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BINAURAL RELEASE FROM MASKING FOR SPEECH:
VALIDATION OF A MODEL

by

Joseph E. Grossman

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of requirements for the degree of Doctor of Philosophy, The City University of New York.

1976

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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TABLE OF CONTENTS

PAGE

CHAPTER

LIST OF TABLES

LIST OF ILLUSTRATIONS

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER I

INTRODUCTION

The following chapter presents a review of the conditions under which Masking Level Differences (MLD's) are obtained. MLD's can be defined as an improvement in the binaural masked threshold for a target signal resulting from appropriate manipulations of the interaural relations of the target signal and noise. The MLD is typically specified as the decrease in the isgnal energy, expressed in decibels, that ia required in order to maintain the listeners's performance constant when differences in the interaural relations are introduced. The MLD may be quantified as the difference in dB between the monaural masking (SmNm) and a specific binaural condition. Alternatively, the SoNo (a listening condition where both, signal and noise are presented in phase at both ears) serves as a reference for quantifying the MLD's.

The improvement that is obtained in binaural release from masking can be illustrated by the following example presented by Jeffress, (1972).

> "Supply noise to one ear (via earphone) at a comfortable listening level, then add a signal consisting of a 500-Hz tone interrupted every quarter of a second, and adjusted in level until it is just inaudible. Now add the same noise to the other

> earphone, and the signal becomes clearly audible. The signal again disappears when it too is added to the channel for the second earphone, making the sounds at the two ears alike. Now if we reverse the connections of either the noise input or the signal input (but not both) to one ear, the signal becomes loud and clear, and can be reduced in level by many decibels before it again becomes inaudible."

A series of binaural listening experiments have demonstrated that superior detection is possible under many conditions in which some interaural changes are introduced, between the signals or the maskers at the two ears. The parameters which have been manipulated included variations of interaural phase, interaural time-delay, interaural intensity, interaural noise correlation, and combinations of monaural and binaural listening.

It would be helpful to summarize the terminology and notations used by investigators to indicate the differences in the listening conditions (See Table I). The feature common to all listening conditions is that the signal is designated as "S", and the masker as "N". Subscripts are used in conjunction with these primary symbols to designate how the stimuli are presented. The subscript "π" indicates a phase reversal at one ear relative to the other; the subscript "o" indicates no phase or time difference between the ears, and the subscript "u" indicates that the masking noise at the two ears is uncorrelated (e.g., the noises are supplied from separate noise generators) and the subscript "m" indicates that the noise is presented monaurally.

Table I - MLD Nomenclature

Symbol	Binaural Phase Relationship
SmNm	Signal and noise both monaural (same ear)
SoNo	Signal and noise both in phase at the ears
SmNo	Signal monaural and noise in phase at the ears
SπNπ	Signal and noise both reversed in phase at one ear relative to the other
SmNπ	Signal monaural, noise reversed in phase
SπNo	Signal reversed in phase (at one ear), noise in phase
SoNπ	Signal in phase, noise reversed in phase (at one ear)
SoNu	Signal in phase, noise uncorrelated
SπNu	Signal reversed in phase, noise uncorrelated
SmNu	Signal monaural, noise uncorrelated

CHAPTER II

REVIEW OF THE LITERATURE - MLD

Effect of Signal Frequency

The original experiment examining the influence of frequency upon binaural release from masking was reported by Hirsh (1948). Three subjects were presented with a pure tone which remained on for one second and off for three seconds in a background of white noise (flat spectrum to 7000 Hz). Six experimental configurations using the psychophysical method of adjustment were examined: (1) SmNo (2) SmNπ (3) SoNo (4) SπNπ (5) SoNπ (6) SπNo, for tones of 100, 200, 500, 1000, and 5000 Hz respectively. Hirsh found that the size of MLD for SmNo and SπNo configurations diminished at frequencies above 1000 Hz and reached a maximum of about 14 dB at 200 Hz. At 100 Hz the size of the MLD was relatively small. Figure 1 is a display of Hirsh's findings. Following this experiment a host of additional investigations were undertaken. Figure 2 presents data from more than a dozen studies where the influence of signal frequency upon binaural release from masking was examined. One may see that above 250 Hz, MLD values decrease from a maximum of 15 dB to about 3-4 dB (Hirsh, 1948; Webster, 1951, Hirsh and Burgeat, 1958; Wilbanks and Whitmore, 1968; and Durlach, 1972).

It should be pointed out that not all studies are directly comparable because several investigators used

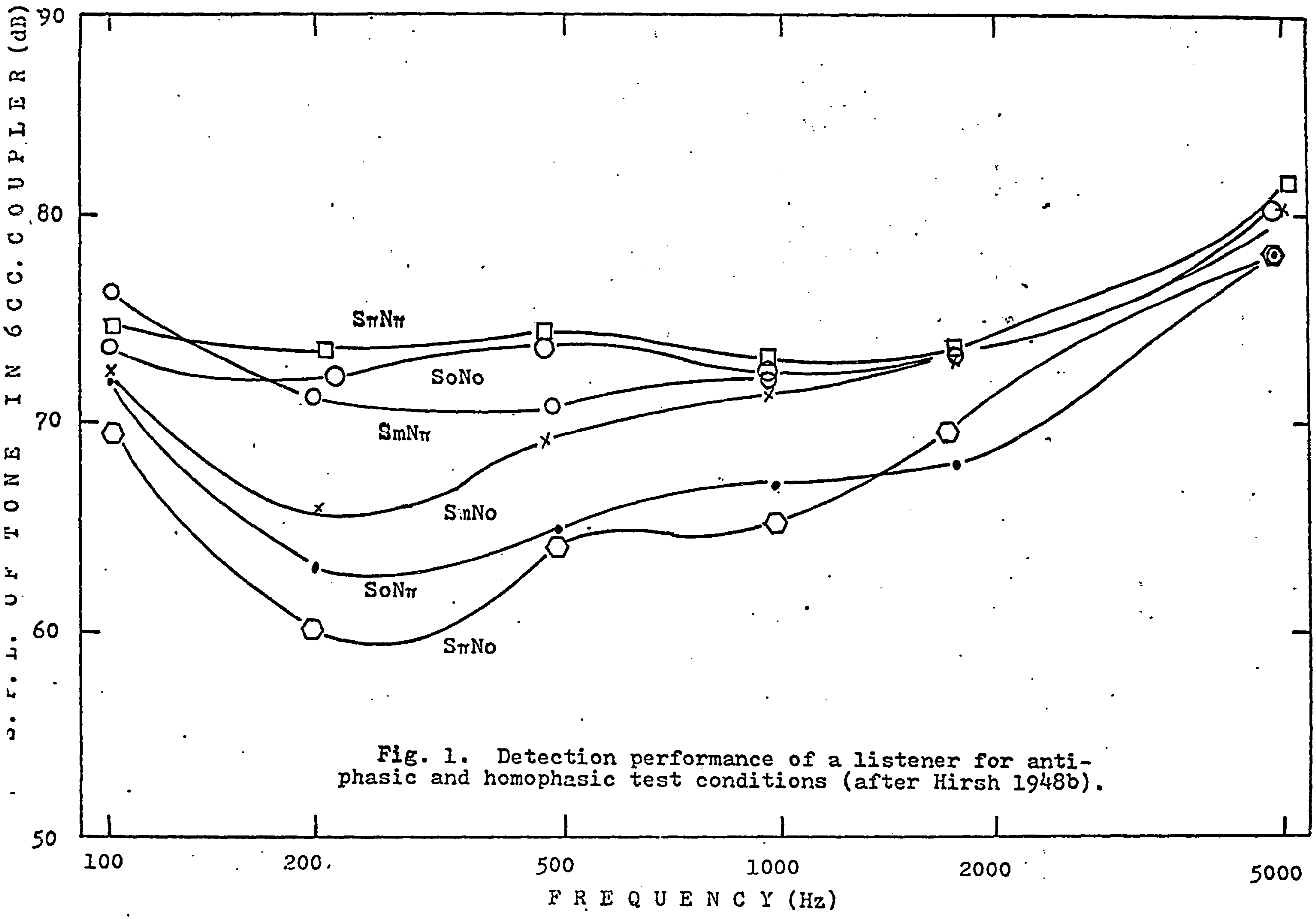

Fig. 1. Detection performance of a listener for antiphasic and homophasic test conditions (after Hirsh 1948b).

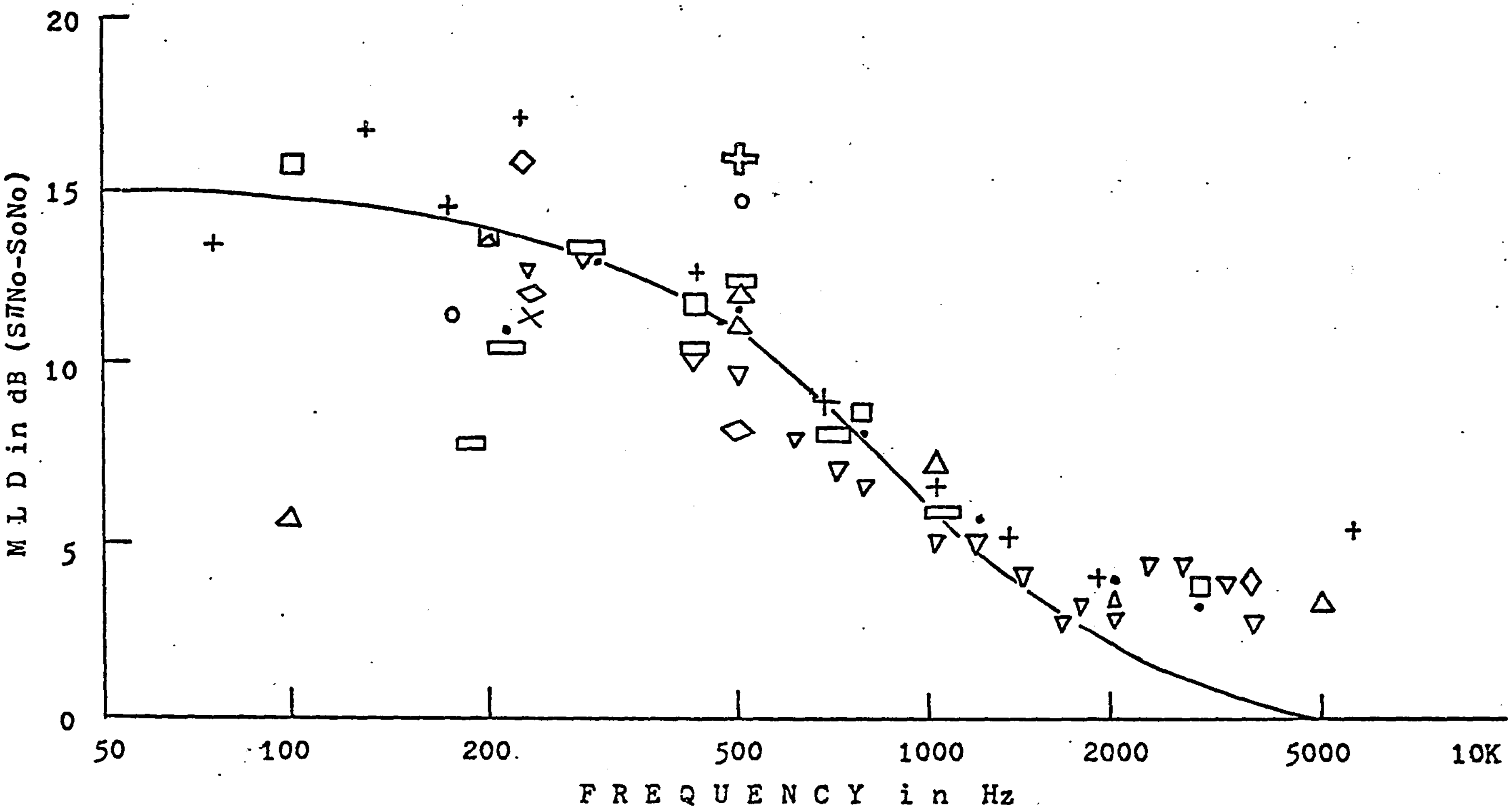

Figure 2. The change in MLD values as a function of tone frequency. The data points represent the diverse results of many studies (after Durlach, 1972).

dissimilar masking levels, and psychophysical methods which may be responsible for some disparities, such as the sizes of MLD's for signal frequencies below 250 Hz.

Webster (1951), Jeffress, Blodgett and Deatherage (1962) and Durlach (1972) have reported MLD's below 250 Hz to be essentially constant, whereas Hirsh (1948a) and Rabiner, Laurence and Durlach (1966) found that MLD's tend to decrease below 250 Hz.

Dolan (1968) re-examined the decrease in MLD's at low frequencies. He systematically varied the level of the experimentally-controlled masking noise and measured the MLD's for $S\pi No$ configurations at 150 Hz and 300 Hz. He suggests that the discrepancies among published results at frequencies below 300 Hz can be attributed to the amount of low-frequency experimentally-controlled masking noise. As the spectrum level of the external masking noise increased, the MLD's steadily increased. At masker spectrum levels of about 50 dB and above, MLD's of about 15 dB were obtained at both 150 Hz and 300 Hz. Green and Henning (1969) suggest that the relatively small MLD's measured at very low signal frequencies and with a low level of masking noise are caused probably by other noises which are not under the experimentor's control, such as those produced by breathing, heartbeat, muscle tonus and room noise. They assume that at very low signal frequencies, the level of those previously mentioned noises is sufficient to obscure the low intensity noise introduced via the headphones. These internal noises at one ear are only partially correlated with those at the other ear. Green and Henning believe that this situation resembles to some degree the Nu condition described earlier. Since a condition like SπNu results in a very small MLD, there is a small MLD obtained for these low frequency signals when the experimentally controlled noise is low in level.

Effect of Masker Level

Another variable of major significance which determines the amount of MLD's is the intensity level of the masking noise. Hirsh (1948a) and Blodgett, Jeffress and Whitworth (1962) investigated this parameter. Their experiments indicated that there was no difference in the size of MLD's between the SmNm and the SmNo configurations until the spectrum level* of the noise exceeded about 20 dB. Above 20 dB to about 40 dB spectrum level of the masking noise, there was a substantial increase in the masking level difference. McFadden (1968) also measured MLD values as a function of masking noise level. His results too indicated that MLD's increased gradually as the spectrum level of the masking noise increased. His results were basically

---

*The term spectrum level refers to the power per unit bandwidth of the noise, or sound pressure level per Hz bandwidth.

in agreement with the previous studies. Canahl and Small (1965) also found that as the overall level increased there was an increase in the size of the MLD's. However, at extremely high noise levels there was a slight drop in the MLD. Dolan, (1968) whose study was reviewed in the previous paragraph, also found that as the spectrum level of the masking noise increased, the MLD steadily increased. Figure 3 presents data obtained by Hirsh (1948a) which demonstrates the dependence of MLD's upon the spectrum level of the masking noise.

Effect of Interaural Phase

Hirsh (1948b) in his experiment varied the phase of a 200 Hz tone in 30 degrees steps in both $S\phi No$ and $S\phi N\pi$ configurations (the suffix "ϕ" = phase in rads). The largest MLD's were obtained when the interaural phase difference of the signal was 180 degrees, (i.e. π radians), that is when the configuration was $S\pi No$. When the phase shift is introduced into the masking noise, in the antiphasic configuration ($SoN\pi$) the MLD is maximal, however, it is somewhat smaller than in the $S\pi No$ configuration. Later studies by Jeffress, Blodgett and Deatherage (1952), Colburn and Durlach (1965), and Egan (1965) confirmed these results.

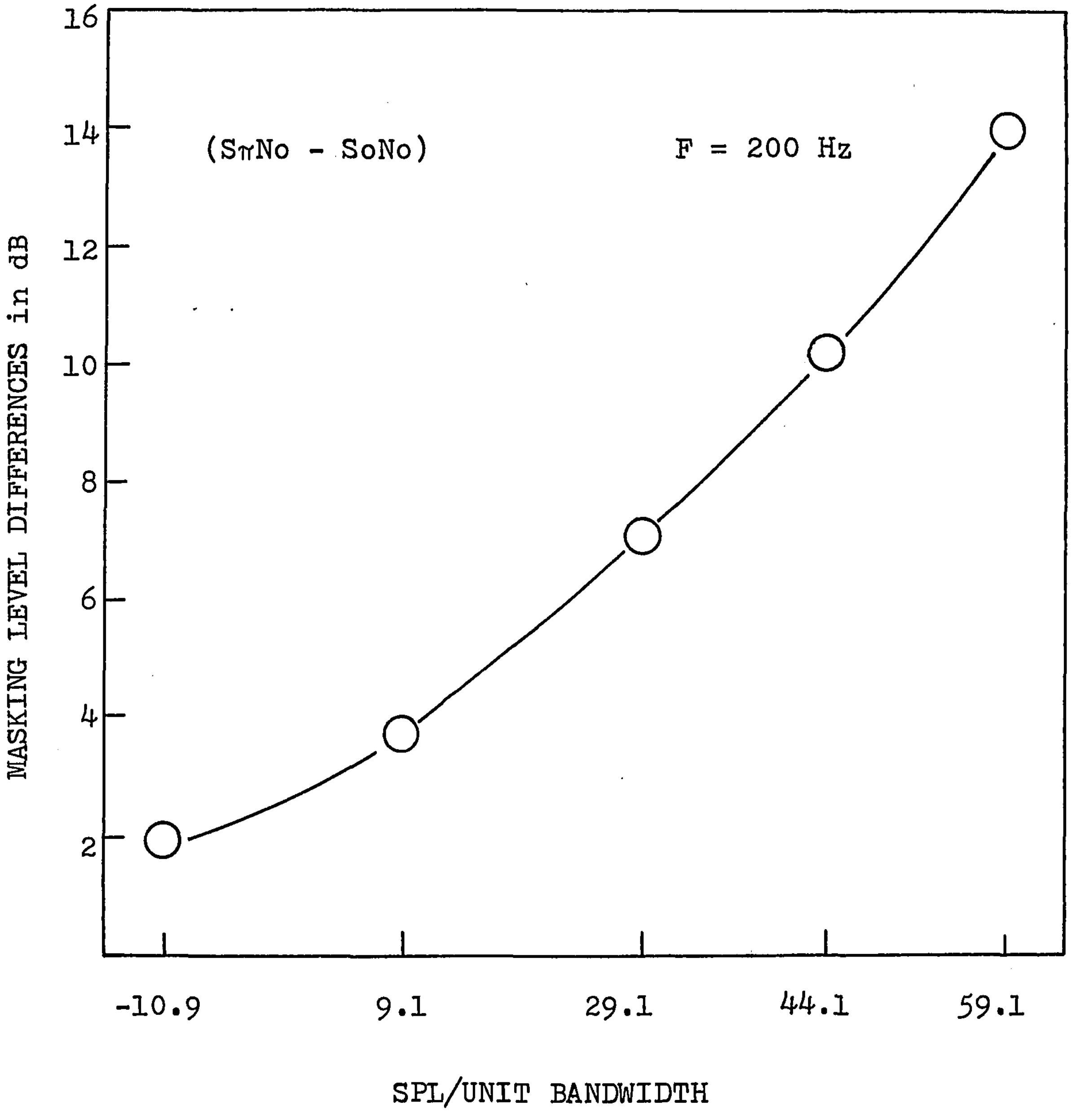

Figure 3. Masking Level Differences as a function of the spectrum level of a white noise background.(After Hirsh, 1948a).

Effect of Interaural Time-Delay

The fact that MLD's vary with interaural phase, leads one to anticipate that the time-delay should also bring about a masking level difference. Figure 4 presents results of a study by Rilling and Jeffress (1965) where the signal was either a 500 Hz tone or a narrow band of noise centered at 500 Hz. As can be seen from this graph, an introduction of a time delay has the effect of gradually increasing the MLD until the maximum release from masking is obtained at a time delay equivalent to half the period of the 500 Hz tone. (A one msec time delay introduced into a 500 Hz sinusoid is equivalent to the $S\pi No$ configuration). As can be seen from Figure 4 identical functions are obtained for the 500 Hz sinusoid and the narrow band of noise which is centered at 500 Hz.

Effect of Signal Bandwidth

Several investigators used short duration sinusoids (Blodgett, Jeffress, and Taylor, 1958, McFadden and Pulliam, 1971), pulse trains (Flanagan and Watson, 1966) as signals in MLD experiments that they conducted. Because of the very short durations, these signals have acoustical energy spread over a wide range of frequencies. In general, these experiments presented similar results. The largest MLD's are found when the out-of-phase portion of the signal included spectral components in the 250-500 Hz region.

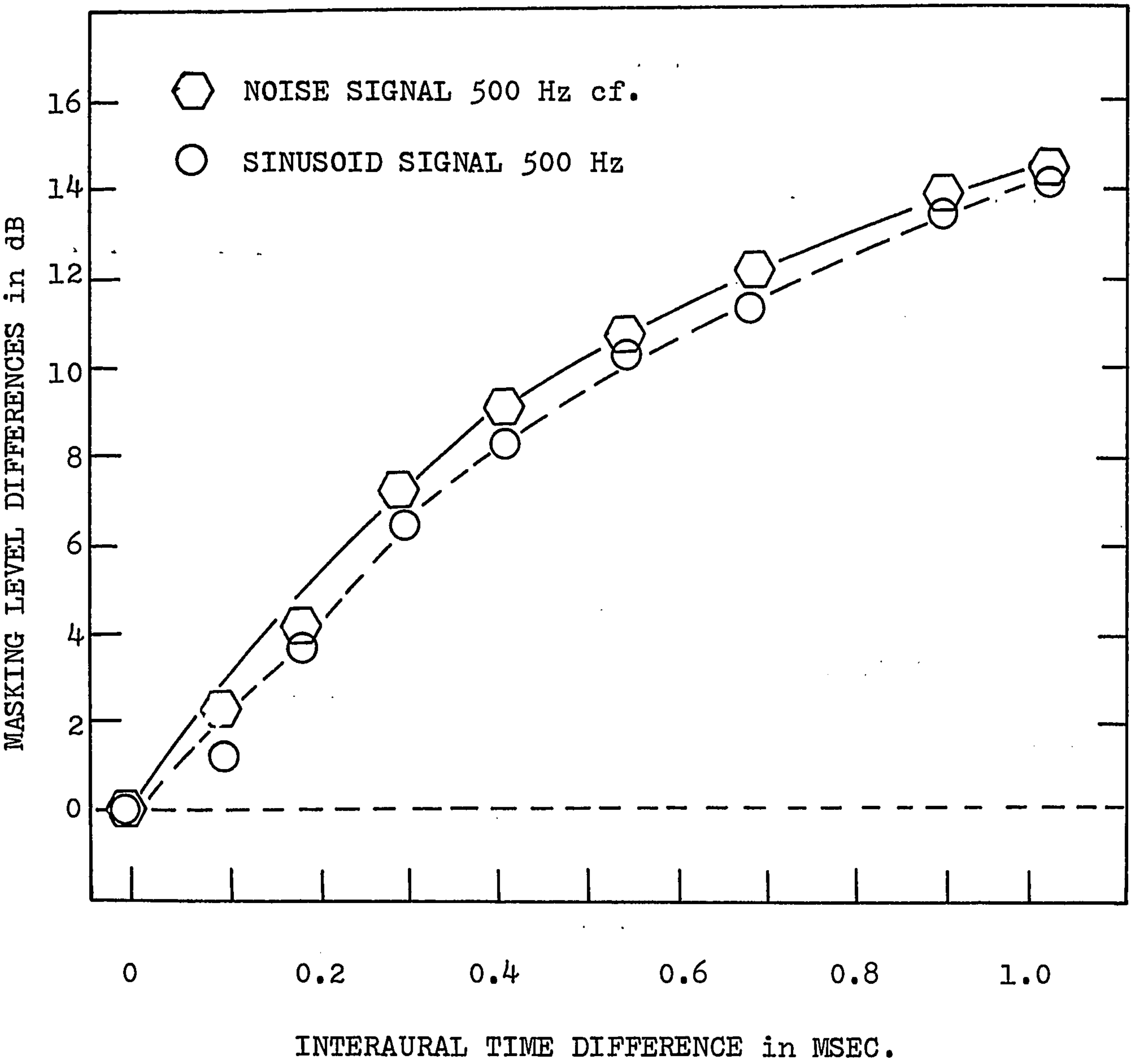

Figure 4. MLD's as a function of interaural time difference showing the function when time-delay is introduced into the signal. In one case the signal is a sinusoid, in the other a narrow band of noise centered around 500 Hz.

In Flanagan and Watson's (1966) study, periodic pulses were used as the target signal. They filtered the signal spectrum into high-pass and low-pass bands, and used each band as a target signal whose interaural phase was manipulated. Pulse rate around 250 pulses per second yielded the largest MLD's. A spectrum splitting technique similar to that employed by Flanagan and Watson (1966) was employed also by Levitt and Rabiner (1967a), however, they used monosyllabic words as their target signal. Their spectrum splitting technique was more elaborate in that it permitted the entire spectrum of the signal to be presented at the two ears with a selected frequency range interaurally out of phase. The results study were in agreement with those of Flanagan and Watson, and confirmed the previous findings which indicated that largest MLD's are obtained primarily due to interaural phase opposition in the low frequency (500 Hz) region.

