065	0.0094	0.0097	0.0131	0.0000	0.0000	0.0000	0	0	1	1	1	1	0	1	1	1
0.0077	0.0085	0.0089	0.0072	0.0078	0.0102	0.0129	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	0	1	1
0.0078	0.0081	0.0079	0.0067	0.0074	0.0095	0.0128	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	1	0	1
0.0076	0.0085	0.0084	0.0064	0.0080	0.0093	0.0099	0.0000	0.0000	0.0000	0	0	1	1	1	1	1	1	1	0
0.0051	0.0075	0.0056	0.0063	0.0078	0.0074	0.0099	0.0000	0.0000	0.0000	0	1	0	0	1	1	1	1	1	1
0.0050	0.0073	0.0061	0.0065	0.0083	0.0076	0.0100	0.0000	0.0000	0.0000	0	1	0	1	0	1	1	1	1	1
0.0049	0.0070	0.0074	0.0065	0.0081	0.0078	0.0098	0.0000	0.0000	0.0000	0	1	0	1	1	0	1	1	1	1
0.0049	0.0070	0.0072	0.0059	0.0078	0.0077	0.0100	0.0000	0.0000	0.0000	0	1	0	1	1	1	0	1	1	1
0.0050	0.0072	0.0078	0.0064	0.0066	0.0080	0.0099	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	0	1	1
0.0049	0.0069	0.0071	0.0060	0.0064	0.0079	0.0098	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	1	0	1
0.0047	0.0072	0.0074	0.0058	0.0067	0.0078	0.0077	0.0000	0.0000	0.0000	0	1	0	1	1	1	1	1	1	0
0.0045	0.0058	0.0063	0.0068	0.0089	0.0076	0.0105	0.0000	0.0000	0.0000	0	1	1	0	0	1	1	1	1	1
0.0043	0.0056	0.0078	0.0068	0.0085	0.0078	0.0102	0.0000	0.0000	0.0000	0	1	1	0	1	0	1	1	1	1
0.0044	0.0056	0.0077	0.0061	0.0083	0.0077	0.0104	0.0000	0.0000	0.0000	0	1	1	0	1	1	0	1	1	1
0.0044	0.0056	0.0084	0.0066	0.0069	0.0080	0.0103	0.0000	0.0000	0.0000	0	1	1	0	1	1	1	0	1	1
0.0043	0.0057	0.0076	0.0061	0.0066	0.0083	0.0102	0.0000	0.0003	0.0000	0	1	1	0	1	1	1	1	0	1
0.0041	0.0056	0.0080	0.0060	0.0070	0.0082	0.0077	0.0000	0.0003	0.0000	0	1	1	0	1	1	1	1	1	0
0.0043	0.0059	0.0075	0.0070	0.0092	0.0081	0.0103	0.0000	0.0003	0.0000	0	1	1	1	0	0	1	1	1	1
0.0043	0.0058	0.0076	0.0065	0.0089	0.0078	0.0106	0.0000	0.0003	0.0000	0	1	1	1	0	1	0	1	1	1
0.0044	0.0059	0.0078	0.0072	0.0072	0.0083	0.0105	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	0	1	1
0.0042	0.0059	0.0075	0.0066	0.0068	0.0089	0.0103	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	1	0	1
0.0040	0.0059	0.0078	0.0065	0.0072	0.0088	0.0079	0.0000	0.0000	0.0000	0	1	1	1	0	1	1	1	1	0
0.0042	0.0057	0.0072	0.0076	0.0087	0.0081	0.0103	0.0000	0.0000	0.0000	0	1	1	1	1	0	0	1	1	1
0.0043	0.0058	0.0074	0.0083	0.0072	0.0085	0.0102	0.0000	0.0003	0.0000	0	1	1	1	1	0	1	0	1	1

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0.0941	0.0058	0.0071	0.0075	0.0068	0.0087	0.0101	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	1	0	1
0.0039	0.0057	0.0073	0.0078	0.0072	0.0085	0.0081	0.0000	0.0000	0.0000	0	1	1	1	1	0	1	1	1	0
0.0043	0.0057	0.0074	0.0081	0.0069	0.0083	0.0105	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	0	1	1
0.0042	0.0058	0.0071	0.0073	0.0064	0.0084	0.0103	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	1	0	1
0.0040	0.0057	0.0074	0.0077	0.0063	0.0083	0.0080	0.0000	0.0000	0.0000	0	1	1	1	1	1	0	1	1	0
0.0042	0.0058	0.0073	0.0080	0.0070	0.0070	0.0102	0.0000	0.0000	0.0000	0	1	1	1	1	1	1	0	0	1
0.0940	0.0057	0.0076	0.0083	0.0068	0.0073	0.0083	0.0000	0.0000	0.0000	0	1	1	1	1	1	1	0	1	0
0.0039	0.0058	0.0073	0.0075	0.0063	0.0070	0.0083	0.0000	0.0000	0.0000	0	1	1	1	1	1	1	1	0	0
0.0069	0.0083	0.0058	0.0068	0.0084	0.0087	0.0120	0.0000	0.0000	0.0000	1	0	0	0	1	1	1	1	1	1
0.0068	0.0081	0.0064	0.0069	0.0091	0.0089	0.0122	0.0000	0.0000	0.0000	1	0	0	1	0	1	1	1	1	1
0.0068	0.0076	0.0080	0.0069	0.0087	0.0092	0.0118	0.0000	0.0000	0.0000	1	0	0	1	1	0	1	1	1	1
0.0068	0.0077	0.0079	0.0062	0.0085	0.0090	0.0121	0.0000	0.0000	0.0000	1	0	0	1	1	1	0	1	1	1
0.0070	0.0078	0.0086	0.0067	0.0071	0.0094	0.0120	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	0	1	1
0.0068	0.0075	0.0078	0.0063	0.0069	0.0086	0.0119	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	1	0	1
0.0066	0.0079	0.0083	0.0061	0.0074	0.0084	0.0092	0.0000	0.0000	0.0000	1	0	0	1	1	1	1	1	1	0
0.0063	0.0066	0.0066	0.0073	0.0090	0.0089	0.0128	0.0000	0.0000	0.0000	1	0	1	0	0	1	1	1	1	1
0.0062	0.0065	0.0086	0.0073	0.0093	0.0091	0.0123	0.0000	0.0000	0.0000	1	0	1	0	1	0	1	1	1	1
0.0063	0.0064	0.0085	0.0063	0.0091	0.0089	0.0127	0.0000	0.0000	0.0000	1	0	1	0	1	1	0	1	1	1
0.0065	0.0064	0.0093	0.0069	0.0075	0.0094	0.0125	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	0	1	1
0.0062	0.0065	0.0083	0.0064	0.0071	0.0092	0.0124	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	1	0	1
0.0061	0.0064	0.0089	0.0063	0.0077	0.0090	0.0091	0.0000	0.0000	0.0000	1	0	1	0	1	1	1	1	1	0
0.0061	0.0068	0.0083	0.0075	0.0102	0.0094	0.0125	0.0000	0.0000	0.0000	1	0	1	1	0	0	1	1	1	1
0.0061	0.0067	0.0083	0.0069	0.0098	0.0092	0.0129	0.0000	0.0000	0.0000	1	0	1	1	0	1	0	1	1	1
0.0064	0.0067	0.0086	0.0077	0.0078	0.0098	0.0128	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	0	1	1
0.0061	0.0068	0.0082	0.0070	0.0073	0.0099	0.0126	0.0000	0.0000	0.0000	1	0	1	1	0	1	1	1	0	1
0.0059	0.0067	0.0086	0.0069	0.0079	0.0098	0.0094	0.0000	0.0003	0.0000	1	0	1	1	0	1	1	1	1	0
0.0062	0.0065	0.0078	0.0083	0.0095	0.0095	0.0125	0.0000	0.0003	0.0000	1	0	1	1	1	0	0	1	1	1
0.0064	0.0065	0.0081	0.0092	0.0078	0.0101	0.0124	0.0000	0.0003	0.0000	1	0	1	1	1	0	1	0	1	1

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0.0061	0.0066	0.0077	0.0081	0.0074	0.0097	0.0123	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	1	0	1
0.0059	0.0065	0.0081	0.0086	0.0079	0.0094	0.0096	0.0000	0.0000	0.0000	1	0	1	1	1	0	1	1	1	0
0.0054	0.0065	0.0081	0.0089	0.0074	0.0097	0.0127	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	0	1	1
0.0062	0.0066	0.0078	0.0079	0.0069	0.0093	0.0126	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	1	0	1
0.0060	0.0065	0.0082	0.0085	0.0067	0.0092	0.0095	0.0000	0.0000	0.0000	1	0	1	1	1	1	0	1	1	0
0.0064	0.0066	0.0090	0.0089	0.0075	0.0076	0.0125	0.0000	0.0000	0.0000	1	0	1	1	1	1	1	0	0	1
0.0061	0.0065	0.0083	0.0092	0.0072	0.0081	0.0099	0.0000	0.0000	0.0000	1	0	1	1	1	1	1	0	1	0
0.0059	0.0066	0.0090	0.0093	0.0068	0.0078	0.0093	0.0000	0.0000	0.0000	1	0	1	1	1	1	1	1	0	0
0.0050	0.0045	0.0061	0.0065	0.0084	0.0075	0.0104	0.0000	0.0000	0.0000	1	1	0	0	0	1	1	1	1	1
0.0058	0.0044	0.0078	0.0065	0.0081	0.0077	0.0101	0.0000	0.0000	0.0000	1	1	0	0	1	0	1	1	1	1
0.0058	0.0044	0.0077	0.0058	0.0079	0.0075	0.0103	0.0000	0.0000	0.0000	1	1	0	0	1	1	0	1	1	1
0.0059	0.0044	0.0082	0.0063	0.0066	0.0078	0.0102	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	0	1	1
0.0058	0.0043	0.0075	0.0059	0.0063	0.0079	0.0101	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	1	0	1
0.0057	0.0041	0.0079	0.0058	0.0067	0.0078	0.0076	0.0000	0.0000	0.0000	1	1	0	0	1	1	1	1	1	0
0.0057	0.0044	0.0073	0.0067	0.0083	0.0079	0.0103	0.0000	0.0000	0.0000	1	1	0	1	0	0	1	1	1	1
0.0057	0.0044	0.0073	0.0063	0.0085	0.0077	0.0105	0.0000	0.0000	0.0000	1	1	0	1	0	1	0	1	1	1
0.0059	0.0044	0.0075	0.0069	0.0069	0.0081	0.0105	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	0	1	1
0.0057	0.0043	0.0072	0.0064	0.0065	0.0085	0.0103	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	1	0	1
0.0056	0.0041	0.0075	0.0063	0.0069	0.0084	0.0078	0.0000	0.0000	0.0000	1	1	0	1	0	1	1	1	1	0
0.0057	0.0043	0.0069	0.0075	0.0082	0.0079	0.0103	0.0000	0.0000	0.0000	1	1	0	1	1	0	0	1	1	1
0.0059	0.0043	0.0071	0.0082	0.0069	0.0083	0.0102	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	0	1	1
0.0057	0.0042	0.0068	0.0074	0.0066	0.0083	0.0101	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	1	0	1
0.0056	0.0040	0.0071	0.0078	0.0069	0.0081	0.0080	0.0000	0.0000	0.0000	1	1	0	1	1	0	1	1	1	0
0.0059	0.0043	0.0071	0.0080	0.0066	0.0081	0.0104	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	0	1	1
0.0057	0.0042	0.0069	0.0073	0.0062	0.0080	0.0103	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	1	0	1
0.0056	0.0040	0.0071	0.0077	0.0061	0.0079	0.0078	0.0000	0.0000	0.0000	1	1	0	1	1	1	0	1	1	0
0.0059	0.0042	0.0070	0.0079	0.0067	0.0067	0.0102	0.0000	0.0000	0.0000	1	1	0	1	1	1	1	0	0	1
0.0057	0.0040	0.0073	0.0082	0.0065	0.0070	0.0081	0.0000	0.0000	0.0000	1	1	0	1	1	1	1	0	1	0

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0.0056	0.0039	0.0070	0.0075	0.0061	0.0068	0.0080	0.0000	0.0000	0.0000	1	1	0	1	1	1	1	1	0	0
0.0055	0.0039	0.0053	0.0070	0.0093	0.0080	0.0107	0.0000	0.0000	0.0000	1	1	1	0	0	0	1	1	1	1
0.0055	0.0039	0.0052	0.0066	0.0091	0.0078	0.0109	0.0000	0.0000	0.0000	1	1	1	0	0	1	0	1	1	1
0.0057	0.0040	0.0052	0.0072	0.0072	0.0082	0.0109	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	0	1	1
0.0055	0.0038	0.0053	0.0066	0.0068	0.0090	0.0107	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	1	0	1
0.0054	0.0037	0.0053	0.0065	0.0072	0.0090	0.0079	0.0000	0.0000	0.0000	1	1	1	0	0	1	1	1	1	0
0.0055	0.0038	0.0051	0.0081	0.0087	0.0080	0.0106	0.0000	0.0000	0.0000	1	1	1	0	1	0	0	1	1	1
0.0057	0.0039	0.0051	0.0088	0.0072	0.0084	0.0106	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	0	1	1
0.0055	0.0037	0.0052	0.0079	0.0068	0.0088	0.0104	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	1	0	1
0.0054	0.0035	0.0051	0.0083	0.0072	0.0086	0.0090	0.0000	0.0000	0.0000	1	1	1	0	1	0	1	1	1	0
0.0057	0.0039	0.0050	0.0086	0.0069	0.0081	0.0108	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	0	1	1
0.0055	0.0037	0.0051	0.0078	0.0064	0.0085	0.0106	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	1	0	1
0.0054	0.0036	0.0051	0.0082	0.0063	0.0084	0.0079	0.0000	0.0000	0.0000	1	1	1	0	1	1	0	1	1	0
0.0057	0.0038	0.0051	0.0084	0.0069	0.0070	0.0106	0.0000	0.0000	0.0000	1	1	1	0	1	1	1	0	0	1
0.0056	0.0036	0.0051	0.0088	0.0067	0.0073	0.0082	0.0000	0.0000	0.0000	1	1	1	0	1	1	1	0	1	0
0.0053	0.0035	0.0052	0.0080	0.0063	0.0070	0.0084	0.0000	0.0000	0.0000	1	1	1	0	1	1	1	1	0	0
0.0055	0.0038	0.0053	0.0075	0.0094	0.0082	0.0109	0.0000	0.0000	0.0000	1	1	1	1	0	0	0	1	1	1
0.0057	0.0039	0.0054	0.0078	0.0075	0.0088	0.0109	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	0	1	1
0.0054	0.0037	0.0054	0.0074	0.0071	0.0095	0.0106	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	1	0	1
0.0053	0.0035	0.0054	0.0077	0.0074	0.0094	0.0083	0.0000	0.0000	0.0000	1	1	1	1	0	0	1	1	1	0
0.0057	0.0039	0.0053	0.0078	0.0075	0.0084	0.0111	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	0	1	1
0.0054	0.0037	0.0054	0.0074	0.0069	0.0091	0.0108	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	1	0	1
0.0053	0.0035	0.0053	0.0078	0.0068	0.0091	0.0081	0.0000	0.0000	0.0000	1	1	1	1	0	1	0	1	1	0
0.0056	0.0038	0.0054	0.0077	0.0075	0.0073	0.0103	0.0000	0.0000	0.0000	1	1	1	1	0	1	1	0	0	1
0.0055	0.0036	0.0054	0.0080	0.0074	0.0076	0.0085	0.0000	0.0000	0.0000	1	1	1	1	0	1	1	0	1	0
0.0053	0.0034	0.0054	0.0076	0.0068	0.0072	0.0091	0.0000	0.0000	0.0000	1	1	1	1	0	1	1	1	0	0
0.0057	0.0038	0.0052	0.0074	0.0086	0.0087	0.0103	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	0	1	1

0.0055	0.0036	0.0053	0.0071	0.0077	0.0090	0.0106	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	1	0	1
0.0052	0.0034	0.0052	0.0074	0.0081	0.0088	0.0083	0.0000	0.0000	0.0000	1	1	1	1	1	0	0	1	1	0
0.0057	0.0037	0.0053	0.0073	0.0085	0.0073	0.0106	0.0000	0.0000	0.0000	1	1	1	1	1	0	1	0	0	1
0.0055	0.0035	0.0052	0.0075	0.0083	0.0076	0.0087	0.0000	0.0000	0.0000	1	1	1	1	1	0	1	0	1	0
0.0053	0.0033	0.0053	0.0072	0.0079	0.0073	0.0088	0.0000	0.0000	0.0000	1	1	1	1	1	0	1	1	0	0
0.0057	0.0037	0.0052	0.0073	0.0082	0.0073	0.0107	0.0000	0.0000	0.0000	1	1	1	1	1	1	0	0	0	1
0.0055	0.0035	0.0052	0.0076	0.0086	0.0071	0.0085	0.0000	0.0000	0.0000	1	1	1	1	1	1	0	0	1	0
0.0053	0.0034	0.0052	0.0073	0.0078	0.0067	0.0086	0.0000	0.0000	0.0000	1	1	1	1	1	1	0	1	0	0
0.0055	0.0034	0.0053	0.0075	0.0084	0.0072	0.0074	0.0000	0.0000	0.0000	1	1	1	1	1	1	1	0	0	0
0.0076	0.0080	0.0076	0.0058	0.0070	0.0086	0.0092	0.0123	0.0000	0.0000	0	0	1	1	1	1	1	1	1	1
0.0048	0.0068	0.0069	0.0054	0.0061	0.0073	0.0073	0.0095	0.0000	0.0000	0	1	0	1	1	1	1	1	1	1
0.0042	0.0056	0.0073	0.0055	0.0063	0.0077	0.0073	0.0099	0.0000	0.0000	0	1	1	0	1	1	1	1	1	1
0.0041	0.0058	0.0073	0.0060	0.0064	0.0082	0.0075	0.0100	0.0000	0.0000	0	1	1	1	0	1	1	1	1	1
0.0041	0.0057	0.0070	0.0072	0.0064	0.0080	0.0077	0.0097	0.0003	0.0000	0	1	1	1	1	0	1	1	1	1
0.0041	0.0056	0.0070	0.0070	0.0058	0.0078	0.0075	0.0100	0.0003	0.0000	0	1	1	1	1	1	0	1	1	1
0.0041	0.0057	0.0072	0.0076	0.0062	0.0066	0.0078	0.0099	0.0000	0.0000	0	1	1	1	1	1	1	0	1	1
0.0040	0.0057	0.0069	0.0069	0.0059	0.0063	0.0078	0.0098	0.0003	0.0000	0	1	1	1	1	1	1	1	0	1
0.0038	0.0057	0.0072	0.0073	0.0057	0.0067	0.0077	0.0076	0.0000	0.0000	0	1	1	1	1	1	1	1	1	0
0.0065	0.0075	0.0075	0.0056	0.0064	0.0078	0.0086	0.0115	0.0000	0.0000	1	0	0	1	1	1	1	1	1	1
0.0060	0.0064	0.0080	0.0057	0.0067	0.0083	0.0085	0.0120	0.0000	0.0000	1	0	1	0	1	1	1	1	1	1
0.0058	0.0067	0.0081	0.0062	0.0069	0.0090	0.0087	0.0121	0.0000	0.0000	1	0	1	1	0	1	1	1	1	1
0.0058	0.0065	0.0076	0.0077	0.0069	0.0087	0.0090	0.0118	0.0000	0.0000	1	0	1	1	1	0	1	1	1	1
0.0059	0.0064	0.0077	0.0076	0.0060	0.0084	0.0088	0.0121	0.0000	0.0000	1	0	1	1	1	1	0	1	1	1
0.0060	0.0065	0.0079	0.0083	0.0066	0.0071	0.0092	0.0119	0.0000	0.0000	1	0	1	1	1	1	1	0	1	1
0.0058	0.0066	0.0076	0.0075	0.0062	0.0068	0.0086	0.0119	0.0000	0.0000	1	0	1	1	1	1	1	1	0	1
0.0056	0.0064	0.0079	0.0080	0.0060	0.0073	0.0084	0.0090	0.0000	0.0000	1	0	1	1	1	1	1	1	1	0
0.0056	0.0042	0.0073	0.0053	0.0060	0.0073	0.0072	0.0098	0.0000	0.0000	1	1	0	0	1	1	1	1	1	1
0.0055	0.0042	0.0071	0.0050	0.0062	0.0079	0.0074	0.0099	0.0000	0.0000	1	1	0	1	0	1	1			

0.0055	0.0041	0.0067	0.0071	0.0062	0.0076	0.0075	0.0097	0.0000	0.0000	1	1	0	1	1	0	1	1	1	1
0.0055	0.0041	0.0068	0.0070	0.0056	0.0074	0.0074	0.0099	0.0000	0.0000	1	1	0	1	1	1	0	1	1	1
0.0056	0.0042	0.0069	0.0075	0.0060	0.0063	0.0077	0.0098	0.0000	0.0000	1	1	0	1	1	1	1	0	1	1
0.0055	0.0041	0.0067	0.0069	0.0057	0.0061	0.0074	0.0097	0.0000	0.0000	1	1	0	1	1	1	1	1	0	1
0.0054	0.0039	0.0069	0.0072	0.0055	0.0054	0.0073	0.0075	0.0000	0.0000	1	1	0	1	1	1	1	1	1	0
0.0053	0.0038	0.0052	0.0060	0.0065	0.0084	0.0074	0.0104	0.0000	0.0000	1	1	1	0	0	1	1	1	1	1
0.0052	0.0037	0.0051	0.0076	0.0064	0.0080	0.0076	0.0101	0.0000	0.0000	1	1	1	0	1	0	1	1	1	1
0.0053	0.0037	0.0050	0.0075	0.0058	0.0078	0.0074	0.0103	0.0000	0.0000	1	1	1	0	1	1	0	1	1	1
0.0054	0.0037	0.0050	0.0081	0.0062	0.0066	0.0077	0.0102	0.0000	0.0000	1	1	1	0	1	1	1	0	1	1
0.0052	0.0036	0.0051	0.0074	0.0058	0.0063	0.0079	0.0101	0.0000	0.0000	1	1	1	0	1	1	1	1	0	1
0.0051	0.0034	0.0051	0.0078	0.0057	0.0057	0.0078	0.0075	0.0000	0.0000	1	1	1	0	1	1	1	1	1	0
0.0052	0.0036	0.0053	0.0073	0.0066	0.0087	0.0078	0.0102	0.0000	0.0000	1	1	1	1	0	0	1	1	1	1
0.0052	0.0036	0.0053	0.0073	0.0062	0.0084	0.0076	0.0104	0.0000	0.0000	1	1	1	1	0	1	0	1	1	1
0.0054	0.0037	0.0053	0.0076	0.0068	0.0068	0.0080	0.0104	0.0000	0.0000	1	1	1	1	0	1	1	0	1	1
0.0051	0.0035	0.0053	0.0072	0.0063	0.0065	0.0084	0.0102	0.0000	0.0000	1	1	1	1	0	1	1	1	0	1
0.0050	0.0034	0.0053	0.0075	0.0062	0.0069	0.0084	0.0077	0.0000	0.0000	1	1	1	1	0	1	1	1	1	0
0.0052	0.0035	0.0051	0.0070	0.0074	0.0082	0.0078	0.0102	0.0000	0.0000	1	1	1	1	1	0	0	1	1	1
0.0054	0.0036	0.0052	0.0071	0.0080	0.0068	0.0082	0.0101	0.0000	0.0000	1	1	1	1	1	0	1	0	1	1
0.0052	0.0035	0.0052	0.0068	0.0073	0.0065	0.0083	0.0100	0.0000	0.0000	1	1	1	1	1	0	1	1	0	1
0.0050	0.0033	0.0052	0.0071	0.0076	0.0069	0.0081	0.0079	0.0000	0.0000	1	1	1	1	1	0	1	1	1	0
0.0054	0.0036	0.0051	0.0072	0.0078	0.0065	0.0080	0.0103	0.0000	0.0000	1	1	1	1	1	1	0	0	1	1
0.0052	0.0035	0.0052	0.0069	0.0071	0.0061	0.0080	0.0102	0.0000	0.0000	1	1	1	1	1	1	0	1	0	1
0.0051	0.0033	0.0051	0.0072	0.0075	0.0060	0.0079	0.0077	0.0000	0.0000	1	1	1	1	1	1	0	1	1	0
0.0053	0.0035	0.0052	0.0071	0.0077	0.0066	0.0067	0.0101	0.0000	0.0000	1	1	1	1	1	1	1	0	0	1
0.0052	0.0033	0.0051	0.0073	0.0080	0.0054	0.0070	0.0080	0.0000	0.0000	1	1	1	1	1	1	1	0	1	0
0.0050	0.0032	0.0052	0.0071	0.0073	0.0061	0.0067	0.0079	0.0000	0.0000	1	1	1	1	1	1	1	1	0	0
0.0039	0.0056	0.0069	0.0067	0.0053	0.0060	0.0072	0.0072	0.0005	0.0000	0	1	1	1	1	1	1	1	1	1

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0.0056 0.0064 0.0075 0.0072 0.0054 0.0064 0.0078 0.0084 0.0115 0.0000   1 0 1 1 1 1 1 1 1 1
0.0053 0.0040 0.0066 0.0067 0.0051 0.0058 0.0069 0.0071 0.0094 0.0000   1 1 0 1 1 1 1 1 1 1
0.0059 0.0035 0.0050 0.0071 0.0053 0.0060 0.0073 0.0071 0.0098 0.0000   1 1 1 0 1 1 1 1 1 1
0.0049 0.0035 0.0052 0.0071 0.0057 0.0061 0.0078 0.0072 0.0099 0.0000   1 1 1 1 0 1 1 1 1 1
0.0049 0.0034 0.0051 0.0068 0.0070 0.0062 0.0076 0.0074 0.0097 0.0000   1 1 1 1 1 0 1 1 1 1
0.0050 0.0034 0.0051 0.0068 0.0069 0.0055 0.0074 0.0073 0.0099 0.0000   1 1 1 1 1 1 0 1 1 1
0.0051 0.0035 0.0051 0.0070 0.0074 0.0059 0.0063 0.0076 0.0098 0.0000   1 1 1 1 1 1 1 0 1 1
0.0050 0.0034 0.0052 0.0067 0.0068 0.0056 0.0061 0.0074 0.0097 0.0000   1 1 1 1 1 1 1 1 0 1
0.0048 0.0032 0.0051 0.0070 0.0071 0.0055 0.0064 0.0073 0.0074 0.0000   1 1 1 1 1 1 1 1 1 0
1
0.0048 0.0033 0.0051 0.0066 0.0065 0.0051 0.0057 0.0069 0.0070 0.0094   1 1 1 1 1 1 1 1 1 1
```


TABLE 8-8

Coef. from Optimization on 75 Speaker Training Portion of Data Base II
Selected Sets for a "Reasonableness" Check

No. of Events	Which Specific Events	20	21	22	23	24	31	32	25-26	27-28	29-30
10	All	47	33	50	66	65	50	57	68	69	94
9	1111101111	49	35	52	71	--	57	61	78	72	100
	1111011111	49	34	51	67	69	--	62	75	74	96
8	1111001111	52	36	53	73			66	87	78	102
7	1111000111	55	38	53	75	--	--	--	95	82	108
	1110001111	55	39	53	--	--	--	70	94	79	107
6	1110000111	58	41	53	--	--	--	--	101	84	114
5	1110000011	65	44	53	--	--	--	--	--	96	123
	1100000111	64	48	--	--	--	--	--	102	85	114
4	1100000011	70	51	--	--	--	--	--	--	98	124
3	1100000001	75	53	--	--	--	--	--	--	--	130
	1000000011	90	--	--	--	--	--	--	--	124	156
2	1000000001	97	--	--	--	--	--	--	--	--	167

which is defined from the distribution functions of Figure 8-5b (and not from the density functions of part (a) of the Figure). These curves are obtained for each of the 1023 sets of events and may be grouped by:

1) n, yielding 10 curves
2) event, yielding 10 curves
3) all lumped together, yielding 1 curve
4) all individual, not grouped, yielding 1023 curves.

The significance of a particular value of Λ is a function of (1) which grouping above is preferred; (2) how detailed a description of "significance" is desired. Several levels of description are possible. For example, the value of Λ may be

(1) significant (two states) — not significant

(2) "significant" on a scale of -10 to 10

(3) interpretable by an auxiliary measure of optimum conditional risk, as discussed in Appendix 7-B.

(4) supported by statements of the following kind:
(a) IF no decision is made N% of the time, then $\Lambda < K_1$ implies "same" and $\Lambda > K_2$ implies "different" with less than M_1% total error on the data base collected and assuming equal a priori probabilities for "same" and "different."
(b) ditto except $\Lambda < K_3 \rightarrow$ "same"
$\Lambda > K_4 \rightarrow$ "different"
with no error on the data base
(c) $\Lambda < K_5$ = "same"
with less than M_2% error, on data base
(d) $\Lambda > K_6$ = "different"
with less than M_3% error, on data base

(5) interpreted as falling within a range Λ_1 to Λ_2 to an L % confidence level.

Choice among these alternatives must be guided by the objective of the system:

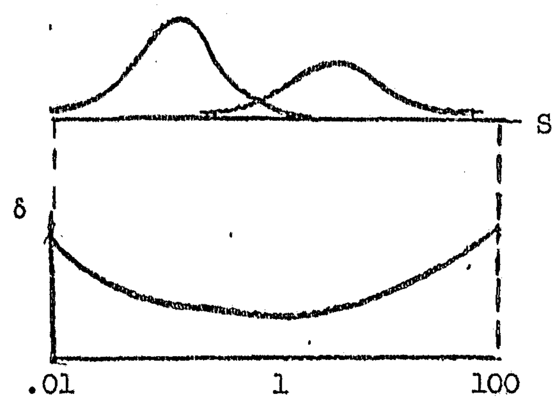
> To provide quantitative evidence to a human-decision-maker to permit him to make a decision in a two-choice-open-decision (TCOD) context and, having so decided, to permit him to assess the error probabilities and confidence bounds.

The results available are the measured error rates and inferences on upper bounds for the actual error rates. Given any one of the 1023 intraspeaker-interspeaker tabulated curves to be used in an operational situation, two basic questions arise:

- if the values of S and Λ are used to make a decision, what is the confidence (quantitatively) that the decision made is correct?
- given the value of Λ, what are the 95%, say, confidence bounds?

The Appendix to Section 7.0 above presents one answer to the first question under the assumption that the decision will be made solely along traditional decision theoretic lines. The optimum risk conditioned on the observed point emerges as an inverse measure of confidence - i.e., the more the risk, the less the confidence. The properties shown in Figure 7.B-2 are satisfying. The highest risk, lowest confidence decisions are those in the overlap region. While there is no question that this approach is on firm theoretical ground (leaving aside the annoying necessity to make some judgment on at least the combinational relation of the a priori class probabilities and the "costs" of incorrect decisions), one is left with a nagging feeling that a supplementary interpretation, like that to be given for Λ, is required to make the results not only quantitative but intuitively quantitative - i.e., heuristic.

Qualitatively, the solution desired for the Λ confidence intervals ought to reflect the fact that for a given confidence bound, say 95%, the Λ's associated with the tails of the distributions are the most uncertain. Figure 8-6 illustrates the notion that the interval size δ around a given $\hat{\Lambda}$ is a function



Given $\Lambda = \hat{\Lambda}$ then Prob. $\{\hat{\Lambda} - \delta \le \Lambda \le \hat{\Lambda} + \delta\} \ge 0.95$

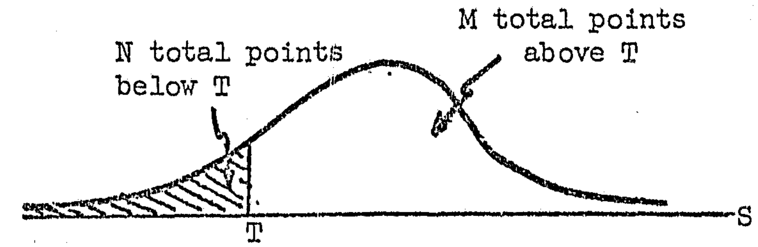
Figure 8-6

Qualitative Illustration of the Behavior of δ with Λ and S for a Given Confidence Level

of the $\hat{\Lambda}$, and hence of the position along the S axis, for a given confidence level.

Λ is defined as the ratio of the estimates for the probability distribution functions of the interspeaker to the intraspeaker cases. These distribution function estimates are based on integration of a probability density curve of the form shown in Figure 8-7.

The estimate may be viewed at each point T as an N-fold repetition of a simple alternative and the standard binomial distribution and bounds may be used to obtain various confidence intervals at each point T. A qualitative appreciation is obtained by examining Figure 2-7, repeated here as Figure 8-8, with the knowledge that N + M = 1180 for the intraspeaker distribution and 13,530 for the interspeaker distribution.



$\hat{p} = \frac{N}{N+M}$

Figure 8-7

Estimation of the Probability Distribution Function for the Interspeaker Case, at the Point S = T.