Effect of Signal Duration

Jeffress, Blodgett, and Deatherage (1956) reported changes in the values of MLD's as a function of signal duration. For a 500 Hz tone of 500 msec duration the MLD was about 13 dB. Maintaining all conditions constant except for stimulus durations of 25 msec to 50 msec will produce somewhat larger MLD, an increase of about 2-3 dB. The spectrum level of the masking noise in this experiment was 58 dB. Green (1956) also studied the effect of signal duration upon MLD's. In his study he used a 250 Hz tone (2.5 msec rise decay time) of 10, 100, and 1000 msec duration, masked by wide band noise at 55 dB spectrum level. For 1000 and 100 msec durations, the amount of MLD's was identical. An increase in MLD's of about 3 dB was produced by reducing the signal duration to 10 msec.

Generally, the psychometric function relating the percentage of correct detection to the signal level is approximately the same for many durations (McFadden and Pulliam, 1971) however, for very short durations of less than about 50 msec the MLD's tend to increase by about 3 dB.

Effect of Interaural Signal Level

The hierarchy of the size of MLD's indicates that in the SπNo configuration the MLD is about 6 dB larger than that for SmNo. One may infer from here that the size of MLD's depends on the relative signal levels at the two ears. This parameter has been investigated by Blodgett, Jeffress, and Whitworth (1962), Egan (1965), Colburn and Durlach (1965), and Zerlin (1966). In general, the results of these studies indicated that the MLD's decreased as the interaural disparities in the signal level increased, if the balanced condition was SπNo, while the reverse is true for the SoNo configuration. In each case, the change in MLD's due to interaural intensity differences ranged from 6 to 8 dB.

The preceding studies generated some speculation as to the similarities between the phenomena of binaural release from masking and binaural lateralization, since interaural intensity differences in either the masker or target signal give rise to shifts in both the lateralization and threshold detection performance of the listener. Colburn and Durlach (1965) who also investigated the influence of interaural amplitude ratio upon MLD's, used in their experiment a 500 Hz tone masked by random noise. Based upon their results they suggest that in order to clarify the relation of binaural unmasking to lateralization, it is important to obtain further data on binaural-masked lateralization. However, it appears that release from masking and lateralization are separate and distinct phenomena arising from different binaural mechanisms.

Effect of Masker Bandwidth

The question the experimentors asked when this parameter was investigated, was, when a wide band of noise is used, what part of that band is actually responsible for the masking that results in an MLD? In answering this question, two different experimental methods were employed. Bourbon and Jeffress' (1965) method involved narrowing the bandwidth of a wide-band noise by systematically filtering the masking noise in an $S\pi No$ configuration. In general, their results indicated that as the bandwidth decreased there was an increase in the size of the MLD. In a similar experiment, Metz, von Bismark, and Durlach (1967) reported that the size of the MLD increased by about 10 dB as the bandwidth of the masking noise centered around a 250 Hz tone was reduced from 250 Hz to 4.2 Hz.

It should be pointed out that this method is unsatisfactory since filtering of the noise results in a decrease in the overall level of the masker. It has been pointed out earlier that the size of the MLD is a function of the level of the masker.

The other method used by Sondhi and Guttman (1966) attempted to solve this problem which eliminated changes in the intensity level of the masker when the effect of bandwidth upon MLD is determined. Their method involved digital filtering which enabled the amplitude spectrum to remain constant throughout the experiment, by reversing the phase of only the central segment of the masker, whereas the remainder of the noise spectrum was presented in a homophasic configuration. This study also indicated that the size of the MLD increased as the bandwidth size decreased. For a 250 Hz tone an MLD of 15 dB was obtained when the width of the noise band was approximately 125 Hz wide.

Effect of Interaural Correlation

Licklider (1948) was the first to study systematically the effect of noise correlation on masking-level differences. It should be pointed out that when a noise from a noise generator is split and led to earphones at the two ears, the noise at the ears has a perfect positive correlation ($\rho=+1.0$) when binaurally in phase, or a perfectly negative correlation ($\rho=-1.0$) when binaurally out of phase. If two separate generators supply the noise to the two ears, the noise is uncorrelated ($\rho=0.0$). Licklider (1948) varied the noise correlation by using three noise sources. The waveform coming from one source was split and added to the waveforms from the two independent noise sources, each of which was presented to only one ear. The interaural correlation is determined by the relative amount of noise from the common source which has a perfect positive correlation, to the amount of the other noises which were uncorrelated. Licklider found that the correlation had little effect till it was greater than 0.70. Robinson and Jeffress (1963) applied the same technique in studying the effect of noise correlation, however, they used a 500 Hz sinusoid, whereas in Licklider's experiment speech served as the signal stimulus. In Figure 5 data from the preceding two studies are shown. One may notice that there are rather substantial differences in the size of MLD's obtained in these studies. As shall be discussed later, binaural release

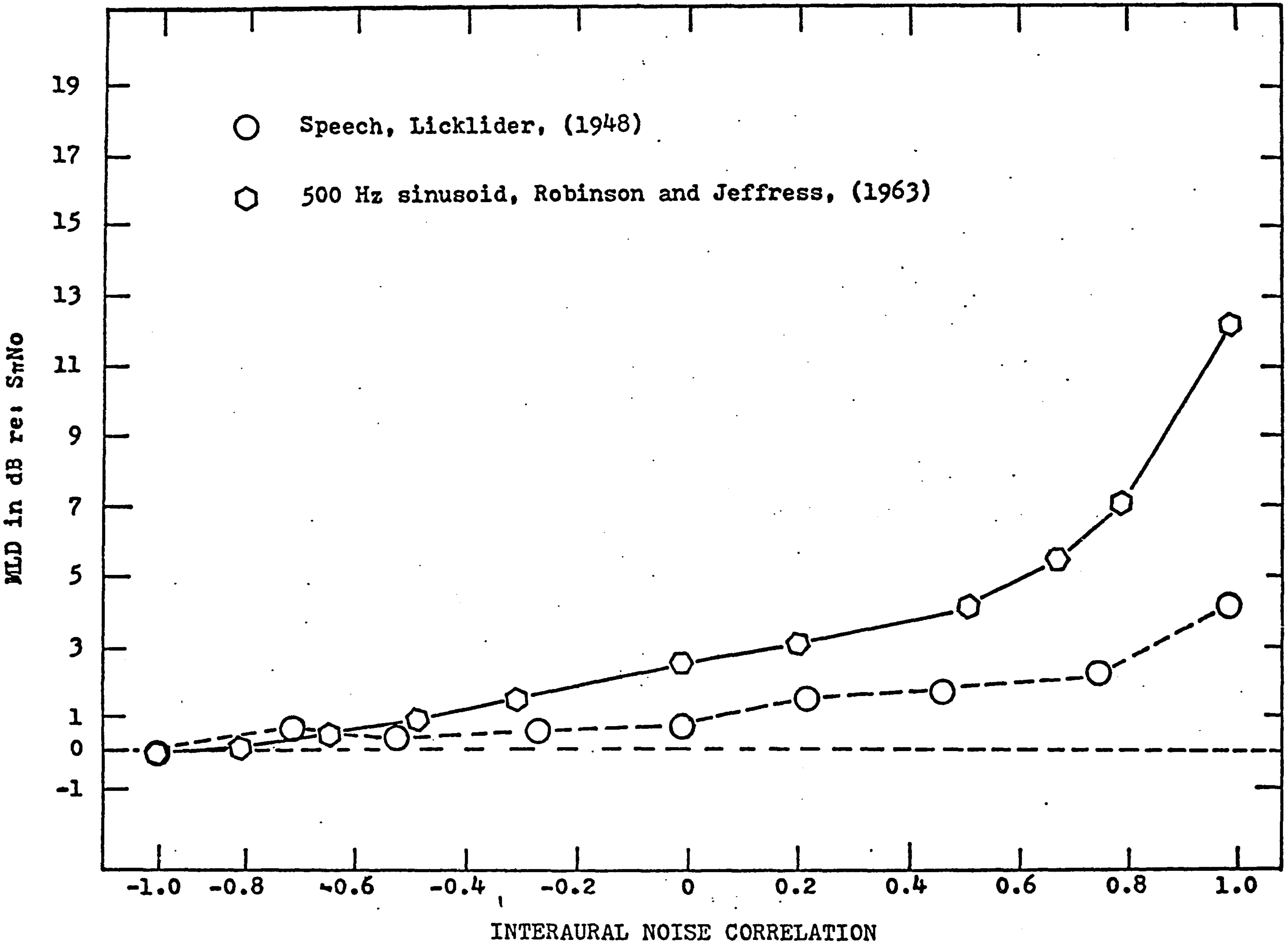

Figure 5. Masking Level Differences as a Function of Interaural Noise Correlation

from masking for speech is typically smaller than for tonal signals.

Binaural Release from Masking for Speech

Before reviewing studies of masking level differences where speech has been used as the experimental signal, it is appropriate to present the methods by which binaural release from masking for speech may be quantified. The following definitions are based upon Levitt and Rabiner (1967a). Two methods are mentioned. One method is to measure the gain in percent intelligibility for a given signal-to-noise (S/N) ratio. The other is to measure the reduction in S/N ratio for a given percent intelligibility. The latter method is analogous to that used in defining MLD's for pure tone signals.

Detection Threshold: is that signal level at which the listener, under a given set of conditions, and maintaining a fixed criterion, judges the signal to be present for 50% of the time (i.e., "signal present" or "signal absent").

p% intelligibility level: is that signal level under a given set of conditions, and maintaining a fixed criterion, correctly identified p% of the words presented.

Masking Level Difference (MLD): is the difference in detection threshholds (in decibels) between two binaural conditions.

Intelligibility Level Difference (ILD): is the difference in p% intelligibility levels (in decibels) between two binaural conditions (i.e., between SoNo and SπNo). Unless stated otherwise, the 50% intelligibility level is implied.

Licklider (1948) was the first to investigate the improvement in intelligibility for binaural antiphasic listening conditions. He administered the articulation test at seven different S/N ratios (-12 to + 12 dB in 4 dB steps). The speech material used in this experiment consisted of recorded word lists (Psycho-Acoustic Laboratory 50-word PB lists). Licklider's results indicated that: a) generally there was an improvement in intelligibility in the antiphasic (SπNo) configuration over the homophasic (SoNo) configuration; b) with decreasing S/N there was an increase in the size of the ILD. Thus, at 20-30% intelligibility (for homophasic listening) there was an ILD of about 5 dB observed, whereas at 65-70% intelligibility level (for homophasic listening) the articulation functions of SoNo and SπNo converged; antiphasic listening configurations did not produce any improvement in intelligibility over homophasic listening configurations.

Following Licklider's study many experiments were conducted where speech stimuli were used in examining the size of ILD's. The various experiments differed in terms of the speech material being used, (monosyllables, sentences), the task to be performed by the listener, (identification, or detection), and the background masker against which the speech stimuli were presented. Kock (1950), Schubert (1956), Pollack and Pickett (1958a), Schubert and Schultz (1962), Feldman (1965), and Tobias (1970), all used broad-band Gaussian noise. Carhart, Tillman, and Johnson (1966) used amplitude modulated noise, and interrupted noise, respectively. Pollack and Pickett (1958b) presented their speech stimuli against a background of competing speech. Carhart, Tillman and Johnson (1967) also investigated the effect of interaural-time delay on release from masking for speech. When interaural time-delays are introduced between the speech signals arriving at the ears, and not between the maskers, the ILD's increased as the delays increased from 0.1 to 0.8 msec. The observed ILD's for interaural time-delays never reached the amount of ILD's in an $S\pi No$ configuration. Figure 6, and Table II represent a summary of selected studies where masking level differences for speech were investigated. Inspection of Figure 6 clearly indicates that in all investigations the prominent feature is the increased binaural gain in intelligibility at low S/N ratios. Levitt and Rabiner (1967b) provided a theoretical model which, among other predictions pertaining to binaural release from masking for speech, predicts larger increases in ILD's as S/N ratios decrease. The authors demonstrated the ef-

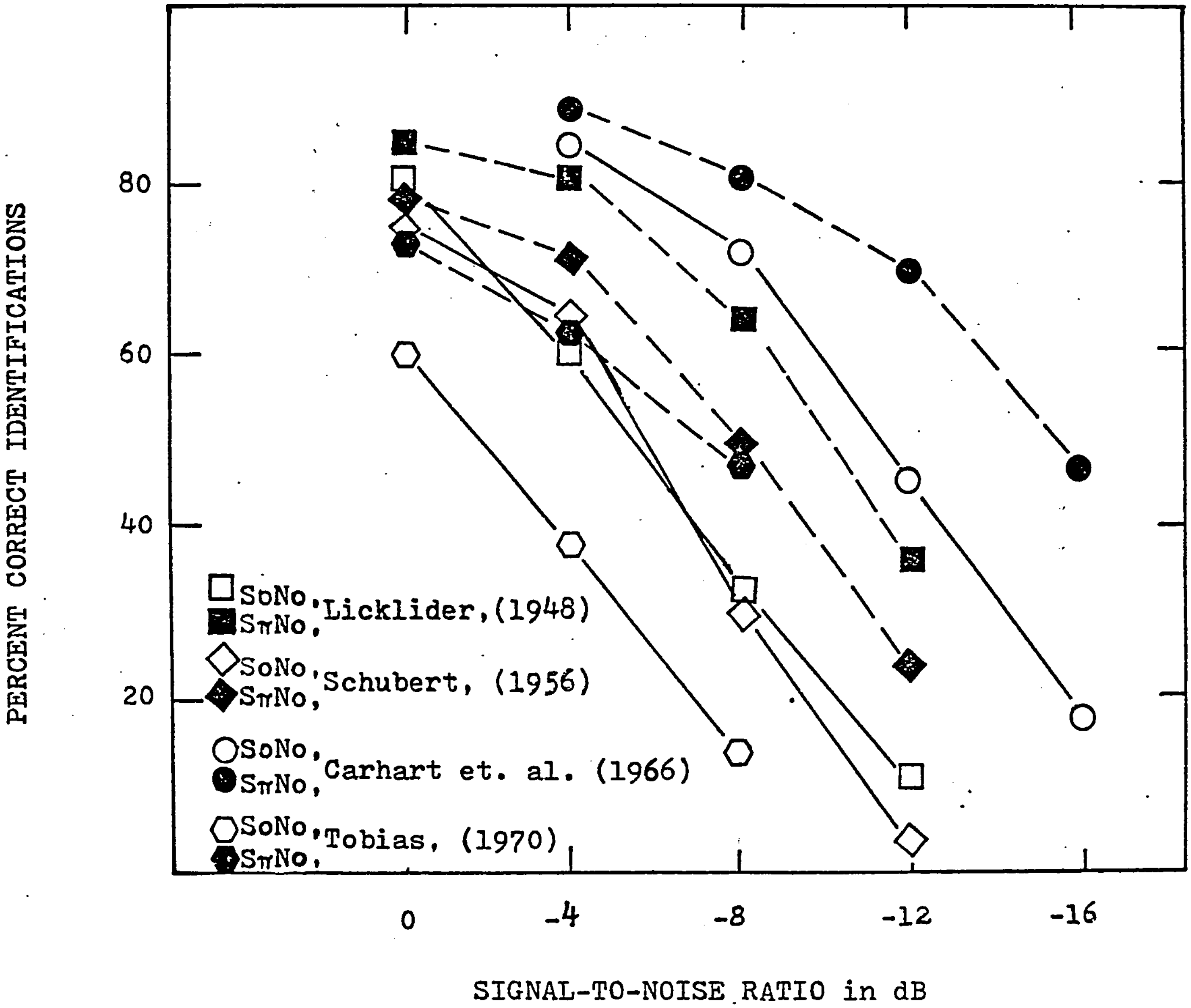

Figure 6. Binaural Improvement in Intelligiblity as a Function of Signal-to-Noise Ratio.

TABLE II

STUDIES EVALUATING BINAURAL MASKING LEVEL DIFFERENCES FOR SPEECH AS A FUNCTION OF S/N RATIOS

STUDY	TASK	S/N RATIO	TEST MATERIAL	MASKER	NUMBER OF SUBJECTS
Licklider (1948)	Identification	-12 to +12 dB (7x4 dB steps)	PB-50's	White noise	3
Kock (1950)	Not clear	Not stated	Sentence	White noise	Not stated
Schubert (1956)	Identification	-14 to 0-dB (8x2 dB steps)	Passage-120 words	White noise	Not stated
Schubert & Schultz (1962)	Identification	-3 to +3 dB (3x3 dB steps)	Passage-120 words	White noise	15
Carhart, Tillman & Johnson (1966)	Identification	-30 to -6 dB (5x6 dB steps)	NU-6 Monosyllables	White noise	9
Tobias (1970)	Identification	-10 to +5 dB (4x5 dB steps)	Passage-120 words	White noise	25

fectiveness of this model for monosyllabic words in white noise. They did not, however, examine the validity of this model for other types of noise. The examination of this model is the objective of the present investigation.

CHAPTER III

THE PROPOSED STUDY

Levitt and Rabiner (1967b) in their model of binaural release from masking for speech state that the effect of binaural processing in the auditory system can be represented by a frequency dependent equivalent reduction in the level of the applied masking noise. The magnitude of this reduction is derived from data on release from masking for the corresponding binaural configuration. Predictions for speech intelligibility and the binaural gain in intelligibility (ILD) for speech in noise are based upon the Articulation Index (AI) (Kryter, 1962) as computed for the equivalent masking noise of the model. These predictions are based on the long-term average speech spectrum of the ideal male speaker as used in the calculations of the AI by Kryter, (1962)*.

A. It was predicted that:

a) The ILD decreases with increasing AI, i.e. when speech is masked by white noise and relatively high levels of intelligibility are obtained in a homophasic (SoNo) configuration, smaller ILD's can be expected.

b) For white noise and for low AI, i.e. poor intelligibility in the homophasic (SoNo) configuration, interaural

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*There are other researchers who presented different long-time average speech spectra, French and Steinberg, (1947), and Miller, (1947(.

phase opposition between signal and noise in the low frequency region is the primary factor contributing to the ILD's.

c) For high AI, i.e. relatively high level of intelligibility obtained in the homophasic (SoNo) listening configuration, phase opposition in the low frequency region contributes negligibly to ILD's. In this case only high frequency phase opposition contributes to gain in intelligibility and is limited to about 3 dB. As stated before, this prediction is limited for white noise.

d) For the case of non-white noise, the predictions may be different depending on the noise spectrum. It is predicted that a noise where the power spectrum decreases with increasing frequency at about the same rate as that for speech, high frequency phase information will contribute to gain in intelligibility. However, in upward-sloping noise (+6dB/octave) gain in intelligibility will be restricted to the low frequency region of the speech spectrum.

Rationale for Predictions

In order to show the relationship between the predictions and the AI, the manner in which the AI is computed is briefly reviewed. The speech spectrum is broken up into 20 contiguous bands, each of which makes an equal contribution to intelligibility. Within each band the intensity level of the speech varies over a range of roughly 30 dB. The contribution of each band toward the AI is 1/600 of the

S/N (in dB) for that band. Negative S/N ratios make no contribution, and S/N ratios of 30 dB or larger make the maximum allowable contribution per band of 0.05. The increase in the contribution for each band as a consequence of change from SoNo to SπNo conditions for white noise is shown in Figure 7 for selected values of S/N ratios (left-hand panel). The right-hand panel depicts the idealized speech spectrum and the applied and equivalent noise spectra used in computing the AI.

The spectral distribution for typical speech is such that there is relatively more power in the low frequency domain, the amount of power decreasing with increasing frequency. Hence, for speech in white noise at low S/N ratios the speech power in only the low frequency bands contributes to intelligibility. Thus, at low S/N ratios, interaural phase opposition in the low frequency region is of prime importance for improving intelligibility. It is in this frequency region that the reduction in the equivalent noise level is greatest due to phase opposition of the speech wave in white noise. Figure 7 is a graphical representation of this frequency dependent reduction of the applied noise.

As may be seen in Figure 7, the increase in AI at

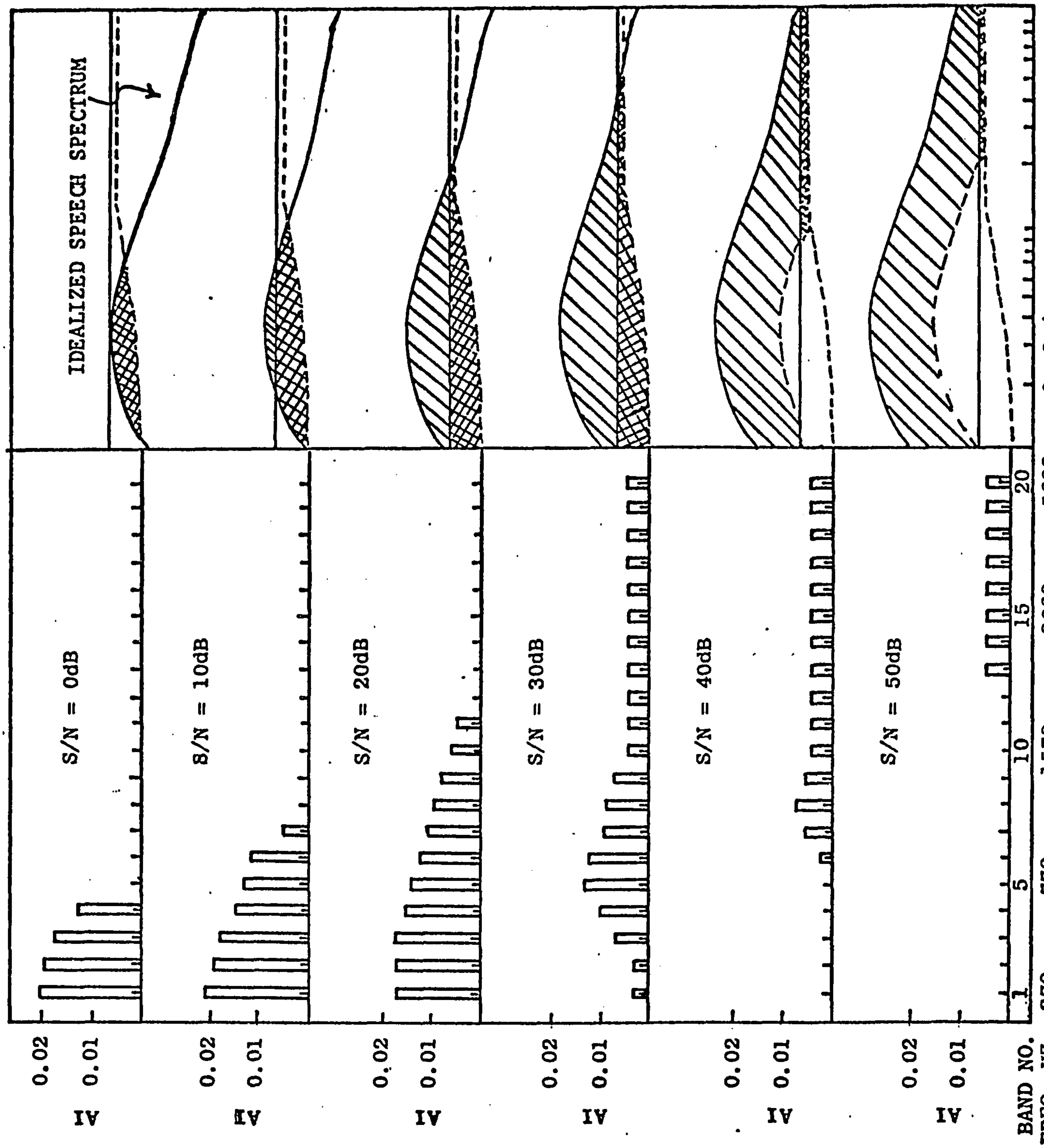

Figure 7. Increment in the Articulation Index per Frequency Band for White Noise. The left-hand panel shows the increase in the contribution of each band used in computing the AI as a consequence of the change from SoNo to the SπNo conditions. The right-hand panel shows the idealized speech spectrum and the applied and equivalent noise spectra used in computing the AI. The single-hatched area represents the region contributing to intelligibility for the SoNo condition. The cross-hatched area represents the region contributing to the binaural improvement in intelligibility as a consequence of the change from the SoNo to the SπNo condition. At low S/N ratios the increment is restricted to the low frequency bands. At high S/N ratios the increment is restricted to the high-frequency bands. (after, Levitt and Rabiner 1967b).

both 0-dB* and 10-dB S/N ratios is relatively large and restricted to the low frequency bands (left panel). Similarly the largest gain in intelligibility is achieved at those low S/N ratios as exhibited in the right panel. At moderate S/N ratios ILD's are relatively smaller, since gain in intelligibility depends upon interaural phase information in the mid-frequency region where reduction in equivalent noise level is relatively smaller. At very high S/N ratios all frequency bands contribute to intelligibility. At this level, however, the speech power in the low and mid-frequency bands are making their maximum contribution towards intelligibility and any reduction in the equivalent noise level at these frequencies will not increase intelligibility. At overall S/N ratios exceeding about 40 dB the ILD's are solely dependent upon high frequency interaural phase information. The predicted ILD's at such high S/N ratios where gain in intelligibility depends upon frequencies above 1400 Hz equals to a fixed value of about 3-dB of the applied noise.