The key assumption on this binomial model is that the trials are independent. For the original speaker data this is certainly valid. However, the "points" in the distributions being discussed here are distances which are obtained by averaging over triad-pair triplets, as discussed in Section 8.2 above. The triad-pair triplets are formed by rule, as shown in Table 8-2. Hence the "points" are not strictly independent and the validity of the binomial model may be questioned. The Chebychev inequality does not rely on a known form of a distribution but depends only on the extistence of the mean and variance of the random variable being estimated. Hence, it seems reasonable to use the simple alternate form of the Chebychev inequality as a realistic to conservative estimate of the confidence intervals being obtained. Hence, consider the Chebychev bound

$$\text{Prob. } \{|\hat{p} - p| < \delta\} \ge 1 - \eta \ \forall\, n \ge \frac{pq}{\delta^2 \eta}$$

where $\hat{p} = \frac{N}{N+M}$, $n = N+M$

p = prob. of success (i.e., an observed point falls in in the interval $S \le T$)

$p + q = 1$

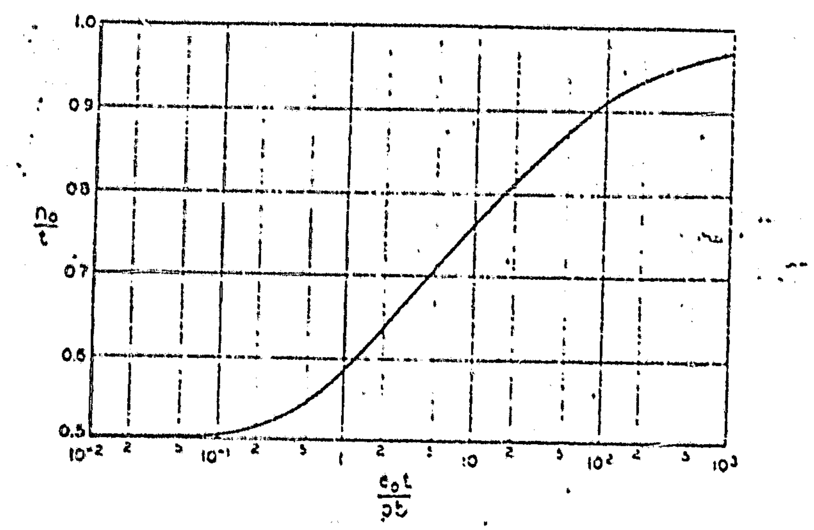


Figure 8-8. Optimum Partitioning

Consider fixing η at some value determined by subjective judgments concerning what is a reasonable confidence level. n is known and fixed from the data (n_{inter} = 13530 and n_{intra} = 1180). So the side constraint becomes one on the function $\delta(p)$ - i.e., the interval around p needed to achieve the specified confidence is a function of p (and if our estimates are to be useful for all practical purposes we can consider this to be identical to $\delta(\hat{p})$).

Hence, the condition becomes

$$\delta(p) \geq \left[\frac{p(1-p)}{n\cdot\eta}\right]^{\frac{1}{2}}$$

and the equality may be assumed without loss of generality. The asymptotic behavior with p is intuitively satisfying:

a) for $p \ll 1$ $\quad \frac{\delta^2(p)}{p} \geq \frac{p}{n\cdot\eta}\Big/p = \frac{1}{n\cdot\eta}$

b) for p intermediate $\quad \frac{\delta^2(p)}{p} \geq \frac{p-p^2}{n\cdot\eta}\Big/p = \frac{1}{n\cdot\eta} - \frac{p}{n\cdot\eta}$

c) for $p \rightarrow 1$ $\quad \delta^2(p) \geq a \rightarrow 0$

So that graphically we obtain:

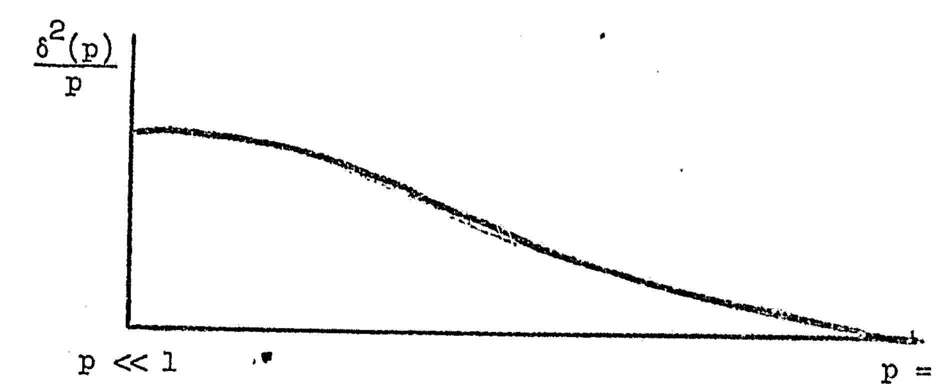


Figure 8-9

i.e., the largest uncertainty is indeed found in the tail of the distribution where the sampling is the sparcest.

Since $\hat{\Lambda} \triangleq \dfrac{\hat{p}_{inter}}{\hat{p}_{intra}}$

the $1-\eta$ confidence limits for Λ are

$$\left(\frac{1 - \delta'_{inter}}{1 + \delta'_{intra}}\right)\hat{\Lambda} \leq \Lambda \leq \left(\frac{1 + \delta'_{inter}}{1 - \delta'_{intra}}\right)\hat{\Lambda} \qquad \circledast$$

where

$$\delta'_{intra} \triangleq \frac{\delta_{intra}}{\hat{p}_{intra}}$$

$$\delta'_{inter} \triangleq \frac{\delta_{inter}}{\hat{p}_{inter}}$$

and where the $1-\eta$ confidence bounds on the distributions are

$$\hat{p}_{inter}\,(1 \pm \delta'_{inter})$$

$$\hat{p}_{intra}\,(1 \pm \delta'_{intra})$$

In summary, a specific procedure and rationale for SASIS's confidence bounds on the likelihood Λ is:

1) Use the simple alternative form of the Chebychev inequality to obtain the interval size for a 95% confidence bound on the intraspeaker and interspeaker distributions.

$$\delta'_i = \frac{\delta_i}{\hat{p}_i} = \left[\frac{\hat{p}_i(1-\hat{p}_i)}{n_i \cdot \eta}\right]^{\frac{1}{2}} \Big/ \hat{p}_i$$

where $\eta = 0.05$

$i = 1$ is the intraspeaker case, $n_1 = 1180$

$i = 2$ is the interspeaker case, $n_2 = 13530$

The $\hat{p}_i$ are calculated for each of the 200 histogram points and the δ'_i are calculated for all $\hat{p}_i \neq 0$.

2) Use equation $\circledast$ to obtain the Λ interval.

Table 8-9 shows the 95% confidence ranges for the interspeaker and intraspeaker distributions for estimates from 0.01 to 0.99 in increments of 0.01. If the range of the estimate goes negative (or exceeds 1) it may, of course, be truncated at 0 (or 1) and the confidence bound remains valid. For high and low values of Λ this results in particularly conservative bounds.

8.4 Discussion of Selected Evaluation Results

Table 8-10a,b,c presents the density, distribution and SASIS Operating Characteristic (SOC) curves for ten of the initial two event cases extracted from the full tabulation of 1023 combinations. The density curves' vertical axis range is 0.0 to 0.5; the horizontal axis similarity range is tabulated on each plot. The higher variance of the intraspeaker with respect to that of the interspeaker data, discussed in Section 8.2 above, is clearly evident. The distribution curves vertical is 0.0 to 1.0; the horizontal range is, of course, the same as for the density curve and is repeated on each plot. The SOC curve's range is 0.0 to 0.5 on each axis. The range of the similarity function is repeated adjacent to each plot for convenience and does not refer to the SOC curves' axes.

Examination of the three curve forms of Table 8-10 suggests that the SOC curves' concentration on presenting the overlap regions of the interspeaker and intraspeaker data is useful in making rapid qualitative comparisons of the merits of various event combinations: For example, the two event case 1000010000 (consisting of 20(|m|) and 31(   )) is superior to the adjecent case 0110000000 (consisting of 21(|n|) and 22(|ŋ|)).

TABLE 8-9

Intraspeaker

$\hat{p}$	δ'	Interval	$\hat{p}$	δ'	Interval
0.010	1.295	0.032- [illegible]	0.510	0.129	0.445- 0.575
0.020	0.911	[illegible]	0.520	0.12[illegible]	0.455- 0.585
0.030	0.749	[illegible]	0.530	0.12[illegible]	0.465- 0.595
0.040	0.658	0.014- [illegible]	0.540	0.12[illegible]	0.475- 0.605
0.050	0.537	0.022- 0.078	0.550	0.117	0.485- 0.615
0.060	0.513	0.029- 0.091	0.560	0.115	0.495- 0.625
0.070	0.475	0.037- 0.103	0.570	0.112	0.505- 0.634
0.080	0.441	0.045- 0.115	0.580	0.111	0.516- 0.644
0.090	0.414	0.053- 0.127	0.590	0.10[illegible]	0.526- 0.654
0.100	0.391	0.061- 0.139	0.600	0.106	0.536- 0.664
0.110	0.370	0.069- 0.151	0.610	0.104	0.546- 0.674
0.120	0.351	0.078- 0.162	0.620	0.102	0.557- 0.683
0.130	0.337	0.086- 0.174	0.630	0.10[illegible]	0.567- 0.693
0.140	[illegible]	0.095- 0.185	0.640	0.098	0.578- 0.702
0.150	0.300	0.104- 0.196	0.650	0.096	0.588- 0.712
0.160	0.29[illegible]	0.112- 0.208	0.660	0.093	0.598- 0.722
0.170	0.280	0.121- 0.219	0.670	0.091	0.609- 0.731
0.180	0.273	0.130- 0.230	0.680	0.089	0.619- 0.741
0.190	0.26[illegible]	0.139- 0.241	0.690	0.087	0.630- 0.750
0.200	0.260	0.148- 0.252	0.700	0.085	0.640- 0.760
0.210	0.252	0.157- 0.263	0.710	0.083	0.651- 0.769
0.220	0.245	0.166- 0.274	0.720	0.081	0.662- 0.778
0.230	0.238	0.175- 0.285	0.730	0.079	0.672- 0.788
0.240	0.232	0.184- 0.296	0.740	0.077	0.683- 0.797
0.250	0.225	0.194- 0.306	0.750	0.075	0.694- 0.806
0.260	0.220	0.203- 0.317	0.760	0.073	0.704- 0.816
0.270	0.214	0.212- 0.328	0.770	0.071	0.715- 0.825
0.280	0.209	0.222- 0.338	0.780	0.069	0.726- 0.834
0.290	0.204	0.231- 0.349	0.790	0.067	0.737- 0.843
0.300	0.199	0.240- 0.360	0.800	0.065	0.748- 0.852
0.310	0.194	0.250- 0.370	0.810	0.063	0.759- 0.861
0.320	0.190	0.259- 0.381	0.820	0.061	0.770- 0.870
0.330	0.186	0.269- 0.391	0.830	0.059	0.781- 0.879
0.340	0.181	0.278- 0.402	0.840	0.057	0.792- 0.888
0.350	0.177	0.288- 0.412	0.850	0.055	0.804- 0.896
0.360	0.174	0.298- 0.422	0.860	0.053	0.815- 0.905
0.370	0.170	0.307- 0.433	0.870	0.050	0.826- 0.914
0.380	0.166	0.317- 0.443	0.880	0.048	0.838- 0.922
0.390	0.163	0.327- 0.453	0.890	0.046	0.849- 0.931
0.400	0.159	0.336- 0.464	0.900	0.043	0.861- 0.939
0.410	0.156	0.346- 0.474	0.910	0.041	0.873- 0.947
0.420	0.153	0.356- 0.484	0.920	0.038	0.885- 0.955
0.430	0.150	0.366- 0.494	0.930	0.036	0.897- 0.963
0.440	0.147	0.375- 0.505	0.940	0.033	0.909- 0.971
0.450	0.144	0.385- 0.515	0.950	0.030	0.922- 0.978
0.460	0.141	0.395- 0.525	0.960	0.027	0.934- 0.986
0.470	0.138	0.405- 0.535	0.970	0.023	0.948- 0.992
0.480	0.13[illegible]	0.415- 0.545	0.980	0.019	0.962- 0.998
0.490	0.13[illegible]	0.425- 0.555	0.990	0.01[illegible]	0.977- 1.003
0.500	0.130	0.435- 0.565			

Interspeaker

$\hat{p}$	δ'	Interval	p'	δ'	Interval
0.010	0.387	[illegible]- 0.014	0.510	0.038	0.491- 0.529
0.020	0.260	0.015- 0.025	0.520	0.037	0.501- 0.539
0.030	0.219	0.023- 0.037	0.530	0.036	0.511- 0.549
0.040	0.183	0.032- 0.048	0.540	0.035	0.521- 0.559
0.050	0.168	0.042- 0.058	0.550	0.035	0.531- 0.569
0.060	0.152	0.051- 0.069	0.560	0.034	0.541- 0.579
0.070	0.140	0.060- 0.080	0.570	0.033	0.551- 0.589
0.080	0.130	0.070- 0.090	0.580	0.032	0.561- 0.599
0.090	0.122	0.079- 0.101	0.590	0.032	0.571- 0.609
0.100	0.115	0.088- 0.112	0.600	0.031	0.581- 0.619
0.110	0.109	0.098- 0.122	0.610	0.031	0.591- 0.629
0.120	0.104	0.108- 0.132	0.620	0.030	0.601- 0.639
0.130	0.099	0.117- 0.143	0.630	0.029	0.611- 0.649
0.140	0.095	0.127- 0.153	0.640	0.029	0.622- 0.658
0.150	0.092	0.136- 0.164	0.650	0.028	0.632- 0.668
0.160	0.088	0.146- 0.174	0.660	0.028	0.642- 0.678
0.170	0.085	0.156- 0.184	0.670	0.027	0.652- 0.688
0.180	0.082	0.165- 0.195	0.680	0.026	0.662- 0.698
0.190	0.079	0.175- 0.205	0.690	0.026	0.672- 0.708
0.200	0.077	0.185- 0.215	0.700	0.025	0.682- 0.718
0.210	0.075	0.194- 0.226	0.710	0.025	0.693- 0.727
0.220	0.072	0.204- 0.236	0.720	0.024	0.703- 0.737
0.230	0.070	0.214- 0.246	0.730	0.023	0.713- 0.747
0.240	0.068	0.224- 0.256	0.740	0.022	0.723- 0.757
0.250	0.067	0.233- 0.267	0.750	0.022	0.733- 0.767
0.260	0.065	0.243- 0.277	0.760	0.022	0.744- 0.776
0.270	0.063	0.253- 0.287	0.770	0.021	0.754- 0.786
0.280	0.062	0.263- 0.297	0.780	0.020	0.764- 0.796
0.290	0.060	0.273- 0.307	0.790	0.020	0.774- 0.806
0.300	0.059	0.282- 0.318	0.800	0.019	0.785- 0.815
0.310	0.057	0.292- 0.328	0.810	0.019	0.795- 0.825
0.320	0.056	0.302- 0.338	0.820	0.018	0.805- 0.835
0.330	0.055	0.312- 0.348	0.830	0.017	0.816- 0.844
0.340	0.054	0.322- 0.358	0.840	0.017	0.826- 0.854
0.350	0.052	0.332- 0.368	0.850	0.016	0.836- 0.864
0.360	0.051	0.342- 0.378	0.860	0.016	0.847- 0.873
0.370	0.050	0.351- 0.389	0.870	0.015	0.857- 0.883
0.380	0.049	0.361- 0.399	0.880	0.014	0.868- 0.892
0.390	0.048	0.371- 0.409	0.890	0.014	0.878- 0.902
0.400	0.047	0.381- 0.419	0.900	0.013	0.888- 0.912
0.410	0.046	0.391- 0.429	0.910	0.012	0.899- 0.921
0.420	0.045	0.401- 0.439	0.920	0.011	0.910- 0.930
0.430	0.044	0.411- 0.449	0.930	0.011	0.920- 0.940
0.440	0.043	0.421- 0.459	0.940	0.010	0.931- 0.949
0.450	0.043	0.431- 0.469	0.950	0.009	0.942- 0.958
0.460	0.042	0.441- 0.479	0.960	0.008	0.952- 0.968
0.470	0.041	0.451- 0.489	0.970	0.007	0.963- 0.977
0.480	0.040	0.461- 0.499	0.980	0.00[illegible]	0.975- 0.985
0.490	0.03[illegible]	0.471- 0.509	0.990	0.004	0.986- 0.994
0.500	0.03[illegible]	0.481- 0.519			

Table 8-11 is the first sheet of a 1023 page detailed tabulation for all combinations of the ten events. It lists the similarity measure, density values, distribution values, and the resulting likelihood ratio, Λ. Table 8-9 and formula ⊛ on page 8-24 may be used to obtain the 95% confidence interval for the probabilities and Λ. For comparison with these illustrations the 10 event results are shown in Table 8-12. Examination of the full set shows that the results generally improve as the number of events increases, as would be expected, but that certain event combinations are significantly superior to others. The improvement is much more marked in the low numbers of events region. This indicates that the number of events used is sufficient to extract substantially all the information that is available under the SASIS problem formulation. The fact that the higher order curves do not asymptote to perfect separation may be interpreted as stating that the intrinsic dimensionality of the formulation is less than ten. It is especially important to note at this point that these results, of course, depend on the suitability of the data organization and processing to represent realistic operational data. The perfect separation case may be approached more nearly, for example, by removing the requirement, stated on page 8-7 of Section 8.2, that the data be structured into triad-pair triplets and averaging over all the data in the base. This indicates that the results presented will be conservative, indicating more overlap than is actually present if more samples are available operationally.

TABLE 8-10a

Density Curves for Ten Two-Event Cases

10/14/74 13:42:49 SASIS REAL-TIME MONITOR 3.1 PAGE 1

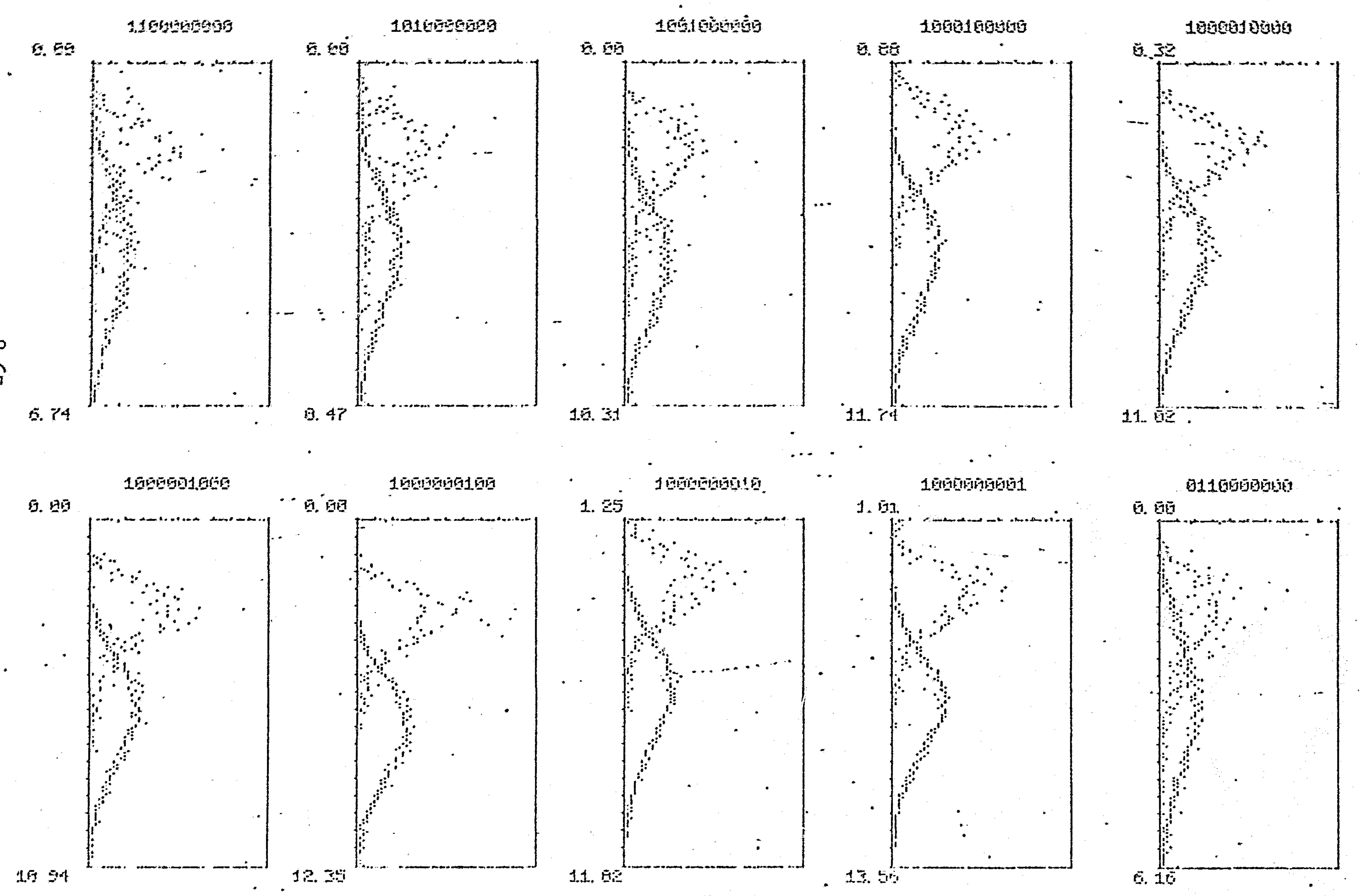


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TABLE 8-

Distribution Curves

10/14/74 13:47:22 SASIS REAL-TIME MONITOR 3.1 PAGE 1

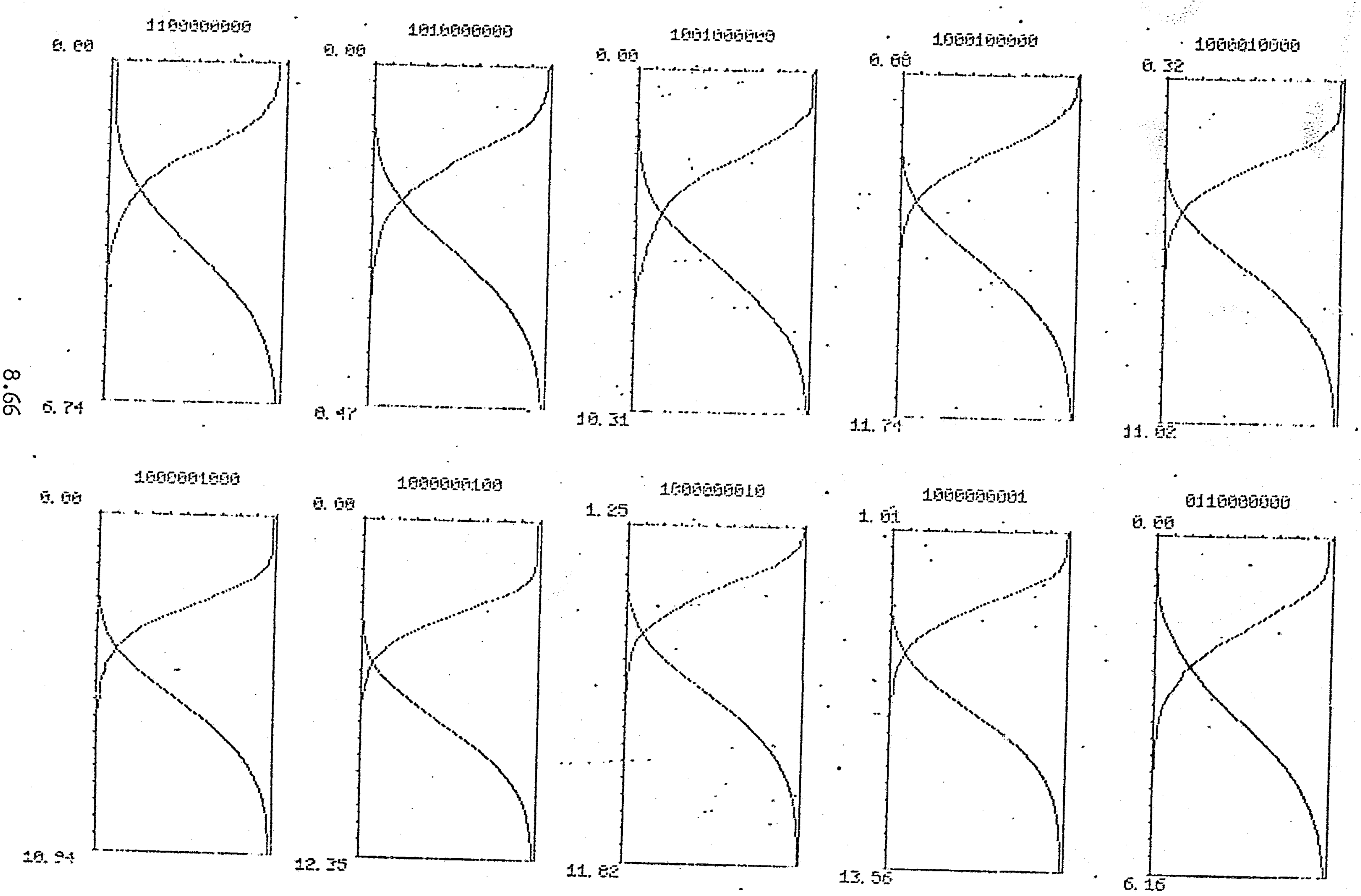

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TABLE 8-10c

SOC Curves

10/16/74 16:13:19 SASIS REAL-TIME MONITOR 3.1 PAGE 1

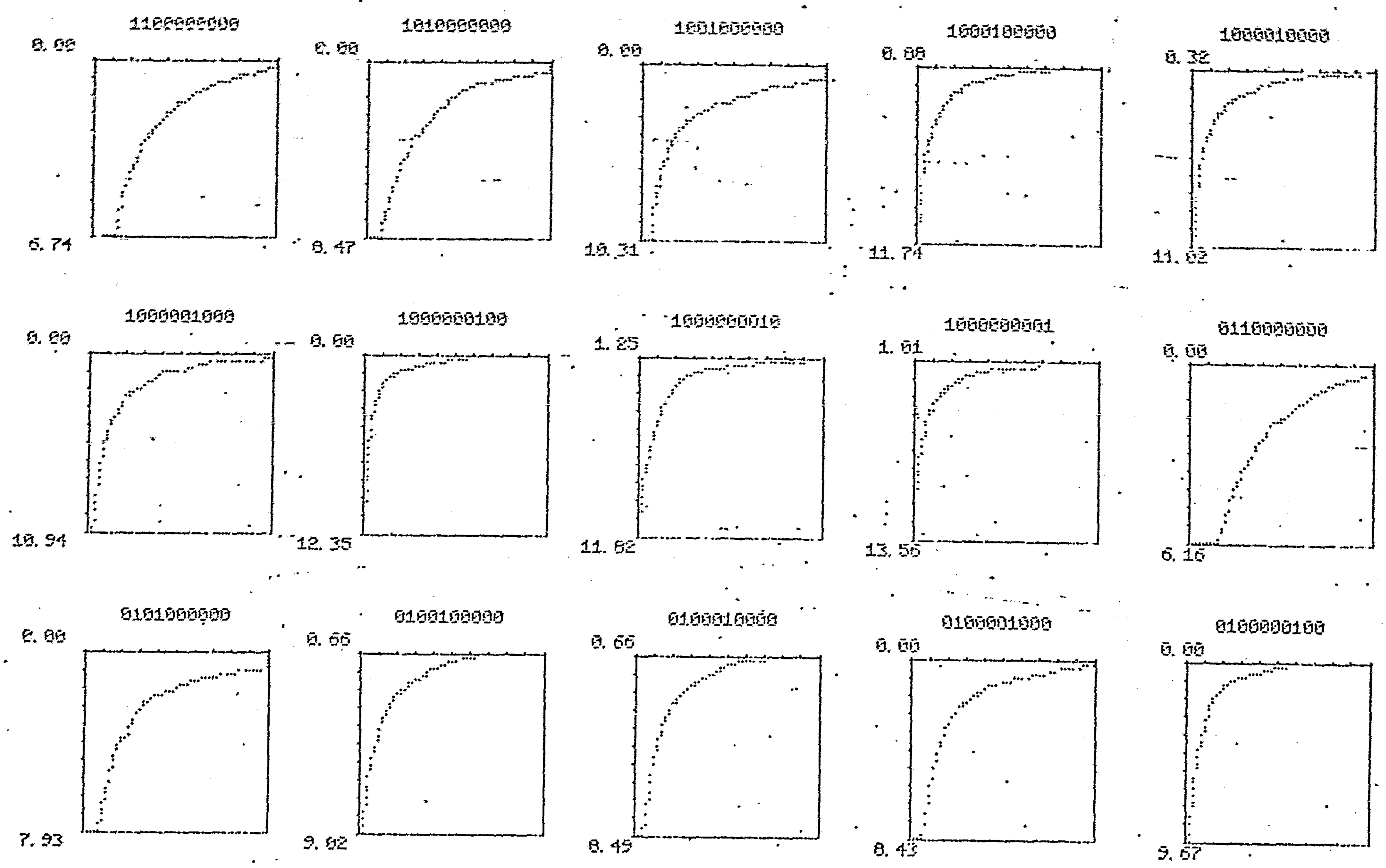

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TABLE 8-11

First Sheet from 1023 Page Detailed Tabulation

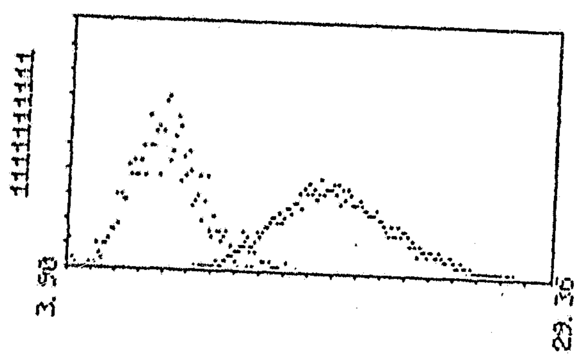
09:19:32 SASISTAB REAL-TIME MONITOR 3.1 PAGE 1

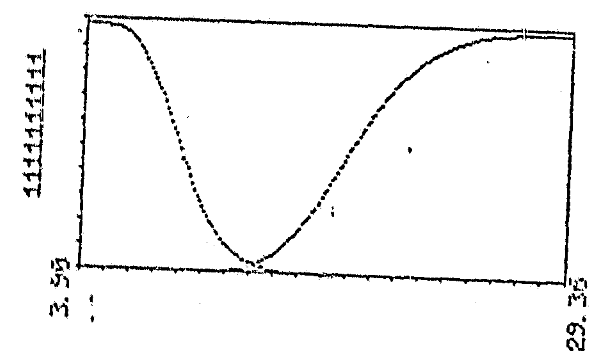
SIM	LAMBDA	E1	E2	P1	P2	SIM	LAMBDA	E1	E2	P1	P2	SIM	LAMBDA	E1	E2	P1	P2	SIM	LAMBDA	E1	E2	P1	P2
0.00	100.00	100	0	34	31	1.72	9.13	56	6	37	2	3.40	0.13	5	39	1	7	5.09	0.01	0	84	0	6
0.07	31.23	96	3	0	0	1.75	8.27	52	6	23	4	3.44	0.13	5	40	2	8	5.12	0.01	0	85	0	5
0.10	31.23	96	3	0	0	1.79	7.44	50	6	25	2	3.47	0.12	4	40	2	10	5.16	0.01	0	85	1	6
0.13	31.23	96	3	0	0	1.82	6.87	48	7	19	3	3.50	0.11	4	41	2	11	5.19	0.01	0	86	0	5
0.17	31.23	96	3	0	0	1.85	6.33	46	7	25	3	3.54	0.10	4	42	2	13	5.22	0.01	0	86	0	6
0.20	30.97	96	3	0	0	1.89	5.75	43	7	16	4	3.57	0.10	4	44	4	10	5.26	0.01	0	87	0	4
0.24	30.97	96	3	0	0	1.92	5.26	42	8	22	4	3.61	0.08	3	45	1	11	5.29	0.01	0	87	0	5
0.27	30.97	96	3	0	0	1.95	4.75	39	8	19	5	3.64	0.08	3	46	2	10	5.32	0.01	0	88	0	4
0.30	30.97	96	3	0	0	1.99	4.27	38	8	13	3	3.67	0.07	3	47	12	9	5.36	0.01	0	88	0	5
0.34	30.97	96	3	0	0	2.02	3.99	36	9	18	6	3.71	0.05	2	48	1	8	5.39	0.01	0	89	0	4
0.37	30.97	96	3	1	0	2.06	3.56	34	9	8	5	3.74	0.04	2	49	0	10	5.43	0.01	0	89	0	4
0.40	30.94	95	3	0	0	2.09	3.31	34	10	17	4	3.77	0.04	2	50	1	12	5.46	0.01	0	90	0	5
0.44	30.94	95	3	0	0	2.12	3.03	32	10	9	4	3.81	0.04	2	51	1	9	5.49	0.01	0	90	0	5
0.47	30.94	95	3	0	0	2.16	2.84	31	11	15	7	3.84	0.04	2	52	1	12	5.53	0.01	0	91	0	5
0.51	30.94	95	3	10	0	2.19	2.54	30	11	8	5	3.88	0.04	1	53	1	10	5.56	0.01	0	91	0	3
0.54	30.61	94	3	0	0	2.22	2.37	29	12	8	4	3.91	0.03	1	54	1	10	5.59	0.01	0	91	0	4
0.57	30.61	94	3	1	0	2.26	2.24	28	12	20	5	3.94	0.03	1	55	2	9	5.63	0.01	0	92	0	3
0.61	30.58	94	3	2	0	2.29	2.00	26	13	22	6	3.98	0.03	1	56	1	11	5.66	0.01	0	92	0	3
0.64	30.52	94	3	3	0	2.33	1.75	24	13	7	5	4.01	0.02	1	57	1	12	5.69	0.01	0	92	0	3
0.67	30.42	94	3	11	0	2.36	1.54	23	14	9	7	4.04	0.02	1	58	3	15	5.73	0.01	0	93	0	3
0.71	30.06	93	3	1	0	2.39	1.51	22	15	8	6	4.08	0.02	1	60	3	10	5.76	0.01	0	93	0	3
0.74	30.03	93	3	3	0	2.43	1.40	21	15	5	6	4.11	0.01	0	61	3	9	5.80	0.01	0	93	0	2
0.78	29.94	92	3	10	0	2.46	1.31	21	16	8	5	4.14	0.01	0	61	1	9	5.83	0.01	0	94	0	1
0.81	29.61	91	3	13	0	2.49	1.23	20	16	7	7	4.18	0.01	0	62	0	9	5.86	0.01	0	94	0	3
0.84	29.19	90	3	3	1	2.53	1.14	19	17	11	7	4.21	0.01	0	63	0	8	5.90	0.01	0	94	0	2
0.88	28.19	90	3	1	0	2.56	1.03	18	18	3	6	4.25	0.01	0	64	0	10	5.93	0.01	0	94	0	3
0.91	28.16	90	3	14	2	2.59	0.98	18	18	6	6	4.28	0.01	0	65	0	10	5.96	0.01	0	94	0	3
0.94	26.09	88	3	4	0	2.63	0.92	17	19	9	7	4.31	0.01	0	66	0	9	6.00	0.01	0	95	0	3
0.98	25.97	88	3	5	0	2.66	0.84	16	20	11	6	4.35	0.01	0	67	0	8	6.03	0.01	0	95	0	3
1.01	25.82	87	3	6	0	2.70	0.77	15	20	7	6	4.38	0.01	0	68	0	9	6.07	0.01	0	95	0	2
1.04	25.65	87	3	9	0	2.73	0.71	15	21	6	10	4.41	0.01	0	69	0	7	6.10	0.01	0	96	0	2
1.08	25.38	86	3	7	1	2.76	0.65	14	22	13	8	4.45	0.01	0	69	0	10	6.13	0.01	0	96	0	2
1.11	24.46	85	3	13	1	2.80	0.57	13	23	4	7	4.48	0.01	0	70	0	8	6.17	0.01	0	96	0	3
1.15	23.42	84	3	16	1	2.83	0.54	12	23	4	9	4.52	0.01	0	71	0	9	6.20	0.01	0	96	0	2
1.18	22.35	82	3	14	2	2.86	0.50	12	24	4	8	4.55	0.01	0	72	0	10	6.23	0.01	0	96	0	1
1.21	20.85	81	3	12	0	2.90	0.47	12	25	6	7	4.58	0.01	0	73	0	9	6.27	0.01	0	97	0	2
1.25	20.54	80	3	14	0	2.93	0.44	11	26	5	9	4.62	0.01	0	74	0	7	6.30	0.01	0	97	0	1
1.28	20.18	78	3	11	1	2.97	0.40	10	27	3	8	4.65	0.01	0	75	0	7	6.33	0.01	0	97	0	2
1.31	19.40	77	4	8	1	3.00	0.38	10	27	11	9	4.68	0.01	0	75	0	8	6.37	0.01	0	97	0	1
1.35	18.73	75	4	8	1	3.03	0.33	9	28	4	7	4.72	0.01	0	76	0	9	6.40	0.01	0	97	0	1
1.38	18.10	76	4	22	3	3.07	0.31	9	29	5	9	4.75	0.01	0	77	1	9	6.44	0.01	0	97	0	2
1.42	16.40	73	4	31	2	3.10	0.28	8	30	3	9	4.78	0.01	0	78	0	8	6.47	0.01	0	97	0	1
1.45	15.04	70	4	19	3	3.13	0.27	8	31	7	8	4.82	0.01	0	79	0	10	6.50	0.01	0	98	0	1
1.48	13.76	68	5	18	1	3.17	0.24	7	32	4	10	4.85	0.01	0	80	0	7	6.54	0.01	0	98	0	1
1.52	13.14	67	5	19	1	3.20	0.22	7	33	3	10	4.89	0.01	0	80	1	6	6.57	0.01	0	98	0	1
1.55	12.52	65	5	19	2	3.23	0.20	6	34	3	11	4.92	0.01	0	81	0	8	6.60	0.01	0	98	0	1
1.58	11.70	63	5	8	2	3.27	0.19	6	35	3	10	4.95	0.01	0	82	0	7	6.64	0.01	0	98	0	1
1.62	11.14	62	5	10	2	3.30	0.17	6	36	2	9	4.99	0.01	0	83	0	6	6.67	0.01	0	98	0	1
1.65	10.59	61	5	25	2	3.34	0.16	6	37	4	12	5.02	0.01	0	83	0	7	6.71	0.01	0	98	0	1
1.69	9.82	59	6	23	2	3.37	0.15	5	38	6	11	5.05	0.01	0	84	0	4	6.74	0.01	0	98	0	8

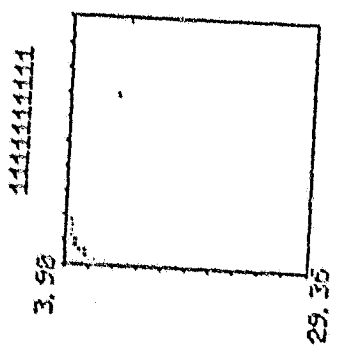
1100000000
20 21
NE NE

TABLE 8-12

Ten Event Density, Distribution and SOC Curves







9.0 CHANNEL EQUALIZATION STUDY

9.1 INTRODUCTION

The basic objective of this study is to define algorithms which will enhance the correct classification of a suspect speaker when the suspect utterance has undergone transformation due to unknown channel distortion. The scope of this study has been limited to the modification of an existing technique utilized successfully in channel normalization for speech (word) recognition (Vitols and Paul, 1973). The goals of the two applications are somewhat different, since in speech recognition, it is desirable to normalize the channel as well as speaker-dependent characteristics, while in the SASIS application it is desirable to normalize only the channel-introduced distortions.

9.2 EXPERIMENTAL PROCEDURE

The algorithm utilized in previous speech recognition work consists of modifying the output of each spectral channel by application of bias and subsequent gain change such that the long-term range is between 0.0 and 1.0 units of energy. In that particular application, "long-term" was used as 2.5 seconds; this was the maximum allowed by certain system constraints.

Preliminary analysis indicated that direct application of this algorithm to channel normalization in speaker identification applications created some undesirable effects and a modification was necessary.

The first phase of the study was to create a reference "speaker" in the form of a cassette tape recorder on which were recorded several test sentences obtained from Data Base I. The acoustic characteristics of the recorder playback were measured. This reference "speaker" cassette tape recorder was taken to eight different locations including a phone booth and several open and closed offices with different acoustic environments. A total of eight different recordings were made and, in each case, effort was made to have the placement of telephone handset and tape recorder positions approximate as nearly as possible those of a human speaker.

The resultant recordings were spectrally analyzed and channelized. Density functions were plotted for each spectral channel showing the frequency of occurrence of a given amplitude level. Channel bandwidths used were the same as in section 3.1.2. A sample of the density functions, along with their corresponding distribution functions, are shown in Figure 9.1 for two channels.

The previous normalization of speech for recognition purposes expanded each channel to full range; i.e., each channel undergoes the transformation

$$x_i = (y_i - A_i)/(B_i - A_i)$$

where: y_i - the values for the i^{th} channel

x_i - the normalized values for the i^{th} channel

A_i - the minimum value of the i^{th} channel

B_i - the maximum value of the i^{th} channel

While this provides near optimum results for word recognition, where both stressed and unstressed signals are important, it does not do so for speaker identification work where the decision is based on stressed sounds.

Analysis of the channelized data distribution functions showed that background noise effects are predominant over the 0.0 to 0.3 range of the distribution function (range A of Figure 9.1) with occasional disturbances extending to the 0.5 level (range B of Figure 1). Similarly, saturation effects affect the data between the 0.85 and 1.0 level (range C of Figure 1). The data from each given channel of the spectral analyzer is least affected by the environment of the speaker when its value is in the 50 to 85 percentile range (range D of Figure 9.1). Thus, the normalization point should be chosen to be in this range in order that it reflects only spectral normalization, and it is not affected by background noises.

Further analysis was performed to determine which percentile points on the distribution function were the most speaker invariant for the case of a fixed-amplitude signal recorded in a single environment (sound booth). This corresponds to the 0.75 to 0.85 range of the distribution curves (range E of Figure 9.1). That is, when amplitude distribution functions of the channelized spectral data is plotted for different speakers but of the same amplitude and in the same environment, the points of least variance are between 75 and 85 percentile range. Thus, the best normalization (maximum telephone channel normalization with the least speaker normalization) is achieved when a reference point in the 75 to 85 percentile point is selected as the anchor. The point chosen was the 80 percent point. For normalization, the gain of the channels is adjusted to bring the 80 percentile points (points F in Figure 9.1) to standard positions.

Summary to this point: A technique has been described which generates a spectral response function of a communications channel similar to a

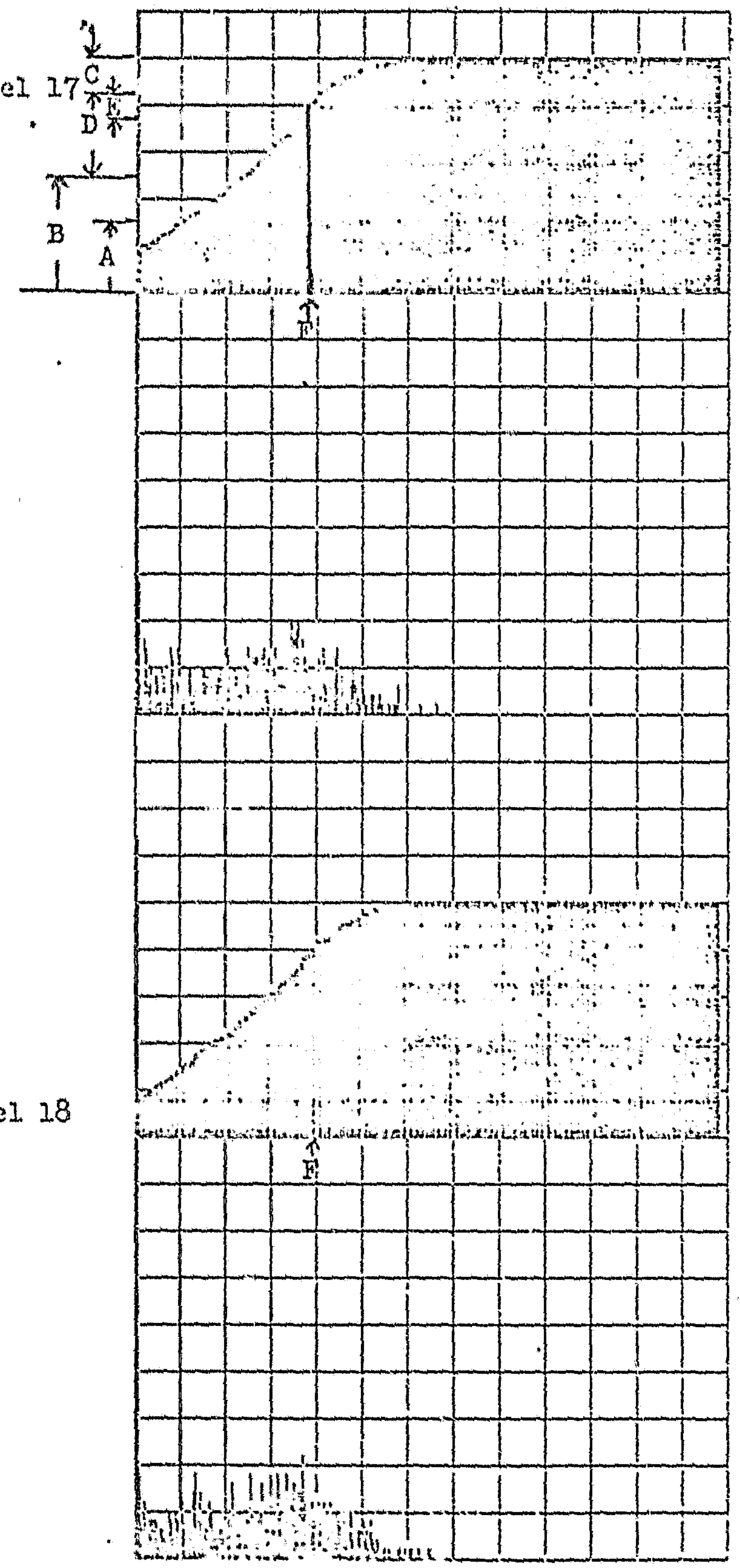


FIGURE 9.1 - Examples of density and distribution functions for two channels

long-term power spectrum but is less affected by background noise and non-linearities and further tends to be more independent of speaker characteristics. The technique essentially consists of looking at the eightieth percentile points of the spectrum analyzer outputs.

A question remains as to the duration of speech to be processed in order to obtain a statistically stationary sample. For this experiment, test sentences of various lengths were generated by concatenation of Data Base I sentences. The 80 percentile point power spectra was computed for the variable-length utterances. Two independent sets of sentences were generated to verify the stationarity of the results. The power spectra were compared across speakers for the same location (sound booth) and across locations for the same standard speaker. The mean and standard deviations (in 1/4 db units) for nine speakers from the same location are shown in Table 9.1 for five different sentence lengths and two independent sets of sentences. The average standard deviation as a function of speech duration is plotted as curve A in Figure 9.2. Curve B shows the same comparison for only two speakers. Similarly, the average spectral deviance for the same speakers for different sample lengths is shown in Table 9.2. The average deviance over 10 speakers compared with themselves is plotted as curve C in Figure 9.2.

Individual eightieth percentile spectral samples for the "standard" speaker over different telephone channels and locations are shown in Figure 9.3. (Scale 5 db/unit) Note that 5 - 10 db channel-to-channel variance is common with occasional 20 db variations.

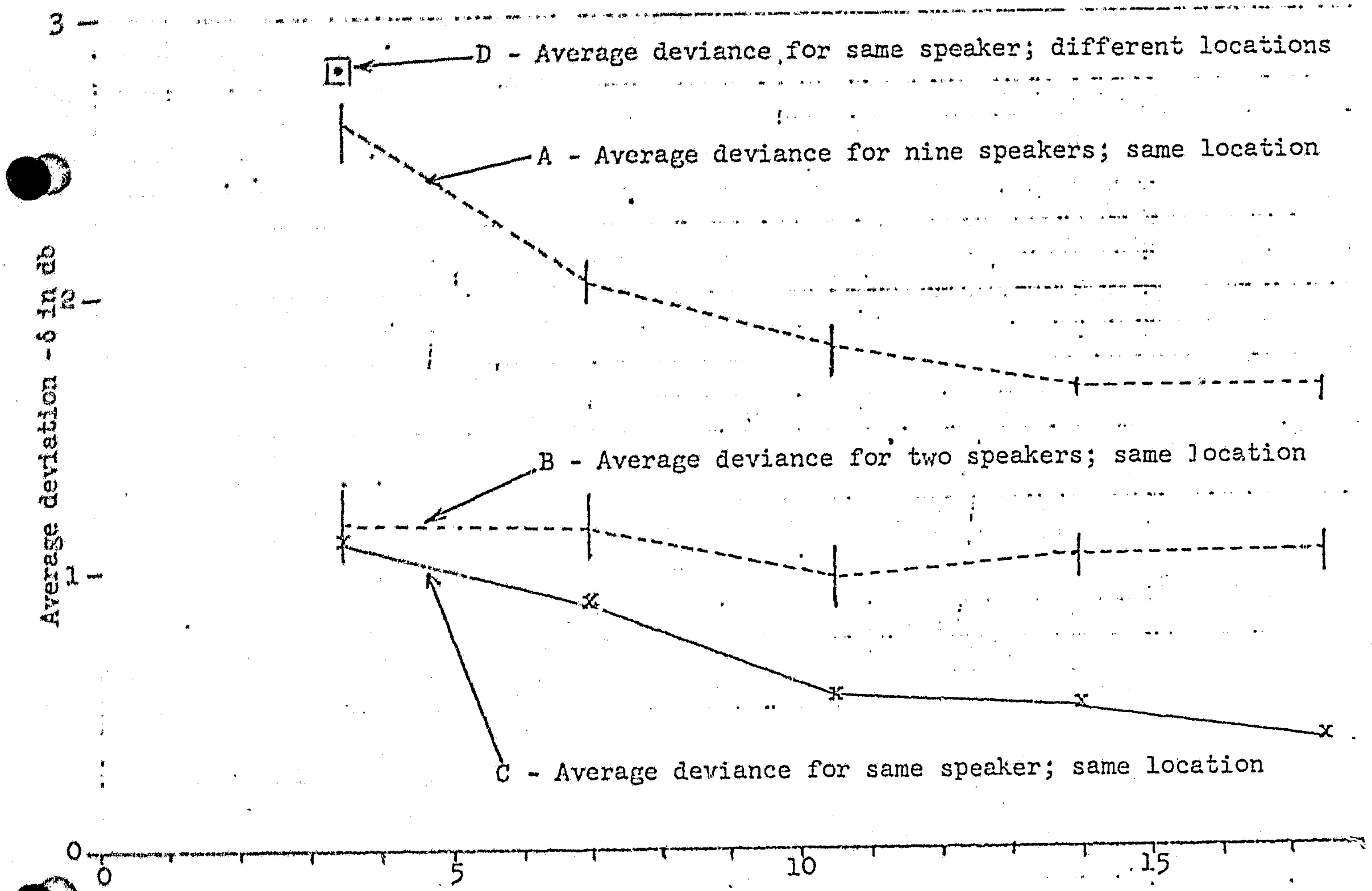


FIGURE 9.2

TABLE 9.2

Average Spectral Deviation as
a Function of Sample Duration

Duration / Speaker	3.5 sec.	7.0 sec.	10.5 sec.	14 sec.	17.5 sec.
3	3.71	3.62	2.71	1.95	1.1
1	2.83	2.78	1.5	1.19	1.79
29	4.62	3.16	1.19	1.03	
27	5.88	4.26	3.57	4.31	3.02
26	5.76	5.4	2.41	2.14	1.03
25	5.09	5.17	3.28	2.43	1.45
21	6.34	3.53	2.22	1.03	1.38
14	3.4	2.09	1.52	1.00	1.72
11	2.57	1.04	1.91	2.98	2.05
5	3.88	4.05	1.10	2.07	1.43
Average	4.41	3.51	2.14	2.01	1.66
Average in db	1.10	0.88	0.54	0.50	0.415

FIGURE 9.3 (Description)

Spectral response curves for two different sentences spoken by the "standard" speaker from eight different locations. The ordinate represents the spectral response (in 5 db units) for 28 channels plotted along the abscissa. The right-most abscissa position (equivalent to channel 32) contains the amplitude of the wideband signal. Figures 3(a) through 3(h) are for sentence number 16 of data base C and 3(i) through 3(p) for sentence number 19.

Location and Connection		Figure	
Original tape recording		a	i
Booth-closed	local	b	j
Office No. 1	local	c	k
Computer room	local	d	l
Office No. 2	local	e	m
Booth - open	local	f	n
Office No. 3	casnet	g	o
"Standard" speaker		h	p

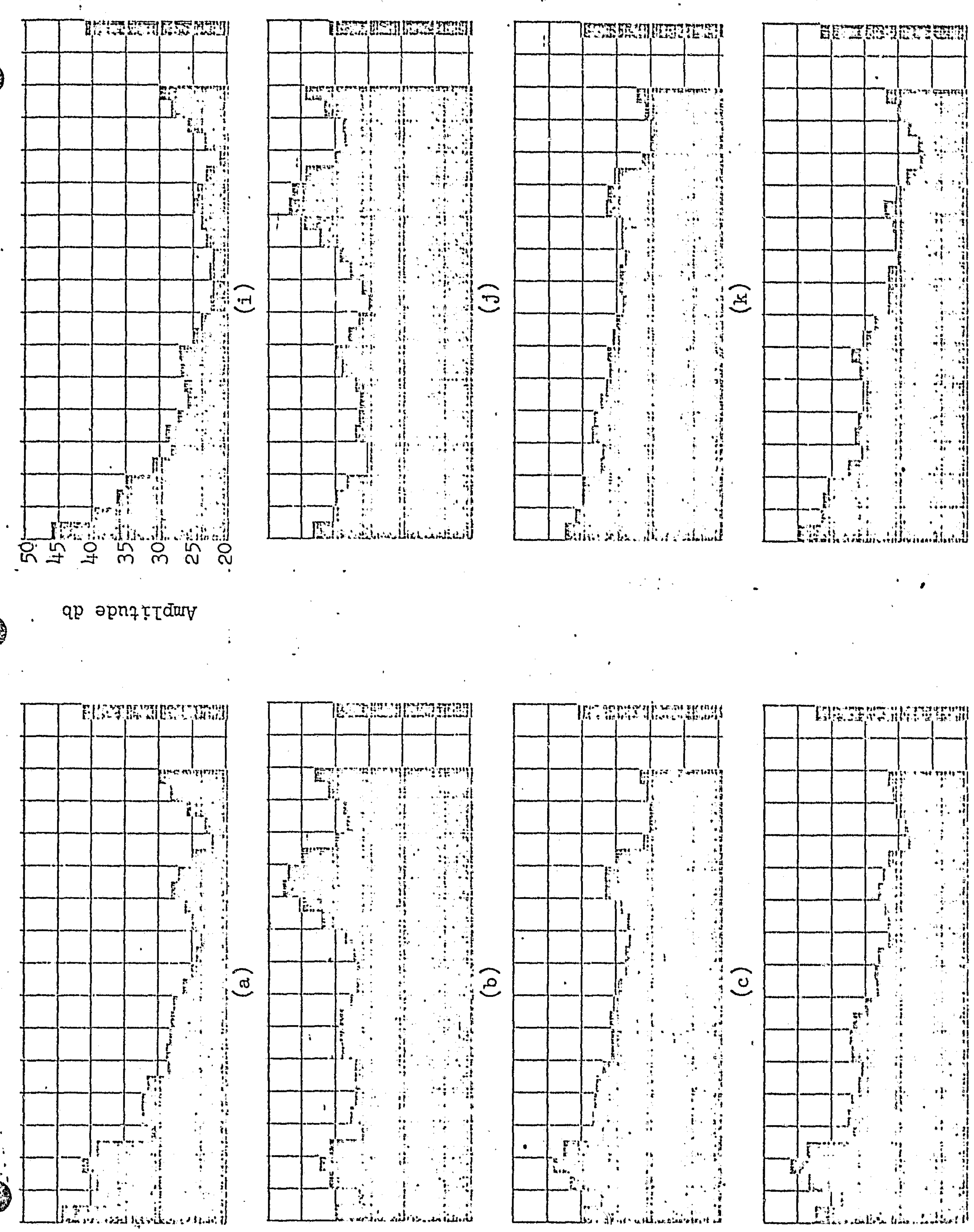


FIGURE 9.3

9.3 CONCLUSIONS

A sample length of 15 seconds is desirable for long-term speaker statistics extraction. Shorter samples down to five seconds can still be expected to produce improvements in channel normalization over un-normalized data. Channel normalization is essential for operation over unknown channels. (NOTE: Average intraspeaker variation for same channel - 0.5 db; average interspeaker variation for same channel - 1.6 db; average intraspeaker variation for multiple channel - 2.8 db. That is, the channel-induced spectral variations are more significant than any speaker-induced long-term spectral characteristics.)

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APPENDIX 2A

DATA BASE I VOCABULARY

The following vocabulary is organized into words including each of the remaining vowels (the word list for $|i|$ is given in Table 2.3). Each word list is organized into High-Vowel-High, Middle-Vowel-Middle, and Low-Vowel-Low hub context as defined in Section 2.0.

/I/

	Vocabulary Members		Hub Position
Jitter	Tissue		
Did	Dish		
Dit	Condition		
	Tidbit		H
Kick	Kiss	Stitch	
Gig	Signal		
Thistle	Sick		
This	Sixty		
Sister	Scissors		
Sizzle	Persist		M
Fifty			
Vivian			
Fib			L

/ɛ/

Shed
Ted
Dead
Debt

Jet
Shetland
Steady

H

Together
Keg
Guest
Guess

Says
Access
Success
Excess
Recess
Process

Seven
Seventy
Zest
Incessant
Section
Session

Segment

M

Pep
Pebble
Beverly
Bev

L

/a/

Tadpole
Dad
Dash

Shatter
Chat

Tattered

H

Cagney
Gag
Cust
Sack
Sag
Sassy
Zig Zag

Castle
Ransack
Casual
Sacrifice
Outcast

M

Pablo
Babble
Baboon
Fabulous
Baffle

Fabricate

L

/ɑ/

Tod
Tot
Shot
Dot
Shoddy
Jot

Dodge
Dodge City

H

Cog
Goggle
Soggy
Sock

M

Pop
Popsicle
Bup
Bop
Populous

L

/ɔ/

Taught
Daughter

H

Caulk
Saws
Sause
Gawk
Caught
Cost
Caustic
Cause
Because

M

Pauper
Involve
Revolve

L

/U/ Words

Should

H

Cook

M

L

Put	Good	Book
Foot	Soot	
Shook	Pudding	
Sugar	Push	
Cushion	Bush	

<u>Sup</u>

/u/

Toot
Tutor
Dude
Shoot
Chute
Do To
Duty

H/U/H

Substitute	Student
Attitude	Studio

Cougar
Kook
Enthusiasm
Sooth
Suzan
Zeus
Azusa
Zoos
Couth
Sioux City

Goose

M

Poop
Boob

1 u 1

/ʌ/

Dudley
Does
Shut
Dud
Suds
Judge
Jut
Shuttle

Shutter
Study

Touch
Dutch

H

Suck
Gus
Gust
Thus
Thug
Susman
Sucker

Disgust

Sustain
Discuss

M

Pup
Puppy
Pub
Puff
Buff, etc.
Buffer
Above
Buffalo

L

/ɜ/

Dirt
Shirt
Dirty
Jittered

Flittered
Sturdy

Dunkirk

Girth

Curse

Talkers
Walkers

Thursday

Beserk

Backers
Thirsty
Sirs
Packers

Circuit
Circus

Third

Burp

Perforate
Perfect

Perform
Perfume
Perfuse
Pervert
Pervious

Suburb

Purpose

APPENDIX 3A

TELEPHONE LINE SIMULATOR FOR SASIS

The spoken sentences are recorded by a two-channel audio recorder (Ampex AG440A) via a carbon telephone microphone and a mixed pair of SHURE 565 dynamic microphones. The channel on which the carbon microphone has been recorded is subsequently played through a transmission line link to the computer-input analog-to-digital converter (ADC).

The transmission link provides the functions of sample filtering and telephone channel simulation. Figure 1 shows the link. The audio recorder signal is band limited by a low-pass sampling filter and is then passed through a C2 telephone line simulator. A variable gain amplifier restores the signal amplitude to the ADC range (±5.0 volts).

The lowpass sampling filter is a 12th order elliptic passive low-pass filter having characteristics given in Table 1.

TABLE 1

Lowpass Filter Characteristics

± 0.25 dB	0 ≥ F ≥ 2.8 kHz
- 3.0 dB	F = 3.2 kHz
> - 40 dB	F ≥ 3.4 kHz

The telephone line simulator is a SEG 3002 and models an unconditioned C2 telephone channel. The characteristics of this channel are very similar to those of voice-grade dial-up channels in the Los Angeles area. The specifications (worst case) for a C2 line are given in Table 2, and the measured gain and delay characteristics of the SEG simulator (Model FA-1447, N905242) are given in Figures 2 and 3. The measurements show the simulator to be a reasonable model of the C2 line.