In this investigation we shall attempt to test the following predictions which are based upon the previously decribed model.

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*0-dB S/N ratio refers to a situation where the overall intensity of the masking noise equals to that of the speech peaks.

1. Simulation of Binaural Equivalent Noise

A central assumption of the model is that the effect of binaural processing may be represented by an equivalent reduction in the level of the applied noise. The spectrum of the equivalent noise is obtained by subtracting from the applied noise the MLD for pure tones at each frequency. See Figure 2.

Two hypotheses are postulated:

a) Speech stimuli presented against a background of white noise in an SπNo configuration will produce the same masking effect as that as the equivalent noise presented in an SoNo configuration.

b) Speech stimuli presented against a background of white noise in an SoNo configuration will produce the same masking effect as the inverse equivalent noise presented in an SπNo configuration. The spectrum of the inverse equivalent noise is obtained by adding to the applied noise the MLD values for pure tones at each frequency. Figure 8 is a graphical illustration depicting applied and equivalent noise spectra (according to the model). The left-hand panel shows the spectra of the applied noise. The binaural configuration of the signal and noise is given between the left- and right-hand panels. The right-hand panel shows the equivalent noise spectrum which results from binaural processing. Four listening

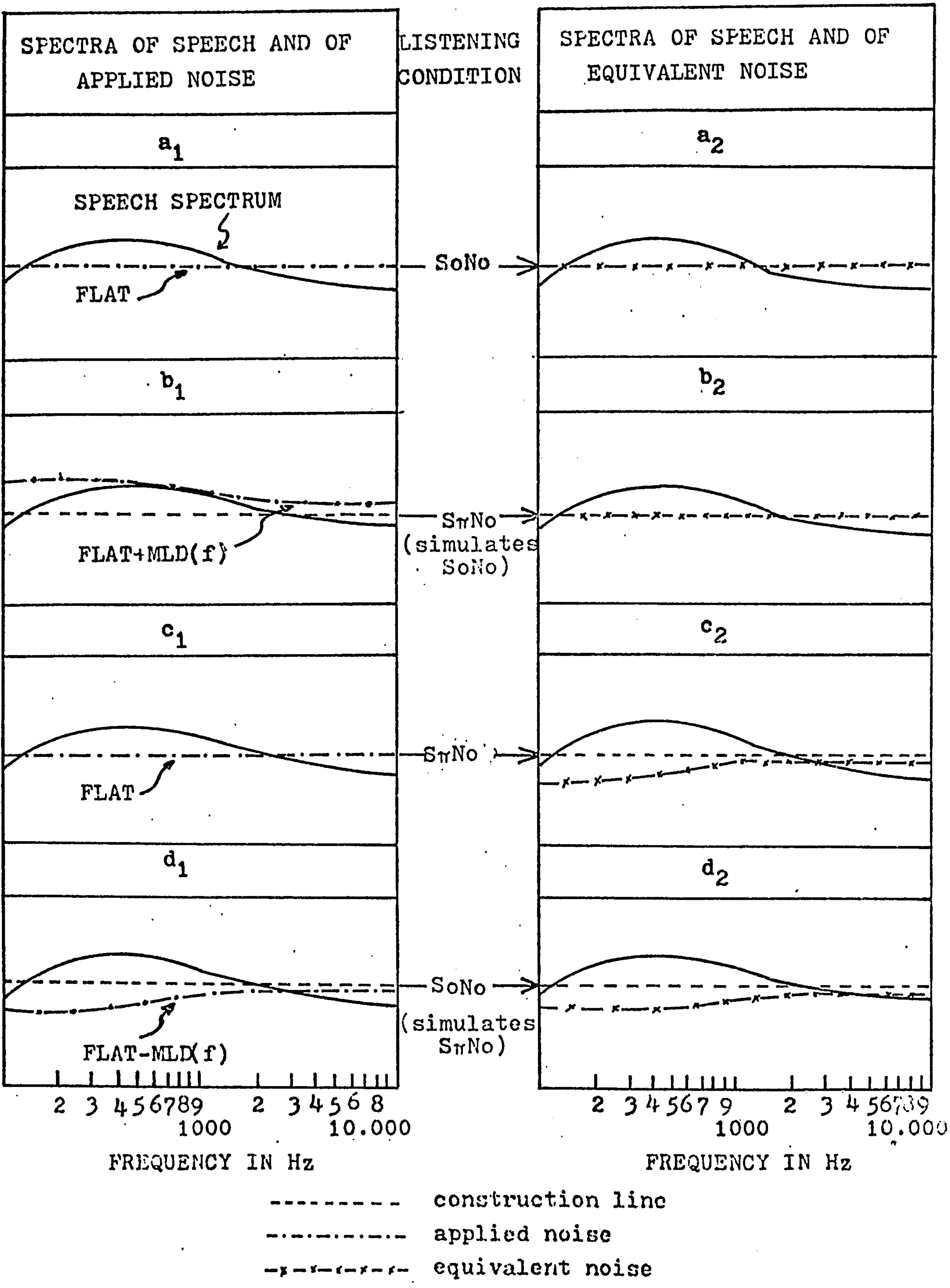

Figure 8. Spectra of applied and equivalent flat noise and typical speech.

configurations are described. In Figure 8(a_1) speech is presented against the background of white noise in a homophasic (soNo) configuration. Since homophasic presentation of speech in noise does not produce any reduction in the applied noise, the resultant equivalent noise depicted in 8(a_2) is an exact replica of 8(a_1). In graph 8(b_1) the applied noise spectrum is Flat+MLD(f), where MLD)f) represents MLD values for a pure tone as a function of frequency as predicted by the E-C Model (Durlach, 1963). This noise is presented in an antiphasic (SπNo) configuration, which brings about a flattening of the "inverse equivalent" noise. According to the model this equivalent noise should have the same masking effect as flat noise presented in a homophasic (SoNo) configuration.

In Figure 8(c_1) speech is presented against the background of white noise in an SπNo configuration which results in the equivalent noise shown in 8(c_2). In section 8(d_2) the applied noise has the same spectrum as the equivalent noise in section 8(c_2). In this case, the signal and noise are applied in a homophasic (SoNo) configuration. According to the model, the masking produced by the equivalent noise of section 8(c_2) should be the same as that in section 8(d_2). Note that the equivalent noise of section 8(b_2) and 8(c_2) have the same spectra as the equivalent noises of sections 8(a_2) and 8(d_2) respectively. Condition 8(b_2) is referred to as the simulated SoNo condition, and condition 8(d_2) as the simulated SπNo condition.

Similar predictions are made for noises of other spectra, i.e. for an upward sloping spectrum (+6dB/octave), or downward sloping spectrum (-6dB/octave) respectively. The applied and equivalent spectra for these noises are shown in Figures 9 and 10.

Again, as in the case of flat noise, according to the model it is predicted that the masking produced by the equivalent noise will be the same as that produced by the applied noises of both, the upward- and downward-sloping spectra respectively.

In order to test the effect of the level of intelligibility in the homophasic listening configuration upon the increase in binaural gain in intelligibility during antiphasic (SπNo) presentation, binaural improvement in intelligibility will be measured at three signal-to-noise ratios. It is predicted that the largest binaural improvements in intelligibility will be obtained at the lowest S/N ratios in all three masking noises, respectively.

One of the reasons for choosing noise with a slope of +6dB/octave and -6dB/octave was that since the speech spectrum falls off at high frequencies, ILD's at even low S/N ratios should involve primarily high frequency information (and should be approximately 3 dB). In contrast,

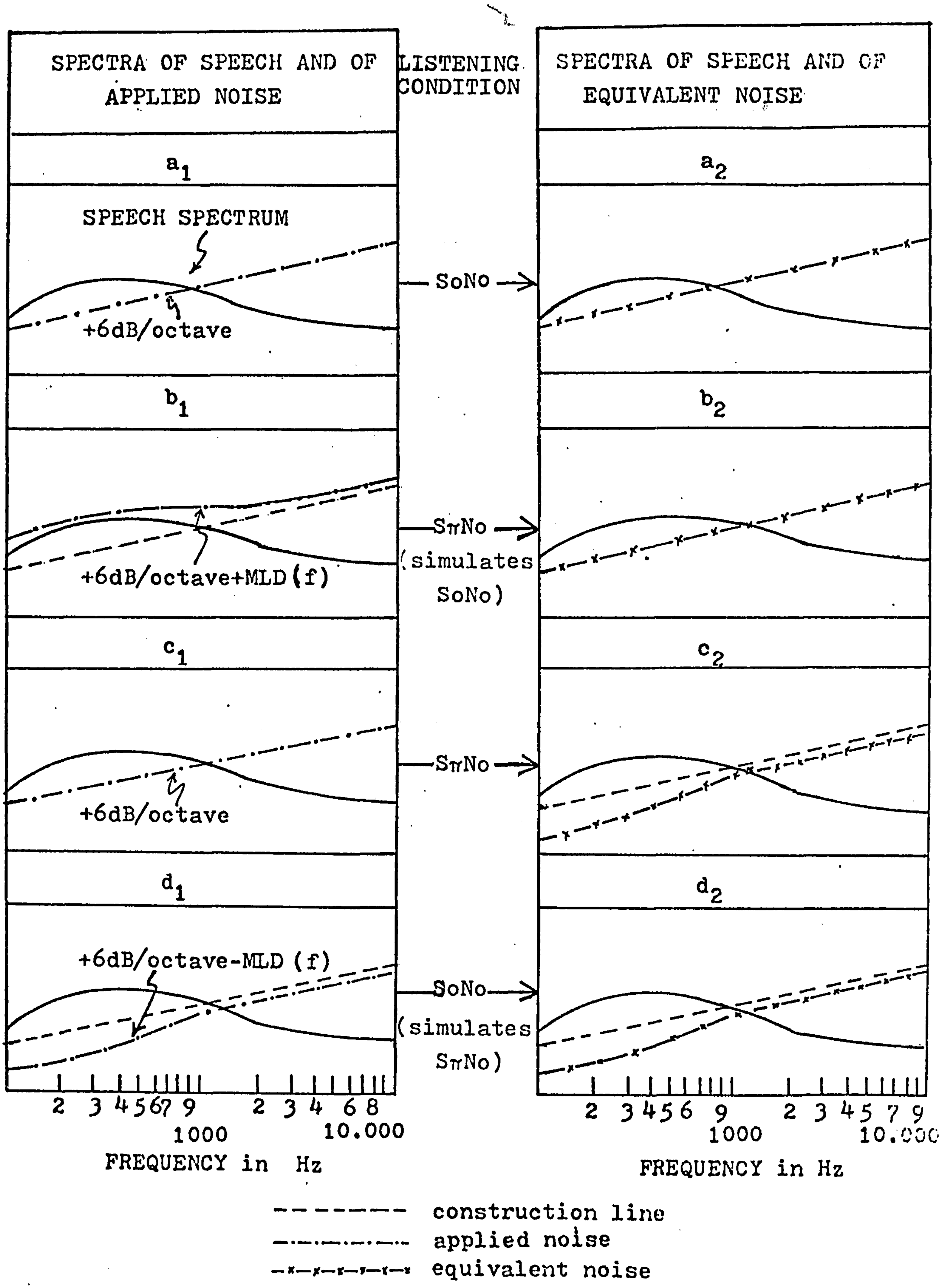

Figure 9. Spectra of applied and equivalent upward sloping noise and typical speech.

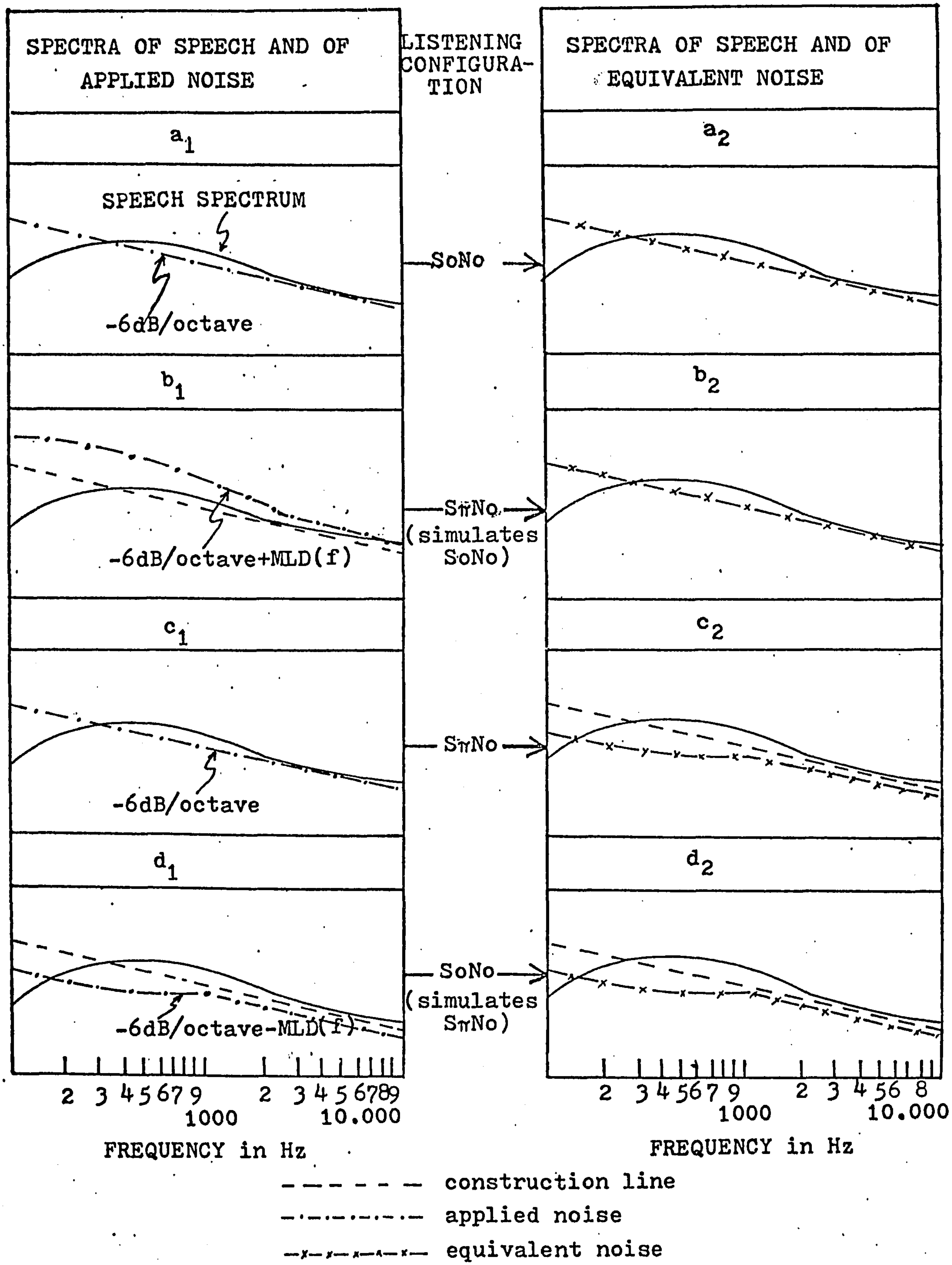

Figure 10. Spectra of applied and equivalent downward sloping noise and typical speech.

for upward sloping (+6dB/octave) noise no ILD's are expected as a result of high frequency phase information.

CHAPTER IV

METHODOLOGY

Experimental Design

The following experimental testing procedures were designed to pursue the investigation outlined in the previous chapter.

1) Speech presented against the background of noise at three different signal-to-noise (S/N) ratios. These were:

  a) at about 50% intelligibility level*
  b) 5 dB below the S/N ratio at which the approximate 50% level was obtained
  c) 10 dB below the S/N ratio at which the approximate 50% level was obtained

2) Noises of three different spectra are used for the masking of speech.

  a) downward sloping, (-6dB/octave)
  b) flat
  c) upward sloping, (+6dB/octave)

3) Homophasic (SoNo) and antiphasic (SπNo) configurations of both regular (applied) and "simulated" (equivalent) noise spectra of all slopes are employed.

4) Four listeners, (two males, and two females) served as subjects.

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*Method for establishing the 50% level of intelligibility is described on page 42.

A block diagram showing the experimental listening conditions employed in this study is presented in Figure 11.

A factorial design was used for the above four factors. Table III lists the 36 listening conditions that were administered to each subject. Each line in the table specifies: a) the noise spectrum, either regular, i.e. -6dB/octave, flat, +6dB/octave, or simulated equivalent, i.e. -6dB/octave-MLD(f), flat-MLD(f), +6dB/octave-MLD(f); b) the S/N ratio at which the test was performed, i.e. 0-, -5, -10 dB; c) the configuration of the speech and the noise, i.e. in phase (SoNo) or out-of-phase (SπNo), the correct percent intelligibility scores obtained by each of the four subjects are listed.

The subjects (two males, and two females) ranging in age from 21 to 36 years, showed 10 dB or better threshhold hearing levels (re ISO-1964 audiometric zero) at 500, 1000, 2000, 3000, 4000, and 6000 Hz. Three of the listeners were native speakers of General American English. One listener was a non-native (English was not her mother tongue) speaker of General American English. Before actual testing procedures were administered, each subject was given a trial period so as to get accustomed to the experimental testing procedure. Each subject participated in nine experimental sessions, one per day. A session lasted about one hour with short rest periods occurring

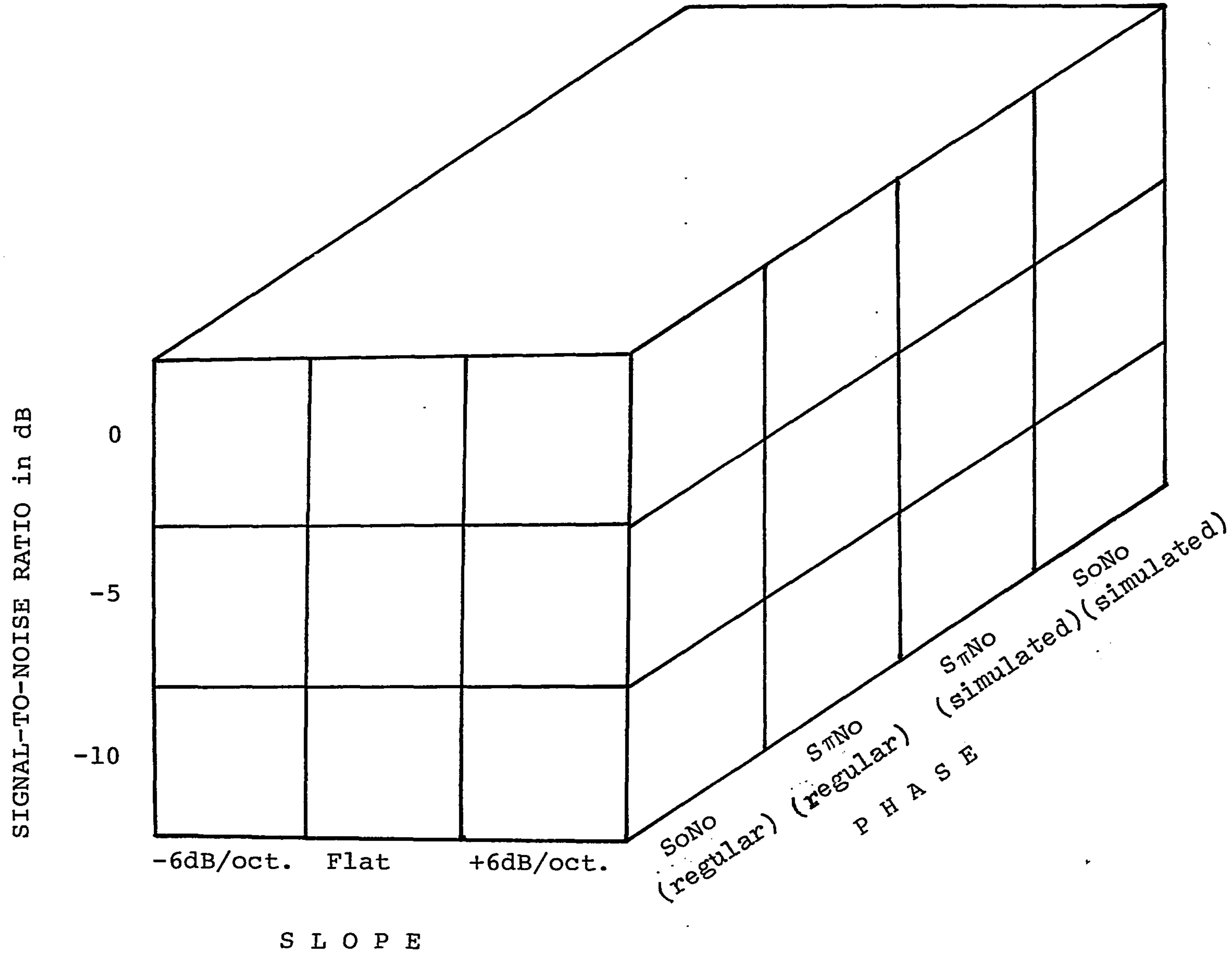

Figure 11. A block diagram showing the experimental listening conditions employed in this study.

TABLE III

SUMMARY OF LISTENING CONDITIONS

TEST NO.	NOISE SPECTRUM	S/N RATIO IN dB	CONFIG-URATION	IDENTICAL TO
1	-6dB/octave	0	SoNo	Regular SoNo
2	-6dB/octave	-5	SoNo	Regular SoNo
3	-6dB/octave	-10	SoNo	Regular SoNo
4	-6dB/octave	0	SπNo	Regular SπNo
5	-6dB/octave	-5	SπNo	Regular SπNo
6	-6dB/octave	-10	SπNo	Regular SπNo
7	-6dB/octave-MLD(f)	0	SoNo	Simulated SπNo
8	-6dB/octave-MLD(f)	-5	SoNo	Simulated SπNo
9	-6dB/octave-MLD(f)	-10	SoNo	Simulated SπNo
10	-6dB/octave+MLD(f)	0	SπNo	Simulated SoNo
11	-6dB/octave+MLD(f)	-5	SπNo	Simulated SoNo
12	-6dB/octave+MLD(f)	-10	SπNo	Simulated SoNo
13	FLAT	0	SoNo	Regular SoNo
14	FLAT	-5	SoNo	Regular SoNo
15	FLAT	-10	SoNo	Regular SoNo
16	FLAT	0	SπNo	Regular SπNo
17	FLAT	-5	SπNo	Regular SπNo
18	FLAT	-10	SπNo	Regular SπNo
19	FLAT-MLD(f)	0	SoNo	Simulated SπNo
20	FLAT-MLD(f)	-5	SoNo	Simulated SπNo
21	FLAT-MLD(f)	-10	SoNo	Simulated SπNo
22	FLAT+MLD(f)	0	SπNo	Simulated SoNo
23	FLAT+MLD(f)	-5	SπNo	Simulated SoNo
24	FLAT+MLD(f)	-10	SπNo	Simulated SoNo
25	+6dB/octave	0	SoNo	Regular SoNo
26	+6dB/octave	-5	SoNo	Regular SoNo
27	+6dB/octave	-10	SoNo	Regular SoNo
28	+6dB/octave	0	SπNo	Regular SπNo
29	+6dB/octave	-5	SπNo	Regular SπNo
30	+6dB/octave	-10	SπNo	Regular SπNo
31	+6dB/octave-MLD(f)	0	SoNo	Simulated SπNo
32	+6dB/octave-MLD(f)	-5	SoNo	Simulated SπNo
33	+6dB/octave-MLD(f)	-10	SoNo	Simulated SπNo
34	+6dB/octave+MLD(f)	0	SπNo	Simulated SoNo
35	+6dB/octave+MLD(f)	-5	SπNo	Simulated SoNo
36	+6dB/octave+MLD(f)	-10	SπNo	Simulated SoNo

every 15 minutes.

Psychometric Procedure

The simple up-down psychometric procedure (Levitt, 1971) was used to establish the 50% intelligibility level. In this type of procedure the listener is presented with a signal masked by noise. On his response sheet he indicates the syllable he heard. The subject's response determines the following stimulus intensity level. If a correct identification is made, the signal-to-noise ratio is decreased on the test trials (noise level is kept constant) by one dB. If an incorrect identification is made, the S/N ratio is increased by one dB. An error occurring after attenuation of the signal constituted a reversal and marked the beginning of an upward series of steps, known as a run. The estimation procedure is as follows: the midpoint of every second run constitutes the estimate X_{50}, corresponding to 50% positive responses. Figure 12 depicts a hypothetical subject's response pattern showing several runs.

The Masking Noise

The masking noise was produced by a noise generator (Grason Stadler, Model 901 B). The output of the noise generator was led to a spectrum shaper (GR Multifilter, Model 1925, one-third octave; 250 Hz - 20 KHz, and then to a tape recorder (Sony, Model TD-352 D). Altogether

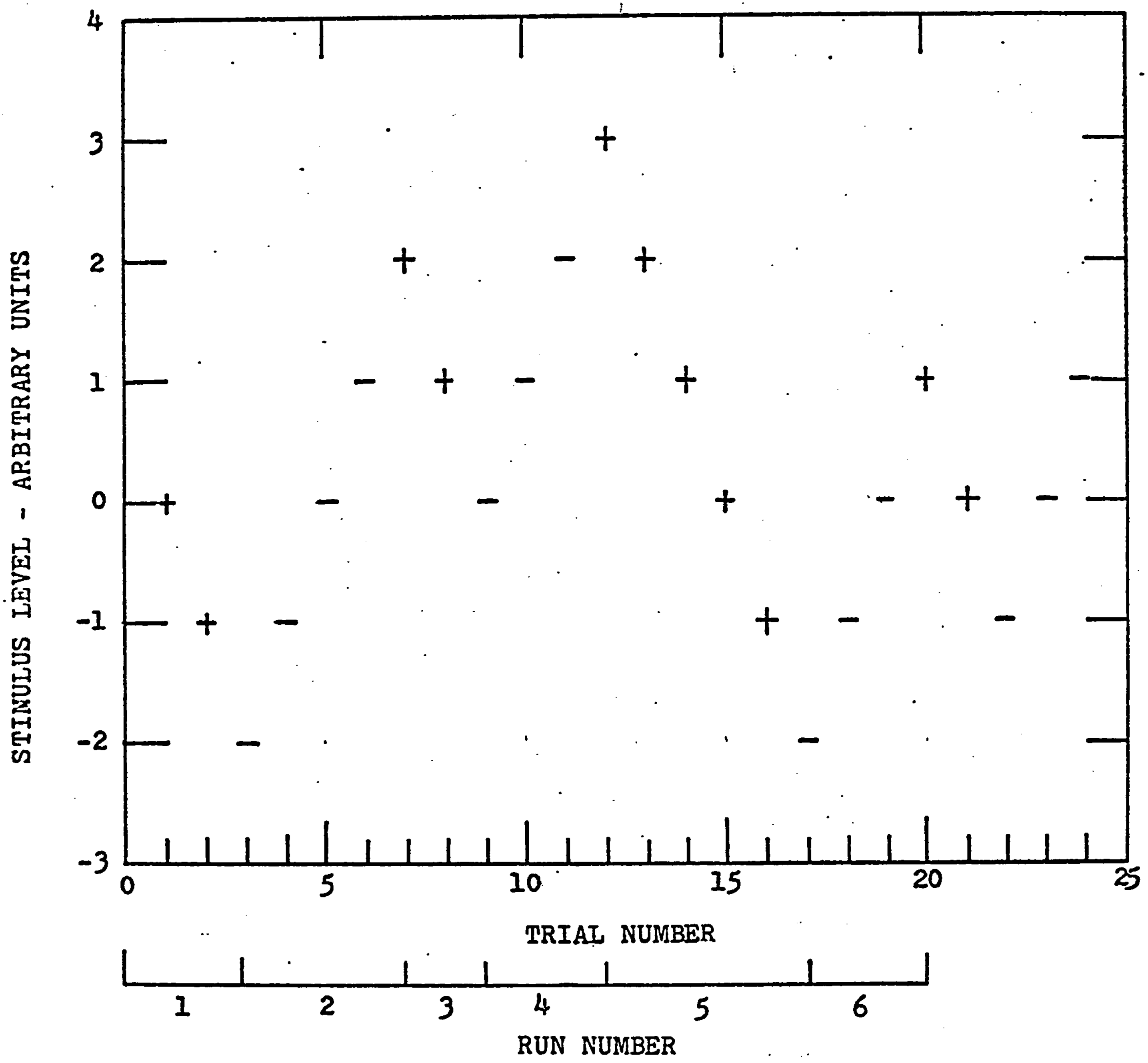

Figure 12. Typical response pattern for the simple up-down procedure. The midpoint of every second run was used in the estimation of 50% correct identification. In this hypothetical case the estimates would be 0, 1.5, -0.5 for runs 2, 4, and 6, respectively. (After, Levitt, 1971.)

nine experimental magnetic tapes, each consisting of one of the noise spectra used in this investigation were prepared. Because of the limited dynamic range of the tape recorder and the spectrum shaper, the spectra produced on these test tapes differed slightly from the intended spectra. The differences between the intended and measured spectra of the test tapes are shown in Figures 13, 14, and 15. In each of these figures the left-hand panel shows the one-third octave band spectra as measured on a graphic level recorder, (Bruel & Kjaer, Type 203). The right-hand panel shows the intended spectra as converted to one-third octave band values, i.e. the spectrum of the flat noise (Figure 14, upper right-hand panel) instead of having a 0-dB slope, has a slope of +3dB/octave.

In only one case, that of the noise spectrum +6dB/octave-MLD(f) (Figure 15 - mid panel), was there a significant difference between the intended and measured spectrum. This was because the dynamic range required of the intended spectrum was close to 60 dB. The effect of the system's noise is shown by the flattening of the noise spectrum in the lower frequency bands. The measured rather than the intended spectra were used in calculating all predictions of the model.

The Speech Stimuli

A Nonsense Syllable Test (NST) Resnick, Dubno, Hofnung,

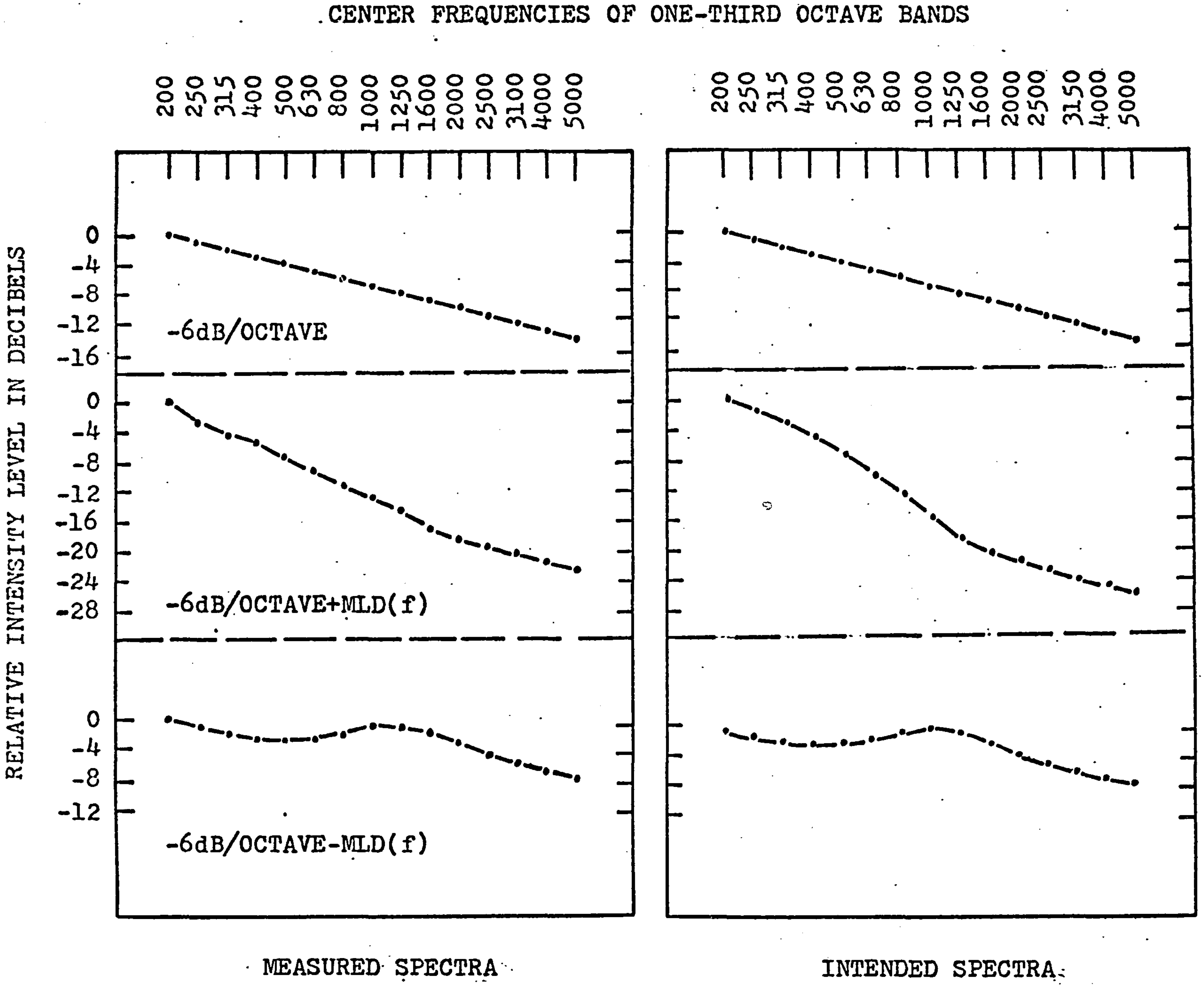

Figure 13. Plots based upon one-third octave band analyses of graphic level recording measurements of -6dB/octave, -6dB/octave+MLD(f), and -6dB/octave -MLD(f) noise spectra, (left-hand panel). Intended spectra are presented in right-hand panel.

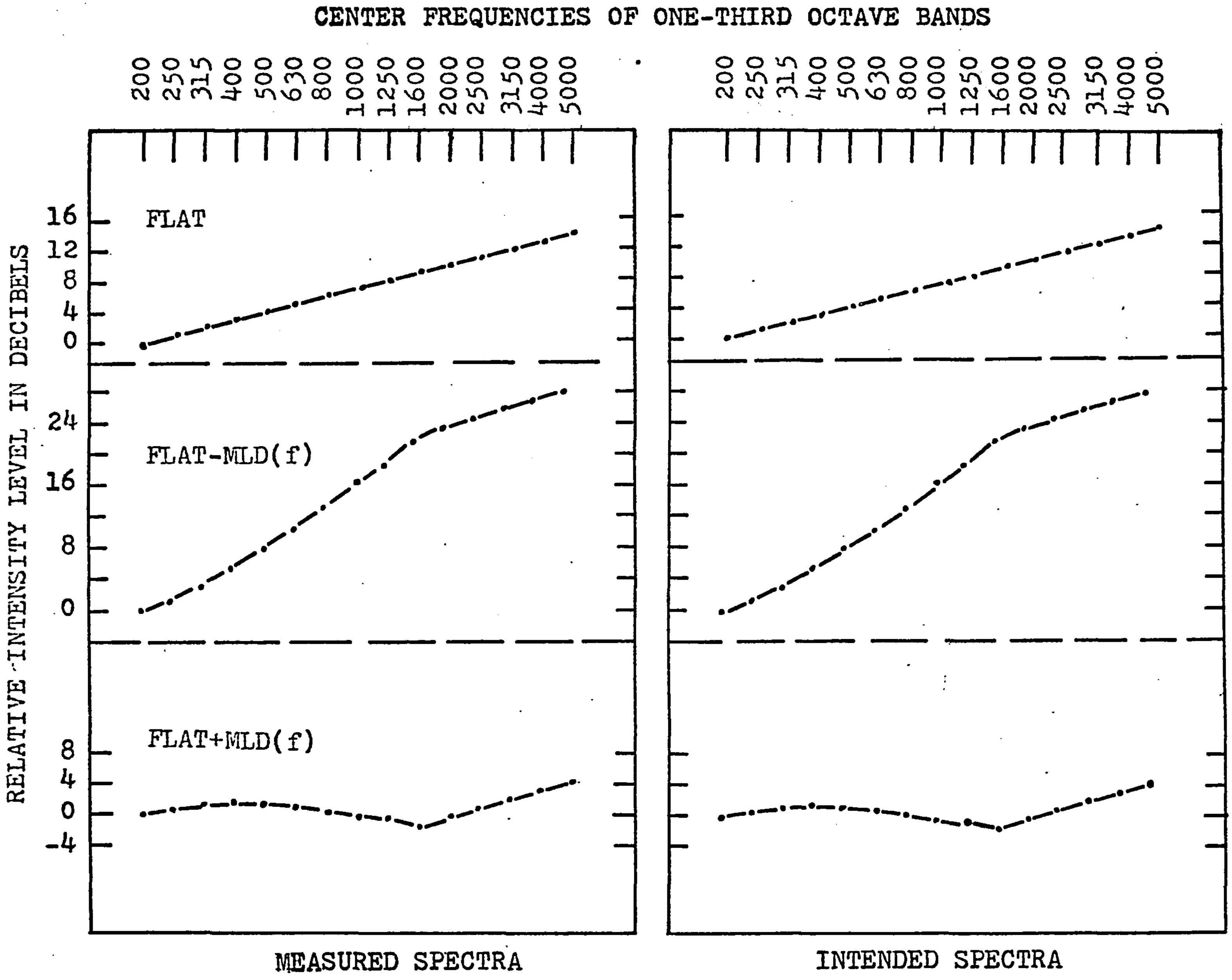

Figure 14.. Plots based upon one-third octave band analyses of graphic level recording measurements of flat, flat-MLD(f) and flat+MLD(f) noise spectra, (left-hand panel). Intended spectra are presented in left-hand panel.

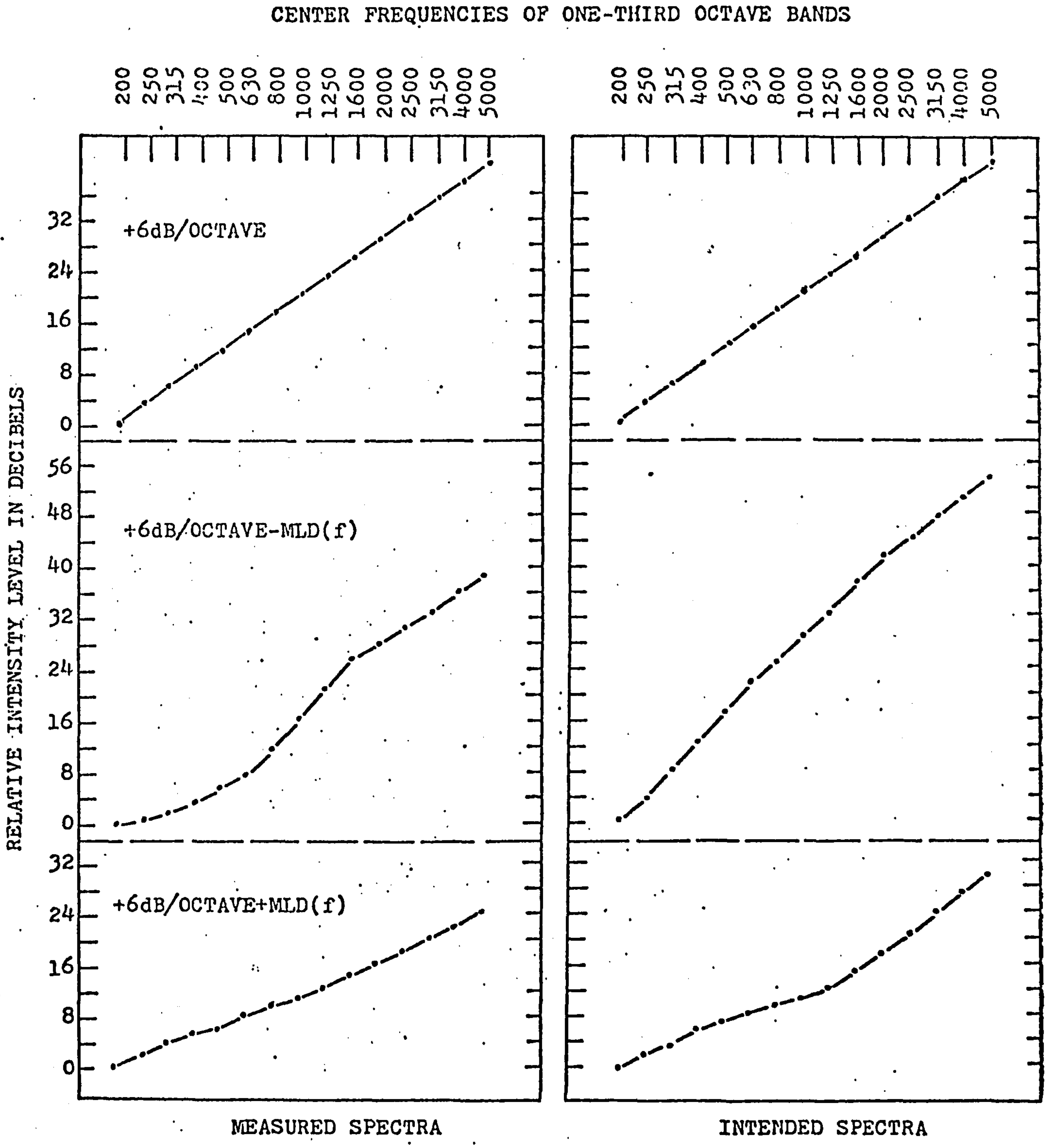

Figure 15. Plots based upon one-third octave band analyses of graphic level recording measurements of +6dB/octave, +6dB/octave-MLD(f), and +6dB/octave +MLD(f) noise spectra,(left-hand panel). Intended spectra are presented in right-hand panel.

and Levitt, (1975), was used as the speech signal. The NST is a closed response test consisting of CV, VC, and CVC syllables organized into 12 subtests. All but one of the subtests are designed to provide information on the discriminability of consonants. Seven of those subtests were used in this study, and are shown in Table IV. The subject's responses to syllables within a given subtest are limited to other syllables within the same subtest. The construction of the subtests was based on information regarding the frequency of occurrence of phoneme identification errors by normal hearing and hearing impaired individuals. The subject, therefore, has the opportunity to make errors of manner and place in phoneme identification within each subtest, but errors of voicing are not possible. Of the seven subtests used in this experiment, Subtests 1, 2 and 3 are designed to provide information pertaining to the discriminability of final unvoiced phonemes in three vowel contexts: /i/, /a/, and /u/. Subtest 4 provides assessment of the discriminability of final voiced phonemes in the /a/ context. The discriminability of initial phonemes is evaluated in Subtest 5. Subtests 6 and 7 permit evaluation of initial voiced phonemes.

Instrumentation

The instrumentation was designed so as to enable in-

TABLE IV

THE NONSENSE SYLLABLES SUB-TESTS

1	2	3	4	5	6	7
af	uθ	iʃ	ab	fa	la	na
aʃ	up	if	að	ta	ba	va
at	us	it	ad	pa	da	ma
ak	uk	ik	am	ha	ga	za
as	ut	is	az	θa	ra	ga
ap	uf	iθ	ag	tʃa	ja	ba
aθ	uʃ	ip	an	sa	dʒa	ða
			aŋ	ʃa	wa	da
			av	ka		

Subtests 1, 2, 3, and 5 contain only voiceless consonants, and subtests 4, 6, and 7 contain only voiced consonants.

dependent control of the noise and signal channels in order to provide the interaural phase relationship required for each listening condition.

A block diagram of the instrumentation is presented in Figure 16. The noise tapes were played on one tape recorder; (Sony, Model TC-270) at 7 1/2 ips, and the tapes of the speech materials were played on a second tape recorder (Sony, Model TC-352 D 7 1/2 ips). The output of each tape recorder was led to a separate amplifier. A Heathkit amplifier (Model AA-14) was used in the noise channel; a General Radio amplifier (Type 1203-B) was used in the signal channel. Signal and noise intensity were controlled separately by attenuators, one having a 10-dB, the other a 1-dB size step. From the attenuators, each channel was led to a transformer (United Transformer Co., Type HA-108) with input switches allowing the polarity of the noise and speech stimuli, respectively, to be reversed. Appropriate setting of the switch yielded either So (in phase) or Sπ (180° out of phase) relations for the speech signal. The experimental design called for phase reversal of only the speech stimulus, whereas the noise stimulus was presented binaurally in phase (No) in all experimental procedures. The two channels were then led each to an adder, whereby the two mixed stimuli were then presented to matched earphones (Telephonics, TDH-49) wired

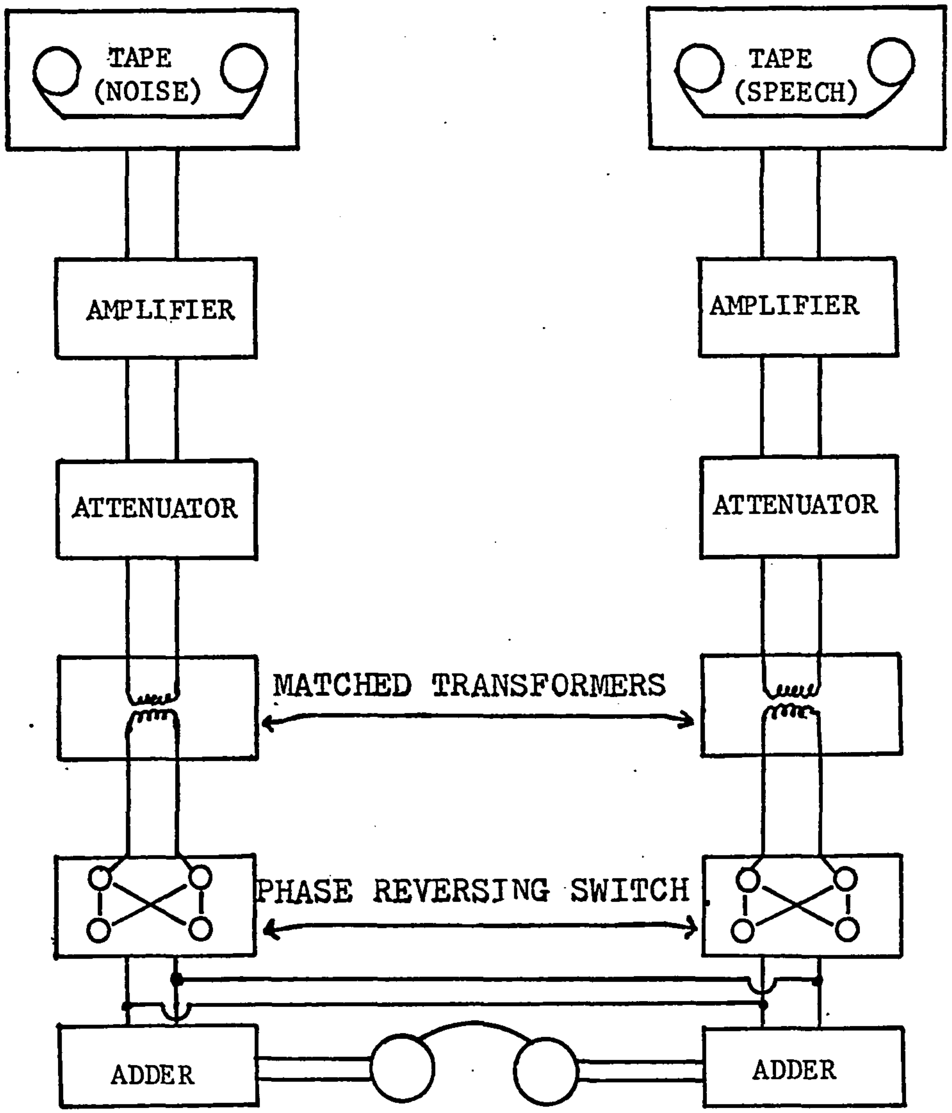

Figure 16. Block Diagram of Apparatus.

in parallel for binaural presentation.

Calibration Procedures

It was necessary to insure that the earphones used were matched as closely as possible. The earphones to be used were coupled with a calibrated sound level meter (Bruel & Kjaer, Type 2203), and a Type 4152 artificial ear.

The measurements showed that the frequency response of each earphone (Telephonics TDH-49) was flat from 50 to 6000 Hz within 1 dB. The intensity balance between the earphones was checked by measuring the acoustic output of each earphone while the output of the noise generator, adjusted to 87 dB was passed through the network. The measurement revealed that the differences in intensity level between the earphones was no greater than 1 dB.

The frequency response of the two tape recorders used for the presentation of the signal and noise stimuli was also found to be essentially flat ±2 dB from 50 to 6000 Hz.

The linearity of all attenuators was measured before the experimental testing started, once during the period of data collecting, and at the completion of the investigation. A pure tone signal was passed through the system and successive voltage readings were made across the earphones, using a vacuum voltmeter (Hawlett-Packard, Model 400 D).

A check of the interaural phase relations and relative intensities for binaural signals was made by using a 500 Hz sine wave while setting the switch to So (in phase) and Sπ (180° out of phase). The output was led to a dual beam oscilloscope (Tetronix, Type 564) where the phase relationships could be visually observed.