TABLE 2

C2 Line Characteristics (worst case)

Attenuation: (reference 0 dB at 1 kHz)

300 Hz to 3000 Hz	+ 2 dB to - 6 dB
500 Hz to 2800 Hz	+ 1 dB to - 3 dB

Relative Delay:

1000 Hz to 2600 Hz	.5 msec
600 Hz to 2600 Hz	1.5 msec
500 Hz to 2800 Hz	3 msec

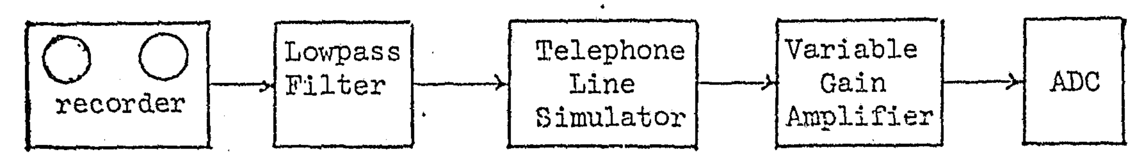

Figure 1

SASIS Transmission Line Configuration

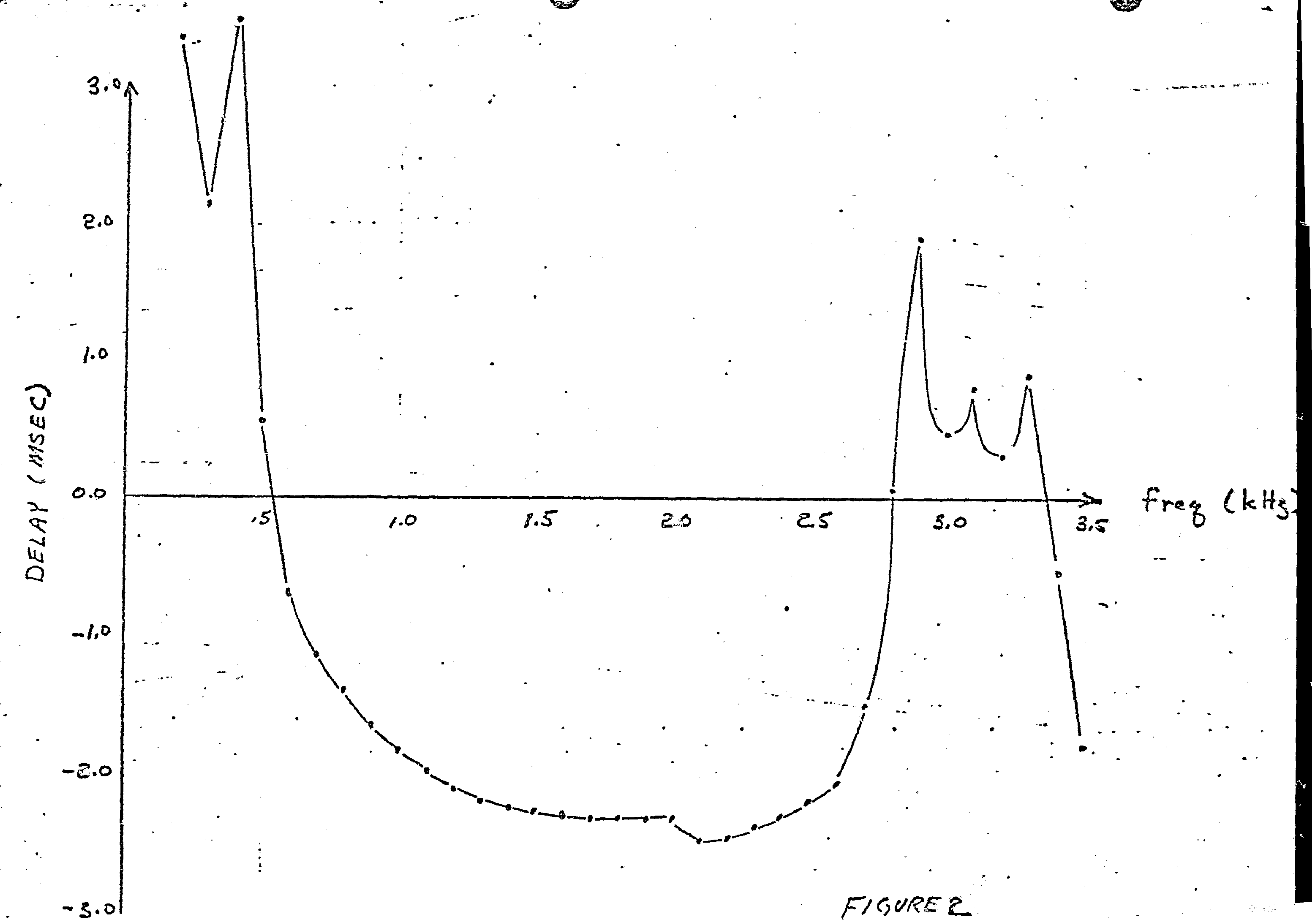

FIGURE 2
MEASURED RELATIVE DELAY
FOR SEG 3002 C-2 LINE
SIMULATOR 10/31/73

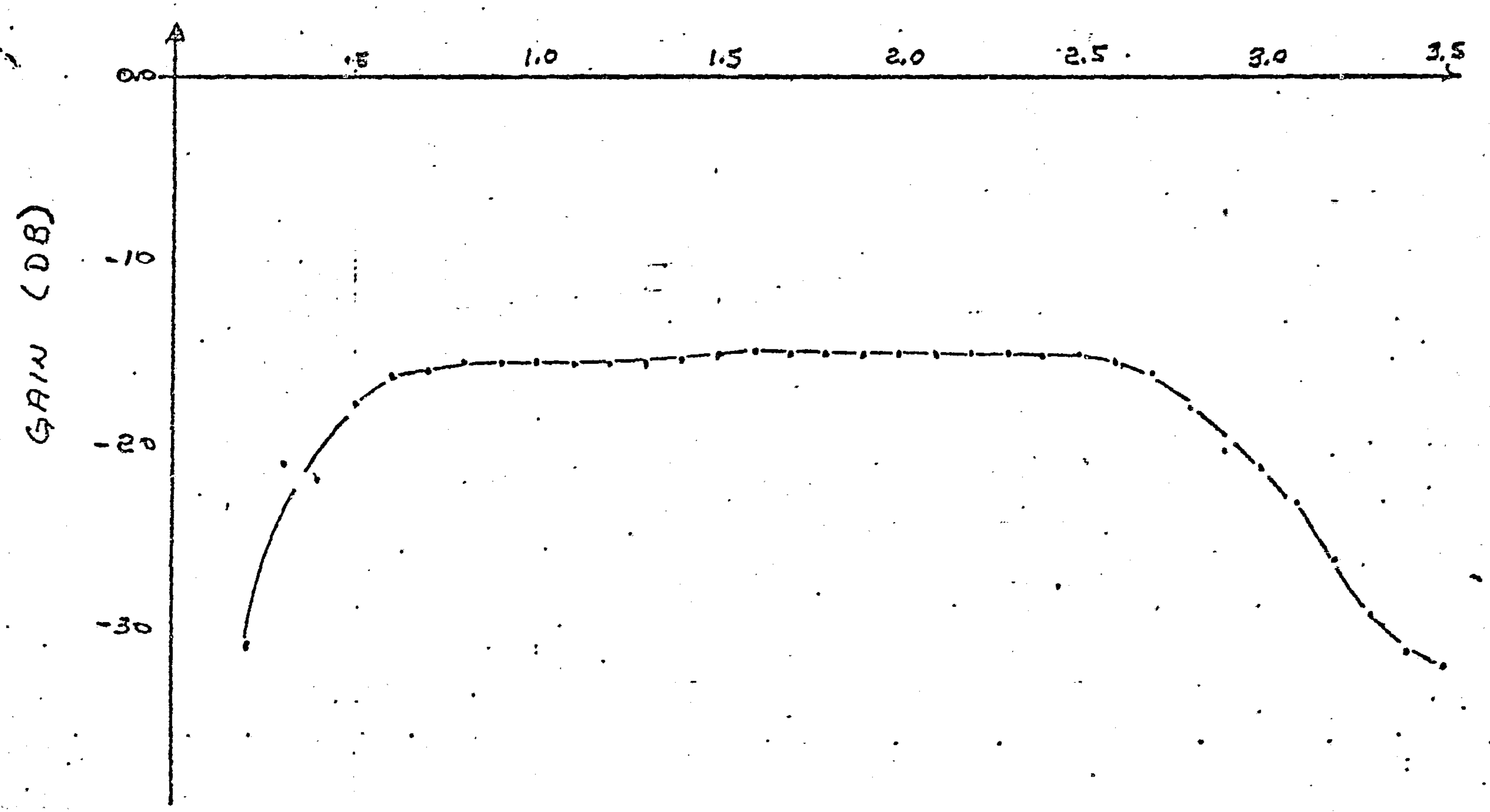

FIGURE 3
MEASURED RELATIVE GAIN
OF SEG 3002 C2 LINE
SIMULATOR 10/31/73

APPENDIX 3E

SUGGESTED READING MATERIAL
IN
ACOUSTIC PHONETICS AND SPEAKER IDENTIFICATION

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APPENDIX 5A

OPTIMAL SELECTION OF FEATURE SPACES

The problem is to find a linear subspace or hyperplane in the original pattern space such that the points representing utterances of each given speaker will be close together compared with the points representing utterances of different speakers. Using the measure defined by (5) below as the criterion of merit we proceed in the following paragraphs to find an exact solution to the problem of optimal linear feature selection.

Let us consider an input pattern space defined by the set of quantities $(x_1, \ldots, x_K)$. We wish to select a set of features $(y_1, \ldots, y_M)$ where $M < K$ and where each quantity y_m is linearly related to the quantities x_k, i.e.,

(1) $$y_m = \sum_{k=1}^{K} a_{mk} x_k \ , \ m = 1, \ldots, M.$$

For convenience we will require the features y_m to be uncorrelated in the sense that

(2) $$(y_m, y_{m'}) = 0, \ m \neq m' \ ,$$

where the inner product symbol is defined for any two arbitrary quantities u and v by the expression

(3) $$(u, v) = \frac{1}{S} \sum_{s=1}^{S} \left(E(uv|s) - E(u|s)\, E(v|s) \right) .$$

The norm is, of course, given by

(4) $$||u|| = (u,u)^{\frac{1}{2}} .$$

In (3), $E(\cdot|s)$ is the sample average of property $(\cdot)$ over the utterances of the s^{th} speaker and S is the total number of speakers. As a criterion of merit of a given feature set we will use the measure**

(5) $$M(y_1, \ldots, y_M) = \sum_{m=1}^{M} M(y_m)$$

where

(6) $$M(y_m) = \frac{2}{S(S-1)} \sum_{\substack{s,s'=1 \\ s>s'}}^{S} \frac{(\delta_{ss'}\mu_m)^2}{||y_m||^2}$$

in which

(7) $$\delta_{ss'}\mu_m = E(y_m|s)\, E(y_m|s') .$$

An alternative expression for $M(y_m)$ is

(8) $$M(y_m) = \frac{2}{S-1} \sum_{s=1}^{S} \frac{(\delta_s \mu_m)}{||y_m||^2}$$

where

(9) $$\delta_s \mu_m = E(y_m | s) - E(y_m)$$

where in turn

(10) $$E(y_m) = \frac{1}{S} \sum_{m=1}^{M} E(y_m | s).$$

Either (6) or (8) may be employed; however (8) will be more convenient for our problem.

The problem to be solved here is the determination of the best set of features y_m given by (1) using (5), combined with (8), as a criterion of merit. The optimization process is subject to the orthogonality, or uncorrelatedness, condition (2).

In order to facilitate the solution it is convenient to introduce somewhat more abstract notation. We let

(11) $$x = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_K \end{pmatrix}$$

and

(12) $$y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{pmatrix}$$

letting

(13) $$a_m = \begin{pmatrix} a_{m1} \\ a_{m2} \\ \vdots \\ a_{mK} \end{pmatrix}$$

(1) takes the form

(14) $y_m = a_m^T x$.

We introduce the two KxK matrices

(15) $D = \frac{2}{S-1} \sum_{s=1}^{S} \delta_{s\mu} \delta_{s\mu}^T$

and

(16) $C = (x, x^T)$

where

(17) $\delta_{s\mu} = E(x|s) - E(x)$.

In these terms (8) can be rewritten in the form

(18) $M(y_m) = \frac{a_m^T Da_m}{a_m^T Ca_m}$

and thus

(19) $M(y) \equiv M(y_1, \ldots, y_M) = \sum_{m=1}^{M} M(y_m)$

The orthogonality, or uncorrelatedness, condition for the y_m's now takes the form

(20) $(y_m, y_{m'}) = a_m^T C a_m' = 0, \; m \neq m'$.

It is particularly convenient to "pre-whiten" x-space, i.e., we assume that

(21) $(x, x^T) = C = I$

where I is the KxK identity matrix. This could be accomplished by a Schmidt process including normalization. Then (19) reduces to

(22) $M(y) = \sum_{m=1}^{M} \frac{a_m^T D a_m}{a_m^T a_m}$

and (20) reduces to

(23) $(y_m, y_m') = a_m^T a_m' = 0, \; m \neq m'$.

Our problem is now the maximization of (22) subject to the conditions (23).

Let us consider the problem of determining the principal axes of D. This is equivalent to determining the stationary points of

(24) $\frac{a^T Da}{a^T a}$

in the K-dimensional a-space. It is well known that this is also equivalent to the solution of the eigenvalue problem

(25) $Da_m = \lambda_m a_m$,

in which case the stationary points lie along lines passing through the origin in directions parallel to the eigen vectors a_m and the stationary values of (24) are the corresponding eigen values λ_m. It can be readily demonstrated that D is a non-negative definite real symmetric matrix. This implies that the eigen values λ_m are real and non-negative and that the eigen vectors a_m satisfy the orthogonality relations

(26) $a_m^T a_{m'} = 0, \; m \neq m'$.

Normalization is unnecessary in our problem.

It can be shown that a stationary (i.e., saddle point, maximum or minimum) value for M(y) under the side conditions (23) is attained if (but not only if) the a_m in (22) are eigenvectors of D, i.e., they are repeating (15), it follows that any vector perpendicular to all of the $\delta_s\mu$ is an eigenvector corresponding to a vanishing eigenvalue. Since, according to definition (17), $\delta_s\mu$ satisfies the relation

$$(31) \qquad \sum_{s=1}^{S} \delta_s\mu = 0$$

it follows that there are at most S-1 linear independent vectors $\delta_s\mu$. Assuming that there are exactly S-1 linearly independent vectors $\delta_s\mu$, it follows that $K \geq S-1$ and that these vectors span an (S-1) - dimensional subspace $\mathcal{R}$ of the K-dimensional x-space if $K > S-1$ and all of x-space if $K = S-1$. Thus, $\mathcal{R}$ may be regarded as a hyperplane of minimum dimensionality that can pass through all of the class means $\mu_s = E(x|s)$ but with the origin of x-space shifted to coincide with the global mean E(x). All of the eigenvectors corresponding to nonvanishing eigenvalues lie in $\mathcal{R}$ and conversely all eigenvectors lying in $\mathcal{R}$ have nonvanishing eigenvalues. Thus there are S-1 eigenvectors corresponding to nonvanishing eigenvalues and furthermore there are K-S+1 eigenvectors perpendicular to $\mathcal{R}$ having vanishing eigenvalues.

At this point we must consider M, the number of desired features, in relation to S, the number of speakers. As before, we assume that there are S-1 linearly independent vectors $\delta_s\mu$. There are three distinct cases: (a) $M > S-1$, (b) M=S-1, and (c) $M < S-1$. In (a) there are S-1 features having possible discriminatory power. These correspond to a_m, m=1, ..., S-1, in the subspace $\mathcal{R}$ spanned by the vectors $\delta_s\mu$, s=1, ... S-1.

Therefore, there is no utility in considering more features than those contained in $\mathcal{R}$. In case (b), the appropriate course of action is obvious: one simply chooses the features corresponding to a_m, m=1, ..., S-1, in $\mathcal{R}$. Here and in (a) it does not matter if the a_m are not eigenvectors of D as long as they are mutually orthogonal. In case (c), we encounter a nontrivial problem, namely choosing smaller set of a_m from $\mathcal{R}$ such that M(y) is maximized.

Since the a_m are in $\mathcal{R}$, we write

$$(32) \qquad a_m = \sum_{s=1}^{S} \delta_s\mu \; b_{sm} .$$

For convenience, we use the over-complete set $\delta_s\mu$, s=1, ..., S, to span $\mathcal{R}$. Substitution of (32) into (25) yields

$$(33) \qquad \sum_{s=1}^{S} \delta_s\mu \left[\sum_{s'=1}^{S} Q_{ss'} b_{s'm} - \lambda_m b_{sm} \right] = 0$$

where

$$(34) \qquad Q_{ss'} = \frac{2}{S-1} \; \delta_s\mu^T \; \delta_{s'}\mu .$$

Thus, a sufficient condition for the validity of (33) is that the quantities in the square bracket vanish, i.e.

$$(35) \qquad \sum_{s'=1}^{S} Q_{ss'} \, b_{s'm} = \lambda_m \, b_{sm} .$$

We then solve this equation for the eigenvalues λ_m and eigenvectors b_{sm}. As before, we will impose the ordering

$$(36) \qquad \lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_S .$$

Because of the relation (31) there will be a vanishing eigenvalue corresponding to an eigenvector in which b_{sm} is independent of s. Because of the ordering (36), this case must correspond in general to m=S and thus $\lambda_S = 0$.

To obtain the optimal set of M features when M < S-1 we choose the eigenvectors b_{sm} corresponding to the M largest eigenvalues. Thus, with the ordering (36), we choose $b_{s1}, \ldots, b_{sM}$. The corresponding vectors a_m are given by (32). The final features are then

$$(37) \qquad y_m = a_m^T x = \sum_{s=1}^{S} \delta_s \mu^T x \, b_{sm} .$$

A final comment is concerned with the uncorrelatedness of y_m and $y_{m'}$, $m \neq m'$, as defined by $(y_m, y_{m'}) = 0$ and the uncorrelatedness as defined by

$$(38) \qquad [y_m, y_{m'}] \triangleq E(y_m y_{m'}) - E(y_m)\, E(y_{m'}) = 0$$

where the global mean $E(\cdot)$ is given by (10). A simple calculation yields

$$(39) \qquad [y_m, y_{m'}] = (y_m, y_{m'}) + \frac{S-1}{2S} a_m^T D a_{m'}$$

Thus if $(y_m, y_{m'}) = 0$ and if a_m and $a_{m'}$ are different eigenvectors of D, then $[y_m, y_{m'}] = 0$ also.

STATIONARY VALUES OF M(y)

Here we prove that a stationary value of M(y) is attained when the a_m are independent eigenvectors of D defined by (15) and the stationary value is the sum of the corresponding eigenvalues. The proof of the above assertion closely parallels the theory of the Karhunen-Loève series.

$$(A\text{-}1) \qquad M(y) = \sum_{m=1}^{M} M(y_m)$$

where

$$(A\text{-}2) \qquad M(y_m) = \frac{a_m^T D a_m}{a_m^T a_m}$$

The vector a_m defines the linear relation between y_m and x as follows

$$(A\text{-}3) \qquad y_m = a_m^T x .$$

In (A-2) we have assumed that

$$(A\text{-}4) \qquad (x, x^T) = I.$$

Under this assumption the condition

$$(A\text{-}5) \qquad (y_m, y_{m'}) = 0, \; m \neq m'$$

is equivalent to the condition

$$(A\text{-}6) \qquad a_m^T a_{m'} = 0, \; m \neq m' ,$$

i.e. the vectors a_m are mutually orthogonal.

To simplify the investigation, let us introduce the orthonormal vectors

$$(A\text{-}7) \qquad b_m = (a_m^T a_m)^{-\frac{1}{2}} a_m ,$$

in terms of which (A-2) reduces to

(A-8) $$M(y_m) = b_m^T D\, b_m \,.$$

The orthogonality (A-6) combined with the normalization inherent in (A-7) leads to the new conditions

(A-9) $$b_m^T b_{m'} = \delta_{mm'} \,.$$

Using the Lagrange multiplier method for handling the side conditions (A-9) the constrained stationary value of M(y) is given by the unconstrained stationary value of

(A-10) $$\phi = \sum_{m=1}^{M} b_m^T D\, b_m - \sum_{m,m'=1}^{M} \lambda_{mm'}\, b_m^T b_{m'} \,.$$

Differention of φ with respect to each component of each b_m yields

(A-11) $$Db_m = \sum_{m'=1}^{M} \lambda_{mm'}\, b_{m'} \,,$$

i.e., the set of vectors $b_1, \ldots, b_M$ forms an M-dimensional representation of D. In other words, the subspace spanned by the b_m is invariant to D, i.e., D applied to any vector in this subspace yields another vector in the same subspace.

The corresponding stationary value of M(y) is

(A-12) $$M(y) = \sum_{m=1}^{M} \lambda_{mm} \,.$$

This value is invariant to the transformation

(A-13) $$b_m \rightarrow \Sigma\, U_{mm'}\, b_{m'}$$

where $U_{mm'}$ is an orthogonal matrix satisfying the conditions

(A-14) $$\sum_{m=1}^{M} U_{mm'}\, U_{mm''} = \delta_{m'm''} = \sum_{m=1}^{M} U_{m'm}\, U_{m''m}$$

which insures the preservation of the orthonormality conditions (A-9). With the transformation (A-13)

(A-15) $$\sum_{m=1}^{M} \lambda_{mm} \rightarrow \sum_{m,m',m''=1}^{M} U_{mm''}\, \lambda_{mm'}\, U_{m'm''} \,.$$

However, from (A-14) we deduce that

(A-16) $$\begin{cases} \displaystyle\sum_{m,m',m''=1}^{M} U_{mm''}\, \lambda_{mm'}\, U_{m'm''} \\ \displaystyle = \sum_{m,m'=1}^{M} \lambda_{mm'} \sum_{m''=1}^{M} U_{mm''}\, U_{m'm''} \\ \displaystyle = \sum_{m,m'=1}^{M} \lambda_{mm'}\, \delta_{mm'} = \sum_{m=1}^{M} \lambda_{mm} \end{cases}$$

Thus proving our assertion.

In particular, let us assume that a transformation of the form (A-14) can be selected which reduces $\lambda_{mm'}$ to diagonal form. Let us imagine that this has already been done, in which case (A-11) is replaced by

(A-17) $$D\, b_m = \lambda_m\, b_m$$

where the λ_m are the diagonal elements of the diagonalized $\lambda_{mm'}$ - matrix. The eigenvalues λ_m correspond to nontrivial solutions $b_m \neq 0$. It can be shown from (A-17) that $b_m^T b_{m'} = 0$, $m \neq m'$. The normalization $b_m^T b_m = 1$ is easily achieved. The corresponding stationary value of M(y) is of course

(A-18) $$M(y) = \sum_{m=1}^{M} \lambda_m \,.$$

It is easy to prove that if normalization is relaxed a_m can replace b_m in (A-17).

APPENDIX 5B

EFFECT OF CORRELATION ON DISCRIMINATORY POWER

Let the original feature set be $x_1, \ldots, x_M$. We now introduce the following notation for subvectors

$$(1) \quad \begin{cases} x^{\{i\}} = x_i \text{ (scalar)} \\ x^{\{ij\}} = \begin{pmatrix} x_i \\ x_j \end{pmatrix} \\ x^{\{ijk\}} = \begin{pmatrix} x_i \\ x_j \\ x_k \end{pmatrix} \end{cases}$$

etc.

The discriminatory power of the vector $x^{\{ij\}}$ can be expressed in the form

$$(2) \qquad M(x^{\{ij\}}) = \frac{2}{N(N-1)} \sum_{\substack{s, s'=1 \\ s > s'}}^{N} \delta_{ss'}\mu^{\{ij\}^T} C^{-1} \delta_{ss'}\mu^{\{ij\}}$$

where N is the number of speakers, C^{-1} is the inverse of the class-averaged intraclass covariance matrix

$$(3) \qquad C = \frac{1}{N} \sum_{s=1}^{N} \operatorname{Cov}(x^{\{ij\}}|s)$$

and where

$$(4) \qquad \delta_{ss'}\mu^{\{ij\}} = E(x^{\{ij\}}|s) - E(x^{\{ij\}}|s')$$

It is of interest to note that (2) can be rewritten in the equivalent form

$$(5) \qquad M(x^{\{ij\}}) = \frac{2}{N-1} \sum_{s=1}^{N} \delta_s\mu^{\{ij\}^T} C^{-1} \delta_s\mu^{\{ij\}}$$

where

$$(6) \qquad \delta_s\mu^{\{ij\}} = E(x^{\{ij\}}|s) - E(x^{\{ij\}})$$

where in turn

$$(7) \qquad E(x^{\{ij\}}) = \frac{1}{N} \sum_{s=1}^{N} E(x^{\{ij\}}|s).$$

The equivalence of (2) and (5) will not be proved here.

It can be readily shown that if x_i and x_j are uncorrelated in the sense that C is diagonal or, in other terms, in the sense that

$$(8) \qquad (x_i, x_j) \triangleq \frac{1}{N} \sum_{s=1}^{N} [E(x_i x_j|s) - E(x_i|s)\, E(x_j|s)] = 0,$$

then

$$(9) \qquad M(x^{\{ij\}}) = M(x_i) + M(x_j).$$

Thus, when x_i and x_j are uncorrelated in the above sense, the discriminatory power of x_i and x_j combined is the sum of the discriminatory powers of x_i and x_j separately. When x_i and x_j are correlated in the sense that (x_i, x_j) does not vanish, then (9) must be rewritten with a correction term, namely

$$(9a) \qquad M(x^{\{ij\}}) = M(x_i) + M(x_j) + G(x^{\{ij\}}).$$

Thus $G(x^{\{ij\}})$ is increment of discriminatory power added (or subtracted, if $G(x^{\{ij\}})$ is negative) by the combination of x_i and x_j relative to the discriminatory powers contributed separately by x_i and x_j. It can be used as a redundancy measure with increasing redundancy corresponding to increasing negative values of $G(x^{\{ij\}})$.

To obtain an explicit expression for $G(x^{\{ij\}})$ we first obtain

$$(10)\quad \begin{cases} M(x^{\{ij\}}) = \\ \dfrac{1}{1-c_{ij}^2}\left(M(x_i) + M(x_j) - 2\, c_{ij}\, \gamma_{ij}\, M^{\frac{1}{2}}(x_i)\, M^{\frac{1}{2}}(x_j)\right), \end{cases}$$

where

$$(11)\quad \begin{cases} c_{ij} = (x_i, x_j)\,||x_i||^{-1}\,||x_j||^{-1}, \\ ||x_i|| = (x_i, x_j)^{\frac{1}{2}}, \end{cases}$$

$$(12)\quad \gamma_{ij} = \sum_s \delta_s\mu_i\ \delta_s\mu_j \left(\sum_s (\delta_s\mu_i)^2\right)^{-\frac{1}{2}} \sum_s\left((\delta_s\mu_j)^2\right)^{-\frac{1}{2}}.$$

The quantity c_{ij} is called the intraclass correlation coefficient (class-averaged, of course) and it measures the correlation of x_i and x_j within classes. On the other hand, γ_{ij} is called the interclass correlation coefficient and this quantity measures the correlation of x_i and x_j among the classes.

We finally obtain

$$(13)\quad G(x^{\{ij\}}) = \frac{c_{ij}^2}{1-c_{ij}^2}\left(M(x_i) + M(x_j)\right) - \frac{2c_{ij}\gamma_{ij}}{1-c_{ij}^2}\, M^{\frac{1}{2}}(x_i)\, M^{\frac{1}{2}}(x_j).$$

It is to be noted that $G(x^{\{ij\}})$ can be either positive or negative.

Several properties are to be noted:

(a) If $c_{ij} = 0$, then $G(x^{\{ij\}}) = 0$, as one would expect.

(b) If $\gamma_{ij} = 0$, then

$$(14)\quad G(x^{\{ij\}}) = \frac{c_{ij}^2}{1-c_{ij}^2}\left(M(x_i) + M(x_j)\right) \geq 0$$

corresponding to an improvement of discriminatory power by considering x_i and x_j together.

(c) If $M(x_i) = M(x_j) = M_o$, $c_{ij} = 1-\epsilon$ and $\gamma_{ij} = 1-\eta$ where $0<\epsilon$, $\eta \ll 1$, then

$$(15)\quad G(x^{\{ij\}}) = \frac{\eta-\epsilon}{\epsilon}\, M_o .$$

This result gives the limiting value of $G(x^{\{ij\}})$ as x_i and x_j approach linear dependence (except for an additive constant) under the restriction $M(x_i) = M(x_j)$.

Clearly, there are many more properties that can be enumerated.

It is perhaps puzzling that the correction term $G(x^{\{ij\}})$ can be either positive or negative. To provide further insight into this question we consider the following example. Let us assume that

$$(16)\quad \begin{aligned} x_1 &= x_1 \\ x_2 &= ax_1 + b + u \end{aligned}$$

where u is uncorrelated with x_1, i.e.,

(17) $(x_1, u) = 0$.

It is easy to show that

(18) $M(x^{\{12\}}) = M(x_1) + M(u)$

where, of course,

(19) $M(u) = \frac{2}{N-1} \frac{\sum_s(\delta_s\mu_u)^2}{||u||^2}$

where in turn

(20) $\delta_s\mu_u = E(u|s) - E(u)$.

We also obtain

(21) $M(x_2) = \frac{2}{N-1} \cdot \frac{\sum_s (a\delta_s\mu_1 + \delta_s\mu_u)^2}{a^2||x_1||^2 + ||u||^2}$.

We are interested in investigating the behavior of

(22)
$$G(x^{\{12\}}) = M(x^{\{12\}}) - M(x_1) - M(x_2)$$
$$= M(u) - M(x_2) .$$

In general, it is easy to see that $G(x^{\{12\}})$ is positive if the discriminatory power of u, the part of x_1 representing new information, is larger than the discriminatory power of $x_2 (= ax_1 + b + u)$ by itself -- and vice versa.

In the special case in which $\delta_s\mu_u = 0$, i.e., the discriminatory power of u is zero, we obtain

(23)
$$G(x^{\{12\}}) = - M(x_2)$$
$$= - \frac{a^2||x_1||^2}{a^2||x_1||^2 + ||a||^2} \quad M(x_1).$$

On the other hand, in the second special case in which $\delta_s\mu_1 = 0$, i.e. the discriminatory power of x_1 is zero, we obtain

(24) $G(x^{\{12\}}) = \frac{a^2||x_1||^2}{a^2||x_1||^2 + ||u||^2} \quad M(u)$.

In the first case x_2 is a redundant variable since the term u, representing new information, has no discriminatory power and thus it is obvious that the correction term $G(x^{\{12\}})$ should be negative. In the second case in which u has all the discriminatory power, $M(x_2)$ is smaller than $M(u)$ because x_2 is contaminated with x_1 which only adds noise. Thus $M(x_2)$ is an underestimate of $M(x^{\{12\}})$ and hence $G(x^{\{12\}})$ is positive.

APPENDIX 5C

THE SCHMIDT PROCESS IN FEATURE SELECTION

Let us define the inner product of two random variables u and v by the expression

(1) $$(u, v) = \frac{1}{N} \sum_{s=1}^{N} E\,(\Delta_s u \Delta_s v | s)$$

and the corresponding norm by

(2) $$\| u \| = (u, u)^{\frac{1}{2}}.$$

In (1), N is the number of speakers, s is the speaker label (s = 1, ..., N). E(·|s) is the sample average of (·) over the utterances of speaker s and

(3) $$\Delta_s(\cdot) = (\cdot) - E\,(\cdot|s).$$

Now suppose that we are presented with the set of features $x_1, \ldots, x_M$ which in general are not uncorrelated. We wish to find a second set of uncorrelated transformed features $y_1, \ldots, y_M$, where

(4) $$y_m = \sum_{m^1=1}^{M} a_{mm^1} x_{m^1}.$$

In terms of the definitions of the previous paragraph, the term "uncorrelated" in the present context means that

(5) $$(y_m, y_{m^1}) = 0 \text{ if } m \neq m^1.$$

Clearly, the problem of finding a set of uncorrelated variables y_m does not have a unique solution.

However, if the features $x_1, \ldots, x_M$ are ordered according to some rule, for example, in accordance with their individual discriminatory powers (with the largest first), then we can apply the Schmidt process with unique results. This process is the following:

(6) $$\begin{cases} y_1 = x_1 \\ y_2 = x_2 - b_{21} x_1 \\ \vdots \\ y_m = x_m - \sum_{m^1=1}^{m-1} b_{mm^1} x_{m^1} \end{cases}$$

such that

(7) $$\begin{cases} (y_2, y_1) = 0 \\ \vdots \\ (y_m, y_{m^1}) = 0, \; m^1 = 1, \ldots, m-1. \end{cases}$$

Actually, the process can be considerably simplified by rewriting (6) in the equivalent form

(8) $$\begin{cases} y_1 = x_1 \\ y_2 = x_2 - c_{21} y_1 \\ \vdots \\ y_m = x_m - \sum_{m^1=1}^{m-1} c_{mm^1} y_{m^1} \end{cases}$$

Application of the orthogonality (uncorrelatedness) conditions yields

(9) $$\begin{cases} (y_2, y_1) = (x_2, y_1) - c_{21} \|y_1\|^2 = 0 \\ \vdots \\ (y_m, y_{m^1}) = (x_m, y_{m^1}) - c_{mm^1} \|y_{m^1}\|^2 = 0 \; m^1 = 1, \ldots, m-1. \end{cases}$$

Thus, we finally obtain.

$$\text{(10a)} \quad \begin{cases} c_{21} = (x_2, y_1) \, \|y_1\|^{-2} \\ c_{31} = (x_3, y_1) \, \|y_2\|^{-2} \\ c_{32} = (x_3, y_2) \, \|y_2\|^{-2} \end{cases}$$

and, in general,

$$\text{(10b)} \quad c_{mm^1} = (x_m, y_{m^1}) \, \|y_{m^1}\|^{-2}, \; m^1 = 1, \ldots, m-1.$$

The above is not the only orthogonalization process that one may encounter in feature selection. For example, in some cases one may wish to orthogonalize x_m with respect to a given set of features x_i, $i \in \mathcal{S}$, $m \notin \mathcal{S}$. More specifically, we wish to find

$$\text{(11)} \quad y_m = x_m - \sum_{i \in \mathcal{S}} d_{mi} \, x_i$$

such that

$$\text{(12)} \quad (y_m, x_i) = 0, \; i \in \mathcal{S}$$

The result is

$$\text{(13)} \quad d_{mk} = \sum_{i^1 \in \mathcal{S}} (x_m, x_{i^1}) \, (x_{i^1}, x_i)^{-1}$$

where $(x_{i^1}, x_i)^{-1}$ is the matrix inverse of (x_{i^1}, x_i).

No matrix inversion is involved in the simpler problem of orthogonalizing x_m with respect to the set y_i, $i \in \mathcal{S}$. We assume also that x_m cannot be expressed as a linear combination of the y_i. We write

$$\text{(14)} \quad y_m = x_m - \sum_{i \in \mathcal{S}} g_{mi} \, y_i$$

It, of course, follows from the previous assumption that y_m cannot be expressed as a linear combination of the y_i. We then require that

$$\text{(15)} \quad (y_m, y_i) = 0 \quad i \in \mathcal{S}$$

with the result

$$\text{(16)} \quad g_{mi} = (x_{mi}) \, \|y_i\|^{-2}.$$

APPENDIX 5D

FLUCTUATION OF SAMPLE VARIANCES

In examining two subsets of data base II, it was found that the inter and intra sample variances were not as consistent as one might expect. It is thus of interest to consider the effect of sampling fluctuations based upon a model parent population.

Let us assume that the parent population is described by the stochastic process

$$x_{sn} = y_s + z_{sn};\ s=1,\ldots,S;\ n=1,\ldots,N_s, \tag{1}$$

where x_{sn} is a possible value of a given feature for a specified event and triad (all understood). It is also assumed that this quantity represents the nth sample from the sth person. Two important model assumptions are: (a) y_s represents the "intrinsic" behavior of the sth person and is independent of n, while z_{sn} represents the deviation associated with the nth sample; and (b) y_s and z_{sn} are Gaussian random variables with the properties

$$Ey_s = \mu_y$$

$$Ez_{sn} = 0 \tag{2}$$

$$E\Delta y_s \Delta y_{s'} = \sigma_y^2 \delta_{ss'}$$

$$E\Delta y_s z_{sn} = 0 \tag{3}$$

$$Ez_{sn} z_{s'n'} = \sigma_z^2 \delta_{ss'} \delta_{nn'}$$

where

$$\Delta(\cdot) = (\cdot) - E(\cdot), \tag{4}$$

i.e., the deviation from the parent population mean. A further, rather unimportant assumption introduced for the sake of analytical convenience is that N_s, the number of samples for person s, is independent of s, i.e., $N_s = N$.