The intensity level of the masking noise was maintained at 87 dB SPL measured under the earphones throughout the entire experiment. The bandwidth of the noise was effectively limited by the characteristics of the earphones. The spectrum level of the experimental noise was 49.2 dB SPL.

The signal and noise magnetic tapes, respectively, had a 400 Hz calibration tone recorded at the initial portion, so as to enable an accurate setting of the desired S/N ratio.

CHAPTER V

RESULTS

1. Simulation of Binaural Equivalent Noise

A summary is presented in Table V, where scores obtained by each of the four subjects under each testing condition are given. Figures 17-19 portray the average percent intelligibility scores obtained in homophasic and antiphasic listening configurations when speech was presented against the background of downward-sloping (-6dB/octave), flat, and upward-sloping (+6dB/octave) noise spectra respectively. The ordinate represents the percent correct identification, the abscissa, the S/N ratio at which these scores were obtained, for homophasic (SoNo) and antiphasic (SπNo) configurations. Scores obtained for the simulated equivalent noise listening conditions are superimposed on those obtained for the regular noise conditions. Inspection of Figures 17-19 indicates that the data obtained under simulated noise conditions fit reasonably well those obtained under regular listening conditions. This statement holds true, with one exception, for all three noise spectra, and at every S/N ratio. The one exception is that for downward-sloping noise (-6dB/octave), (Figure 17) in the homophasic configuration at 0-dB S/N ratio. For this case scores are lower by about 13% for the simulated noise condition.

TABLE V

SUMMARY OF RESULTS FOR ALL LISTENING CONDITIONS

TEST NO.	NOISE SPECTRUM	S/N RATIO IN dB	CONFIGURATION	SUBJECTS' SCORES IN % INTELLIGIBILITY			
				S1	S2	S3	S4
1	-6dB/octave	0	SoNo	60	72	72	67
2	-6dB/octave	-5	SoNo	47	52	52	44
3	-6dB/octave	-10	SoNo	21	27	27	29
4	-6dB/octave	0	SπNo	71	82	82	81
5	-6dB/octave	-5	SπNo	65	66	66	63
6	-6dB/octave	-10	SπNo	52	52	52	47
7	-6dB/octave-MLD(f)	0	SoNo	77	95	95	84
8	-6dB/octave-MLD(f)	-5	SoNo	68	73	73	73
9	-6dB/octave-MLD(f)	-10	SoNo	48	55	55	45
10	-6dB/octave+MLD(f)	0	SπNo	52	65	65	61
11	-6dB/octave+MLD(f)	-5	SπNo	50	52	52	47
12	-6dB/octave+MLD(f)	-10	SπNo	26	26	26	21
13	FLAT	0	SoNo	61	60	71	66
14	FLAT	-5	SoNo	55	55	63	63
15	FLAT	-10	SoNo	48	48	47	48
16	FLAT	0	SπNo	76	68	71	66
17	FLAT	-5	SπNo	60	60	63	63
18	FLAT	-10	SπNo	47	48	47	48
19	FLAT-MLD(f)	0	SoNo	76	68	71	66
20	FLAT-MLD(f)	-5	SoNo	60	60	63	63
21	FLAT-MLD(f)	-10	SoNo	47	44	42	45
22	FLAT+MLD(f)	0	SπNo	66	65	69	66
23	FLAT+MLD(f)	-5	SπNo	53	50	50	42
24	FLAT+MLD(f)	-10	SπNo	34	36	36	32
25	+6dB/octave	0	SoNo	68	76	76	63
26	+6dB/octave	-5	SoNo	50	53	53	47
27	+6dB/octave	-10	SoNo	39	53	53	40
28	+6dB/octave	0	SπNo	69	74	74	68
29	+6dB/octave	-5	SπNo	58	60	60	52
30	+6dB/octave	-10	SπNo	48	55	55	47
31	+6dB/octave-MLD(f)	0	SoNo	77	77	77	69
32	+6dB/octave-MLD(f)	-5	SoNo	60	66	66	61
33	+6dB/octave-MLD(f)	-10	SoNo	53	65	65	62
34	+6dB/octave+MLD(f)	0	SπNo	60	74	74	60
35	+6dB/octave+MLD(f)	-5	SπNo	55	60	60	48
36	+6dB/octave+MLD(f)	-10	SπNo	42	47	47	42

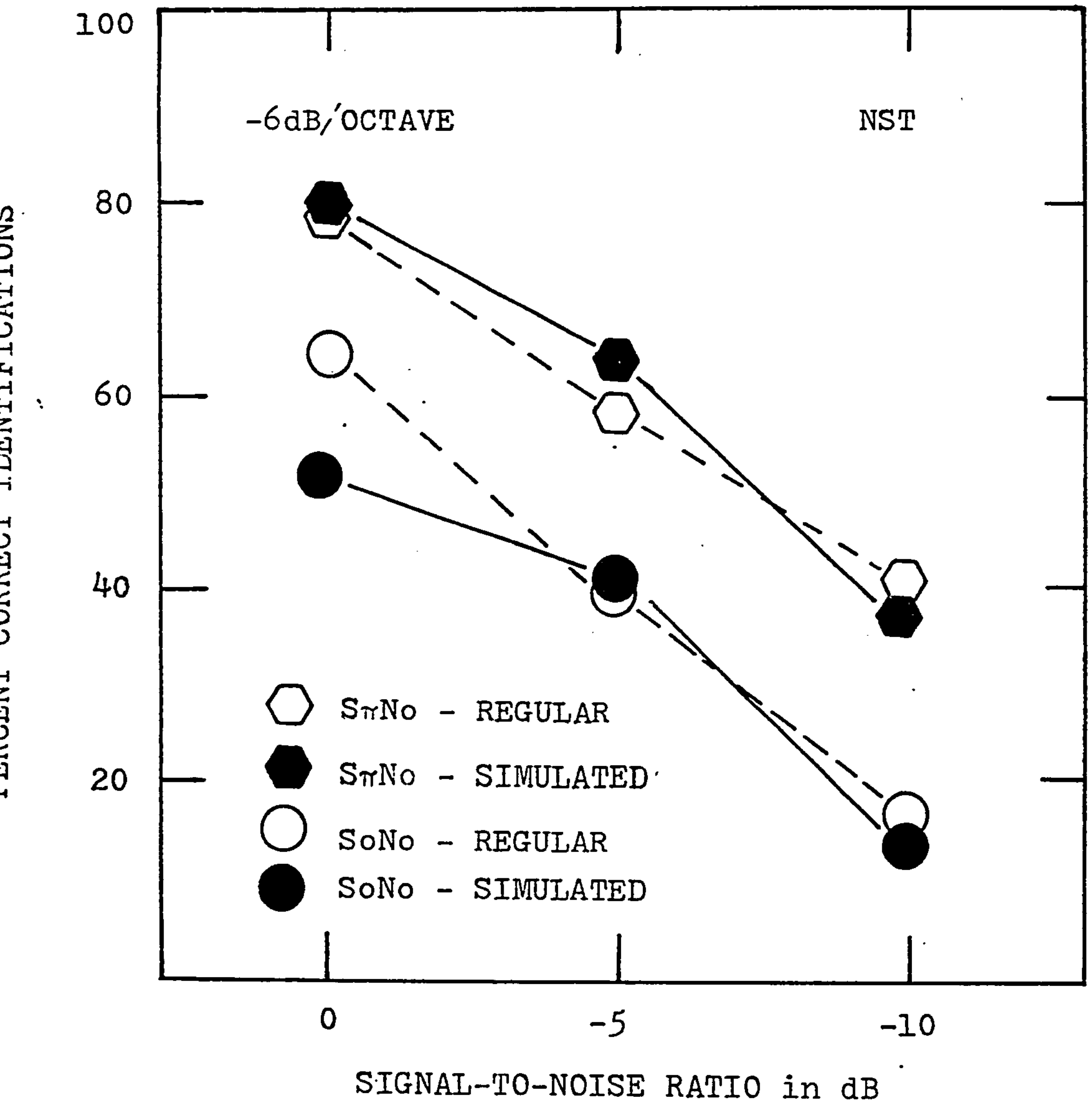

Figure 17. Binaural improvement in intelligibility for the NST masked by -6dB/octave sloping noise (regular and simulated) at three different S/N ratios). The plotted data have a standard error on the order of 2.9 percentage points.

Note on Standard Error of Plotted Points

Since the variance of a percentage varies as a function of the value of the percentage, an average standard error is cited for each diagram. This average is the standard error for 75% correct identifications. The standard error at 50% correct is roughly 15% greater and at 90% correct it is roughly 45% smaller. It should be noted that all the statistical tests were carried out using an arc-sine transformation to stabilize the error variance. The data, however, have been plotted in terms of percent correct since this is common practice.

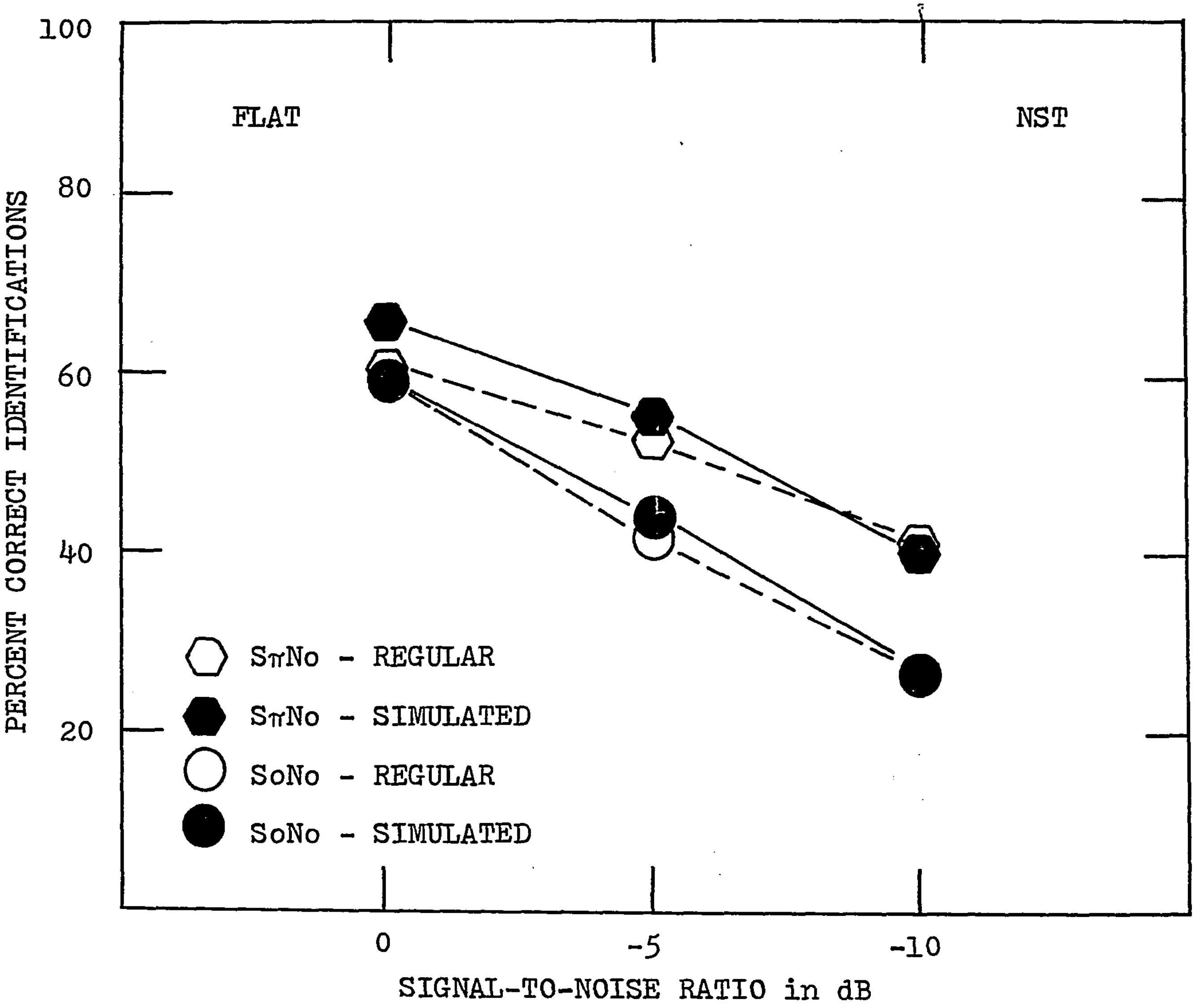

Figure 18. Binaural improvement in intelligibility for the NST masked by flat noise (regular and simulated) at three different S/N ratios. The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

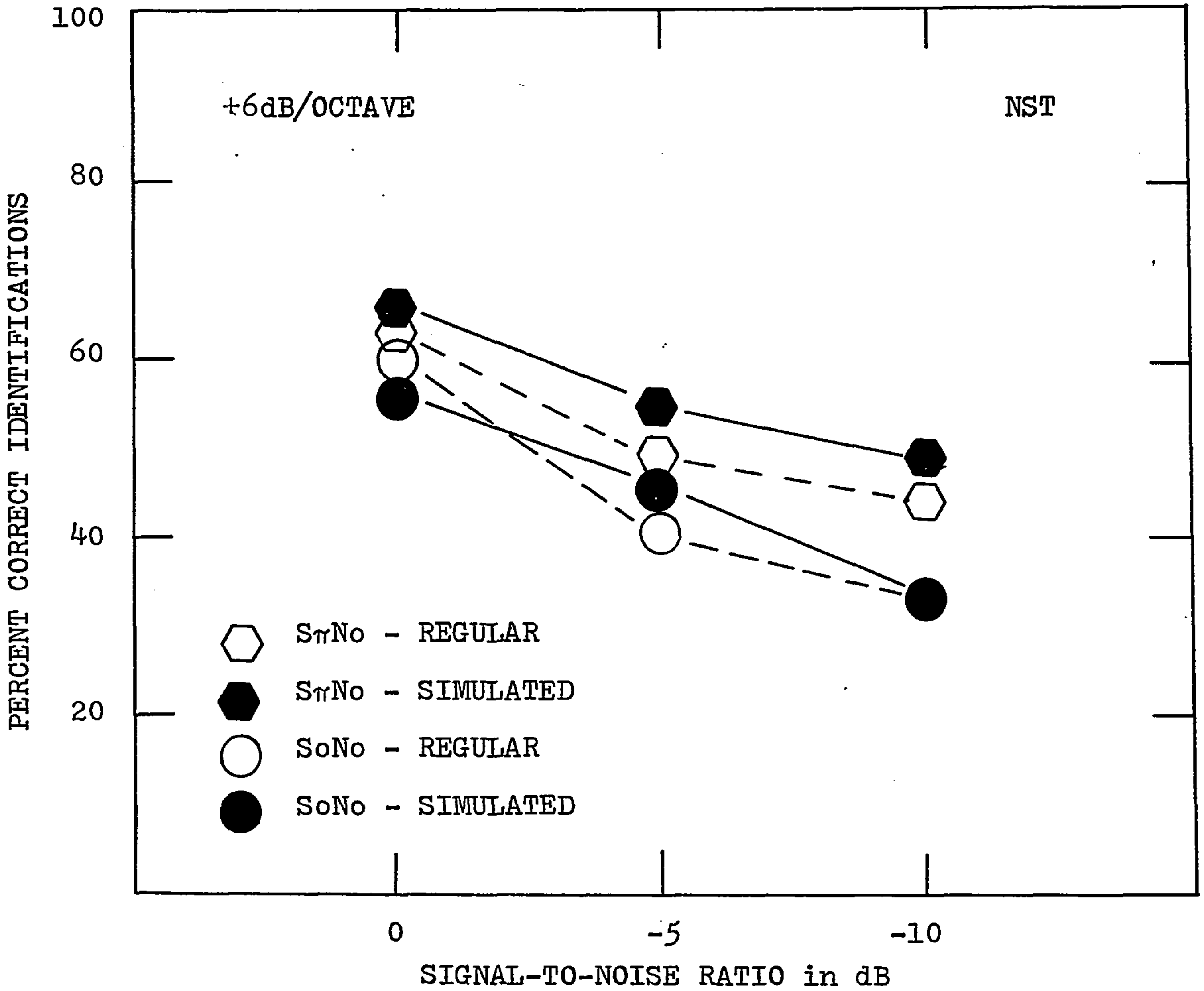

Figure 19. Binaural improvement in intelligibility for the NST masked by +6dB/octave sloping noise (regular and simulated) at three different S/N ratios. The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

In order to further examine the validity of the model as far as the prediction of the identical masking effect of simulated and regular noise, scores for voiced and voiceless consonants masked by simulated and regular noises, respectively, are plotted separately, as presented in Figures 20-22. Inspection of the scores indicate that not only for the NST list as a whole, as shown in Figures 17-19, but also for specific consonant classes, the masking effect of real and simulated noises did not significantly differ. Again, this statement holds true, with the above mentioned exception, for all noise spectra, at all S/N ratios, for both homophasic and antiphasic listening conditions. The separation of voiced versus voiceless consonants, also enable us to trace the locus of disparity, where scores for simulated noise at 0-dB S/N ratio for the homophasic configuration (Figure 20, left panel) showed a 20% difference between regular and simulated noise masking conditions. It can be seen from Figure 20 that this disparity occurrs only for voiceless consonants, and only for the simulated SoNo condition of 0-dB S/N ratio.

Perceptual Confusions

Given that the predictions made by the model (i.e. the effect of binaural processing may be represented by an equivalent reduction in the level of the applied noise), have been demonstrated for the NST as a whole, and for

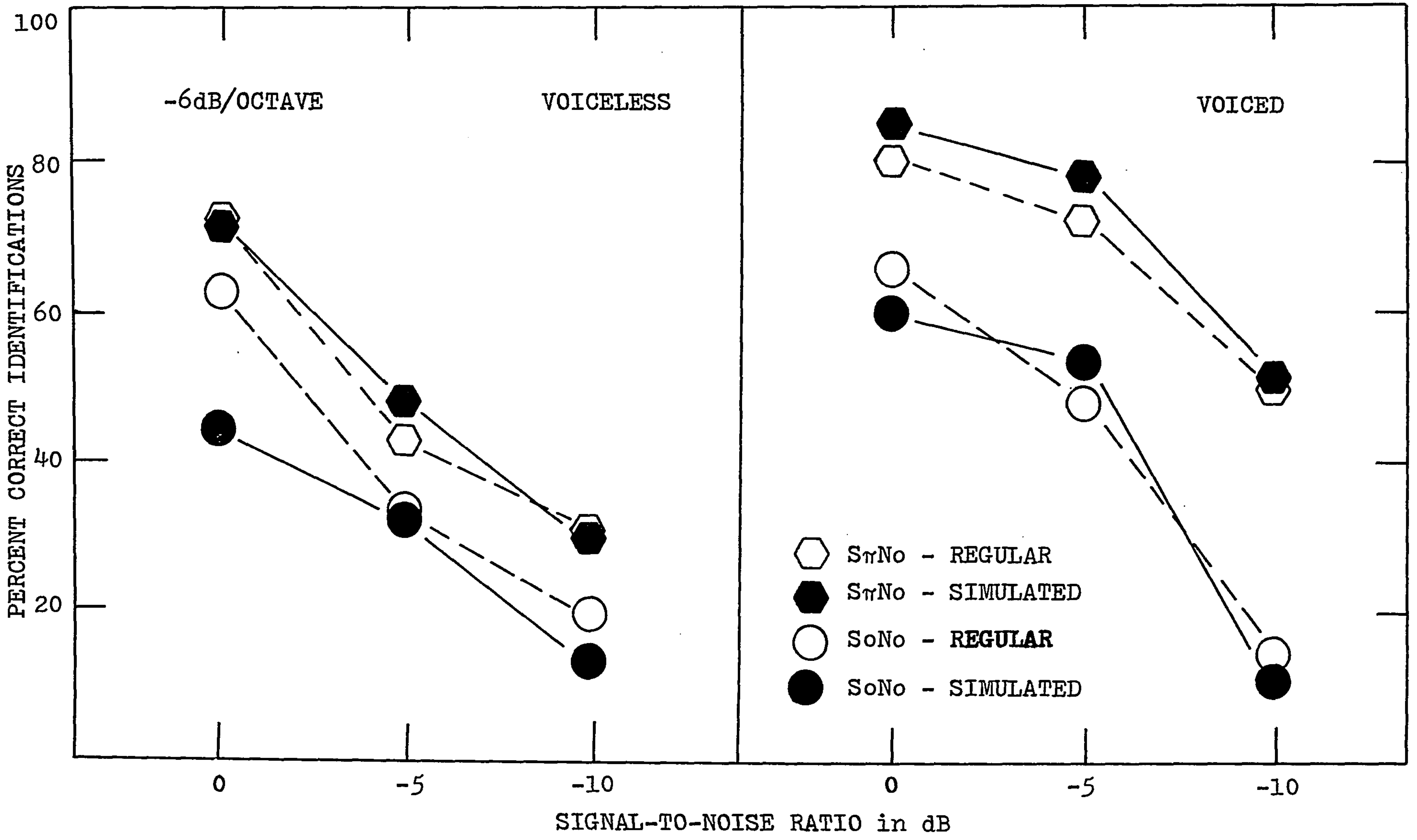

Figure 20. Binaural improvement in intelligibility for voiceless and voiced consonants masked by -6dB/octave sloping noise (regular and simulated) at three different S/N ratios. The plotted data have a standard error on the order of 3.8 percentage points (see note on page 56).

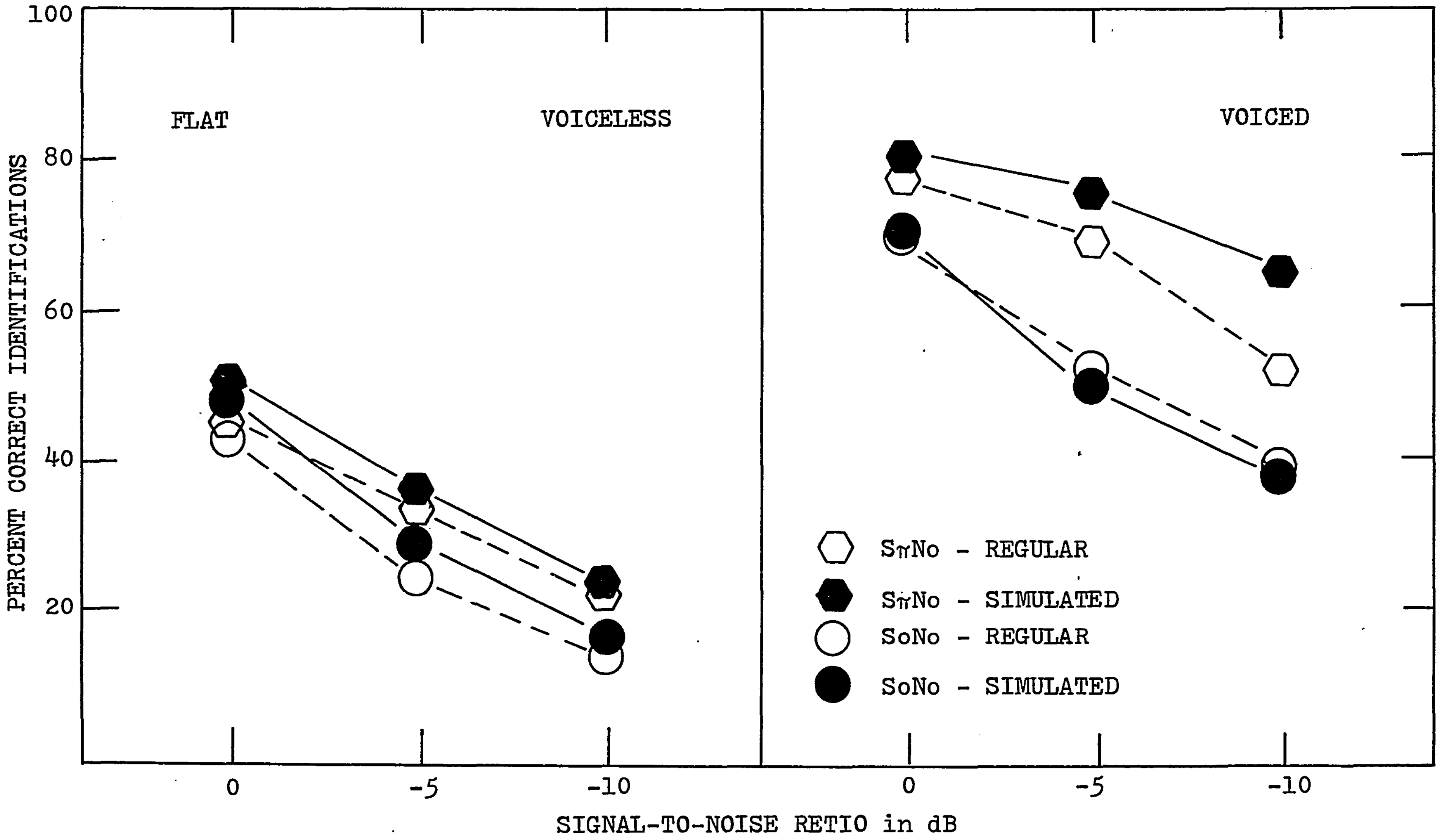

Figure 21. Binaural improvement in intelligibility for voiceless and voiced consonants masked by flat noise (regular and simulated) at three different S/N ratios. The plotted data have a standard error on the order of 3.8 percentage points (see note on page 56).

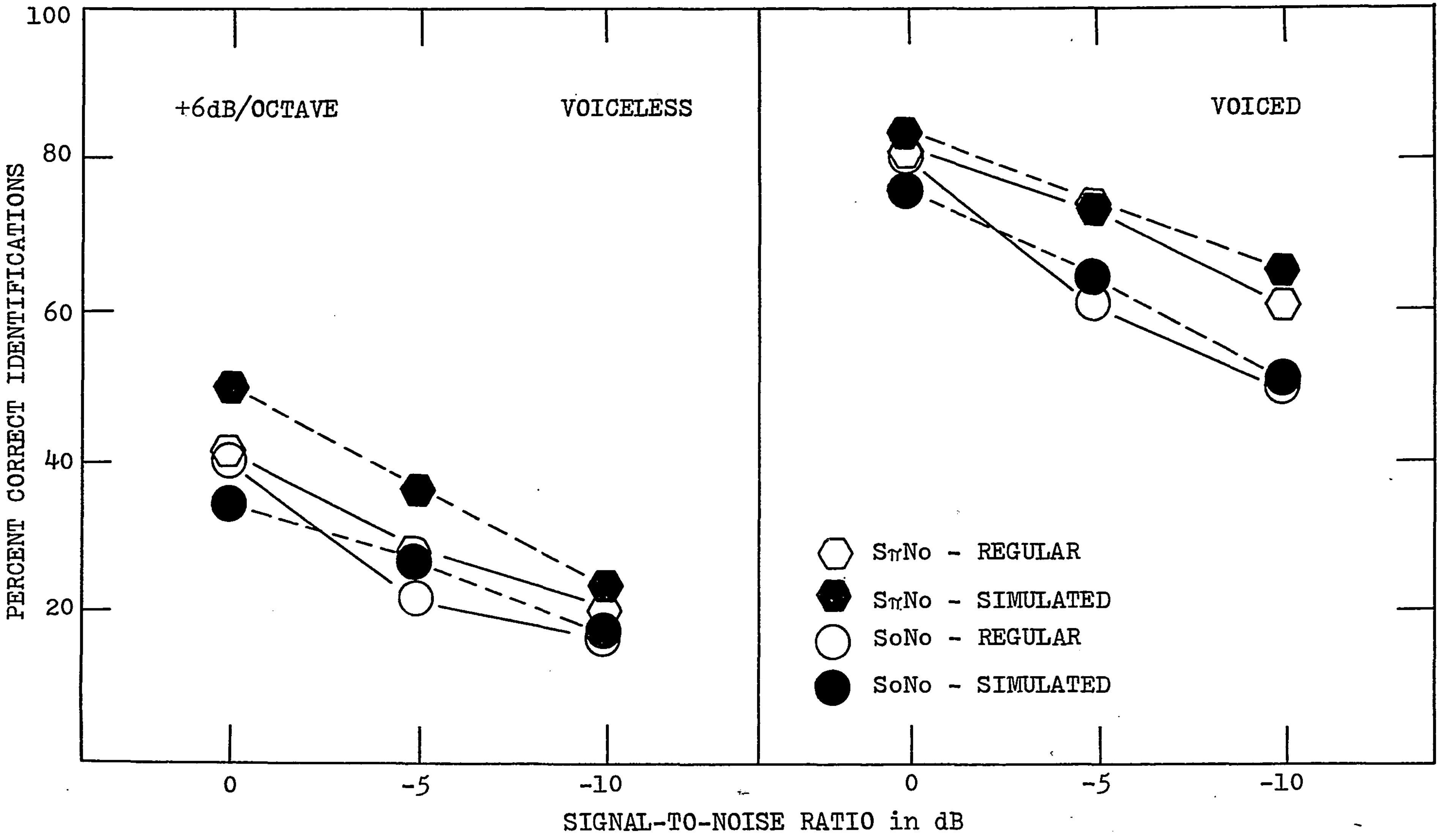

Figure 22. Binaural improvement in intelligibility for voiceless and voiced consonants masked by +6dB/octave sloping noise(regular and simulated)at three different S/N ratios. The plotted data have a standard error on the order of 3.8 percentage points (see note on page 56).

voiced and voiceless consonants. The question remains whether the same results are apparent for the individual phonemes represented in the NST. Therefore, confusion matrices for regular and simulated noise listening conditions for each phoneme in the seven subtests were prepared, are presented in Appendix I. An illustrative example of Subtest #1 is presented on the following page (Table VI).

In each matrix, data obtained for all listeners, for all observations for each subtest are summarized. Thus, each syllable was judged 144 times. In these tables the syllables that were spoken (i.e. target syllables) are indicated horizontally. The responses of the subjects are indicated on the vertical. The number in each cell of the main diagonal indicates the percent correct identification that the target response pair was observed. Thus, in Table VI (representing Subtest #1) the number 0.3611 indicates that the syllable /af/ obtained a 36% correct identification score in all homophasic listening, under regular masking noise conditions. Each table is divided horizontally into four sections. The first section, listing the scores obtained for the regular S_oN_o condition. The second section lists the scores obtained for the regular $S_\pi N_o$ condition. Sections three and four show the scores for simulated $S_\pi N_o$ and simulated

TABLE VI

CONFUSION MATRIX
Subtest #1

	af	aʃ	at	ak	as	ap	aθ	
af	0.3611	0.0833	0.0972	0.0556	0.0833	0.0	0.0972	REAL SoNo
aʃ	0.2500	0.4444	0.0556	0.0139	0.0633	0.1389	0.0417	
at	0.0566	0.0278	0.4722	0.1389	0.0833	0.0556	0.0250	
ak	0.0833	0.1389	0.0417	0.4583	0.4444	0.3333	0.0972	
as	0.1111	0.0556	0.2222	0.1250	0.1111	0.0556	0.0278	
ap	0.1111	0.2222	0.0556	0.1526	0.1111	0.4167	0.0694	
aθ	0.0278	0.0278	0.0556	0.0556	0.0833	0.0	0.5417	
af	0.4722	0.1111	0.1667	0.0833	0.1389	0.0278	0.0694	REAL SπNo
aʃ	0.3056	0.5000	0.0	0.0	0.0833	0.1944	0.0417	
at	0.0556	0.0	0.7500	0.2083	0.1389	0.0833	0.1111	
ak	0.0556	0.1389	0.0556	0.4444	0.2778	0.2222	0.0139	
as	0.0556	0.0833	0.0139	0.0417	0.1111	0.0	0.0417	
ap	0.0556	0,1667	0,0139	0.1389	0.1667	0.4722	0.0972	
aθ	0.0	0.0	0.0	0.0833	0.0833	0.0	0.6250	
af	0.3333	0.0556	0.0	0.0278	0.1111	0.0556	0.0278	SIMULATED SπNo
aʃ	0.2500	0.5278	0.1111	0.0972	0.1111	0.0556	0.0278	
at	0.1111	0.0278	0.5972	0.0833	0.0833	0.0556	0.0972	
ak	0.1111	0.1389	0.1667	0.6111	0.2778	0.1111	0.0417	
as	0.0833	0.0	0.0417	0.0972	0.1944	0.0556	0.0	
ap	0.0833	0.2500	0.0556	0.0694	0.0833	0.5556	0.0694	
aθ	0.0278	0.0	0.9274	0.0139	0.1389	0.0	0.7361	
af	0.2500	0.0556	0.0278	0.1111	0.1111	0.0833	0.0972	SIMULATED SoNo
aʃ	0.3611	0.4167	0.0972	0.0972	0.1111	0.0556	0.0417	
at	0.0633	0.0278	0.5000	0.1111	0.1944	0.0833	0.1528	
ak	0.1389	0.2778	0.0972	0.3750	0.2778	0.2500	0.1389	
as	0.0278	0.0276	0.1389	0.1111	0.1111	0.0556	0.0417	
ap	0.1111	0.1667	0.0278	0.1528	0.1667	0.4444	0.0	
aθ	0.0278	0.0276	0.1111	0.0417	0.0278	0.0278	0.5278	

SoNo conditions respectively. When scores for regular and corresponding simulated conditions are compared, one should always compare Sections 1 vs 4, and Sections 2 vs 3. Based upon these confusion matrices, scattergrams were plotted. Computer printouts for each subtest, one for the SoNo and one for the SπNo, regular and simulated masking conditions, altogether 14 in number of the seven subtests are presented in Appendix II. An illustrative scattergram is presented on the following page, the rest are included in the Appendix II. A summary of data obtained from all scattergrams is presented in Table VII. It can be seen from Table VII, that with one exception (Subtest #7, regular vs simulated SoNo condition) slopes are slightly lower than 1.0. This indicates that on the average error scores for the simulated noise conditions are slightly lower than those for the regular noise conditions.

2. Influence of S/N Ratio Upon Binaural Improvement in Intelligibility

Since the regular and simulated conditions yielded essentially the same scores, more precise representation of the effect of S/N ratio on the binaural release from masking can be obtained by averaging the regular and simulated conditions. This was done in Figures 23, 24, and 25. Inspection of the data shows that as S/N ratio decreases, there is a larger separation between the intelligibility functions. Namely, there is a greater

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MODULE TWO                                                                                    04/01/76         PAGE    8

FILE   NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SPINC                                         (ACROSS) SIMPI
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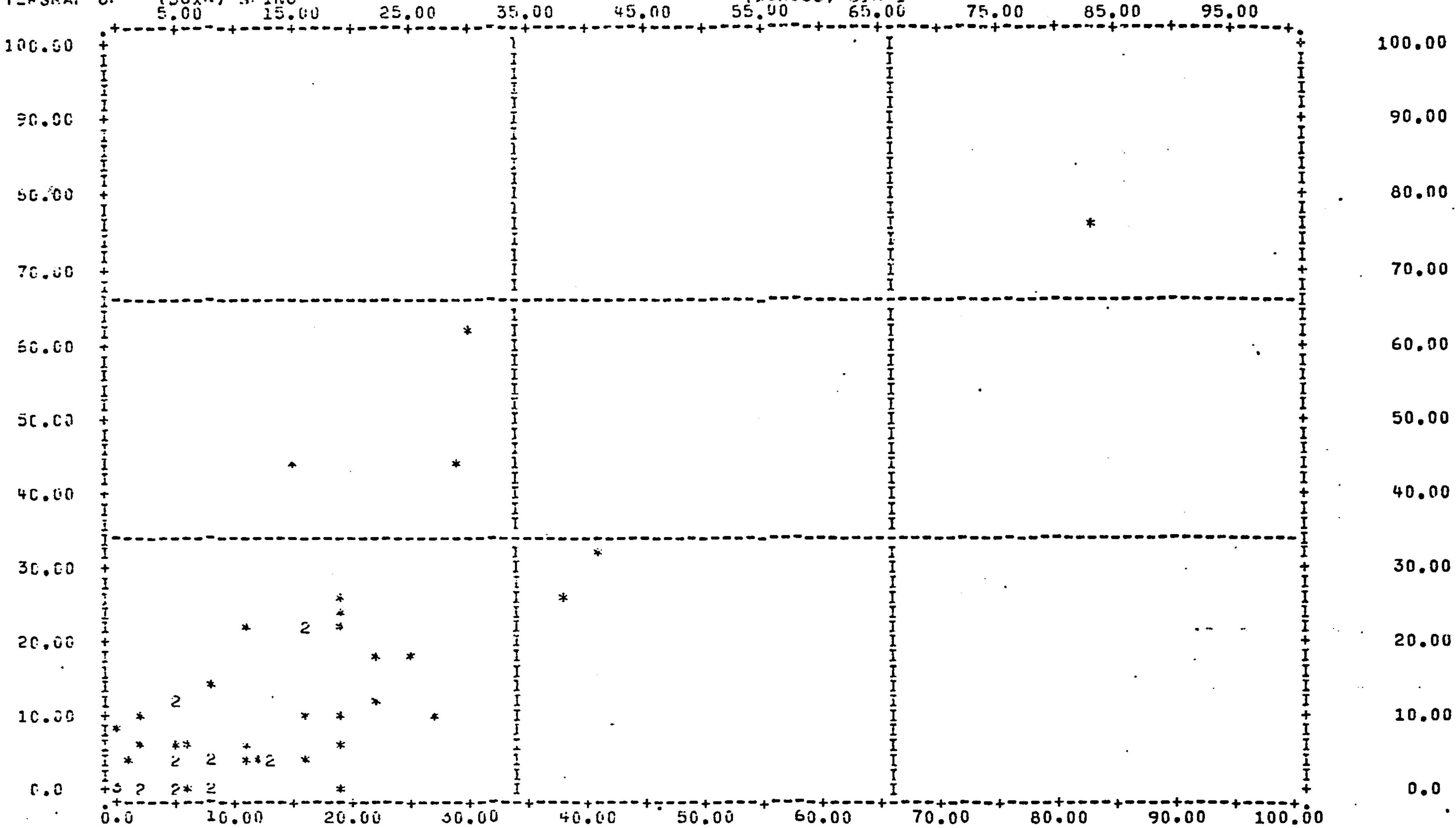

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MODULE TWO                                                                                    04/01/76         PAGE    9

STATISTICS..
  CORRELATION (R)-        0.79699       R SQUARED         -        0.63520       SIGNIFICANCE     -        0.00001
  STD ERR OF EST -        9.70332       INTERCEPT (A)     -        1.37639       SLOPE (B)        -        0.89743
  PLOTTED VALUES -       49             EXCLUDED VALUES-           0             MISSING VALUES -          0

                       ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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TABLE VII

SUMMARY OF SLOPES AND INTERCEPTS

SUBTEST	SLOPE	INTERCEPT
1-SoNo	.98	0.3
1-SπNo	.90	1.5
2-SoNo	.82	2.5
2-SπNo	.90	1.4
3-SoNo	.95	0.6
3-SπNo	.96	0.7
4-SoNo	.97	0.3
4-SπNo	.94	0.7
5-SoNo	.97	0.3
5-SπNo	.94	0.7
6-SoNo	.94	0.3
6-SπNo	.90	0.7
7-SoNo	1.0	0.3
7-SπNo	.94	0.6

Summary of slopes and intercepts based upon data obtained from scattergrams. There are altogether fourteen lines, two for each subtest. One for the SoNo, the other for the SπNo condition.

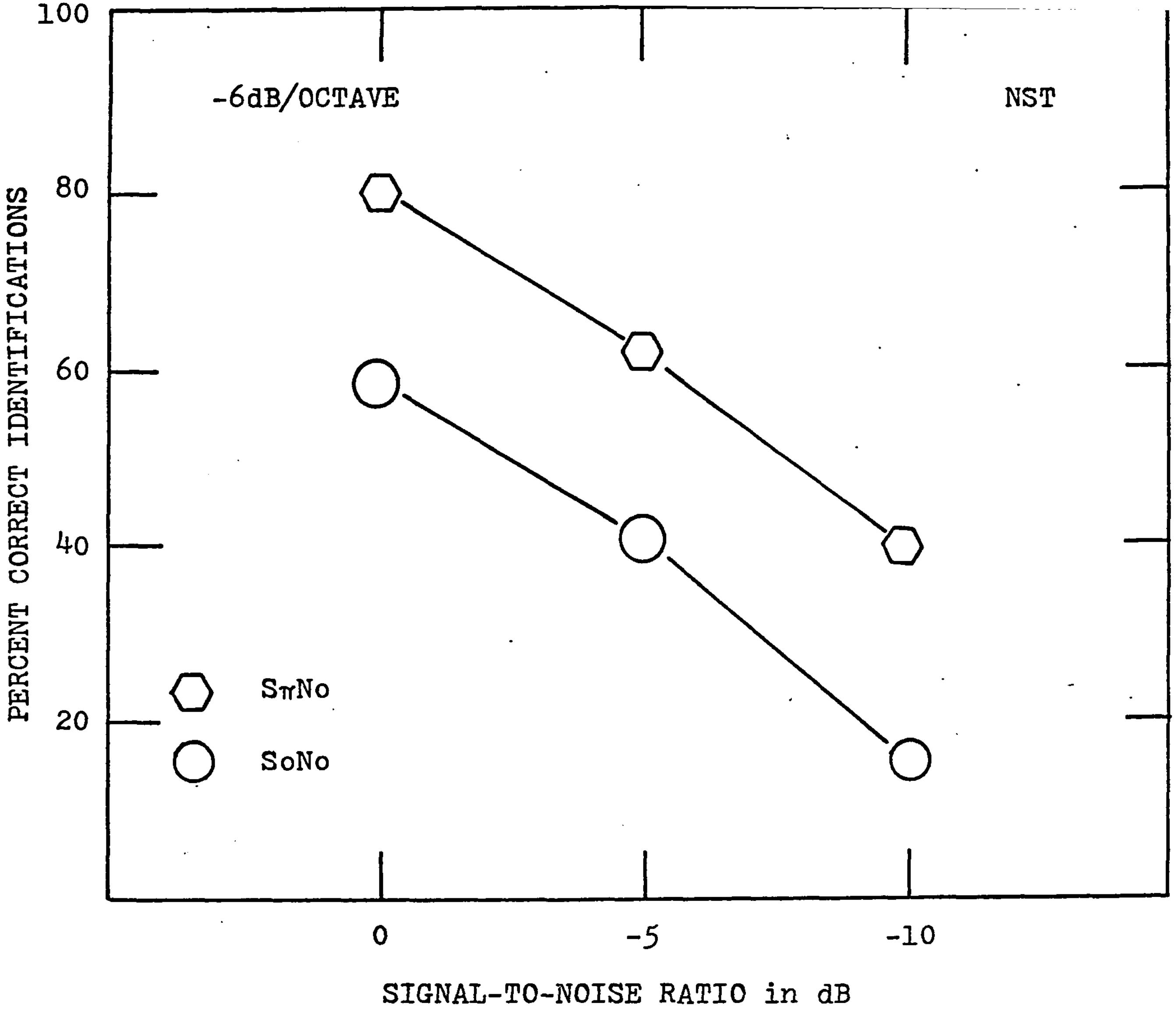

Figure 23. Binaural improvement in intelligibility for the NST masked by -6dB/octave sloping noise at three different S/N ratios. These data have been averaged over both regular and simulated conditions. The plotted data have a standard error on the order of 2.1 percentage points (see note on page 56).

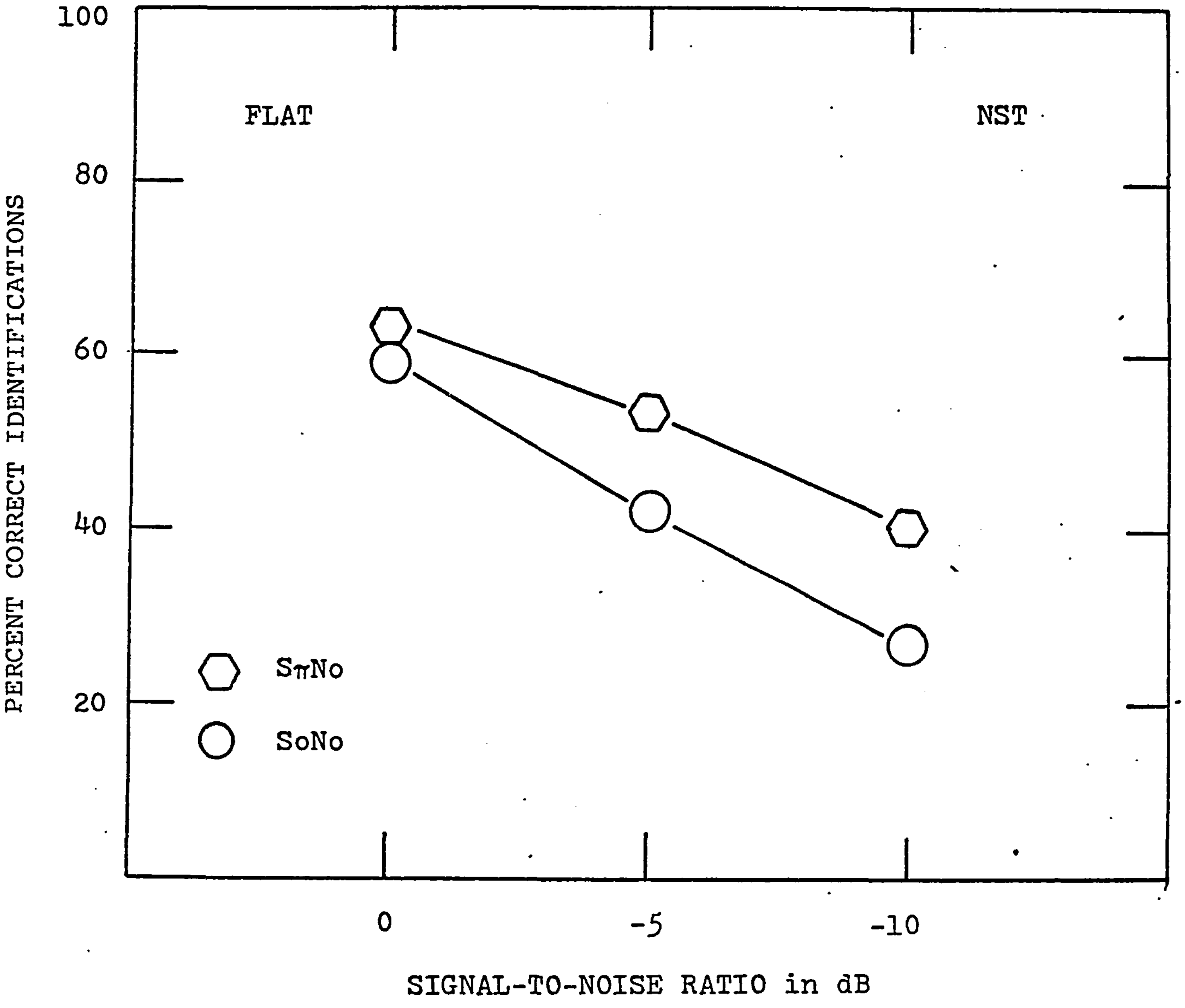

Figure 24. Binaural improvement in intelligibility for the NST masked by flat noise at three different S/N ratios. These dara have been averaged over both regular and simulated conditions. The plotted data have a standard error on the order of 2.1 percentage points (see note on page 56).

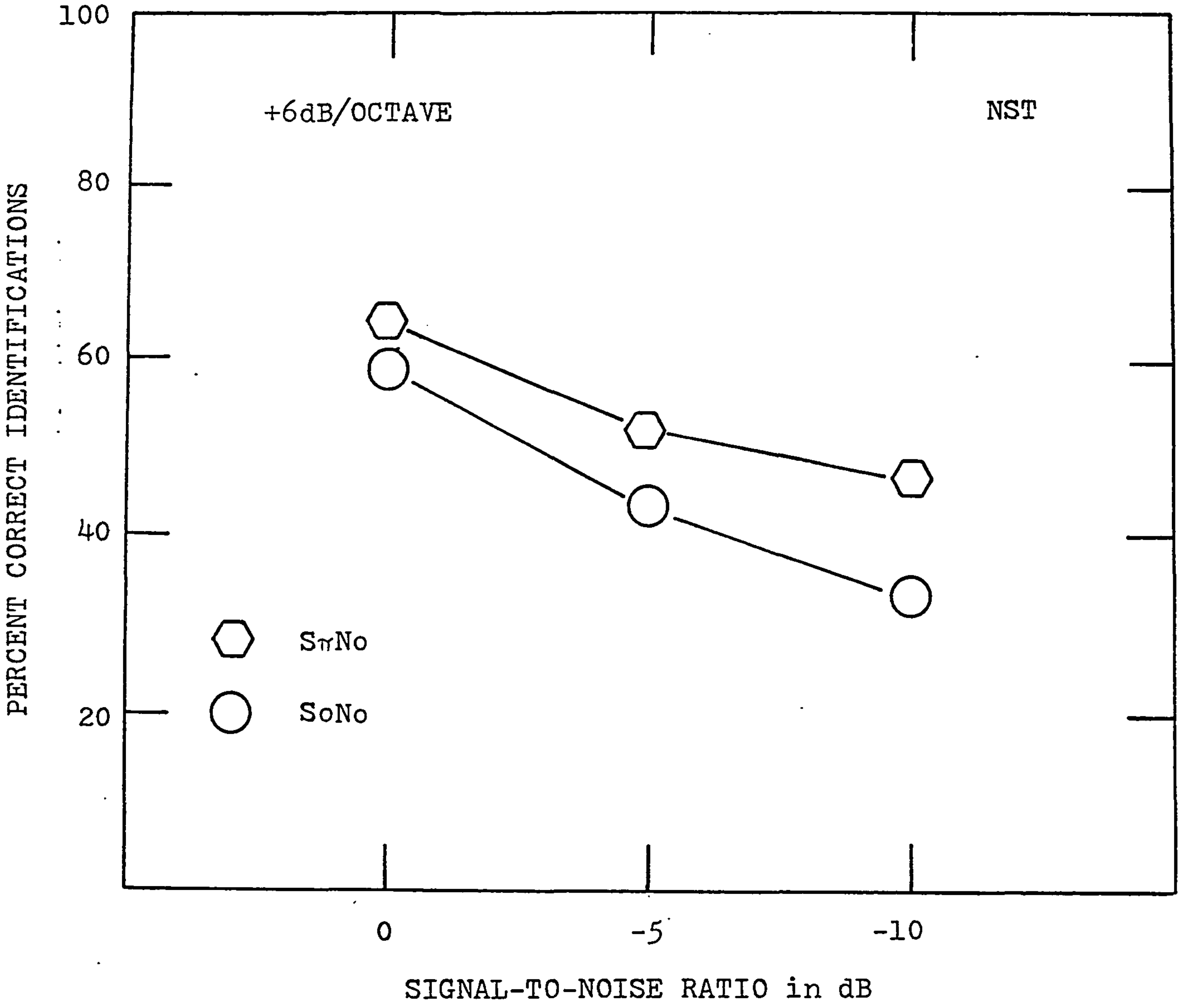

Figure 25. Binaural improvement in intelligibility for the NST masked by +6dB/octave sloping noise at three different S/N ratios. These data have been averaged over both regular and simulated conditions. The plotted data have a standard error on the order of 2.1 percentage points(see note on page 56).

binaural improvement in intelligibility with decreasing S/N ratio. Or stated differently, the lower the scores for SoNo listening condition, the greater is the improvement in intelligibility brought about by the SπNo condition. This phenomenon is noted for all three noise spectra.