Here we define the inter sample variance by

$$\tau^2 = \frac{1}{S-1} \sum_{s=1}^{S} (\bar{x}_s - \bar{x})^2 \tag{5}$$

where

$$\bar{x}_s = \frac{1}{N} \sum_{n=1}^{N} x_{sn} \tag{6}$$

and

$$\bar{x} = \frac{1}{SN} \sum_{s=1}^{S} \sum_{n=1}^{N} x_{sn}. \tag{7}$$

The intra sample variance is defined by

$$\omega^2 = \frac{1}{S(N-1)} \sum_{s=1}^{S} \sum_{n=1}^{N} (x_{ns} - \bar{x}_s)^2. \tag{8}$$

The mean (in the parent population) of τ^2 is

$$E\tau^2 = \sigma_y^2 + N^{-1}\sigma_z^2 \tag{9}$$

and thus τ^2 is not an unbiased estimate, since it picks up some extra variance from the fluctuation of $\bar{x}_s$. The mean (in the same sense) of ω^2 is

$$E\,\omega^2 = \sigma_z^2 \tag{10}$$

and thus ω^2 is indeed an unbiased estimate of σ_z^2.

We turn now to the computation of the variance (in the parent population) of τ^2 and ω^2. A tedious calculation based upon the above assumptions yields

$$\text{Var } \tau^2 = \frac{2}{S-1} (E\,\tau^2)^2 \qquad (11)$$

$$\text{Var } \omega^2 = \frac{2}{(N-1)S} (E\,\omega^2)^2. \qquad (12)$$

It is of interest to note that the relations between the variances and the means are independent of μ_y, σ_y^2 and σ_z^2.

Let us consider samples from two identical populations 1 and 2 yielding the sample variances τ_1^2, τ_2^2, ω_1^2 and ω_2^2. We can show that

$$\text{Std}\left(\frac{\tau_1^2 - \tau_2^2}{\tau_1^2 + \tau_2^2}\right) \simeq \frac{\text{Std}\,(\tau_1^2 - \tau_2^2)}{E\,(\tau_1^2 + \tau_2^2)} = \frac{1}{\sqrt{S-1}}, \qquad (13)$$

and

$$\text{Std}\left(\frac{\omega_1^2 - \omega_2^2}{\omega_1^2 + \omega_2^2}\right) \simeq \frac{\text{Std}\,(\omega_1^2 - \omega_2^2)}{E\,(\omega_1^2 + \omega_2^2)} = \frac{1}{\sqrt{(N-1)S}} \qquad (14)$$

More accurate formulas may be obtained by expanding the denominators of the l.h. sides with respect to the deviations from their means. We make the assumptions (a) that the standard deviations of τ_1^2, τ_2^2, ω_1^2 and ω_2^2 are small compared with their means, and (b) that the corresponding probability densities are nearly Gaussian near the means. We now obtain the more accurate results

$$\text{Std}\left(\frac{\tau_1^2 - \tau_2^2}{\tau_1^2 + \tau_2^2}\right) \simeq \frac{1}{\sqrt{S-1}} \left(1 + \frac{3}{2(S-1)}\right) \qquad (15)$$

$$\text{Std}\left(\frac{\omega_1^2 - \omega_2^2}{\omega_1^2 + \omega_2^2}\right) \simeq \frac{1}{\sqrt{(N-1)S}} \left(1 + \frac{3}{2(N-1)S}\right) \qquad (16)$$

neglecting higher inverse powers of S-1 and (N-1)S, respectively.

Since these results, i.e., (13) - (16), are independent of the feature under consideration, we can estimate the above standard deviations by performing appropriate averaging over the features.
Such estimates are compared with the theoretical results in the table below.

Case	Estimated From Data	Theoretical	
		Approximate	More Accurate
Inter	0.1334	0.1162 (13)	0.1186 (15)
Intra	0.0673	0.0516 (14)	0.0518 (16)

Here we have used the values S = 75 and N = 6. In the table, the numbers enclosed in parentheses refer to the equations from which the quantities to the immediate left of the parentheses are computed.

From these results one can conclude the actual data are roughly consistent with the assumed model population and that hence the apparent lack of consistency between the subsets of data base II is approximately what should be expected.

APPENDIX 5E

OPTIMIZED FEATURE SET FOR SASIS

5E-1

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EVENT= 20   THRESHOLD= 60   /m/

FEATURE NO. =	34	F-RATIO=	4.41	LOCATION=	251	WGHT=	210
FEATURE NO. =	35	F-RATIO=	2.53	LOCATION=	252	WGHT=	159
FEATURE NO. =	140	F-RATIO=	2.28	LOCATION=	292	WGHT=	151
FEATURE NO. =	17	F-RATIO=	2.19	LOCATION=	233	WGHT=	148
FEATURE NO. =	43	F-RATIO=	2.19	LOCATION=	516	WGHT=	148
FEATURE NO. =	123	F-RATIO=	2.19	LOCATION=	275	WGHT=	148
FEATURE NO. =	4	F-RATIO=	1.93	LOCATION=	220	WGHT=	139
FEATURE NO. =	20	F-RATIO=	1.90	LOCATION=	236	WGHT=	138
FEATURE NO. =	25	F-RATIO=	1.85	LOCATION=	241	WGHT=	136
FEATURE NO. =	37	F-RATIO=	1.85	LOCATION=	510	WGHT=	136
FEATURE NO. =	118	F-RATIO=	1.80	LOCATION=	270	WGHT=	134
FEATURE NO. =	54	F-RATIO=	1.77	LOCATION=	527	WGHT=	133
FEATURE NO. =	57	F-RATIO=	1.74	LOCATION=	530	WGHT=	132
FEATURE NO. =	152	F-RATIO=	1.65	LOCATION=	504	WGHT=	129
FEATURE NO. =	40	F-RATIO=	1.44	LOCATION=	513	WGHT=	120
FEATURE NO. =	109	F-RATIO=	1.44	LOCATION=	261	WGHT=	120
FEATURE NO. =	12	F-RATIO=	1.37	LOCATION=	228	WGHT=	117
FEATURE NO. =	29	F-RATIO=	1.28	LOCATION=	245	WGHT=	113
FEATURE NO. =	107	F-RATIO=	1.25	LOCATION=	259	WGHT=	112
FEATURE NO. =	2	F-RATIO=	1.23	LOCATION=	218	WGHT=	111
FEATURE NO. =	3	F-RATIO=	1.23	LOCATION=	219	WGHT=	111
FEATURE NO. =	11	F-RATIO=	1.10	LOCATION=	227	WGHT=	105
FEATURE NO. =	1	F-RATIO=	1.08	LOCATION=	217	WGHT=	104
FEATURE NO. =	5	F-RATIO=	1.08	LOCATION=	221	WGHT=	104
FEATURE NO. =	23	F-RATIO=	1.08	LOCATION=	212	WGHT=	104
FEATURE NO. =	99	F-RATIO=	1.08	LOCATION=	215	WGHT=	104
FEATURE NO. =	69	F-RATIO=	1.04	LOCATION=	533	WGHT=	102
FEATURE NO. =	97	F-RATIO=	1.02	LOCATION=	213	WGHT=	101
FEATURE NO. =	8	F-RATIO=	0.94	LOCATION=	224	WGHT=	97
FEATURE NO. =	13	F-RATIO=	0.85	LOCATION=	229	WGHT=	92
FEATURE NO. =	19	F-RATIO=	0.79	LOCATION=	235	WGHT=	89
FEATURE NO. =	7	F-RATIO=	0.76	LOCATION=	223	WGHT=	87
FEATURE NO. =	163	F-RATIO=	0.74	LOCATION=	515	WGHT=	86
FEATURE NO. =	6	F-RATIO=	0.71	LOCATION=	222	WGHT=	84
FEATURE NO. =	53	F-RATIO=	0.69	LOCATION=	211	WGHT=	83
FEATURE NO. =	50	F-RATIO=	0.66	LOCATION=	214	WGHT=	81
FEATURE NO. =	32	F-RATIO=	0.52	LOCATION=	249	WGHT=	72
FEATURE NO. =	64	F-RATIO=	0.45	LOCATION=	537	WGHT=	68

Table 5.10

Optimized Feature Sets for SASIS

EVENT = 21 THRESHOLD= 60 /n/

FEATURE NO. =	17	F-RATIO=	3.92	LOCATION=	233	WGHT=	196
FEATURE NO. =	34	F-RATIO=	2.46	LOCATION=	251	WGHT=	157
FEATURE NO. =	141	F-RATIO=	2.37	LOCATION=	293	WGHT=	154
FEATURE NO. =	117	F-RATIO=	2.16	LOCATION=	269	WGHT=	147
FEATURE NO. =	16	F-RATIO=	2.16	LOCATION=	232	WGHT=	145
FEATURE NO. =	54	F-RATIO=	2.07	LOCATION=	527	WGHT=	144
FEATURE NO. =	35	F-RATIO=	2.02	LOCATION=	292	WGHT=	142
FEATURE NO. =	148	F-RATIO=	1.99	LOCATION=	308	WGHT=	138
FEATURE NO. =	20	F-RATIO=	1.95	LOCATION=	236	WGHT=	136
FEATURE NO. =	29	F-RATIO=	1.82	LOCATION=	245	WGHT=	135
FEATURE NO. =	151	F-RATIO=	1.82	LOCATION=	303	WGHT=	135
FEATURE NO. =	124	F-RATIO=	1.69	LOCATION=	276	WGHT=	130
FEATURE NO. =	4	F-RATIO=	1.49	LOCATION=	220	WGHT=	122
FEATURE NO. =	40	F-RATIO=	1.49	LOCATION=	513	WGHT=	122
FEATURE NO. =	1	F-RATIO=	1.46	LOCATION=	217	WGHT=	121
FEATURE NO. =	8	F-RATIO=	1.44	LOCATION=	224	WGHT=	120
FEATURE NO. =	73	F-RATIO=	1.44	LOCATION=	546	WGHT=	120
FEATURE NO. =	3	F-RATIO=	1.42	LOCATION=	219	WGHT=	119
FEATURE NO. =	9	F-RATIO=	1.42	LOCATION=	225	WGHT=	119
FEATURE NO. =	107	F-RATIO=	1.23	LOCATION=	259	WGHT=	111
FEATURE NO. =	12	F-RATIO=	1.19	LOCATION=	228	WGHT=	109
FEATURE NO. =	5	F-RATIO=	1.17	LOCATION=	221	WGHT=	108
FEATURE NO. =	19	F-RATIO=	1.10	LOCATION=	235	WGHT=	105
FEATURE NO. =	11	F-RATIO=	1.08	LOCATION=	227	WGHT=	104
FEATURE NO. =	[illegible]	F-RATIO=	1.08	LOCATION=	260	WGHT=	104
FEATURE NO. =	[illegible]	F-RATIO=	1.08	LOCATION=	231	WGHT=	104
FEATURE NO. =	[illegible]	F-RATIO=	1.06	LOCATION=	215	WGHT=	103
FEATURE NO. =	13	F-RATIO=	1.04	LOCATION=	229	WGHT=	102
FEATURE NO. =	2	F-RATIO=	1.02	LOCATION=	218	WGHT=	101
FEATURE NO. =	59	F-RATIO=	1.02	LOCATION=	215	WGHT=	101
FEATURE NO. =	6	F-RATIO=	0.88	LOCATION=	222	WGHT=	[illegible]
FEATURE NO. =	109	F-RATIO=	0.79	LOCATION=	311	WGHT=	89
FEATURE NO. =	7	F-RATIO=	0.69	LOCATION=	222	WGHT=	83
FEATURE NO. =	32	F-RATIO=	0.66	LOCATION=	249	WGHT=	81
FEATURE NO. =	33	F-RATIO=	0.64	LOCATION=	212	WGHT=	80
FEATURE NO. =	58	F-RATIO=	0.58	LOCATION=	214	WGHT=	76
FEATURE NO. =	56	F-RATIO=	0.56	LOCATION=	211	WGHT=	75
FEATURE NO. =	62	F-RATIO=	0.45	LOCATION=	535	WGHT=	67

EVENT = 22 THRESHOLD= 60 /ŋ/

FEATURE NO. =	34	F-RATIO=	2.59	LOCATION=	251	WGHT=	161
FEATURE NO. =	25	F-RATIO=	2.28	LOCATION=	241	WGHT=	151
FEATURE NO. =	37	F-RATIO=	2.04	LOCATION=	510	WGHT=	143
FEATURE NO. =	143	F-RATIO=	1.99	LOCATION=	292	WGHT=	141
FEATURE NO. =	110	F-RATIO=	1.91	LOCATION=	262	WGHT=	139
FEATURE NO. =	42	F-RATIO=	1.77	LOCATION=	515	WGHT=	133
FEATURE NO. =	47	F-RATIO=	1.74	LOCATION=	233	WGHT=	132
FEATURE NO. =	140	F-RATIO=	1.74	LOCATION=	272	WGHT=	132
FEATURE NO. =	121	F-RATIO=	1.69	LOCATION=	303	WGHT=	130
FEATURE NO. =	4	F-RATIO=	1.46	LOCATION=	220	WGHT=	121
FEATURE NO. =	105	F-RATIO=	1.39	LOCATION=	258	WGHT=	118
FEATURE NO. =	2	F-RATIO=	1.37	LOCATION=	218	WGHT=	117
FEATURE NO. =	3	F-RATIO=	1.32	LOCATION=	219	WGHT=	115
FEATURE NO. =	9	F-RATIO=	1.32	LOCATION=	225	WGHT=	115
FEATURE NO. =	29	F-RATIO=	1.32	LOCATION=	245	WGHT=	115
FEATURE NO. =	53	F-RATIO=	1.32	LOCATION=	526	WGHT=	115
FEATURE NO. =	108	F-RATIO=	1.30	LOCATION=	260	WGHT=	114
FEATURE NO. =	11	F-RATIO=	1.25	LOCATION=	227	WGHT=	112
FEATURE NO. =	45	F-RATIO=	1.17	LOCATION=	519	WGHT=	109
FEATURE NO. =	8	F-RATIO=	1.14	LOCATION=	224	WGHT=	107
FEATURE NO. =	12	F-RATIO=	1.14	LOCATION=	228	WGHT=	107
FEATURE NO. =	93	F-RATIO=	1.12	LOCATION=	506	WGHT=	105
FEATURE NO. =	5	F-RATIO=	0.96	LOCATION=	221	WGHT=	98
FEATURE NO. =	7	F-RATIO=	0.94	LOCATION=	223	WGHT=	97
FEATURE NO. =	97	F-RATIO=	0.94	LOCATION=	213	WGHT=	97
FEATURE NO. =	13	F-RATIO=	0.92	LOCATION=	229	WGHT=	96
FEATURE NO. =	157	F-RATIO=	0.90	LOCATION=	309	WGHT=	95
FEATURE NO. =	19	F-RATIO=	0.85	LOCATION=	235	WGHT=	93
FEATURE NO. =	59	F-RATIO=	0.79	LOCATION=	215	WGHT=	89
FEATURE NO. =	100	F-RATIO=	0.77	LOCATION=	216	WGHT=	88
FEATURE NO. =	6	F-RATIO=	0.76	LOCATION=	222	WGHT=	87
FEATURE NO. =	95	F-RATIO=	0.76	LOCATION=	212	WGHT=	87
FEATURE NO. =	55	F-RATIO=	0.71	LOCATION=	211	WGHT=	84
FEATURE NO. =	32	F-RATIO=	0.58	LOCATION=	249	WGHT=	76
FEATURE NO. =	23	F-RATIO=	0.58	LOCATION=	214	WGHT=	75
FEATURE NO. =	64	F-RATIO=	0.52	LOCATION=	537	WGHT=	72

EVENT= 23 THRESHOLD= 60 /i/

FEATURE NO.	F-RATIO	LOCATION	WGHT
33	4.54	259	213
20	2.72	236	165
8	2.24	224	153
51	1.99	524	141
139	1.90	251	138
17	1.82	223	135
14	1.80	270	134
30	1.80	215	134
109	1.72	261	131
9	1.69	225	130
155	1.64	307	128
37	1.61	510	127
34	1.54	240	124
26	1.51	242	123
12	1.49	228	122
39	1.49	533	122
107	1.46	259	121
35	1.39	528	118
29	1.37	245	117
125	1.35	277	116
7	1.28	223	113
1	1.23	217	111
100	1.22	202	111
5	1.17	221	108
158	1.17	260	108
99	1.12	214	105
97	1.10	213	105
95	1.02	211	101
13	0.96	229	98
3	0.94	219	97
99	0.90	215	95
98	0.85	212	92
2	0.83	218	91
4	0.81	220	90
6	0.77	222	88
22	0.74	249	86

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EVENT= 24 THRESHOLD= 60 /I/

FEATURE NO.	F-RATIO	LOCATION	WGHT
34	5.62	251	237
151	2.25	303	150
30	2.22	245	149
100	2.22	216	149
29	2.19	245	148
93	2.13	563	147
48	1.96	521	140
157	1.93	299	138
31	1.85	247	136
147	1.82	299	135
82	1.74	555	132
130	1.74	282	132
6	1.69	222	130
14	1.69	239	130
91	1.66	564	129
8	1.61	224	127
46	1.61	519	127
35	1.59	252	126
2	1.51	218	123
37	1.46	510	121
137	1.44	289	120
32	1.42	238	119
5	1.23	221	111
98	1.23	214	111
12	1.21	228	110
107	1.14	259	107
110	1.14	262	107
24	1.04	240	102
26	0.95	242	98
13	0.94	229	97
4	0.92	225	95
3	0.90	219	95
121	0.90	273	95
15	0.81	211	90
96	0.79	212	89
39	0.77	215	88
32	0.67	249	82

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/e/

EVENT= 25 THRESHOLD= 60

FEATURE NO.	F-RATIO	LOCATION	WGHT
34	5.34	251	231
114	2.34	266	153
112	2.25	264	150
6	2.19	222	148
39	2.02	245	142
152	1.99	304	141
17	1.93	233	139
111	1.90	263	138
27	1.77	243	133
31	1.74	247	132
176	1.69	288	130
46	1.64	519	128
128	1.64	280	128