In Figure 26 a comparison is made between scores in binaural improvement in intelligibility for voiceless consonants masked by downward sloping (-6dB/octave), and upward sloping (+6dB/octave) noise spectra respectively. In Figure 27 the same comparison is made for voiced consonants. Inspection of these figures indicates that for voiceless consonants some binaural improvement in intelligibility is obtained when masked by -6dB/octave sloping noise (Figure 26, left-hand panel), no such phenomenon is noted in +6dB/octave sloping noise (right-hand panel). In Figure 27, articulation functions for voiced consonants masked by -6dB/octave, and +6dB/octave, respectively, are plotted. As can be seen from this figure, binaural improvement in intelligibility is obtained under both, downward- and upward-sloping noise spectra. This data will be discussed in a later part of this investigation when obtained and predicted data will be compared.

Analysis of Variance

An analysis of variance was performed on the data, the results of which are presented in Table VIII. All

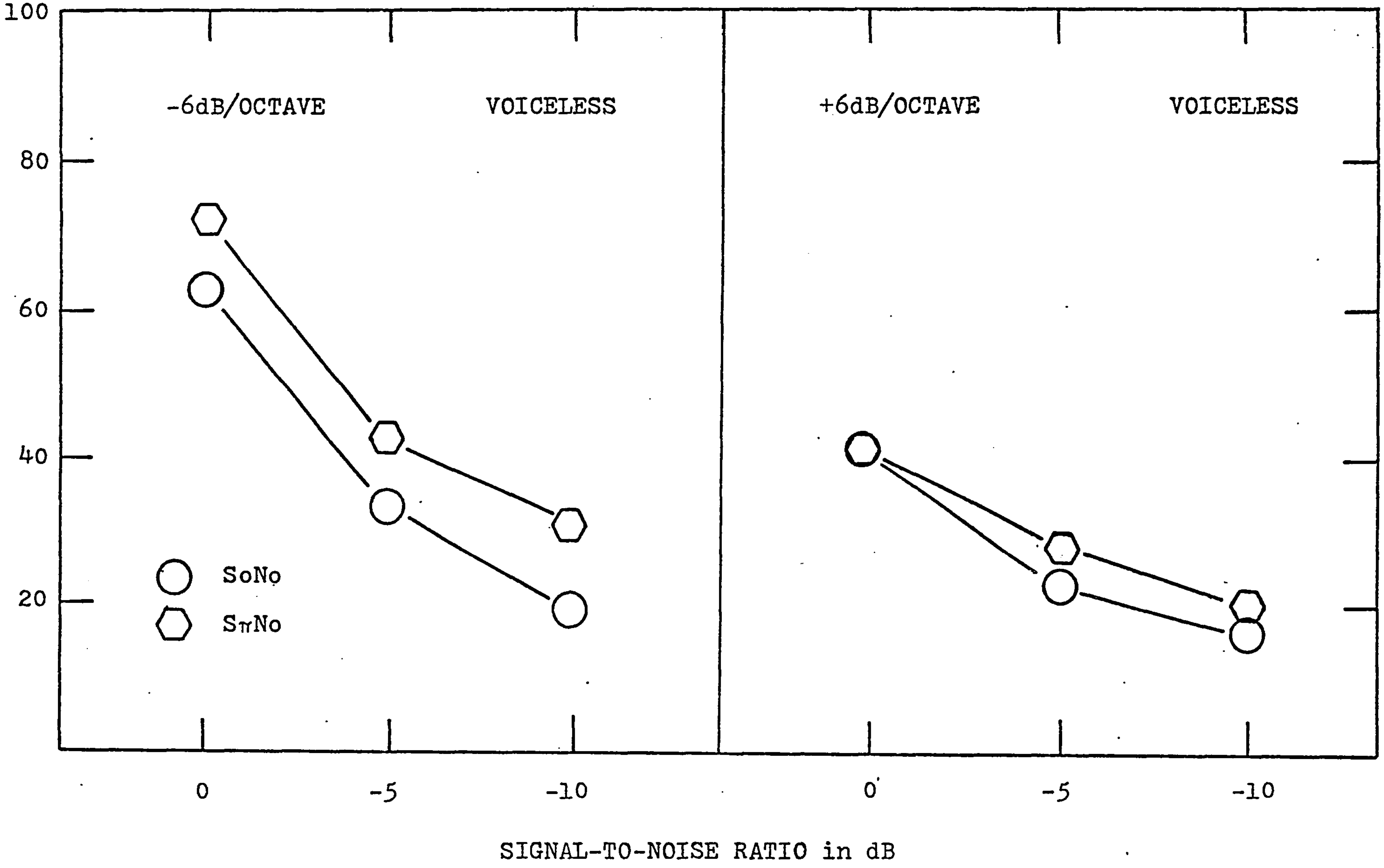

Figure 26. Binaural improvement in intelligibility for voiceless consonants presented against the background of -6dB/octave (left-hand panel), and +6dB/octave sloping noise (right-hand panel). The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

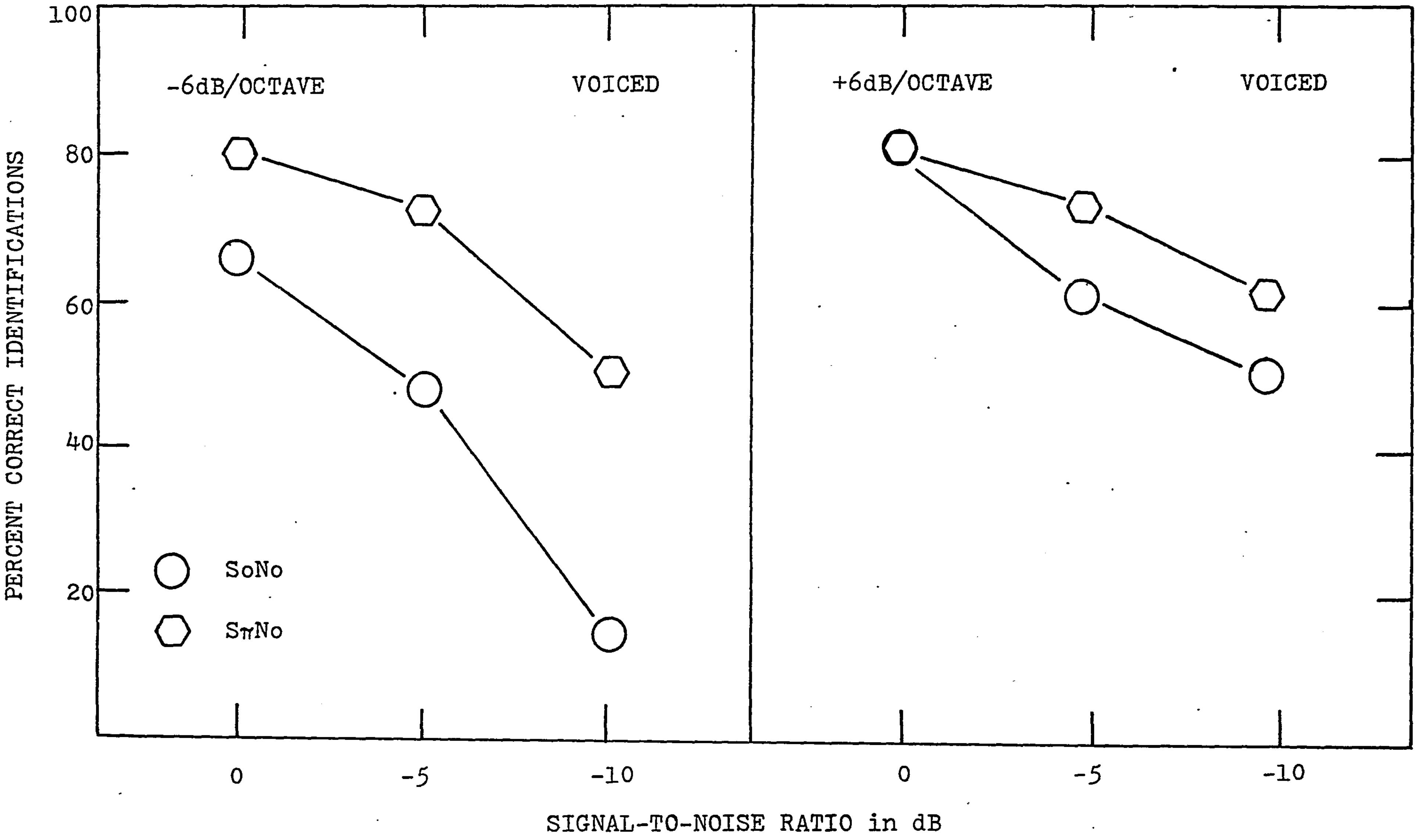

Figure 27. Binaural improvement in intelligibility for voiced consonants presented against the background of -6dB/octave (left-hand panel, and +6dB/octave sloping noise (right-hand panel). The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

ANALYSIS OF VARIANCE......

TABLE

LEVELS OF FACTORS	
L	3
P	4
O	3
S	4
M	7

S/N RATIO	(50%, 50%-5, 50%-10 dB)
PHASE	SoNo, SπNo, Simulated SπNo, Simulated SoNo -6dB/octave, Flat, +6dB/octave
SUBJECTS	Four
SUBTESTS	Seven

Arcsine Transform Has Been Used   Grand Mean   0.46475

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	SIGMIF.
L	71.22496	2	35.61247	295.234	0.001
P	21.17365	3	7.05788	58.511	0.001
LP	1.64184	6	0.27364	2.269	0.038
O	0.46349	2	0.23175	1.921	0.147
LO	4.26571	4	1.06643	8.841	0.001
PO	5.54327	6	0.92368	7.659	0.001
LPO	1.16257	12	0.09688	0.803	0.648
S	9.51909	3	3.17303	26.305	0.001
LS	1.62867	6	0.27145	2.250	0.039
OS	0.80491	9	0.08943	0.741	0.672
LPS	1.01258	18	0.05625	0.466	0.970
OS	2.54812	6	0.42469	3.521	0.003
KOS	0.92972	12	0.07748	0.642	0.805
POS	0.80917	18	0.04495	0.373	0.991
LPOS	1.67328	36	0.04648	0.385	0.999
M	119.53784	6	19.92297	165.165	0.001
LM	3.26964	12	0.27247	2.259	0.010
PM	4.51087	18	0.25060	2.076	0.008
LPM	5.97885	36	0.16608	1.377	0.087
OM	14.43312	12	1.20276	9.971	0.001
LOM	3.33850	24	0.13910	1.153	0.288
POM	5.86060	36	0.16279	1.350	0.101
LPOM	8.85510	72	0.12299	1.020	0.447
SM	5.01411	18	0.27856	2.309	0.003
LSM	4.04658	36	0.11230	0.718	0.925
PSM	4.67888	54	0.08665	0.718	0.925
LPSM	9.86534	108	0.09135	0.757	0.947
OSM	6.87037	36	0.19084	1.582	0.025
LOSM	6.92503	72	0.09618	0.797	0.868
POSM	11.54560	106	0.10690	0.886	0.758
LPOSM	26.05490	216	0.12062		
TOTAL	365.18457	1007			

EXIT

the main factors other than slope (0) showed a statistically significant effect at .01 level. All two-way interactions involving either slope (0) or the subtests of the NST (M) were also found to be statistically significant at the .01 level.

Inspection of Figures 17-22 will aid us in interpreting these results. As expected, the S/N ratio has a significant effect upon intelligibility, and as seen from Figures 17-22, with increasing S/N ratio there is a corresponding increase in percent correct identifications. There is also a significant difference in intelligibility as the interaural phase relationship of the speech wave is changed from SoNo to SπNo. Subjects' performance also varied, one subject performing slightly better than the other. There were also significant differences among the subtests, primarily attributable to differences between scores obtained for voiced versus voiceless consonants. It can be seen from Figures 20-22 that higher scores were obtained for voiced than for voiceless consonants under all masking conditions.

As pointed out earlier the effect of slope showed not to be statistically significant. This was expected in view of the fact that for each noise spectrum the S/N ratio was adjusted so as to obtain the level of about 50% intelligibility. The other two measurements were then taken; one at 5 dB, the other at 10 dB below that level.

The two-way interaction involving consonant class and slope of masking noise (OxM) had a significant effect. To illustrate this interaction, a plot relating intelligibility level of consonant class as a function of noise spectrum is presented in Figure 28. It can be seen that for all the spectra voiceless consonants obtained lower scores than voiced consonants. However, the relative difference between these two classes of consonants was smaller for downward sloping (-6dB/octave) noise, than that for a flat and upward sloping (+6dB/octave) noise spectra respectively.

Figure 29 depicts the level of intelligibility as a function of S/N ratio for the three noise spectra respectively. The interaction between slope and S/N ratio is clearly manifested, particularly the larger rate of decrease of the downward sloping noise (-6dB/octave).

The interaction between phase and slope of masking noise is shown in Figure 30, when it can be seen that the binaural improvement in intelligibility is significantly larger for the downward sloping, as opposed to the flat and upward sloping noise spectra respectively.

In Figure 31 performance of subjects and consonant class is shown. The interaction between subjects and consonant class reached the .0003 level of significance. It

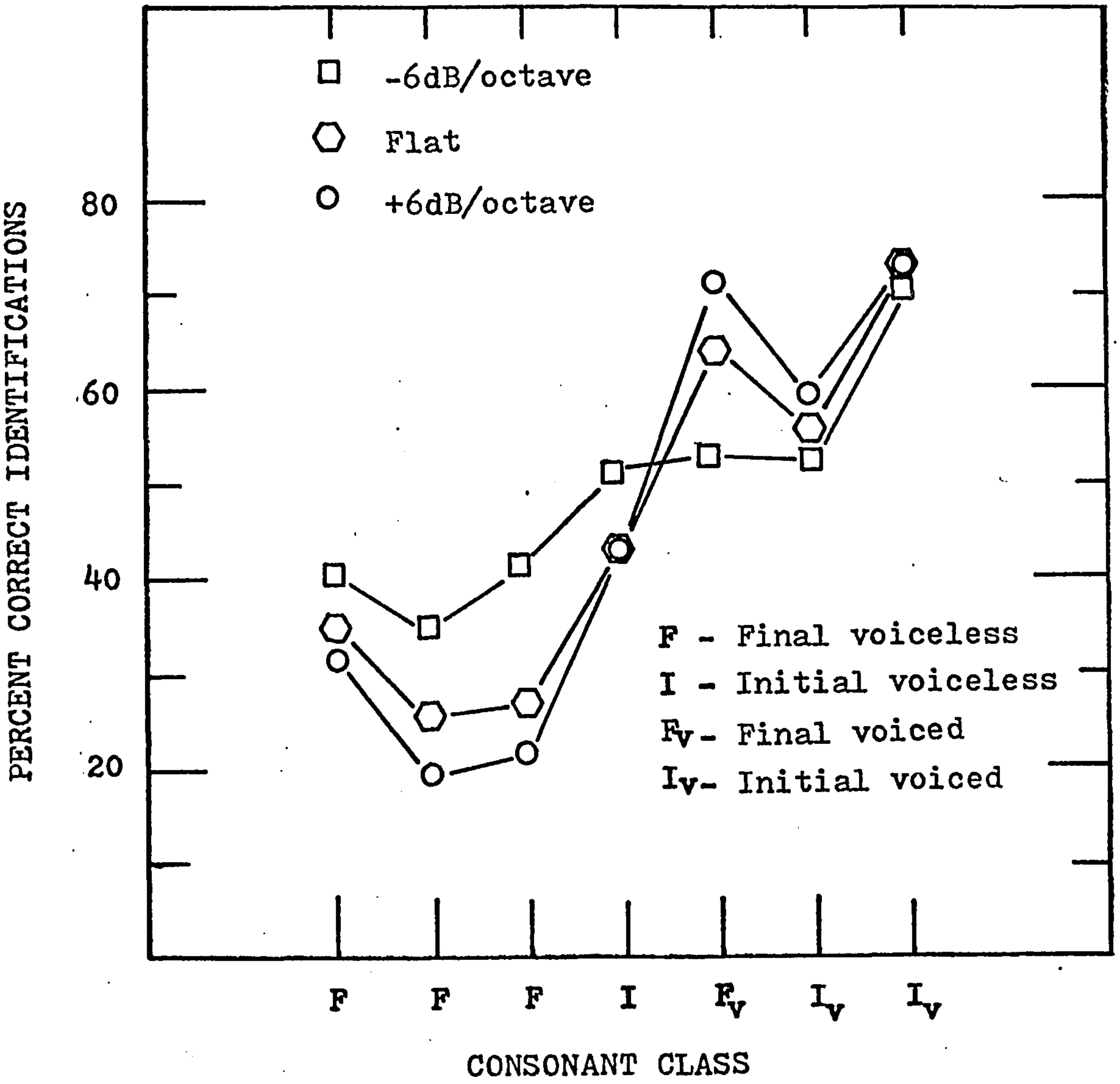

Figure 28. Diagram showing the two-way interaction involving consonant class and slope of masking noises used in this investigation. (Consonant classes included in the subtests are: 1, 2, and 3 final voiceless(F),and initial voiced(I_V1&I_V2), final voiced (F_V), and initial voiceless (I)consonants).

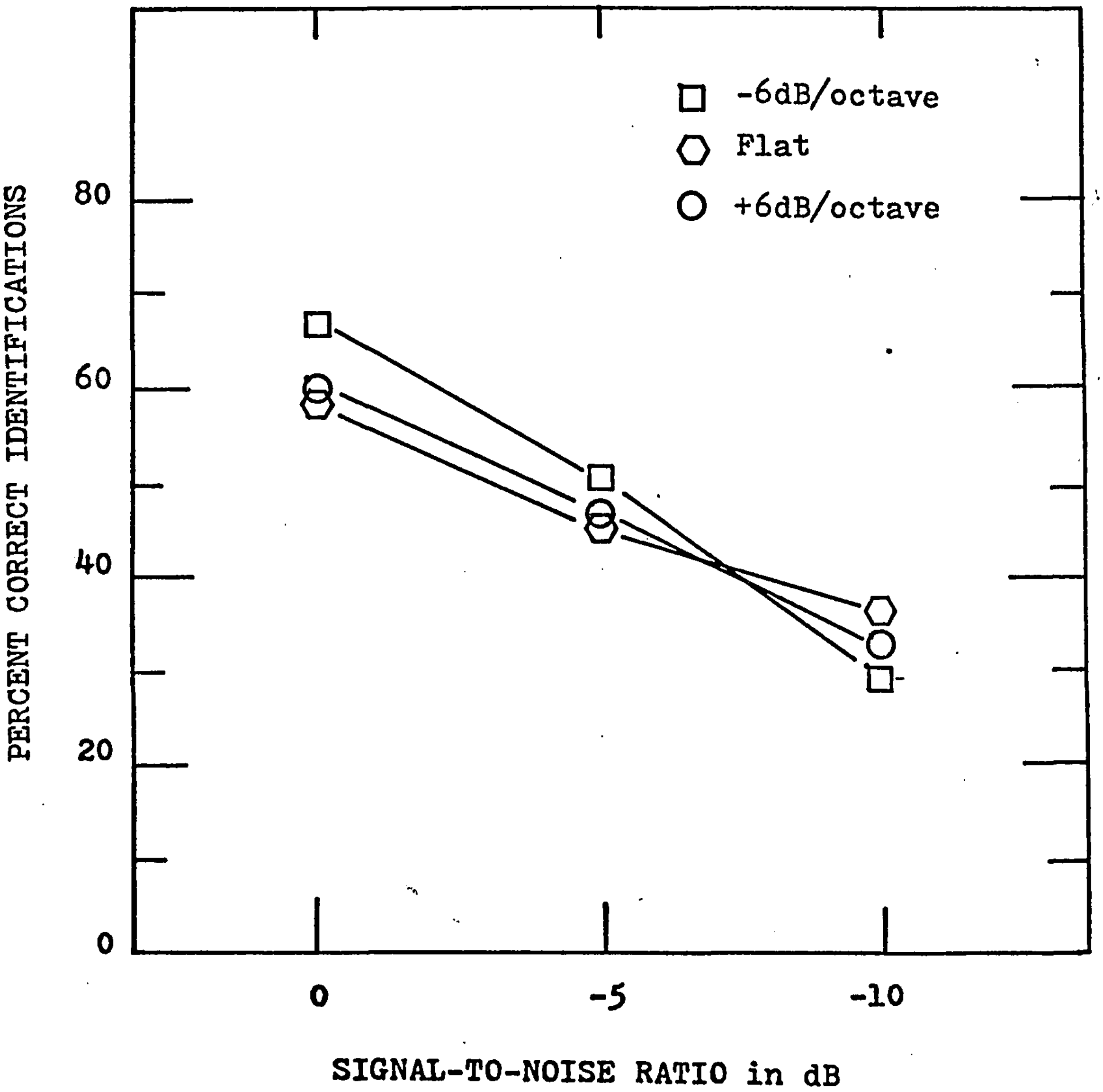

Figure 29. Diagram showing the two way interaction involving signal-to-noise ratio and slope of masking noises used in this investigation.

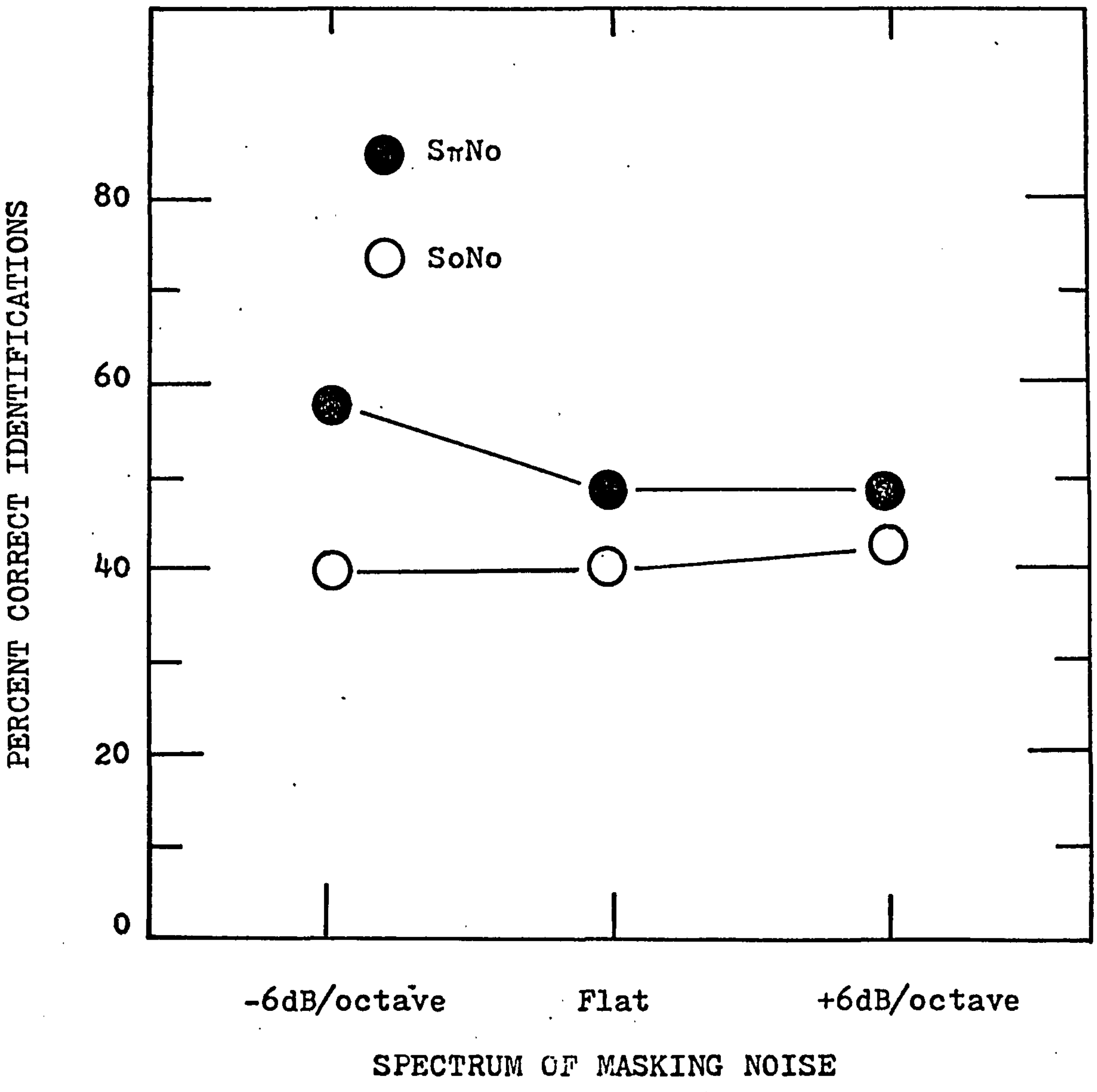

Figure 30. Diagram showing the two-way interaction involving the phase and slope of masking noises used in this study.