40	1.59	513	126
49	1.59	522	126
86	1.59	559	126
22	1.54	238	124
72	1.51	545	123
132	1.46	284	121
2	1.42	218	119
37	1.42	510	119
7	1.37	223	117
97	1.35	213	116
162	1.32	314	115
5	1.25	221	112
3	1.12	219	106
129	1.12	272	106
11	1.10	227	105
59	1.10	215	105
8	1.08	224	104
4	1.02	220	101
12	1.02	228	101
44	1.02	517	101
95	1.00	211	100
98	0.79	214	89
26	0.74	242	86
96	0.71	212	84
13	0.69	229	83
32	0.56	249	75

/a/

EVENT= 26 THRESHOLD= 60

FEATURE NO.	F-RATIO	LOCATION	WGHT
34	5.52	251	235
35	5.52	252	235
25	2.07	241	144
6	1.93	222	139
151	1.93	303	139
115	1.80	267	134
143	1.66	255	129
100	1.61	216	127
109	1.56	232	125
17	1.54	233	124
59	1.51	522	123
20	1.49	236	122
54	1.49	527	122
27	1.46	243	121
47	1.39	520	118
2	1.35	218	116
113	1.35	265	116
40	1.32	513	115
56	1.32	529	115
159	1.28	311	113
31	1.23	524	111
172	1.23	284	111
8	1.21	224	110
176	1.21	278	110
5	1.12	221	106
38	1.10	511	105
29	1.08	245	104
11	1.06	227	103
45	1.06	519	103
97	1.04	213	102
14	0.96	[illegible]	98
12	0.94	228	97
24	0.94	240	97
4	0.90	220	95
15	0.90	241	95
42	0.85	515	92
98	0.83	212	91
99	0.79	215	89
13	0.71	229	84
32	0.53	249	73

EVENT= 27 THRESHOLD= 60

FEATURE NO. =	34	F-RATIO=	4.28	LOCATION=	251	WGHT=	207
FEATURE NO. =	4	F-RATIO=	1.90	LOCATION=	220	WGHT=	138
FEATURE NO. =	128	F-RATIO=	1.54	LOCATION=	280	WGHT=	124
FEATURE NO. =	17	F-RATIO=	1.51	LOCATION=	233	WGHT=	123
FEATURE NO. =	27	F-RATIO=	1.49	LOCATION=	243	WGHT=	122
FEATURE NO. =	113	F-RATIO=	1.49	LOCATION=	265	WGHT=	122
FEATURE NO. =	114	F-RATIO=	1.49	LOCATION=	266	WGHT=	122
FEATURE NO. =	2	F-RATIO=	1.44	LOCATION=	218	WGHT=	120
FEATURE NO. =	5	F-RATIO=	1.44	LOCATION=	221	WGHT=	120
FEATURE NO. =	46	F-RATIO=	1.44	LOCATION=	519	WGHT=	120
FEATURE NO. =	120	F-RATIO=	1.39	LOCATION=	272	WGHT=	118
FEATURE NO. =	3	F-RATIO=	1.37	LOCATION=	219	WGHT=	117
FEATURE NO. =	38	F-RATIO=	1.37	LOCATION=	511	WGHT=	117
FEATURE NO. =	124	F-RATIO=	1.30	LOCATION=	276	WGHT=	114
FEATURE NO. =	18	F-RATIO=	1.28	LOCATION=	234	WGHT=	113
FEATURE NO. =	90	F-RATIO=	1.28	LOCATION=	563	WGHT=	113
FEATURE NO. =	9	F-RATIO=	1.25	LOCATION=	225	WGHT=	112
FEATURE NO. =	146	F-RATIO=	1.25	LOCATION=	298	WGHT=	112
FEATURE NO. =	43	F-RATIO=	1.23	LOCATION=	516	WGHT=	111
FEATURE NO. =	6	F-RATIO=	1.21	LOCATION=	222	WGHT=	110
FEATURE NO. =	100	F-RATIO=	1.17	LOCATION=	216	WGHT=	108
FEATURE NO. =	53	F-RATIO=	1.12	LOCATION=	526	WGHT=	106
FEATURE NO. =	1	F-RATIO=	1.10	LOCATION=	217	WGHT=	105
FEATURE NO. =	29	F-RATIO=	1.10	LOCATION=	245	WGHT=	105
FEATURE NO. =	115	F-RATIO=	1.10	LOCATION=	267	WGHT=	105
FEATURE NO. =	142	F-RATIO=	1.06	LOCATION=	294	WGHT=	103
FEATURE NO. =	99	F-RATIO=	1.00	LOCATION=	215	WGHT=	100
FEATURE NO. =	48	F-RATIO=	0.94	LOCATION=	521	WGHT=	97
FEATURE NO. =	8	F-RATIO=	0.92	LOCATION=	224	WGHT=	96
FEATURE NO. =	19	F-RATIO=	0.92	LOCATION=	235	WGHT=	95
FEATURE NO. =	158	F-RATIO=	0.92	LOCATION=	[illegible]	WGHT=	96
FEATURE NO. =	96	F-RATIO=	0.90	LOCATION=	212	WGHT=	95
FEATURE NO. =	11	F-RATIO=	0.88	LOCATION=	227	WGHT=	94
FEATURE NO. =	62	F-RATIO=	0.81	LOCATION=	535	WGHT=	90
FEATURE NO. =	12	F-RATIO=	0.79	LOCATION=	228	WGHT=	89
FEATURE NO. =	7	F-RATIO=	0.77	LOCATION=	223	WGHT=	88
FEATURE NO. =	95	F-RATIO=	0.77	LOCATION=	211	WGHT=	88
FEATURE NO. =	24	F-RATIO=	0.62	LOCATION=	240	WGHT=	79
FEATURE NO. =	13	F-RATIO=	0.59	LOCATION=	229	WGHT=	77
FEATURE NO. =	32	F-RATIO=	0.56	LOCATION=	249	WGHT=	75
FEATURE NO. =	98	F-RATIO=	0.55	LOCATION=	214	WGHT=	74

5E-9

EVENT= 28 THRESHOLD= 60

FEATURE NO. =	34	F-RATIO=	4.37	LOCATION=	251	WGHT=	209
FEATURE NO. =	114	F-RATIO=	1.99	LOCATION=	266	WGHT=	141
FEATURE NO. =	1	F-RATIO=	1.77	LOCATION=	217	WGHT=	133
FEATURE NO. =	113	F-RATIO=	1.69	LOCATION=	265	WGHT=	130
FEATURE NO. =	44	F-RATIO=	1.64	LOCATION=	517	WGHT=	128
FEATURE NO. =	67	F-RATIO=	1.61	LOCATION=	540	WGHT=	127
FEATURE NO. =	100	F-RATIO=	1.61	LOCATION=	216	WGHT=	127
FEATURE NO. =	18	F-RATIO=	1.56	LOCATION=	234	WGHT=	125
FEATURE NO. =	41	F-RATIO=	1.54	LOCATION=	514	WGHT=	124
FEATURE NO. =	112	F-RATIO=	1.54	LOCATION=	264	WGHT=	124
FEATURE NO. =	153	F-RATIO=	1.51	LOCATION=	305	WGHT=	123
FEATURE NO. =	118	F-RATIO=	1.49	LOCATION=	270	WGHT=	122
FEATURE NO. =	123	F-RATIO=	1.46	LOCATION=	275	WGHT=	121
FEATURE NO. =	3	F-RATIO=	1.42	LOCATION=	219	WGHT=	119
FEATURE NO. =	82	F-RATIO=	1.39	LOCATION=	505	WGHT=	118
FEATURE NO. =	4	F-RATIO=	1.32	LOCATION=	220	WGHT=	115
FEATURE NO. =	23	F-RATIO=	1.28	LOCATION=	239	WGHT=	113
FEATURE NO. =	37	F-RATIO=	1.25	LOCATION=	510	WGHT=	112
FEATURE NO. =	5	F-RATIO=	1.19	LOCATION=	221	WGHT=	109
FEATURE NO. =	70	F-RATIO=	1.19	LOCATION=	543	WGHT=	109
FEATURE NO. =	108	F-RATIO=	1.12	LOCATION=	260	WGHT=	106
FEATURE NO. =	11	F-RATIO=	1.10	LOCATION=	227	WGHT=	105
FEATURE NO. =	9	F-RATIO=	1.08	LOCATION=	225	WGHT=	104
FEATURE NO. =	135	F-RATIO=	1.08	LOCATION=	287	WGHT=	104
FEATURE NO. =	142	F-RATIO=	1.06	LOCATION=	294	WGHT=	103
FEATURE NO. =	12	F-RATIO=	1.04	LOCATION=	228	WGHT=	102
FEATURE NO. =	128	F-RATIO=	1.04	LOCATION=	280	WGHT=	102
FEATURE NO. =	19	F-RATIO=	1.02	LOCATION=	235	WGHT=	101
FEATURE NO. =	51	F-RATIO=	1.02	LOCATION=	524	WGHT=	101
FEATURE NO. =	8	F-RATIO=	0.92	LOCATION=	224	WGHT=	96
FEATURE NO. =	47	F-RATIO=	0.92	LOCATION=	523	WGHT=	96
FEATURE NO. =	24	F-RATIO=	0.88	LOCATION=	240	WGHT=	94
FEATURE NO. =	7	F-RATIO=	0.85	LOCATION=	223	WGHT=	93
FEATURE NO. =	6	F-RATIO=	0.85	LOCATION=	222	WGHT=	92
FEATURE NO. =	13	F-RATIO=	0.83	LOCATION=	229	WGHT=	91
FEATURE NO. =	96	F-RATIO=	0.77	LOCATION=	212	WGHT=	88
FEATURE NO. =	95	F-RATIO=	0.76	LOCATION=	211	WGHT=	87
FEATURE NO. =	98	F-RATIO=	0.69	LOCATION=	214	WGHT=	83
FEATURE NO. =	64	F-RATIO=	0.66	LOCATION=	537	WGHT=	81
FEATURE NO. =	99	F-RATIO=	0.65	LOCATION=	215	WGHT=	81
FEATURE NO. =	32	F-RATIO=	0.61	LOCATION=	249	WGHT=	78

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08/09/74 63:28:40 CORMATRI REAL-TIME MONITOR 3.1 PAGE 65

EVENT= 29 THRESHOLD= 60

FEATURE NO. = 34	F-RATIO= 6.15	LOCATION= 251	WGHT= 248
FEATURE NO. = 20	F-RATIO= 2.10	LOCATION= 236	WGHT= 145
FEATURE NO. = 16	F-RATIO= 1.92	LOCATION= 222	WGHT= 135
FEATURE NO. = 39	F-RATIO= 1.80	LOCATION= 512	WGHT= 134
FEATURE NO. = 109	F-RATIO= 1.80	LOCATION= 261	WGHT= 134
FEATURE NO. = 54	F-RATIO= 1.77	LOCATION= 527	WGHT= 133
FEATURE NO. = 23	F-RATIO= 1.69	LOCATION= 239	WGHT= 130
FEATURE NO. = 141	F-RATIO= 1.66	LOCATION= 293	WGHT= 129
FEATURE NO. = 47	F-RATIO= 1.64	LOCATION= 520	WGHT= 128
FEATURE NO. = 127	F-RATIO= 1.61	LOCATION= 279	WGHT= 127
FEATURE NO. = 67	F-RATIO= 1.54	LOCATION= 540	WGHT= 124
FEATURE NO. = 111	F-RATIO= 1.51	LOCATION= 263	WGHT= 123
FEATURE NO. = 6	F-RATIO= 1.42	LOCATION= 222	WGHT= 119
FEATURE NO. = 51	F-RATIO= 1.32	LOCATION= 524	WGHT= 115
FEATURE NO. = 14	F-RATIO= 1.28	LOCATION= 239	WGHT= 113
FEATURE NO. = 4	F-RATIO= 1.21	LOCATION= 220	WGHT= 110
FEATURE NO. = 68	F-RATIO= 1.12	LOCATION= 541	WGHT= 106
FEATURE NO. = 106	F-RATIO= 1.12	LOCATION= 258	WGHT= 106
FEATURE NO. = 37	F-RATIO= 1.10	LOCATION= 510	WGHT= 105
FEATURE NO. = 122	F-RATIO= 1.08	LOCATION= 274	WGHT= 104
FEATURE NO. = 11	F-RATIO= 1.06	LOCATION= 227	WGHT= 103
FEATURE NO. = 110	F-RATIO= 1.06	LOCATION= 262	WGHT= 103
FEATURE NO. = 8	F-RATIO= 1.02	LOCATION= 224	WGHT= 101
FEATURE NO. = 26	F-RATIO= 1.02	LOCATION= 242	WGHT= 101
FEATURE NO. = 99	F-RATIO= 0.98	LOCATION= 215	WGHT= 99
FEATURE NO. = 24	F-RATIO= 0.96	LOCATION= 240	WGHT= 98
FEATURE NO. = 116	F-RATIO= 0.96	LOCATION= 268	WGHT= 98
FEATURE NO. = 96	F-RATIO= 0.92	LOCATION= 212	WGHT= 96
FEATURE NO. = 12	F-RATIO= 0.90	LOCATION= 228	WGHT= 95
FEATURE NO. = 98	F-RATIO= 0.90	LOCATION= 214	WGHT= 95
FEATURE NO. = 3	F-RATIO= 0.86	LOCATION= 219	WGHT= 93
FEATURE NO. = 95	F-RATIO= 0.81	LOCATION= 211	WGHT= 90
FEATURE NO. = 13	F-RATIO= 0.79	LOCATION= 229	WGHT= 89
FEATURE NO. = 7	F-RATIO= 0.76	LOCATION= 223	WGHT= 87
FEATURE NO. = 32	F-RATIO= 0.53	LOCATION= 249	WGHT= 73

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08/09/74 63:28:40 CORMATRI REAL-TIME MONITOR 3.1 PAGE 71

EVENT= 30 THRESHOLD= 60

FEATURE NO. = 34	F-RATIO= 4.37	LOCATION= 251	WGHT= 209
FEATURE NO. = 100	F-RATIO= 2.69	LOCATION= 216	WGHT= 170
FEATURE NO. = 18	F-RATIO= 2.53	LOCATION= 234	WGHT= 159
FEATURE NO. = 53	F-RATIO= 1.90	LOCATION= 526	WGHT= 138
FEATURE NO. = 20	F-RATIO= 1.89	LOCATION= 236	WGHT= 137
FEATURE NO. = 131	F-RATIO= 1.85	LOCATION= 283	WGHT= 135
FEATURE NO. = 4	F-RATIO= 1.77	LOCATION= 220	WGHT= 133
FEATURE NO. = 44	F-RATIO= 1.77	LOCATION= 517	WGHT= 133
FEATURE NO. = 46	F-RATIO= 1.77	LOCATION= 519	WGHT= 133
FEATURE NO. = 11	F-RATIO= 1.72	LOCATION= 227	WGHT= 131
FEATURE NO. = 14	F-RATIO= 1.66	LOCATION= 230	WGHT= 129
FEATURE NO. = 21	F-RATIO= 1.59	LOCATION= 237	WGHT= 126
FEATURE NO. = 42	F-RATIO= 1.59	LOCATION= 515	WGHT= 126
FEATURE NO. = 125	F-RATIO= 1.56	LOCATION= 277	WGHT= 125
FEATURE NO. = 5	F-RATIO= 1.54	LOCATION= 221	WGHT= 124
FEATURE NO. = 121	F-RATIO= 1.54	LOCATION= 273	WGHT= 124
FEATURE NO. = 3	F-RATIO= 1.37	LOCATION= 219	WGHT= 117
FEATURE NO. = 107	F-RATIO= 1.37	LOCATION= 259	WGHT= 117
FEATURE NO. = 8	F-RATIO= 1.35	LOCATION= 224	WGHT= 116
FEATURE NO. = 24	F-RATIO= 1.30	LOCATION= 240	WGHT= 114
FEATURE NO. = 99	F-RATIO= 1.23	LOCATION= 215	WGHT= 111
FEATURE NO. = 116	F-RATIO= 1.14	LOCATION= 268	WGHT= 107
FEATURE NO. = 109	F-RATIO= 1.12	LOCATION= 261	WGHT= 106
FEATURE NO. = 1	F-RATIO= 1.10	LOCATION= 217	WGHT= 105
FEATURE NO. = 13	F-RATIO= 1.10	LOCATION= 229	WGHT= 105
FEATURE NO. = 6	F-RATIO= 1.08	LOCATION= 222	WGHT= 104
FEATURE NO. = 12	F-RATIO= 1.02	LOCATION= 228	WGHT= 101
FEATURE NO. = 96	F-RATIO= 1.00	LOCATION= 212	WGHT= 100
FEATURE NO. = 2	F-RATIO= 0.96	LOCATION= 218	WGHT= 98
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FEATURE NO. = 98	F-RATIO= 0.69	LOCATION= 214	WGHT= 83
FEATURE NO. = 25	F-RATIO= 0.59	LOCATION= 211	WGHT= 77
FEATURE NO. = 32	F-RATIO= 0.55	LOCATION= 249	WGHT= 74

5E-12

EVENT= 31 THRESHOLD= 60 /A/

FEATURE NO.	F-RATIO	LOCATION	WGHT
34	5. 1	251	226
153	2.31	305	152
100	2.22	216	149
112	2.02	264	142
25	1.82	241	135
77	1.64	550	128
5	1.61	221	127
61	1.59	534	126
109	1.54	261	124
37	1.51	510	123
46	1.51	519	123
115	1.51	267	123
146	1.49	298	122
129	1.42	281	119
9	1.39	225	118
82	1.35	555	116
19	1.30	235	114
29	1.28	245	113
11	1.23	227	111
70	1.23	543	111
4	1.21	220	110
122	1.21	274	110
127	1.17	279	108
12	1.10	228	105
142	1.10	294	105
6	1.08	222	104
3	1.04	219	102
8	1.04	224	102
49	1.04	522	102
95	1.00	211	100
2	0.98	218	98
7	0.96	223	98
51	0.96	524	98
96	0.77	212	88
13	0.76	229	87
99	0.64	215	80
32	0.61	249	78

5E-13

EVENT= 32 THRESHOLD= 60 /3/

FEATURE NO.	F-RATIO	LOCATION	WGHT
34	3.69	251	192
35	3.46	252	186
109	2.28	261	151
5	1.89	221	134
29	1.80	245	134
111	1.64	263	128
44	1.59	517	126
27	1.54	243	124
14	1.51	239	123
66	1.49	539	122
38	1.46	511	121
49	1.44	522	120
119	1.39	262	118
19	1.35	246	116
170	1.35	282	116
25	1.32	241	115
155	1.32	307	115
31	1.30	247	114
46	1.30	519	114
3	1.28	219	113
4	1.23	220	111
6	1.21	222	110
13	1.21	229	110
126	1.21	278	110
2	1.12	219	106
12	1.02	228	101
26	1.00	242	100
121	0.98	273	99
104	0.94	256	97
10	0.85	226	92
9	0.83	225	91
96	0.83	212	91
100	0.76	216	87
99	0.69	215	83
25	0.67	211	82
98	0.65	214	81
32	0.53	249	73

5E-14

/ə/

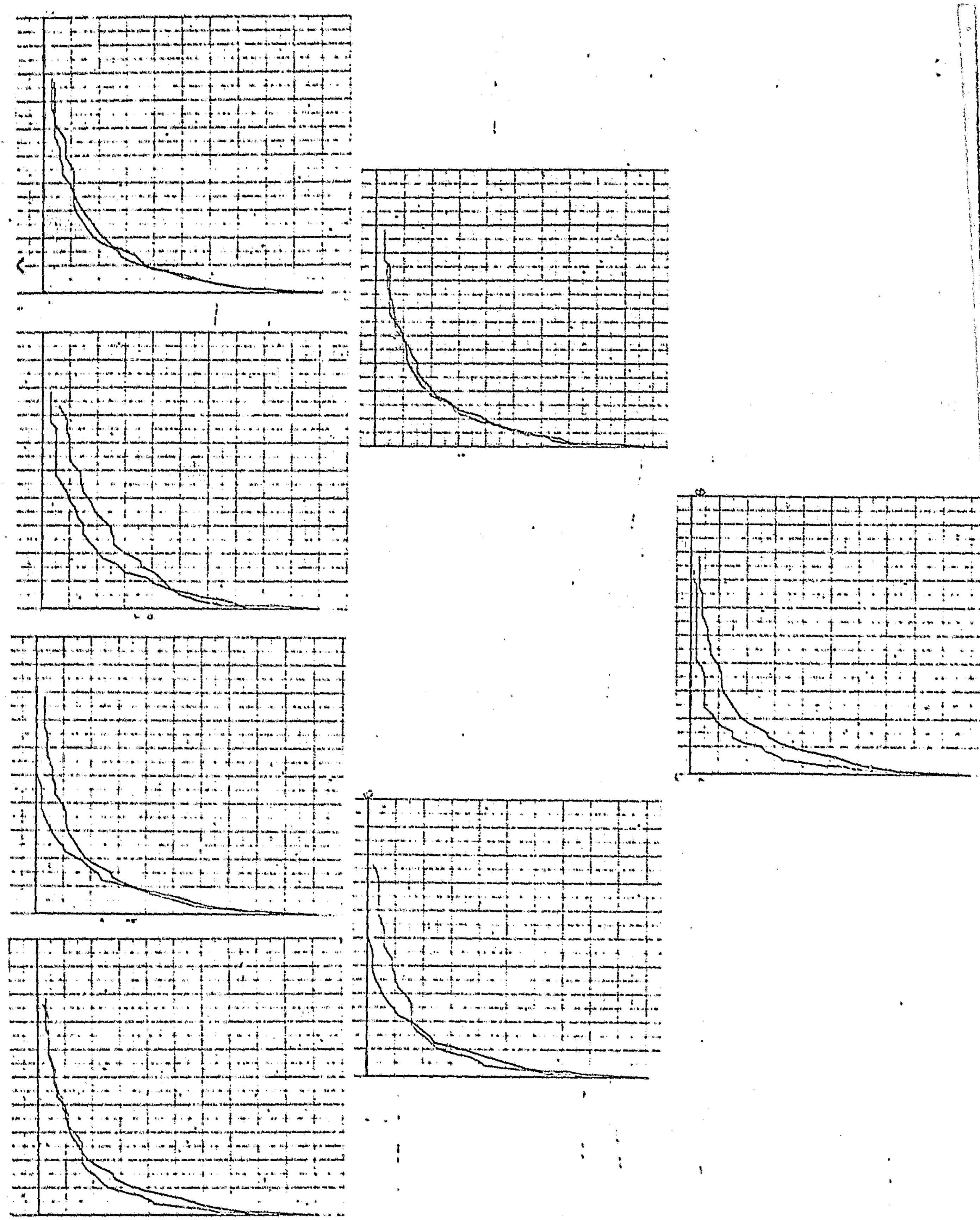
EVENT= 33 THRESHOLD= 60

FEATURE NO. =	30	F-RATIO=	3.65	LOCATION=	246	WGHT=	191
FEATURE NO. =	33	F-RATIO=	2.99	LOCATION=	250	WGHT=	173
FEATURE NO. =	145	F-RATIO=	2.53	LOCATION=	297	WGHT=	159
FEATURE NO. =	22	F-RATIO=	2.31	LOCATION=	238	WGHT=	152
FEATURE NO. =	5	F-RATIO=	2.02	LOCATION=	221	WGHT=	142
FEATURE NO. =	39	F-RATIO=	1.96	LOCATION=	512	WGHT=	140
FEATURE NO. =	42	F-RATIO=	1.74	LOCATION=	515	WGHT=	132
FEATURE NO. =	155	F-RATIO=	1.66	LOCATION=	307	WGHT=	129
FEATURE NO. =	108	F-RATIO=	1.64	LOCATION=	260	WGHT=	128
FEATURE NO. =	110	F-RATIO=	1.61	LOCATION=	262	WGHT=	127
FEATURE NO. =	6	F-RATIO=	1.59	LOCATION=	222	WGHT=	126
FEATURE NO. =	11	F-RATIO=	1.42	LOCATION=	227	WGHT=	119
FEATURE NO. =	73	F-RATIO=	1.39	LOCATION=	546	WGHT=	118
FEATURE NO. =	148	F-RATIO=	1.39	LOCATION=	308	WGHT=	118
FEATURE NO. =	46	F-RATIO=	1.25	LOCATION=	519	WGHT=	112
FEATURE NO. =	122	F-RATIO=	1.19	LOCATION=	274	WGHT=	109
FEATURE NO. =	4	F-RATIO=	1.17	LOCATION=	220	WGHT=	108
FEATURE NO. =	12	F-RATIO=	1.17	LOCATION=	228	WGHT=	108
FEATURE NO. =	29	F-RATIO=	1.12	LOCATION=	245	WGHT=	106
FEATURE NO. =	36	F-RATIO=	1.12	LOCATION=	212	WGHT=	106
FEATURE NO. =	140	F-RATIO=	1.12	LOCATION=	292	WGHT=	106
FEATURE NO. =	3	F-RATIO=	1.08	LOCATION=	219	WGHT=	104
FEATURE NO. =	97	F-RATIO=	1.00	LOCATION=	213	WGHT=	100
FEATURE NO. =	72	F-RATIO=	0.94	LOCATION=	545	WGHT=	97
FEATURE NO. =	63	F-RATIO=	0.86	LOCATION=	536	WGHT=	93
FEATURE NO. =	35	F-RATIO=	0.81	LOCATION=	211	WGHT=	90
FEATURE NO. =	116	F-RATIO=	0.72	LOCATION=	268	WGHT=	85
FEATURE NO. =	24	F-RATIO=	0.71	LOCATION=	240	WGHT=	84
FEATURE NO. =	26	F-RATIO=	0.71	LOCATION=	242	WGHT=	84
FEATURE NO. =	8	F-RATIO=	0.69	LOCATION=	224	WGHT=	83
FEATURE NO. =	13	F-RATIO=	0.62	LOCATION=	229	WGHT=	79
FEATURE NO. =	7	F-RATIO=	0.58	LOCATION=	223	WGHT=	76
FEATURE NO. =	32	F-RATIO=	0.37	LOCATION=	249	WGHT=	61

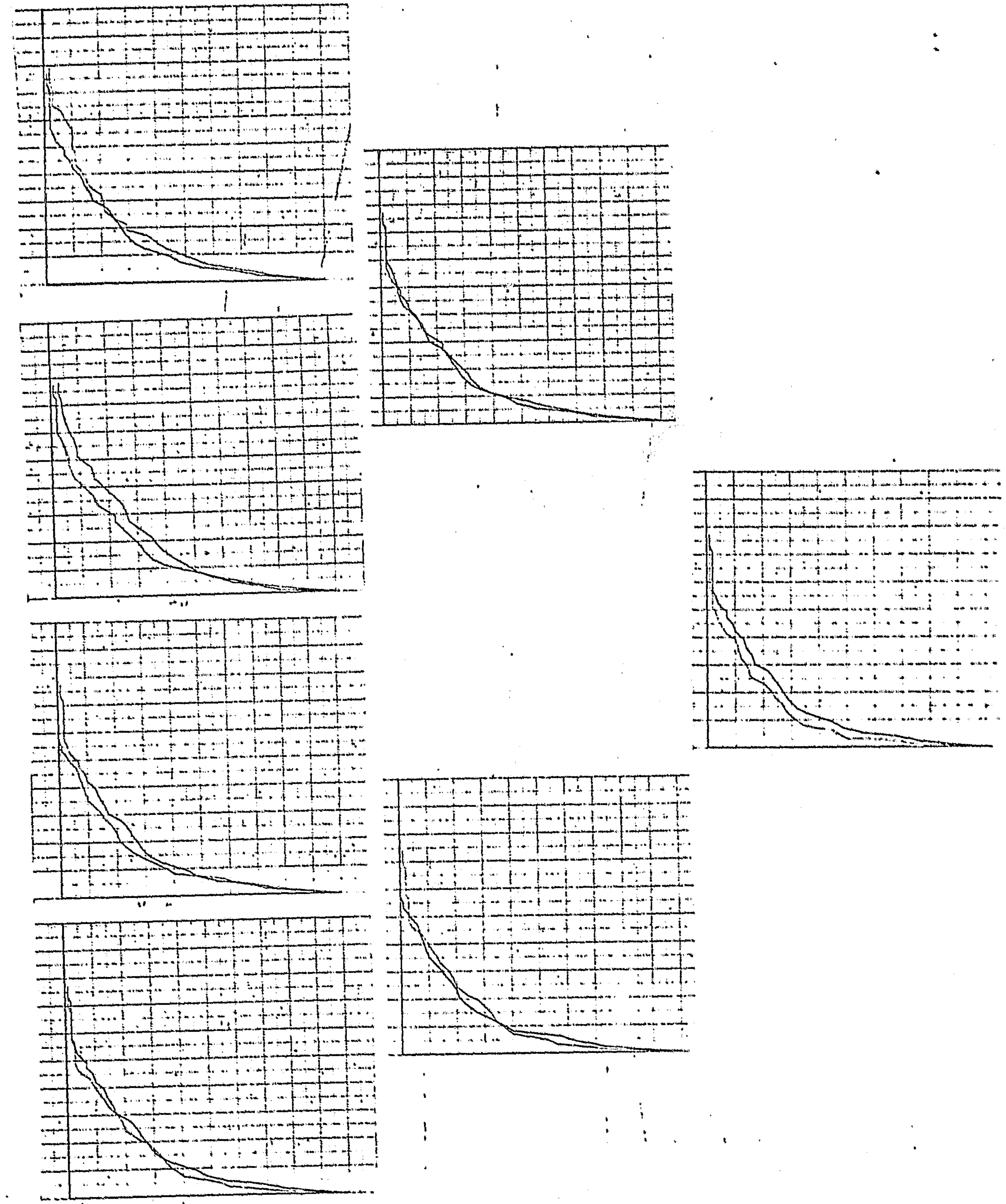
APPENDIX 7A

SOC Curves for Seven Distance Measures and 14 Phonetic Events

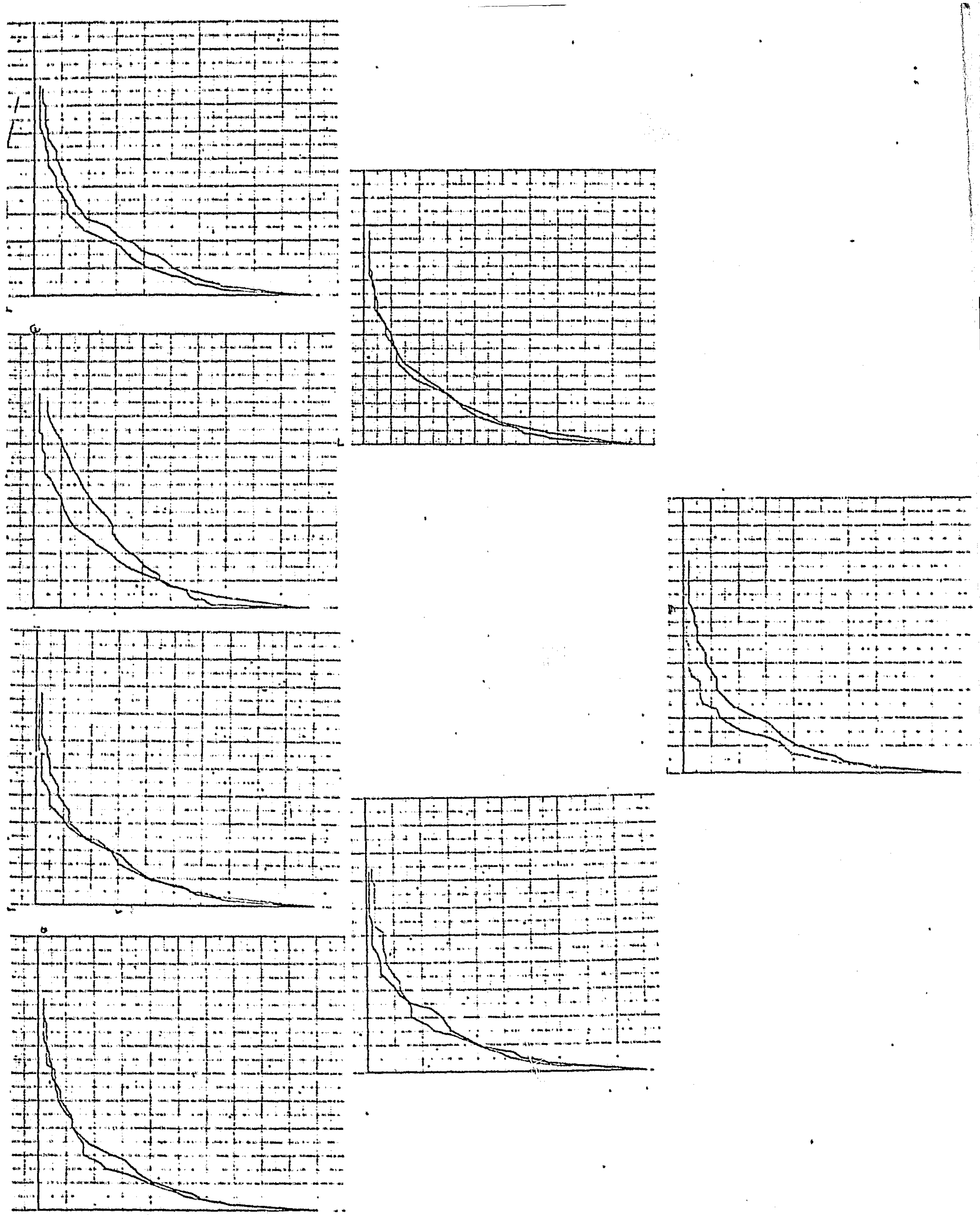
The format for the 14 pages of curves which follow is shown on the summary sheet given in Figure 7-20. In cases where the curves ambiguously cross the small triangles point to the lower numbered distance measure, e.g., for the d_1 - d_7 comparison, they point to d_1.



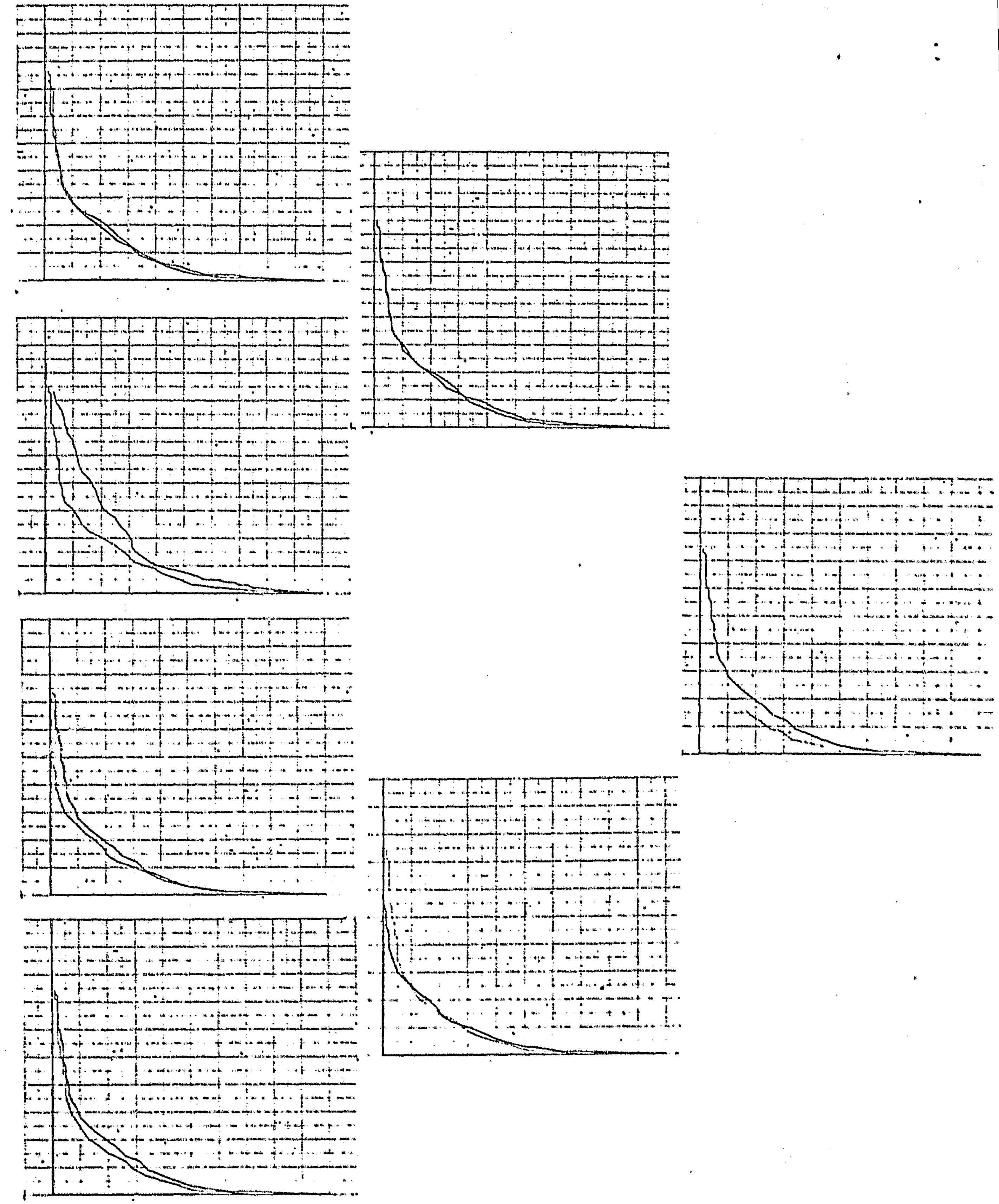
EVENT 20



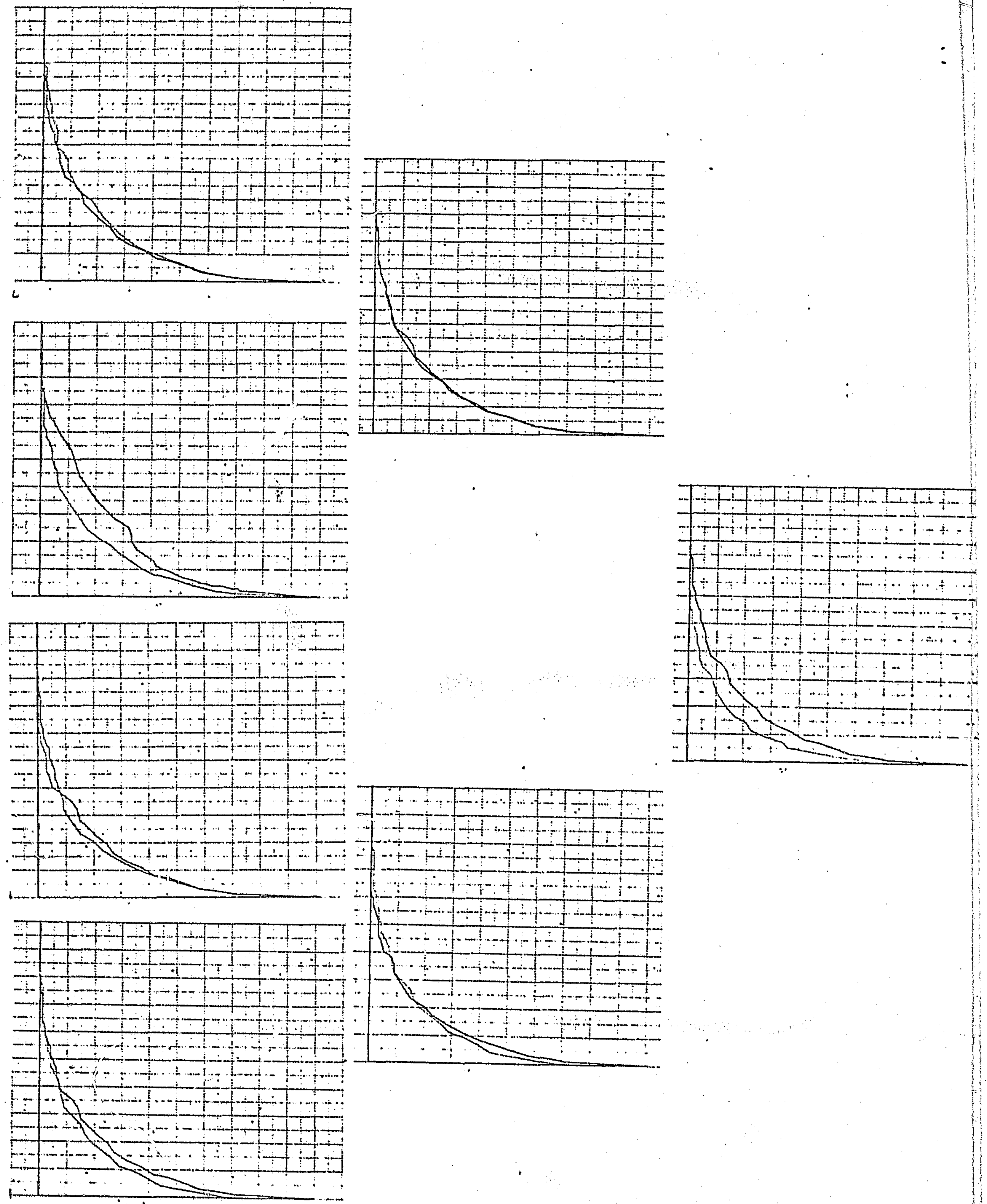
EVENT 21



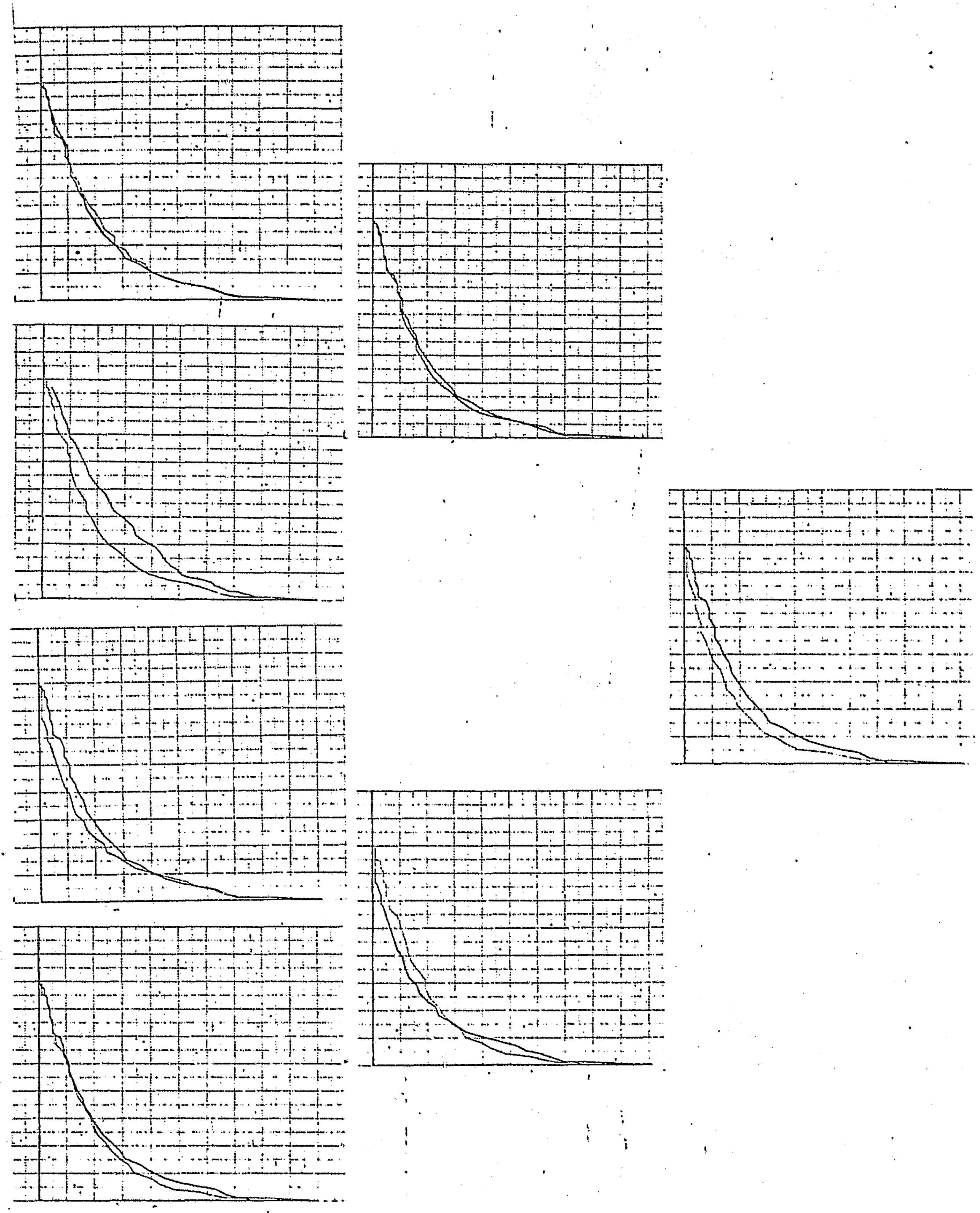
EVENT 22



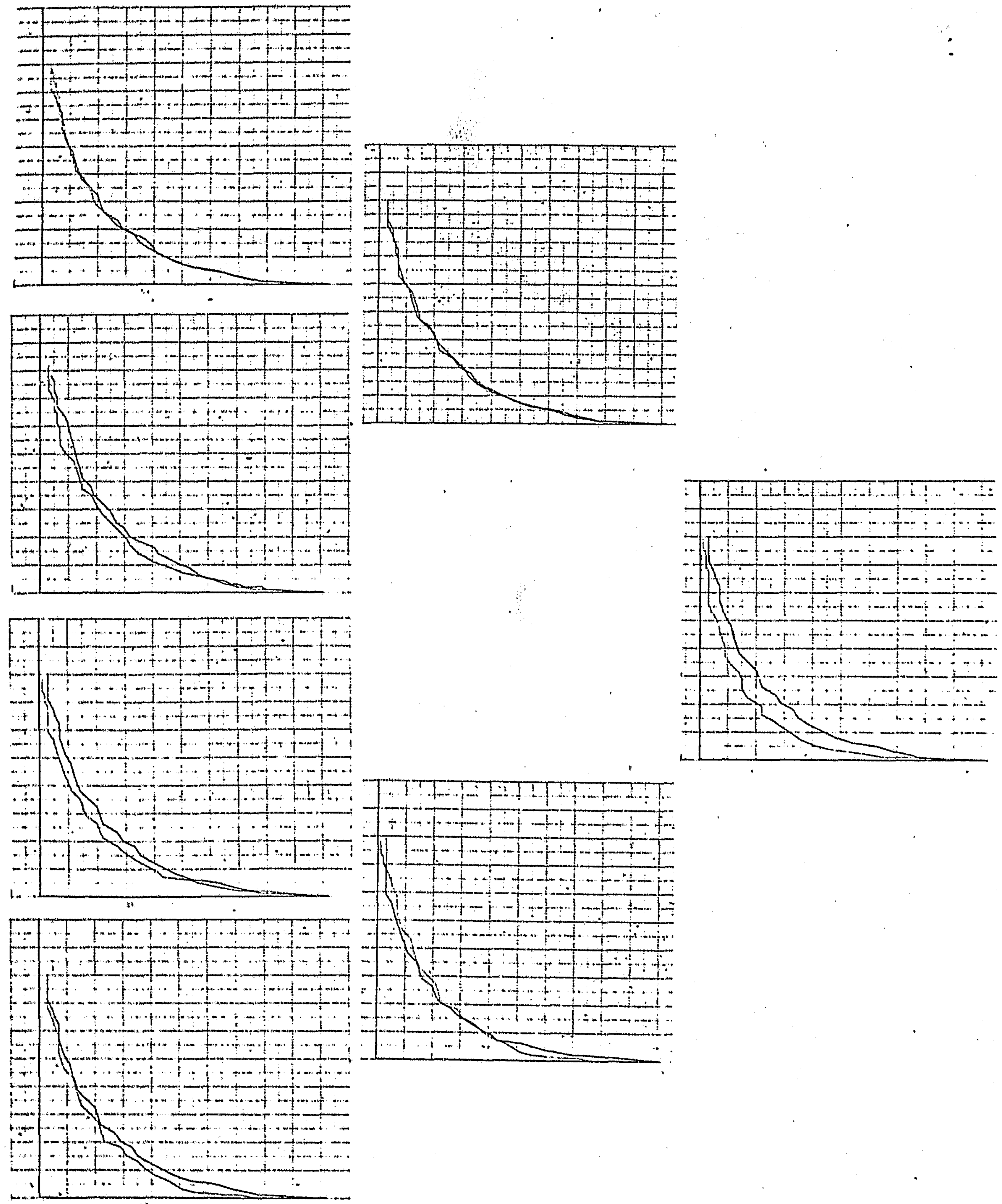
EVENT 23



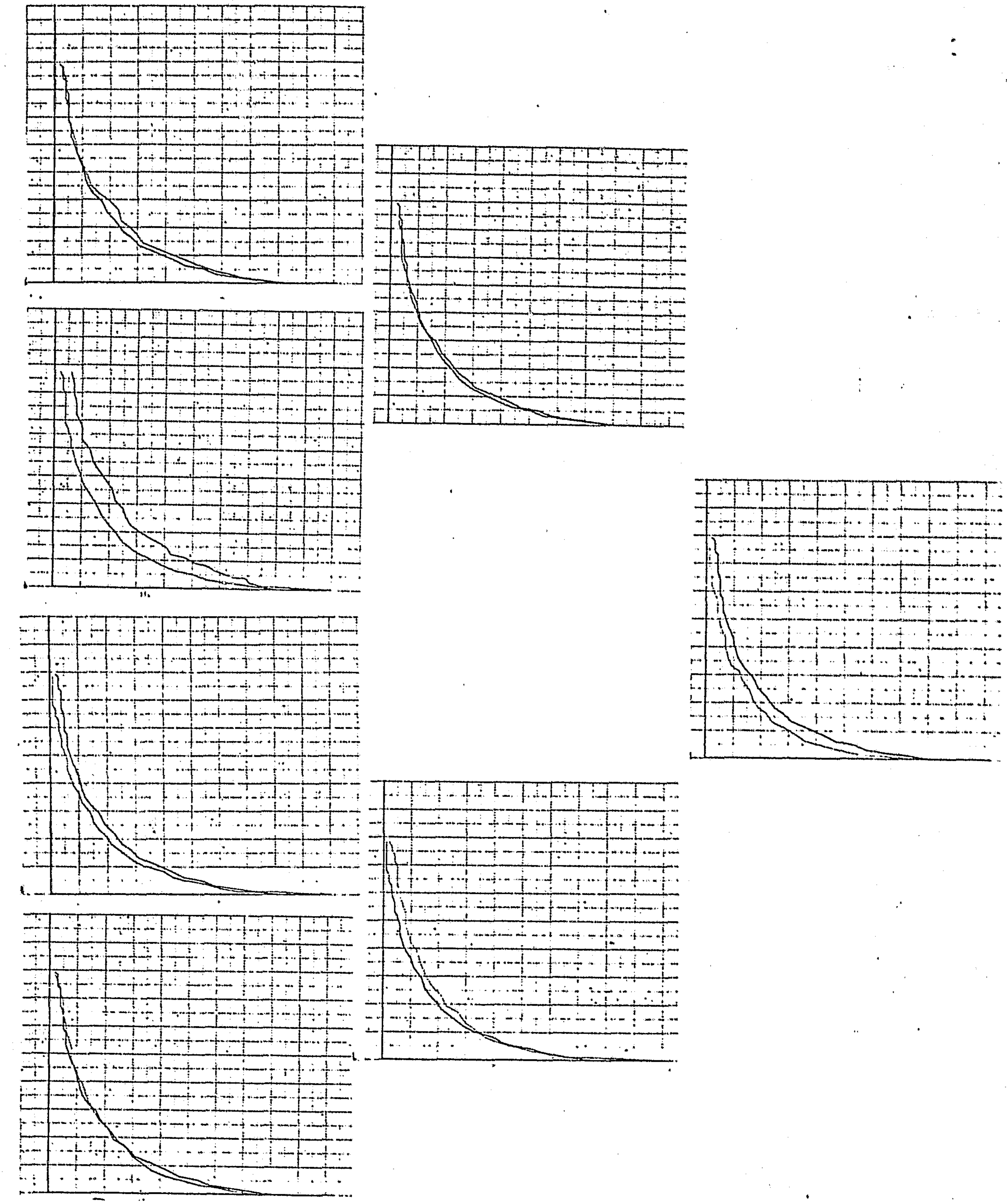
EVENT 24



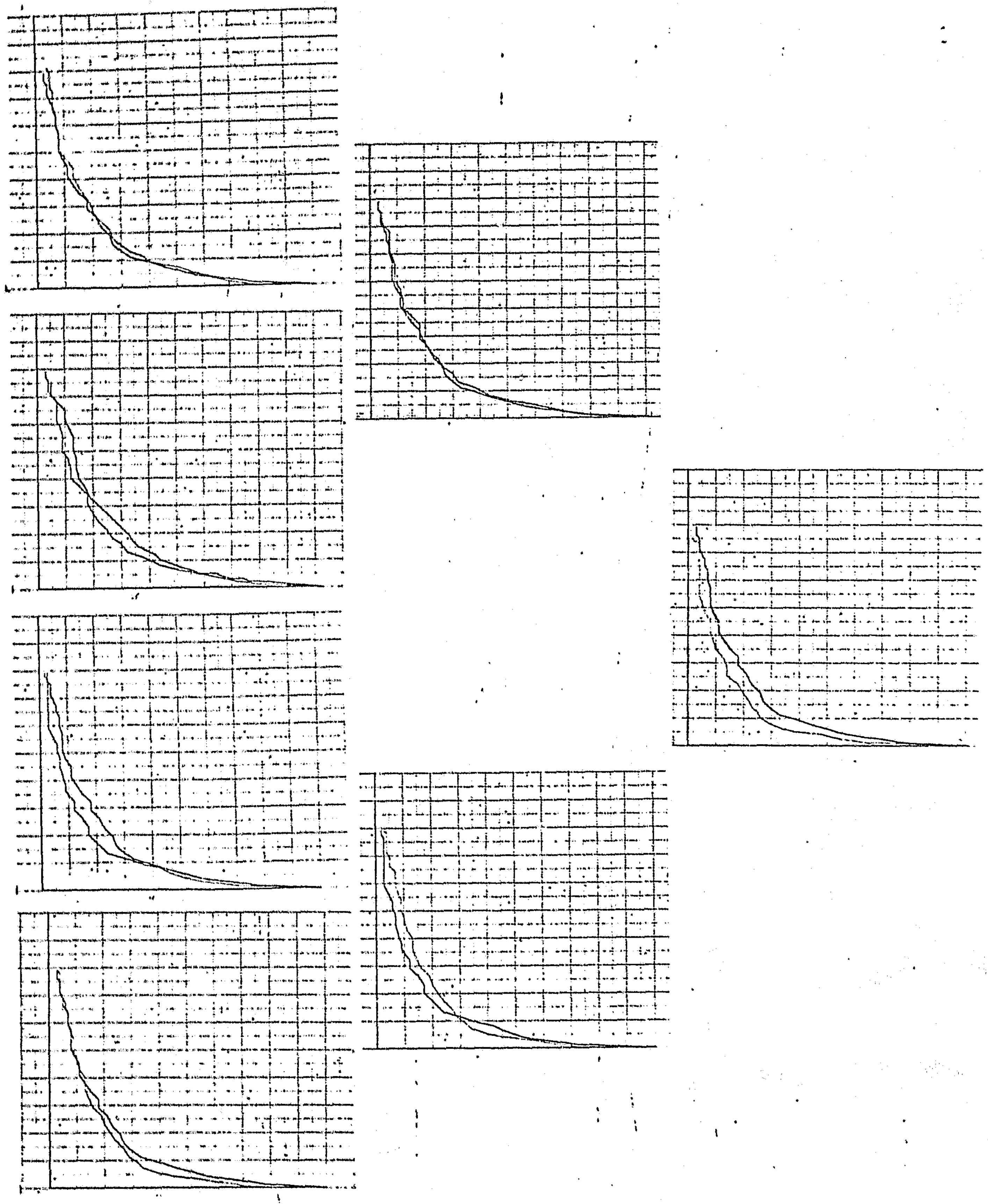
EVENT 25



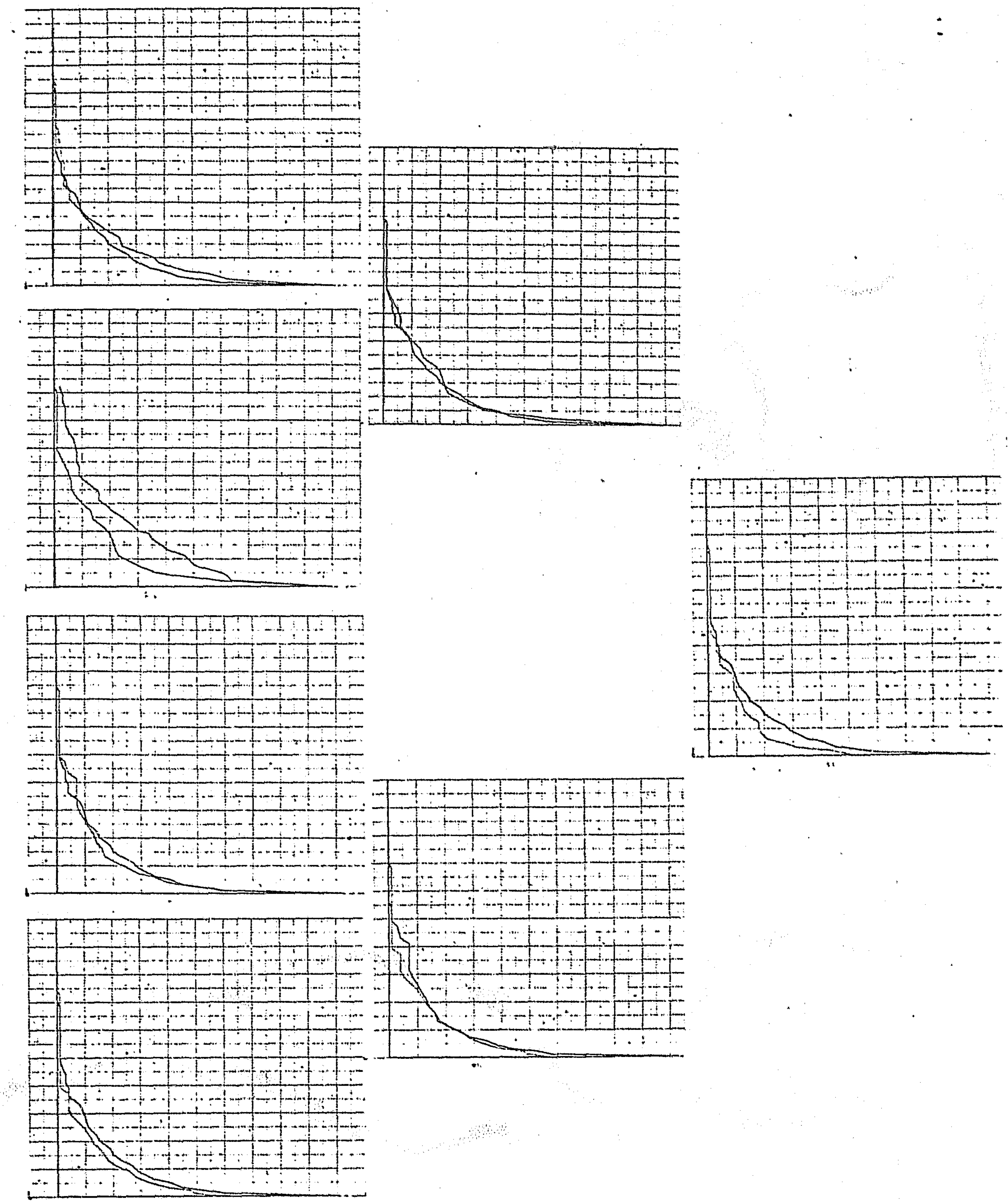
EVENT 26



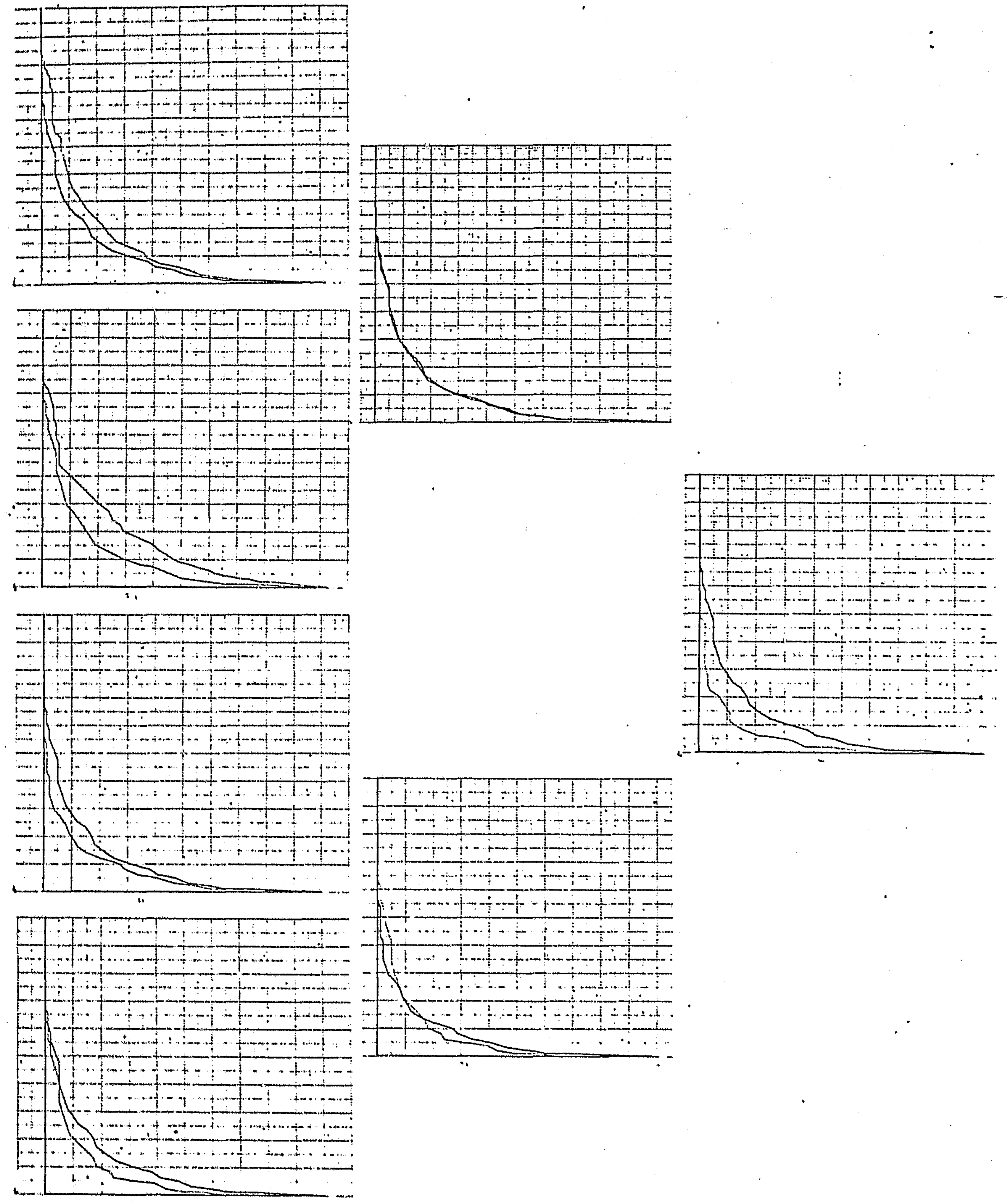
EVENT 27



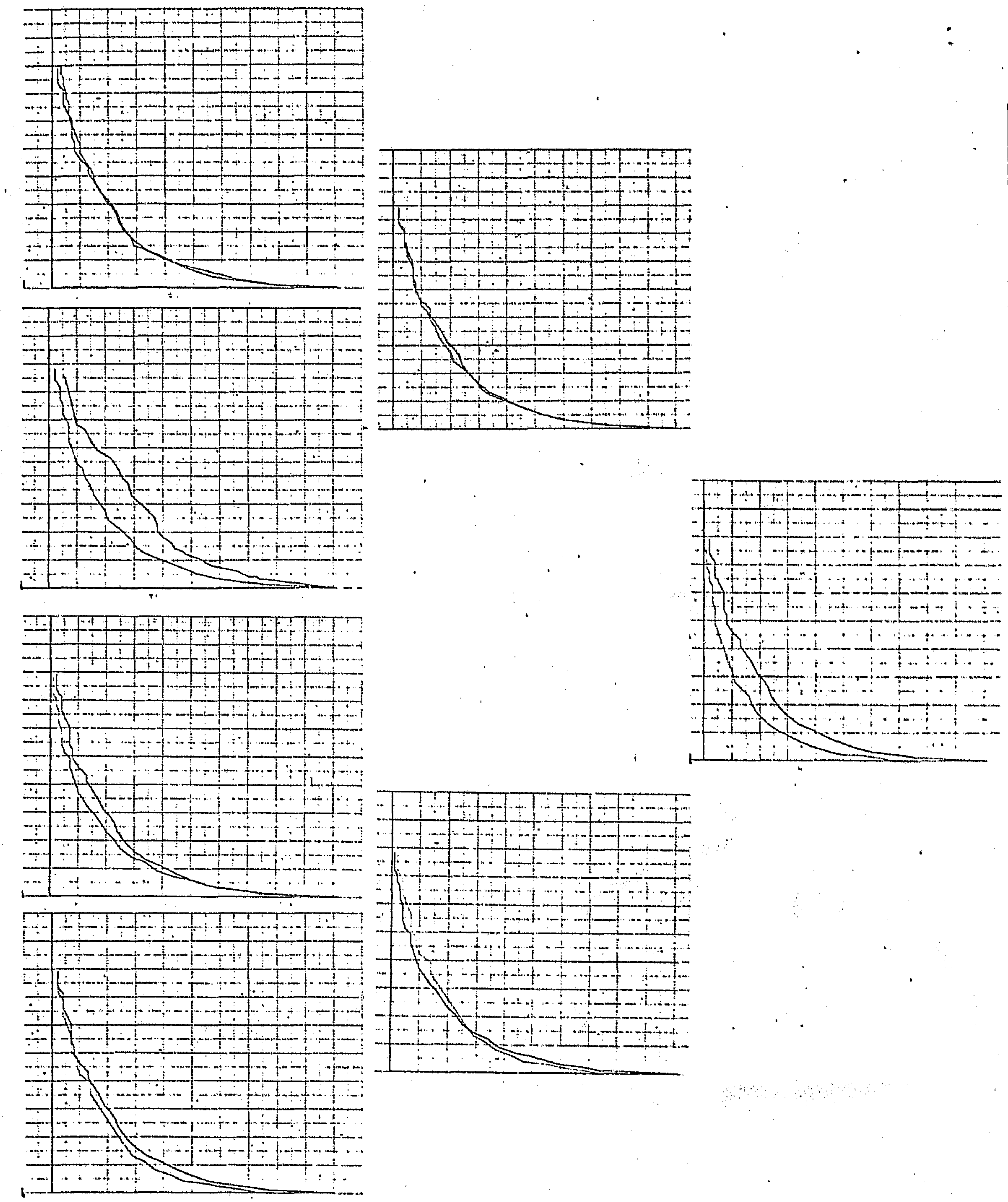
EVENT 28



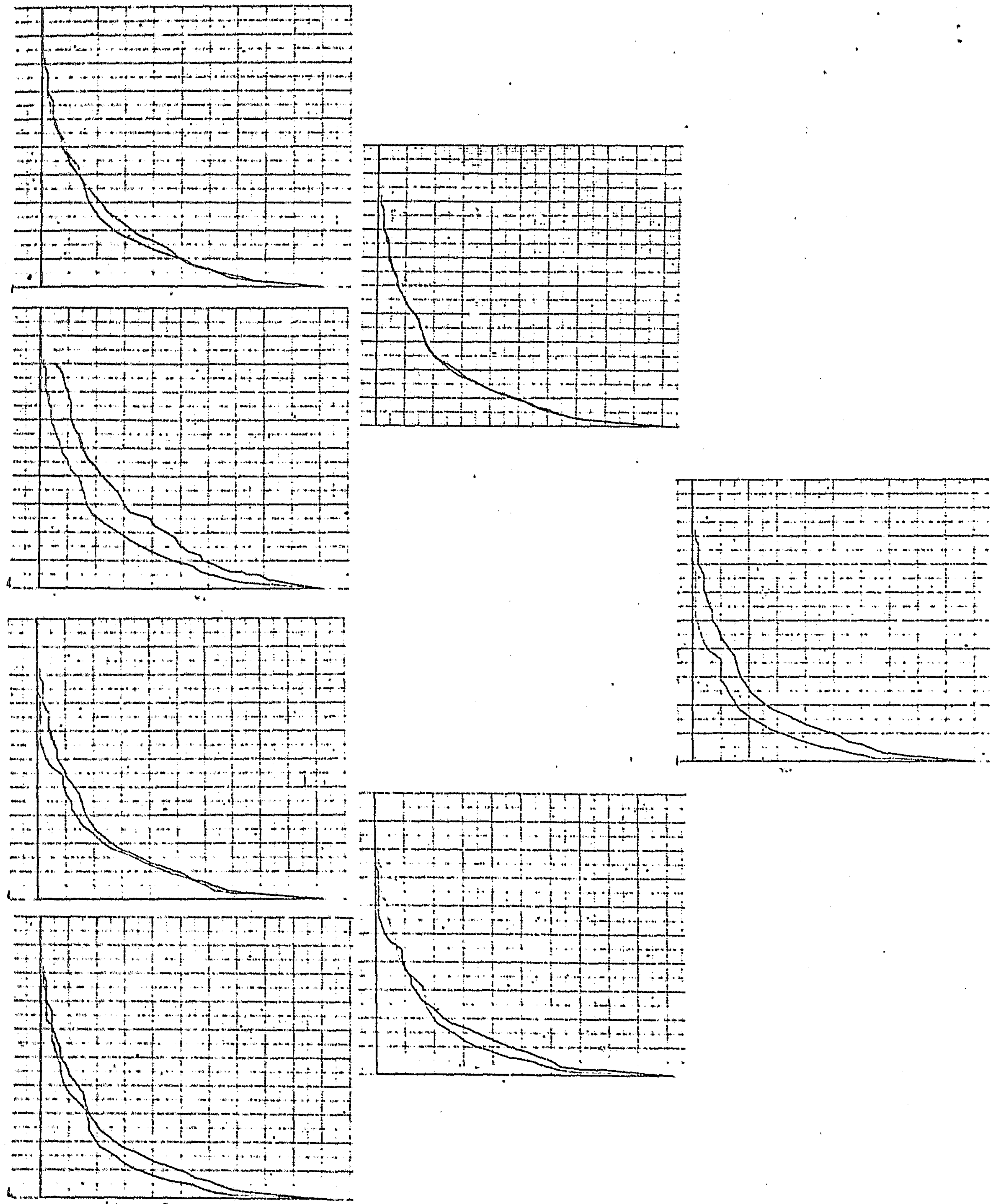
EVENT 29



EVENT 30



EVENT 31



EVENT 32

Appendix 7B.

Discussion of One Possible Interpretation of the Statistics of the Scalar Similarity Measure S

For a particular operational speaker comparison, we consider the vector φ defined by:

(1) $\varphi = \{\varphi_e \mid e \in \mathcal{S}_e\}$

where $\mathcal{S}_e$ is the set of phonetic events available for one-to-one comparisons. We will assume that φ is a column vector and thus the transpose φ^T is a row vector. The dimensionality of φ is N_e, the number of members of $\mathcal{S}_e$.

Now let us consider two classes of comparison situations: namely, class 0, in which the two speakers are different people and class 1, in which the two speakers are the same person. A similarity measure is a function of the observed vector $\tilde{\varphi}$ that gives an indication of how similar the two speakers are, i.e., how likely, in some sense, $\tilde{\varphi}$ belongs to class 1 or conversely how unlikely, in the same sense, it belongs to class 0. One similarity measure accessible to us is the likelihood ratio itself, that is

(2) $S_1(\tilde{\varphi}) = \frac{P(\tilde{\varphi}|1)}{P(\tilde{\varphi}|0)}$.

This measure clearly ties in with an orthodox decision theoretic treatment in which one would use the decision rule:

$S_1 > \lambda$ = two speakers are the same person,

$S_1 < \lambda$ = two speakers are not the same person,

where the threshold λ depends upon the loss function and upon the a priori probabilities of existence of each of the two classes. Alternatively, λ could be adjusted according to experience and subjective judgment.

In assessing the deficiencies of the similarity measure S_1, we must consider whether one intends to use a parametric or nonparametric approach to the determination of $P(\varphi|0)$ and $P(\varphi|1)$ from training data. In the nonparametric approach, one encounters the danger of excessive sensitivity of these probability densities to sampling fluctuations in the training data (i.e., the variations due to differences between sets of data randomly sampled from the same parent population). With the training data set accumulated in the SASIS program, the sensitivities of $P(\varphi|0)$ and $P(\varphi|1)$ (particularly in the latter) to sampling fluctuations are excessive using any of the well known methods of nonparametric density estimation (e.g., Parzen).

If a parametric approach, involving a sufficiently limited set of parameters, can be employed in the determination of the probability densities, then the sensitivity to sampling fluctuations may conceivably be reduced to an acceptable level. For example, if $P(\varphi|0)$ and $P(\varphi|1)$ are nearly Gaussian, the set of parameters involves only the two mean vectors $E(\varphi|0)$ and $E(\varphi|1)$ and the two covariance matrices $Cov(\varphi|0)$ and $Cov(\varphi|1)$. The same quantities are involved in some similarity measures derived with the indirect approaches to be discussed later. Thus, in these later measures, the insensitivity to sampling fluctuations is about the same as in Gaussian parametric treatment of likelihood ratio.

Even though the sensitivity to sampling fluctuations is reduced to a satisfactory level, there is still the question of how well the parameterized probability densities can fit the true functional forms of $P(\varphi|0)$ and $P(\varphi|1)$ that could theoretically be deduced from an infinite set of training samples. It should be interjected at this point that what really matters for our purposes is obtaining a good fit in the neighborhood of the overlap of $P(\varphi|0)$ and $P(\varphi|1)$. It is clear that insensitivity to sampling fluctuations and goodness of fit with few exceptions are, antithetical properties -- the more you have of one property the less you have of the other. This is a direct result of the fact that, generally speaking, the insensitivity to sampling fluctuations decreases and the goodness of fit increases with increasing numbers of parameters and vice-versa. A fortunate exception is the unlikely case in which the true probability densities are very well approximated by parameterized probability densities with satisfactorily small sets of parameters.

In computing S_1, there are several ways of dealing with the multiplicity of sets of available phonetic events $\mathcal{S}_e$. If, for example, $P(\varphi|0)$ and $P(\varphi|1)$ were nearly Gaussian, one could determine $E(\varphi|0)$, $E(\varphi|1)$, $Cov(\varphi|0)$, and $Cov(\varphi|1)$ in real time by extracting from the stored, previously computed, mean vectors and covariance matrices corresponding to the maximum possible set of phonetic events, the subvectors and submatrices corresponding to $\mathcal{S}_e$. From these one could compute $P(\tilde{\varphi}|0)$, $P(\tilde{\varphi}|1)$ and finally $S_1(\tilde{\varphi})$, all in real time. Unfortunately, there seem to be no reasons for supposing that $P(\varphi|0)$ and $P(\varphi|1)$ are nearly Gaussian. However, this question should be investigated further.

If $P(\varphi|0)$ and $P(\varphi|1)$ are not nearly Gaussian, which appears to be likely, one is confronted with (a) storing the probability densities for the two classes and then integrating these down to $P(\varphi|0)$ and $P(\varphi|1)$ in real time, (b) storing $P(\varphi|0)$ and $P(\varphi|1)$ for all of the possible sets $\mathcal{S}_e$, or (c) the application of a cluster expansion technique which we will describe in general terms. First, we must introduce some additional notation. Let φ ee'... denote the vector with only the components φ_e, $\varphi_{e'}$,... present. In particular, we can write

$$
(4) \qquad
\begin{aligned}
\varphi^{\{e\}} &= (\varphi_e)^T = \varphi_e \\
\varphi^{\{ee'\}} &= (\varphi_e, \varphi_{e'})^T \\
\varphi^{\{ee'e''\}} &= (\varphi_e, \varphi_{e'}, \varphi_{e''})^T \\
&\text{etc.}
\end{aligned}
$$

Now, let us consider a function $F(\varphi)$ where φ is defined by (1), i.e., its components are labelled by indices e belonging to $\mathcal{S}_e$. It is understood that the functional form of F(.) depends upon the components present in φ, that is upon the set $\mathcal{S}_e$. It is further understood that the functional form of $F(\varphi^{\{e\}})$ is that of $F(\varphi)$ when $\mathcal{S}_e$ contains only the single event e; that the functional form of $F(\varphi^{ee'})$ is that of $F(\varphi)$ when $\mathcal{S}_e$ contains only the two events of e and e'; and so on. The cluster expansion can now be defined as follows. Let

$$
(5) \qquad F(\varphi) = \sum_{e \in \mathcal{S}_e} G_e + \sum_{\substack{e,e' \in \mathcal{S}_e \\ e > e'}} G_{ee'} + \cdots
$$

where

$$
(6) \qquad
\begin{aligned}
F(\varphi^{\{e\}}) &= G_e \\
F(\varphi^{\{ee'\}}) &= G_e + G_{e'} + G_{ee'} \\
&\text{etc.}
\end{aligned}
$$

We then obtain

$$
(7) \qquad
\begin{aligned}
G_e &= F(\varphi^{\{e\}}) \\
G_{ee'} &= F(\varphi^{\{ee'\}}) - F(\varphi^{\{e\}}) - F(\varphi^{\{e'\}}) \\
&\text{etc.}
\end{aligned}
$$

The value of the cluster expansion is that, if, for example, the third and higher order G functions are negligible, then the first and second order G functions are building blocks from which $F(\varphi)$ for any $\mathcal{S}_e$ can be built up. If there is a maximum of ten possible phonetic events, then it will required $10+\frac{1}{2}(10)(9) = 55$ G functions to build up any of the different functions $F(\varphi)$ corresponding to 1023 possible sets $\mathcal{S}_e$.

Based upon some preliminary analytical investigations, there is reason to expect that $P(\varphi|0)$ and $P(\varphi|1)$ might be developed in cluster expansions with negligible error entailed in omitting third and higher order G functions. For a maximum of ten possible phonetic events there would be 110 G functions (55 for each class). These could be stored and for a given $\mathcal{S}_e$, the similarity measure $S_1(\varphi)$ could be computed in real time.

It is not necessary to confine the definition of likelihood ratio to the case of probability densities on the full vector φ - space. One may consider a scalar function ψ, namely $P(\psi|0)$ and $P(\psi|1)$. One could then define a second similarity measure

$$
(8) \qquad S_2(\tilde{\varphi}) = \frac{P(\tilde{\psi}|1)}{P(\tilde{\psi}|0)}
$$

where $\tilde{\psi} = \psi(\tilde{\varphi})$ and where $\tilde{\varphi}$ is the observed value of φ.

Still less sensitive to sampling fluctuations is the following similarity measure

$$(9) \qquad S_3(\tilde{\varphi}) = \frac{1-F(\tilde{\psi}|1)}{F(\tilde{\psi}|0)}$$

where $F(\psi|c)$ is the cumulative distribution for class c. Since ψ increases as we proceed from the mean of ψ in class 1 to the mean of ψ in class o, $1-F(\tilde{\psi}|1)$ is the probability that in class 1 ψ lies to the right of $\tilde{\psi}$ and $F(\tilde{\psi}|0)$ is the probability that in class 0 ψ lies to the left of $\tilde{\psi}$.

The problem of dealing with the multiplicity of sets $\mathcal{S}_e$ is the same for S_3 as it was for S_2.

If ψ lies between the class means $E(\psi|1)$ and $E(\psi|0)$, the cumulative distributions satisfy the generalized one-sided Tchebychev inequalities

$$(10) \qquad \begin{aligned} 1-F(\psi|1) &\le \left[1+ \mathrm{Var}(\tilde{\psi}|1)^{-1} (\tilde{\psi}-E(\psi|1))^{2}\right]^{-1} \\ F(\tilde{\psi}|0) &\le \left[1+ \mathrm{Var}(\psi|0)^{-1} (\tilde{\psi} - E(\psi|0))^{2}\right]^{-1} \end{aligned}$$

Using the definition of ψ, (9) and (10), we can rewrite the above inequalities in the forms

$$(11) \qquad 1 - F(\tilde{\psi}|1) \le \left[1+(1-\beta)^2 \, \delta E\varphi^T \, \mathrm{Cov}(\varphi|0)^{-1} \, \mathrm{Cov}(\varphi|1) \, \mathrm{Cov}(\varphi|0)^{-1} \, \delta E\varphi\right]^{-1}$$

and

$$(12) \qquad F(\tilde{\psi}|0) \le \left[1+ \beta^2 \, \delta E\varphi^T \, \mathrm{Cov}(\varphi|0)^{-1} \, \delta E\varphi\right]^{-1}$$

where

$$(13) \qquad \beta = \frac{E(\psi|0) - \tilde{\psi}}{E(\psi|0) - E(\psi|1)}$$

and

$$(14) \qquad \delta E(\cdot) = E(\cdot|0) - E(\cdot|1) .$$

These upper bounds, besides being useful in themselves, provide the possibility of a 4th similarity measure given by the ratio of the upper bounds to numerator and denominator of (13), namely,

$$(15) \qquad S_4(\tilde{\varphi}) = \frac{1 + \beta^2 \, \delta E\varphi^T \mathrm{Cov}(\varphi|0)^{-1} \, \delta E\varphi}{1+(1-\beta)^2 \delta E\varphi^T \mathrm{Cov}(\varphi|0)^{-1} \mathrm{Cov}(\varphi|1) \mathrm{Cov}(\varphi|0)^{-1} \delta E\varphi}$$

This is clearly an indirect approach since only the vector means and the covariance matrices of φ in the two classes are required. It is probably the least sensitive to sampling fluctuations of all the similarity measures considered so far. However, S_4 can be criticized on the grounds of accuracy, since the ratio of the upper bounds of $1-F(\tilde{\psi}|1)$ and $F(\tilde{\psi}|0)$ can hardly be regarded as a good approximation to the ratio of these quantities themselves. It should be remarked that (16) provides a rigorous upper bound for the linear discriminator optimized at low false incrimination probability.

The problem of dealing with the multiplicity of sets $_e$ is rather simple in the present case. Undoubtedly, the best procedure is to calculate S_4 in real time. One would store the values of the components of $\delta E\varphi = E(\varphi|0) - E(\varphi|1)$ and the elements of the covariance matrices $\mathrm{Cov}(\varphi|0)$ and $\mathrm{Cov}(\varphi|1)$ for the maximum possible set of phonetic events. In the real time situation, one would pickkout the subvector and submatrices corresponding to the set $\mathcal{S}_e$ of available phonetic events and then compute S_4.

A fifth and final similarity measure is β itself, namely

$$S_5(\tilde{\varphi}) = \beta = \frac{E(\psi|0) - \tilde{\psi}}{E(\psi|0) - E(\psi|1)} .$$

This measure possesses about the same degree of insensitivity to sampling fluctuations as does the previous measure. The multiplicity of $\mathcal{S}_e$ should be handled the same way in this case as in the case of S_4.

We turn now to an evaluation of S_2 and S_3 in terms of the criteria we have formulated above. In terms of criterion (a), dealing with insensitivity to sampling fluctuations, S_3 is quite satisfactory for the training data set presently contemplated. This is because of the scalar nature of the variable ψ and because of the integrations implicit in the cumulative distribution functions. There is also the question of the sensitivity of ψ itself, since according to (3) its definition depends upon the training data set. The principle source of sensitivity is probably the inverse covariance matrix $Cov(\Phi|0)^{-1}$. Since the number of training samples is many times larger than the dimensionality of $Cov(\Phi|0)$ (at most 14, the maximum number of phonetic events to be considered), it is expected that the sensitivity of $Cov(\Phi|0)^{-1}$ to sampling fluctuations will usually be low. The sensitivity of S_2 will also be somewhat larger than that of S_3, since the numerator and denomenator of S_2 are the derivatives (with a change of sign in the numerator) of the numerator and denominator of S_3. It is, of course, assumed that the numerator and denominator of S_3 have been appropriately smoothed. It is clear, however, that the difference of sensitivities of S_2 and S_3 will become unimportant if very large training sets are available.

With respect to criterion (b), dealing with convergence as the training set becomes large, the measure S_3 is certainly satisfactory, as long as the training samples in each set are representative of the parent population. The same question applied to S_2 has an answer that is also dependent upon the smoothing procedure for the cumulation distributions or, equivalently, the method of determining the probability densities. If any asymptotically correct method (e.g., Parzen) is employed, then S_2 will converge properly.

In the case of criterion (c), concerning low false incrimination probability, the evaluation of S_2 and S_3 reduces to the evaluation of Ψ itself. The use of Cov $(\Phi|0)^{-1}$ in (3), instead of the matrix inverse of some average of Cov $(\Phi|0)$ and Cov $(\Phi|1)$, is intended to make Ψ a better discriminant function for a low false incrimination probabilities. This assertion is supported by the computation of certain properties of Ψ from the training data.

Referring now to criterion (d), dealing with subjective elements, there is some subjectivity in the choice of Ψ; however, this can be ameliorated by comparison with alternative choices to demonstrate the superiority of our choice here. Aside from this question, there are no subjective elements, except for some relatively inconsequential smoothing, in the similarity measure S_3. In S_2, the method of smoothing (or, equivalently, the method of density determination) is a relatively sensitive matter and thus the subjectivity associated with the choice of a smoothing method is of possible consequence. It must be emphasized that one would expect the subjectivity associated with smoothing in either S_2 or S_3 to become unimportant for large training sets.

Considering, now, criterion (e), relating to acceptance of subjective elements, it can be stated that our choice of Ψ, namely the Fisher discriminant, is so conventional and widely known among workers in automatic pattern recognition and in mathematical statistics that serious criticism of its use is unlikely, especially if a favorable comparison with alternative discriminant functions is presented. The subjectivity in the choice of a method for density determination for S_2 can be made acceptable by employing a sufficiently well known method (e.g., Parzen).

In regard to criterion (f), concerning usefulness to the low enforcement community, it can be said that neither S_2 nor S_3 is complicated to use, each being a single scalar quantity. There are, however, some subsidiary questions: Namely, what are large and small values of S_2 and S_3, and how do we determine these for various sets $\mathcal{S}_e$ of available phonetic events? These questions are discussed in adequate detail in Section 4.

The final criterion (g) deals with the problems of calculating the similarity measure for a multiplicity of sets $\mathcal{S}_e$. In the case of a maximum of 10 phonetic events, there are $2^{10} - 1 = 1023$ different possible sets $\mathcal{S}_e$. Since S_2 and S_3 are functions of the single scalar variable Ψ, it appears practically feasible to compute S_2 or S_3 as a function of Ψ in advance for all possible sets $\mathcal{S}_e$, store the results and then retrieve them in real time as needed. If the maximum number of phonetic events is substantially larger than 10, other approaches must be considered. Some of these are currently under investigation.

In view of the above discussion, we recommend using S_3 defined by (1), with the set of training samples contemplated for the immediate future. When a sufficient set is available in the future, it is appropriate to consider switching over to S_2, defined by (2). This last measure is more satisfactory in the sense that it fits into the framework of decision theory. In the last case one may, of course, use both S_2 and S_3.

In the last paragraph and in several previous ones, we have used terms such as sufficiently large sets of training samples. To give these terms quantitative meanings in certain contexts, one must conduct an investigation of the effects of sampling fluctuations on quantities like Ψ, S_2, S_3 and perhaps on the confidence measures discussed in the next section. Such an investigation would entail several manmonths of effort and thus it must be planned for some time in the future, if it is to take place at all.

It should be noted that S_2 and S_3 are not independent. In fact, since they are both monotone functions of the single scalar variable Ψ, they can be put into one-to-one correspondence. It is possible to derive a differential equation connecting the two, as we now show. For notational convenience, let us write

(4) $$P_o = F(\Psi|0)$$

(5) $$P_1 = 1 - F(\Psi|1).$$

In these terms we can write

(6) $$S_3(\Psi) = \frac{P_1}{P_o}$$

and

(7) $$S_2(\Phi) = -\frac{dP_1}{dP_o}$$

now regarding P_o as the independent variable. We then obtain the result

(8) $$\frac{d}{dP_o}(P_o S_3) = -S_2$$

with the boundary condition $S_3 = 0$ when $P_o = 1$. If we know S_2 in the interval $[\tilde{P}_o, 1]$, where $\tilde{P}_o$ is the value of P_o corresponding to $\tilde{\Psi}$, then we can compute $S_3(\tilde{\Phi}) = S_3(\tilde{P}_o)$. Conversely, we can compute S_2 knowing S_3 if S_3 has been appropriately smoothed.

Confidence Measures

There are several kinds of confidence measures of concern to us:

(a) A confidence measure indicating the level of credibility to attach to the value of S_2 or S_3 for a given observation. For example, if S_2 exceeds a certain threshold, presumably implying that two speakers are the same person, to what degree should one believe in this conclusion?

(b) A second confidence measure indicating the average decision errors for a large number of independent observations. This is useful in assessing the performance of a given set $\mathcal{S}_e$ of available phonetic events and, for a given $\mathcal{S}_e$, the set features, distance measures, etc., chosen.

(c) A third confidence measure reflecting the possible errors due to sampling fluctuations in the training set. Expressed in other words, this measure should give an indication of the probability of a decision not being wrong because of an unrepresentative or biased sampling of speakers in forming the training set.

In the ensuing paragraphs, we derive suitable versions of the first two measures described in (a) and (b) above. However, the third measure described in (c) requires a thorough investigation of its own, as indicated in the last section, and, for this reason, further discussion of it will be given in a later IL.

To get at the question of confidence measures of the kinds discussed in (a) and (b), it is appropriate to consider the SASIS problem in a decision theory context, even though a definite classification decision is not required. Here, the problem is to find a decision function $\hat{c}(\tilde{\Psi})$ which equals 1 if it is decided that the observed value of Ψ implies class 1 and which equals 0 otherwise. The problem of decision theory is to optimize the functional form of $\hat{c}(\cdot)$ according to some criterion. In Bayesian decision theory, one uses the risk as the criterion, where the risk is the mean of a loss function enumerating the rewards and penalties for right and wrong decisions.

Here, we will consider the typical loss function

(1) $$L(c,\hat{c}) = \lambda_o \delta_{co}(1-\delta_{\hat{c}o}) + \lambda_1 \delta_{c1}(1-\delta_{\hat{c}1})$$

where $\hat{c}$ is an abbreviation for $\hat{c}(\tilde{\Psi})$. This loss function entails a penalty of λ_o if it is decided that the class is 1 when it is actually 0 and conversely a penalty of λ_1 if it is decided that the class is 0 when it is actually 1. Correct decisions correspond to 0 penalty.

The problem of choosing the weights λ_o and λ_1 lies outside of the domain of decision theory. In the present case, it depends on value judgments of law enforcement organizations, the courts and ultimately society on the tolerable balance of the probability of the two kinds of classification errors, i.e., false-incrimination and false-exoneration.

To optimize the functional form of $\hat{c}$, we minimize the risk

(2) $$R = EL(c,\hat{c})$$

where now $\hat{c}$ is regarded as a function of the random variable Ψ (whose statistical properties are determined by a set of training samples, a mathematical model or both) instead of the observed value $\tilde{\Psi}$. The solution is obtained by considering the conditional risk

(3) $$R(|\Psi) = E(L|\Psi)$$
$$= \lambda_o P(o|\Psi)(1-\delta_{\hat{c}o}) + \lambda_1 P(1|\Psi)(1-\delta_{\hat{c}1})$$

in which $\hat{c}$ can now be regarded at a number since its argument has been fixed by the conditioning. Minimizing $R(|\Psi)$ on the value of $\hat{c}$ for each value of Ψ is equivalent to minimizing R on the functional form of $\hat{c}(\Psi)$. The result (in terms of the observed $\tilde{\Psi}$) is

(4) $$\hat{c}(\tilde{\Psi}) = 1 \text{ if } \Lambda(\tilde{\Psi}) > \theta$$
$$= 0 \text{ if } \Lambda(\tilde{\Psi}) < \theta$$

where

(5) $$\Lambda(\tilde{\Psi}) = \frac{P(\tilde{\Psi}|1)}{P(\tilde{\Psi}|0)} = S_2$$

is the likelihood ratio and where the critical value θ is given by

(6) $$\theta = \frac{\lambda_o P(0)}{\lambda_1 P(1)} .$$

The quantities P(0) and P(1) are the a priori probabilities of classes 0 and 1, respectively.

As in the case of λ_o and λ_1, the choice of the a priori probabilities P(0) and P(1) lies outside of the domain of decision theory. In the present SASIS problem, P(0) and P(1) are really not known. Calculating P(0) and P(1) from the number of training sets in classes 0 and 1 is spurious. To answer this question in a meaningful way one should undertake a kind of demographic modelling of criminals and suspects in a manner appropriate to the urban area of concern. In any case for the decision rule, only θ defined by (6) enters the procedure and thus the separate determination of λ_o, λ_1, P(0) and P(1) is unnecessary. It may work out that θ will be determined by court cases and the precedents thereby established.

In deriving the optimal decision rule, we have used the relation

(7) $$P(c|\Psi) = \frac{P(\Psi|c)P(c)}{P(\Psi)}$$
$$= \frac{P(\Psi|c)P(c)}{P(\Psi|0)P(0) + P(\Psi|1)P(1)} .$$

In Figure 1, we plot $P(\Psi|c)$ vs Ψ with $c = 0,1$ for a typical case. In Figure 2, we correspondingly plot $P(c|\Psi)$ vs Ψ with $c = 0, 1$ for the same case. The curves in these figures do not represent actual data. It is to be noted that in the case illustrated $P(0|\Psi) \to 1$ as $\Psi \to \infty$ and $P(1|\Psi) \to 1$ as $\Psi \to -\infty$ (or whatever the lower limit of Ψ is). Thus, functions appear superficially similar to $F(\Psi|0)$ and $1 - F(\Psi|1)$, but are really different.

The optimal conditional risk is then given by

$$
\begin{aligned}
R_{opt}(|\Psi) &= \lambda_o P(0|\Psi) 1(\Lambda(\Psi) - \theta) \\
&\quad + \lambda_1 P(1|\Psi) 1(\theta - \Lambda(\Psi)) \\
&= \text{Min}\,(\lambda_o P(0|\Psi),\ \lambda_1 P(1|\Psi))
\end{aligned}
\tag{8}
$$

where $1(x)$ is the unit step function defined by

$$
\begin{aligned}
1(x) &= 1,\ x \geq 0 \\
&= 0,\ x < 0
\end{aligned}
\tag{9}
$$

and where the symbol $\text{Min}(x,y)$ denotes the lesser of the two quantities x and y. $R(|\Psi)$ is illustrated in Figure 2 by the heavy curve (with $\lambda_o = \lambda_1 = 1$). The optimal risk is given by

$$
\begin{aligned}
R_{opt} &= \int_{-\infty}^{\infty} d\,\Psi\, R_{op}(|\Psi) P(\Psi) \\
&= \int_{-\infty}^{\infty} d\,\Psi\, \text{Min}(\lambda_o P(0,\Psi),\ \lambda_1 P(1,\Psi)) \\
&= \tfrac{1}{2}\lambda_o P(0) + \tfrac{1}{2}\lambda_1 P(1) - \tfrac{1}{2}\int_{-\infty}^{\infty} d\,\Psi\, |\lambda_o P(0,\Psi) - \lambda_1 P(1,\Psi)|
\end{aligned}
\tag{10}
$$

In deriving the last line, we have used the identity

$$
\text{Min}(x,y) = \tfrac{1}{2}(x + y - |x-y|)
\tag{11}
$$

The joint probability $P(c,\Psi)$, $c = 0,1$, is, of course, defined by

$$
\begin{aligned}
P(c,\Psi) &= P(c)P(\Psi|c) \\
&= P(\Psi)P(c|\Psi)\,.
\end{aligned}
\tag{12}
$$

In this paragraph, we have written the equations in terms of Ψ; we could just as well have written them in terms of $\tilde{\Psi}$, the actually observed value of Ψ. This remark also applies to the results in the subsequent paragraphs.

In the simple case in which $\Lambda(\Psi) > \theta$ corresponds to the region $\Psi < \Psi^*$ and conversely $\Lambda(\Psi) < \theta$ corresponds to the region $\Psi > \Psi^*$, the decision rule can be rewritten in the form

$$
\begin{aligned}
\hat{c}(\Psi) &= 1,\ \Psi < \Psi^* \\
\hat{c}(\Psi) &= 0,\ \Psi > \Psi^*.
\end{aligned}
\tag{13}
$$

Clearly, the decision point Ψ^* is given by

$$
\Lambda(\Psi^*) = \theta,
\tag{14}
$$

which in the present case must have a unique solution. The optimal conditional risk now takes the form

(15)
$$R_{opt}(|\Psi) = \lambda_o P(0|\Psi)\, \underline{1}\, (\Psi^* - \Psi) + \lambda_1 P(1|\Psi)\, 1\, (\Psi - \Psi^*) = \min(\lambda_o P(0|\Psi),\ \lambda_1 P(1|\Psi)|$$

It is to be noted that the last line is the same as in (8), even though the optimal decision function is restricted to a simpler form. The optimal risk now reduces to

(16)
$$R_{opt} = \lambda_o P(0)\, F\,(\Psi^*|0) + \lambda_1 P(1)(1 - F(\Psi^*|1))$$

where, as before, $F(\Psi|c)$ is the cumulative distribution for class c.

We can write $P(c|\Psi)$ in terms of the likelihood ratio $\Lambda(\Psi)$ as follows

(17)
$$P(0|\Psi) = \frac{1}{1 + \alpha\Lambda}$$
$$P(1|\Psi) = \frac{\alpha\Lambda}{1 + \alpha\Lambda}$$

where

(18)
$$\alpha = \frac{P(1)}{P(0)}\ .$$

The optimal conditional risk can be simply rewritten in the form

(19)
$$R_{opt}(|\Psi) = \min\left(\frac{\lambda_o}{1 + \alpha\Lambda},\ \frac{\lambda_1\, \alpha\Lambda}{1 + \alpha\Lambda}\right).$$

In other words

(20)
$$R_{opt}(|\Psi) = \frac{\lambda_o}{1 + \alpha\Lambda} \quad \text{if} \quad \frac{\lambda_1\alpha\Lambda}{\lambda_o} > 1$$
$$= \frac{\lambda_1\alpha\Lambda}{1 + \alpha\Lambda} \quad \text{if} \quad \frac{\lambda_1\alpha\Lambda}{\lambda_o} < 1$$

The maximum value of the optimal conditional risk $R_{opt}(|\Psi)$ with respect to Ψ is attained when

(21)
$$\lambda_o P(0|\Psi) = \lambda_1 P(1|\Psi).$$

Using the normalization condition

(22)
$$P(0|\Psi) + P(1|\Psi) = 1$$

we obtain

(23)
$$\text{Max } R_{opt}(|\Psi) = \frac{\lambda_o\, \lambda_1}{\lambda_o + \lambda_1}\ .$$

If we impose the condition $\lambda_o + \lambda_1 = 2$ on the weights, then we obtain the inequality

(24)
$$\text{Max } R_{opt}(|\Psi) \leq \tfrac{1}{2}$$

with the equality holding when $\lambda_1 = \lambda_2 = 1$, the case illustrated in Figure 2.

Returning to our main theme, we propose using the optimal conditional risk $R_{opt}(|\tilde{\Psi})$ as a confidence measure of the first kind, i.e., the risk associated with the optimal decision process when the observed value of Ψ is $\tilde{\Psi}$. Furthermore, we propose using the optimal risk R_{opt} as a confidence measure of the second kind, i.e., the risk, averaged over possible observations, giving a measure of the usefulness of a given set $\hat{\wp}_e$ of phonetic events.

Discussion

In this section, we attempt to pull all of the considerations of the previous sections together into some kind of coherent pattern. We also make some comments concerning how these results might be displayed in an operational system.

In Figure 3, we illustrate a number of curves representing the decision-making aspects, the similarity measure and the confidence measure. The horizontal and vertical coordinates are either P_o* and P_1* or $\tilde{P}_o$ and $\tilde{P}_1$, respectively. These probabilities are given by

$$(1) \quad \begin{aligned} P_o* &= F(Y*|0) \\ P_1* &= 1 - F(Y*|1) \end{aligned}$$

and

$$(2) \quad \begin{aligned} \tilde{P}_o &= F(\tilde{Y}|0) \\ \tilde{P}_1 &= 1 - F(\tilde{Y}|1), \end{aligned}$$

where $F(Y|c)$ is the cumulative distribution for class c. The quantity $Y*$ is the decision point on the Y - axis and $\tilde{Y}$ is the observed point on this axis.

In more explicit terms, P_o* is the probability that a pair of speakers from class 0 (the class in which pairs of speakers are different people) are classified as the same person. Conversely, P_1* is the probability that a pair of speakers from class 1 (the class in which pairs of speakers are the same person) are classified as different people. For the sake of brevity, we will call P_o* the false incrimination probability and P_1* the false exoneration probability.

On the other hand, $\tilde{P}_o$ is the probability that a member of class 0 lies to the left (i.e., more likely to be a member of class 1) of the observed point $\tilde{Y}$. Conversely, $\tilde{P}_1$ is the probability that a member of class 1 lies to the right (i.e., more likely to be a member of class 0) of the observed point $\tilde{Y}$.

In Figure 3, we have a typical false-exoneration false-incrimination curve for a set of available phonetic events $\hat{\wp}_e$. Following the usage in communication theory, we also call these SOC (SASIS Operating Characteristic) curves. The same curves are obtained by plotting $\tilde{P}_1$ vs $\tilde{P}_o$ (instead of P_1* vs P_o*), although their meaning is different. In either case, these curves are given by the parametric equations (1) or (2) as $Y*$ or $\tilde{Y}$ ranges over their common domain of definition.

The likelihood function $\Lambda(\tilde{Y})$, i.e., the similarity measure $S_2(\tilde{\sigma})$, is the negative of the slope of the SOC curve at the point corresponding to $\tilde{Y}$ (or $\tilde{\sigma}$) as is shown in (7) of Section 2. In Figure 3, this fact is illustrated by the tangent to the SOC curve and the horizontal axis subtending an angle of $\tan^{-1}(-\Lambda)$.

The curves of constant $S_3(\tilde{\Phi})$ are straight lines passing through the origin, since according to (6) of Section 2 $S_3(\tilde{\Phi}) = \tilde{P}_1/\tilde{P}_o$.

Also illustrated in Figure 3 are the curves of constant risk defined by (16) of Section 3. This result can be rewritten in the form

(3) $$R_{opt} = \kappa_o P_o^* + \kappa_1 P_1^*$$

where the coefficients are given by

(4) $$\kappa_c = \lambda_c P(c), \; c = 0,1.$$

These curves are straight lines of fixed negative slope with the greater risk curves to the right. The decision point Ψ^*, corresponding to P_o^* and P_1^*, is supposed to correspond only to the point of tangency of a constant risk curve and the SOC curve corresponding to the given set $\mathcal{S}_e$. In other words, the decision point corresponds to the minimum risk point on the appropriate SOC curve. Although the starred quantities refer only to the point of tangency, we have plotted the SOC and risk curves globally as functions of the starred quantities. The author trusts that this will not cause confusion.

As the negative slope of the set of parallel risk curves increases from 0 to ∞, the point of tangency will move along a given SOC curve from the lower right to the upper left. Thus, the SOC curve can alternatively be generated in this manner, i.e., as a function of the parameter

(5) $$\frac{\kappa_1}{\kappa_o} = \frac{\lambda_1 P(1)}{\lambda_o P(0)}$$

defining the slope of the constant risk curves. To that extent, the decision point depends only on the combination of subjective factors embraced in (5). The SOC curve itself is invariant to this parameter and is thus independent of all subjective factors, except those implicit in the choice of the function $\Psi(\Phi)$ and in the choice of smoothing procedures. The risk, however, depends upon the subjective factors in κ_1 and κ_2, separately.

The conditional risk $R_{opt}(|\tilde{\Psi})$, measuring the credibility of a decision based upon the observed value $\tilde{\Psi}$, is given most conveniently for our purposes by (19) of Section 3. One can obtain its value by first obtaining the likelihood ratio Λ from the negative slope of the SOC curve at the observed point and then inserting the result into (19) of Section 3. The value of $R_{opt}(|\tilde{\Psi})$ would measure the nearness of $\tilde{\Psi}$ to Ψ^* in a matter appropriate for a confidence measure derived from a decision theoretic foundation. It is to be noted that the conditional risk depends upon λ_o, λ_1 and $\alpha(= P(1)/P(0))$, separately, and not simply upon the combinations given by (4). It is not feasible to illustrate the conditional risk in Figure 3, although it is related directly to the decision point and the SOC curve.

In the actual operation of SASIS by the end user, it may be useful to present the substance of Figure 3 on a suitable display device. After informing the system of the set $\mathcal{S}_e$ of events available for comparison, the corresponding SOC curve would be displayed with a special marking symbol indicating the point on the curve corresponding to the current observation. If it is desired to put the situation into a decision-theoretic context, the user would choose the ratio of coefficients κ_o and κ_1 in the risk function, whereupon a set of constant risk curves would be displayed (and, furthermore, would be quantitatively indexed if the sum of κ_0 and κ_1 were fixed by some convention). The system could automatically find the point of tangency of SOC curve and one of the constant risk curves (if there are two or more points of tangency, then the one of lower risk should be selected). The decision point, corresponding to the above point of tangency, would then be indicated by a second marking symbol. The conditional risk, if desired, could then be calculated by the system and displayed in alphanumeric symbols. Either of the similarity measures $S_2 (= \Lambda)$ or S_3, or both of them, should be presented. In the case of S_3, one could find the labelled curve of constant S_3 passing closest to the observed point in the display. It could also be displayed in alphanumeric form. However, because it is the negative derivative of the SOC curve at the observation point, it is feasible only to present S_2 in alphanumeric form.

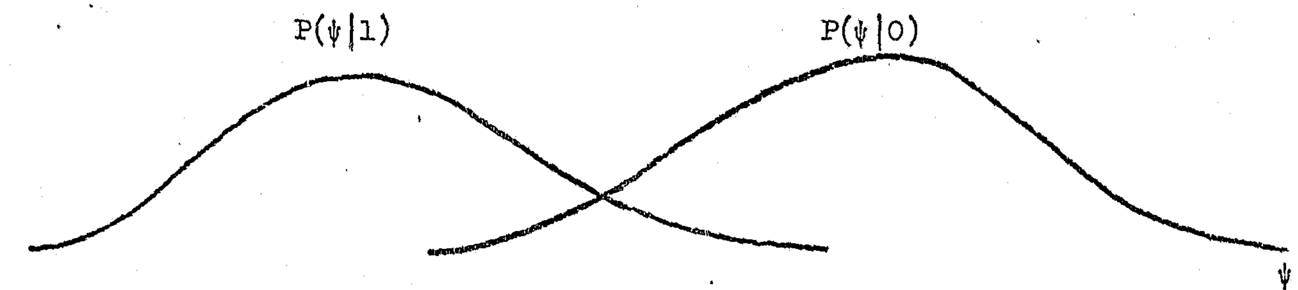


Figure 7-B-1. P(ψ|c) vs ψ

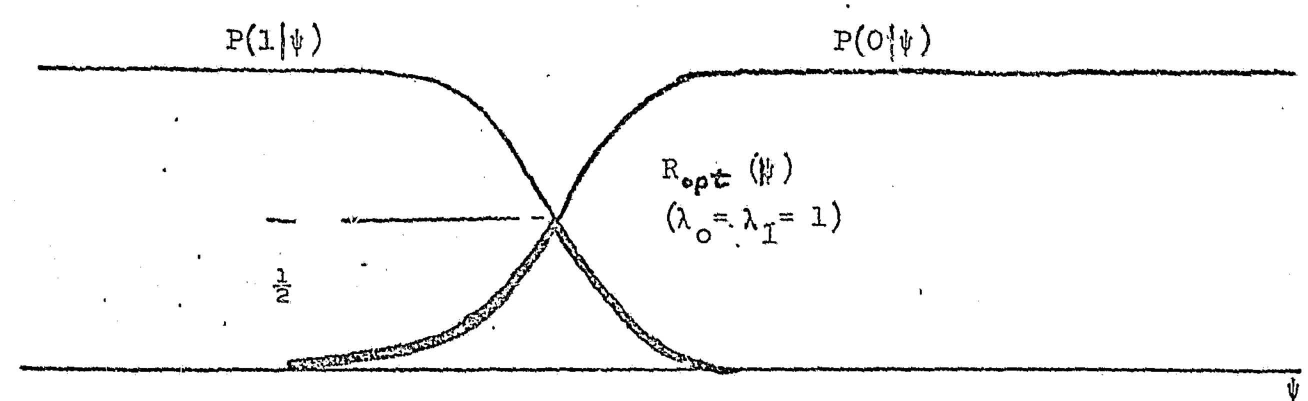


Figure 7-B-2. P(c|ψ) and R(ψ) vs ψ

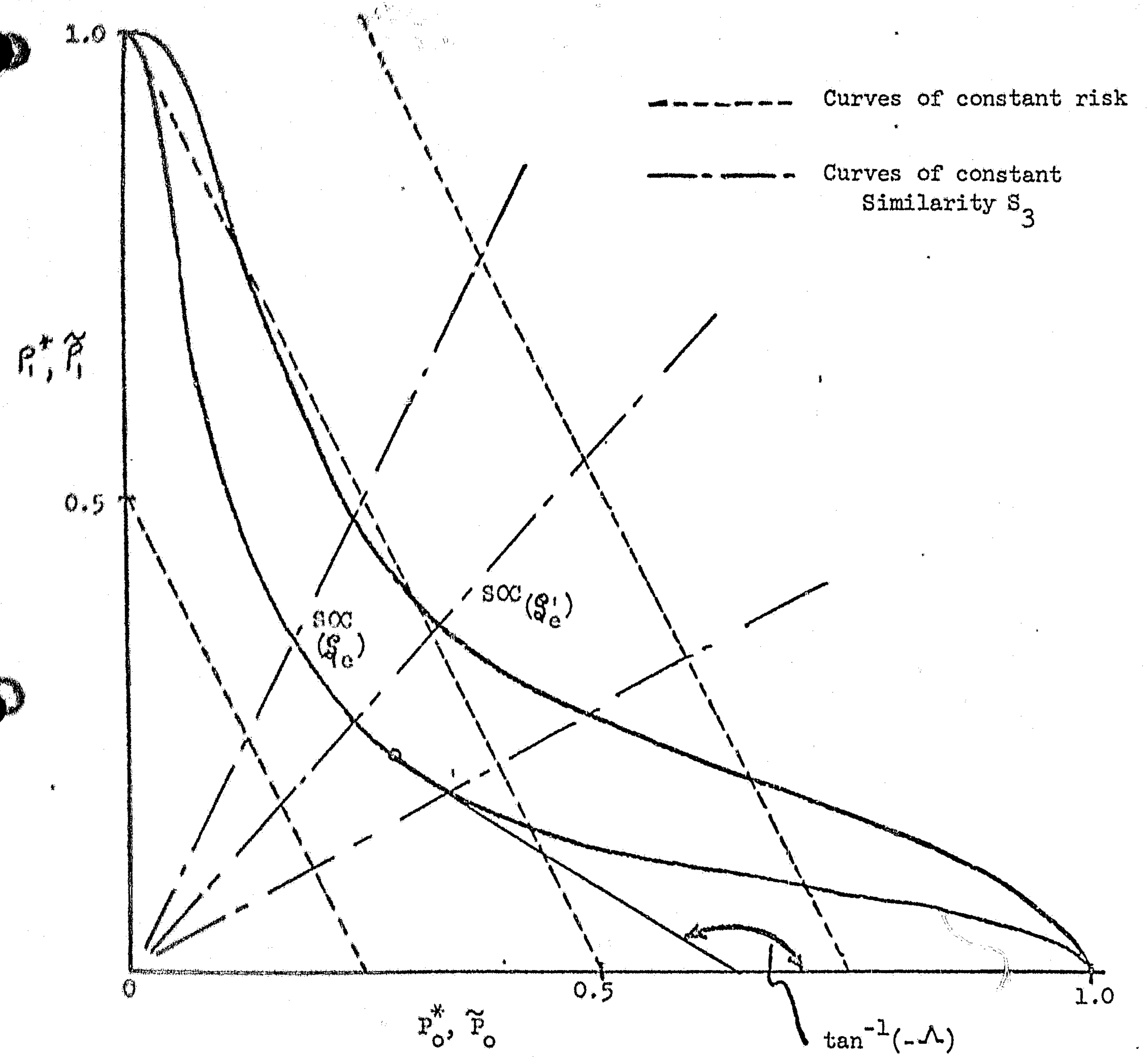


Figure 7-B-3. SOC Curves and other Characteristics

END