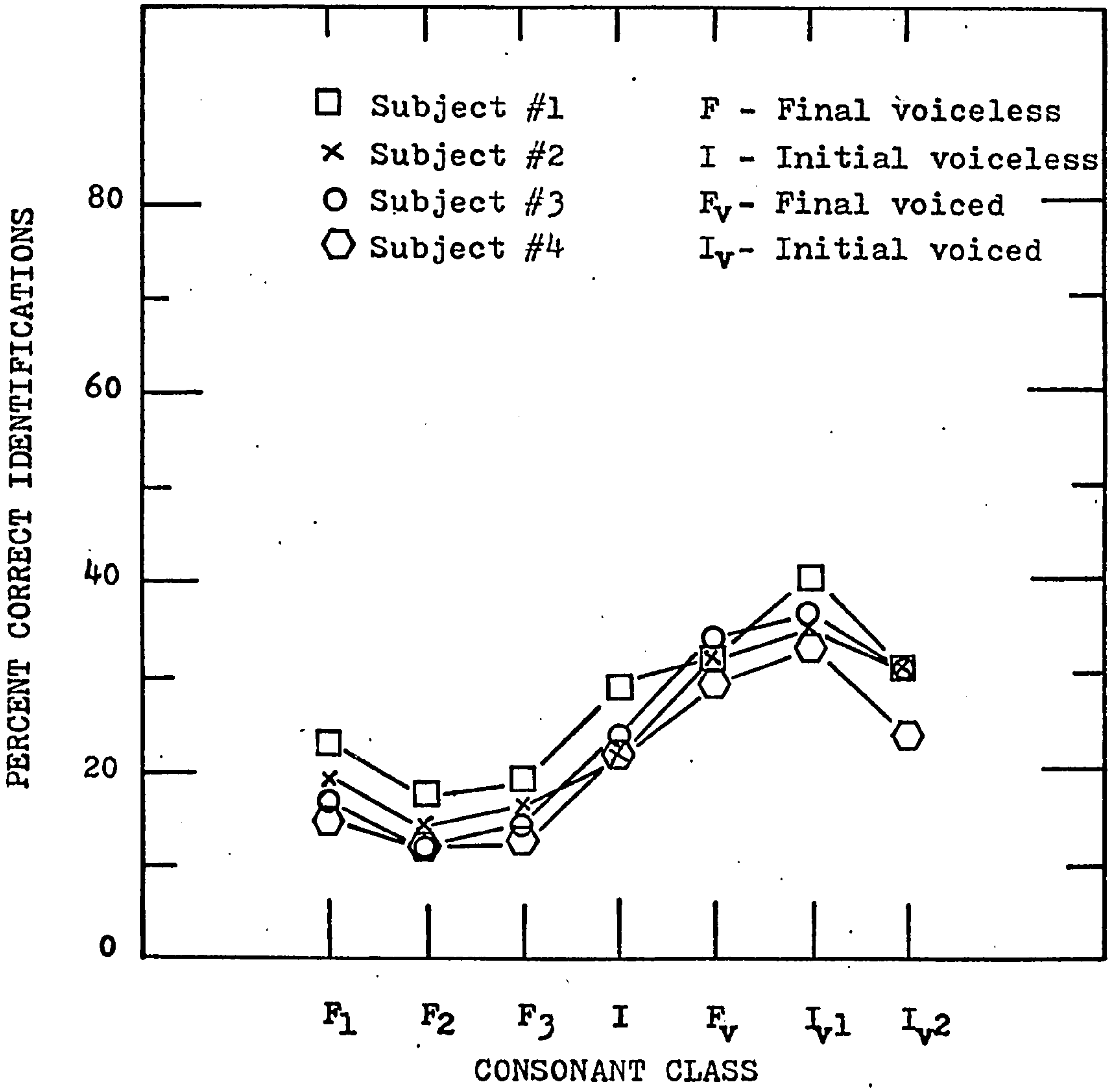

Figure 31. Diagram showing the two-way interaction involving the phase and slope of the masking noises used in tis investigation.

can be seen that there were consistent differences; Subject #1 performing slightly better, and Subject #4 generally scored the lowest. There is some evidence of an interaction between subjects and subtests (i.e. consonant classes). For example, Subject #3 scored best of all on Final voiced consonants (F_V), but was one of the poorest subjects for the voiceless consonants. Although the statistically significant magnitude of these interactions was small, and for practical purposes the scores could be averaged without serious loss of information.

CHAPTER VI

DISCUSSION

The main aim of this investigation was to test the predictions based on the model advanced by Levitt and Rabiner (1967b). The model states that the effect of binaural processing may be represented by an equivalent reduction in the level of the applied noise. Based upon this model the following predictions were made:

A) Speech stimuli presented against the background of noise in an SπNo configuration will show the same masking effect as that shown when the equivalent noise (as specified by the model) is presented in an SoNo configuration.

B) Speech stimuli presented against the background of noise in an SoNo configuration will show the same masking effect as that shown when the inverse equivalent noise is presented in an SπNo configuration.

C) With increasing S/N ratios, there will be a decrease in the size of ILD's. The ILD's are derived using the Articulation Index procedure specified by Kryter (1962).

These predictions have been tested for three noise spectra. Specifically, for flat, downward-sloping (-6dB/octave), and upward-sloping (+6dB/octave) noise spectra, respectively.

D) For a masking noise in which the level of the

the noise spectrum decreases with increasing frequency, high frequency phase information will make a larger contribution to ILD's than for corresponding conditions for a masking noise in which the level of the spectrum increases with increasing frequency. Specifically, it is predicted that larger binaural improvements in intelligibility will be obtained for voiceless consonants presented against the background of -6dB/octave, than +6dB/octave noise.

Discussion of Findings

The previously mentioned predictions in paragraphs (A) and (B) can be discussed by inspecting Figures 17, 18, and 19, where articulation functions for the NST presented against the background of -6dB/octave, flat, and +6dB/octave noises, respectively, are presented. These functions reflect the results obtained for SoNo and SπNo conditions, for regular and simulated noises respectively. It can be seen from these figures that there is a reasonably good fit between the regular and simulated noise articulation functions. This is true for all three noise spectra, and at all S/N ratios. However, the fit is perfect only for the SoNo configuration at -10 dB S/N ratio, in flat and +6dB/octave noises respectively. For the NST masked by -6dB/octave noise (Figure 17) slightly higher scores are obtained for the simulated SπNo condition at 0-dB S/N ratio, and -5 dB S/N ratio, whereas at -10 dB S/N ratio slightly lower scores are obtained for simulated, rather than for the regular noise condition. A somewhat larger disparity is noted between regular and simulated SoNo condition at 0-dB S/N ratio. Here the scores for simulated noise are lower by about 13 percent. When the results of scores obtained for voiced and voiceless consonants masked by -6dB/octave noise are plotted (Figure 20) one may see that the discrepancy between regular and simulated noise conditions occurred primarily for voiceless consonants in the SoNo configuration. For all other conditions, as shown in Figures 20, 21, and 22, where articulation functions for voiced and voiceless consonants presented against the background of the three noise spectra, respectively, are depicted, it can be seen that the fit between the predicted and observed data is reasonably good.

The analysis of the obtained data for the NST as a whole, as well as for voiced and voiceless consonants, demonstrate the validity of the model over a reasonably wide range of spectrum slopes and S/N ratios. In order to examine whether the same results are apparent for individual phonemes, an additional analysis was carried out by comparing confusion matrices for regular and simulated noise conditions. These confusion matrices (Appendix I) show that not only the scores, but also the pattern of the errors are the same for regular and simulated conditions.

Based upon these confusion matrices, scattergrams were also plotted. Computer printouts for each subtest, one for the SoNo, and one for the SπNo (plotted: regular versus simulated) conditions, for the seven subtests are presented in Appendix II. Table VII* represents a summary of the slopes and intercepts of the line fitted to each scattergram. One should note that the slope in every case (save one) is slightly less than 1.0, and the intercept is also slightly greater than 0. This indicated that, on the average, simulated error scores are slightly lower than those for regular conditions for those error types that occur infrequently, but over most of the range (error types that occur moderately to very frequently) error scores for simulated conditions are slightly greater than error scores for regular conditions. These deviations from the ideal situation (errors on simulated conditions = errors on regular conditions) are small. It should be noted that one may not expect a perfect fit between regular and simulated conditions, since the equivalent noise spectra were not adjusted so as to account for the differences in the spectrum level in various frequency regions of the noise spectra, i.e. for noise with an upward sloping spectrum of +6dB/octave, the spectrum level in the low-frequency region is significantly lower than in the high-

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*For Table VII see page 67

frequency region (see Figure 15). As noted by Hirsh (1948a) the magnitude of the MLD varies as a function of the spectrum level (see Figure 3). Although taking this effect into account in deriving the equivalent noise spectrum leads to relatively small differences, these differences may account, in part, for the small consistent differences observed between the regular and simulated conditions.

In summary, the obtained data for simulated conditions match closely the data for regular conditions. For the overall test scores the fit is good for a very wide range of slope and S/N ratios. The only major discrepancy was that for the voiceless consonants in the downward sloping noise. No obvious explanation for this observation could be found. The possibility of measurement error should not be ruled out. A more detailed analysis of the individual error types shows also a good fit except for a very small average disparity, the more frequent error types are slightly greater for simulated, than for the regular conditions.

The predictions stated in paragraph (C) indicated that based upon the model one may anticipate that with decreasing S/N ratios, larger improvements in intelligibility will be obtained. Stated differently, with increasing intelligibility scores for the SoNo condition smaller improvements in intelligibility will be obtained for corresponding SπNo condition. Figures 23, 24, and 25 where intelligibility functions for the NST for SoNo and SπNo (averaged over regular and simulated) conditions are shown, indicate that, as predicted, with decreasing S/N ratios, the separation between SoNo and SπNo articulation functions increases.

As for predictions included in paragraph (D), Table IX provides the basis for the following discussion. This table is a summary of qualitative predictions based upon the relative location of the speech and noise spectra for the experimental conditions used in this investigation. These predictions are based on the spectra shown in Figures 32, 33, and 34. Panel (a_3) in each of these figures is most revealing since it shows the change in noise spectra as a consequence of changing from the SoNo to the SπNo condition.

What we are interested in is to assess the gain in intelligibility that is brought about as a result of changing the listening condition from SoNo to SπNo. The predictions listed in Table IX are qualitative since they are based upon the idealized speech spectrum which is not necessarily that of the speech stimuli actually used in this investigation. In order to illustrate the major effects, only the extreme cases, i.e. slope of +6dB/octave, and -6dB/octave, and -10 dB S/N ratio, and 0-dB S/N are

TABLE IX

PREDICTIONS FOR SPEECH MASKED BY -6dB/OCTAVE, AND +6dB/OCTAVE NOISES, RESPECTIVELY, THAT RESULT FROM A CHANGE FROM SoNo TO SπNo CONDITION

NOISE SLOPE	AI for SoNo CONDITION	GAIN in AI	GAIN in PERCENT INTELLIGIBILITY	FREQUENCY REGION IN-VOLVING GAIN	CONSONANTS BENEFITING FROM GAIN	S/N RATIO in dB
-6dB/ OCTAVE	SMALL	LARGE	LARGE	PRIMARILY BELOW 2000 Hz	$\bar{V} < V^*$	-10
-6dB/ OCTAVE	MODERATE	MODERATE	MODERATE	ALL FREQUENCIES	$\bar{V} = V$	0
+6dB OCTAVE	MODERATE	SMALL	SMALL	500-1000 Hz	VOICED FAVORED	-10
+6dB/ OCTAVE	LARGE	SMALL	SMALL	1000-2000 Hz	VOICED FAVORED	0

*V - stands for voiced consonants $\bar{V}$ - stands for voiceless consonants

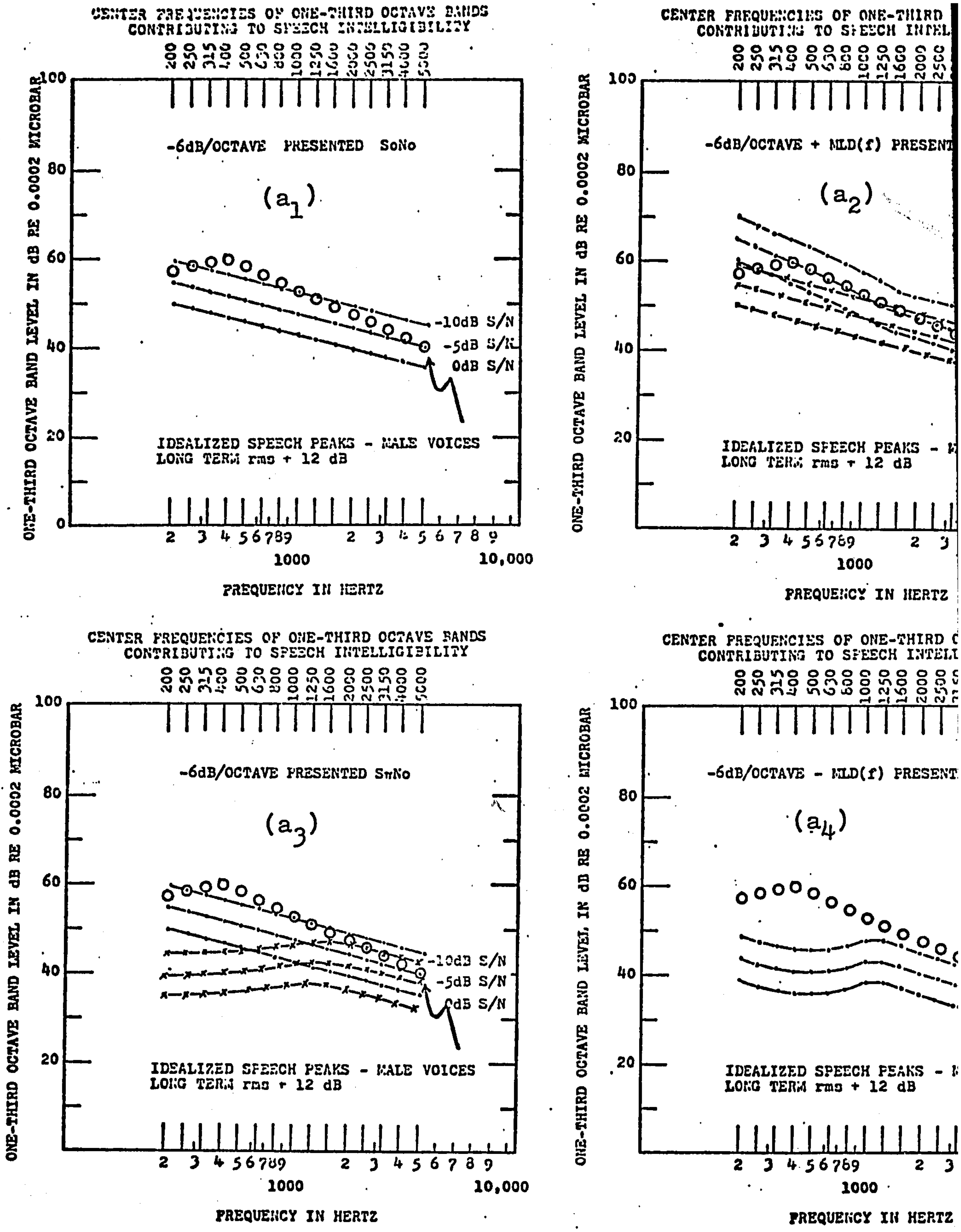
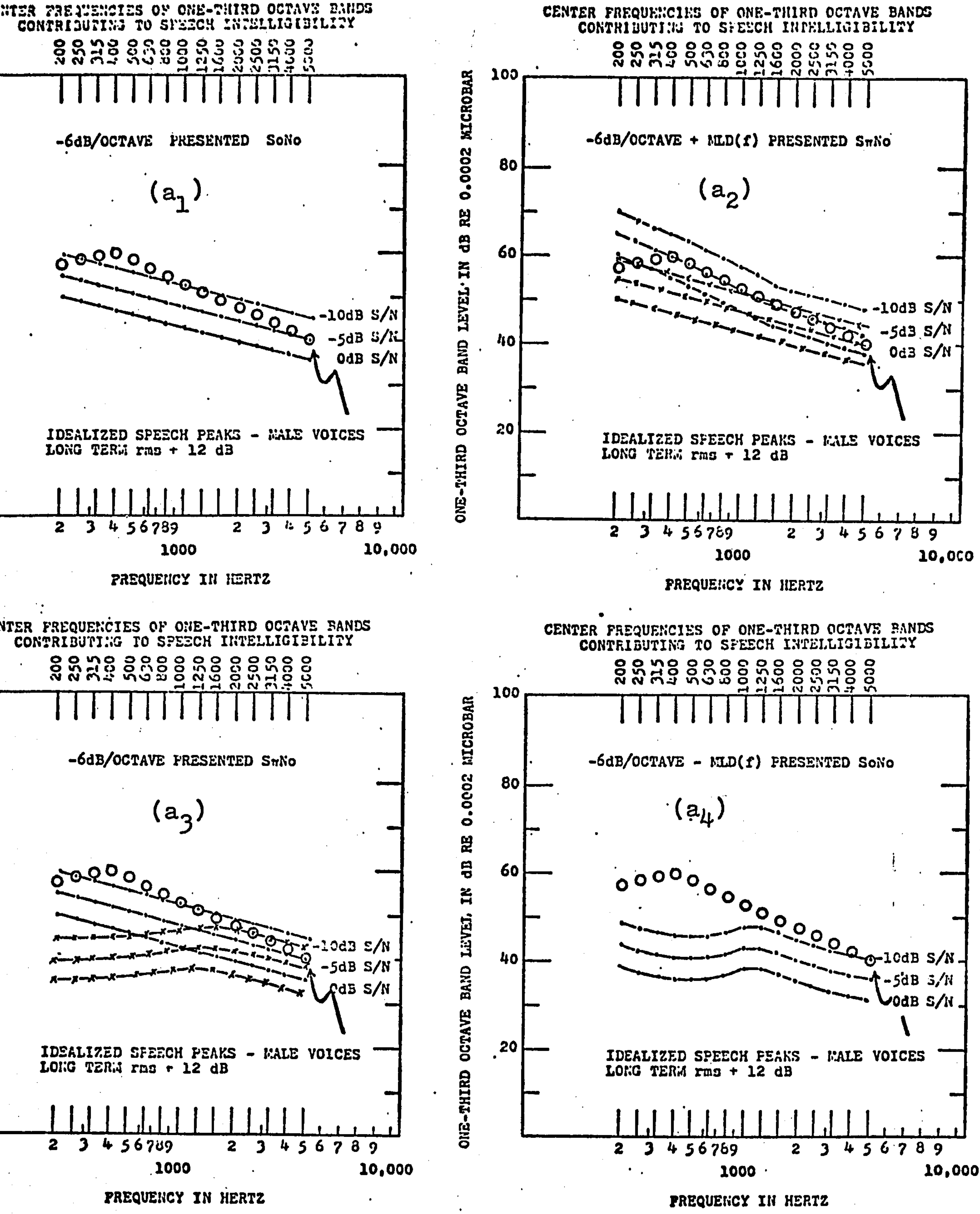


Figure 32. One-third octave band spectra of idealized speech si
of noise (regular and simulated). Three spectra are shown for e
corresponding to S/N ratios of 0, -5, and -10 dB. The noise in
ure has a spectrum of -6dB/octave.



ure 32. One-third octave band spectra of idealized speech signal, and
noise (regular and simulated). Three spectra are shown for each noise
responding to S/N ratios of 0, -5, and -10 dB. The noise in this fig-
has a spectrum of -6dB/octave.

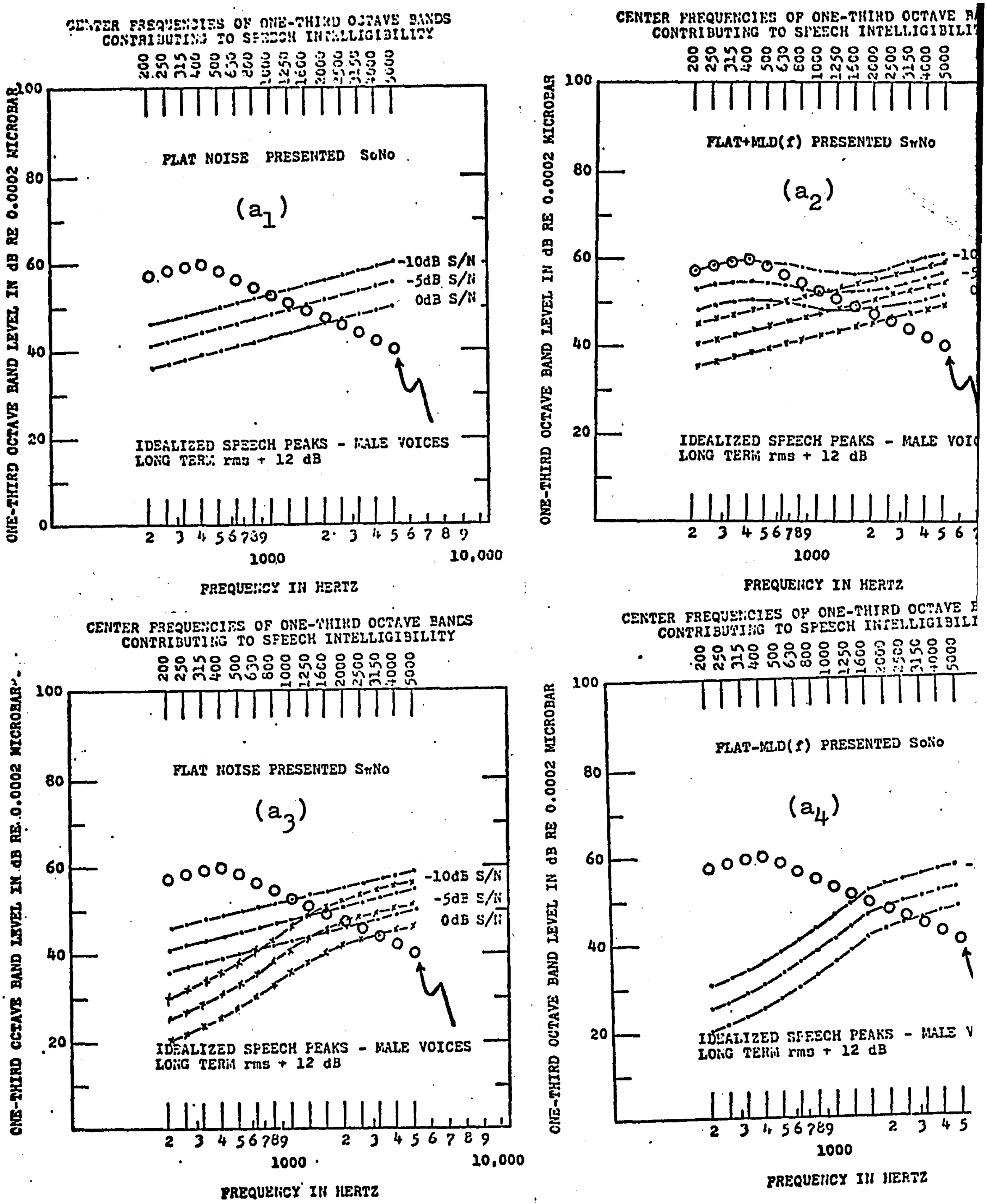
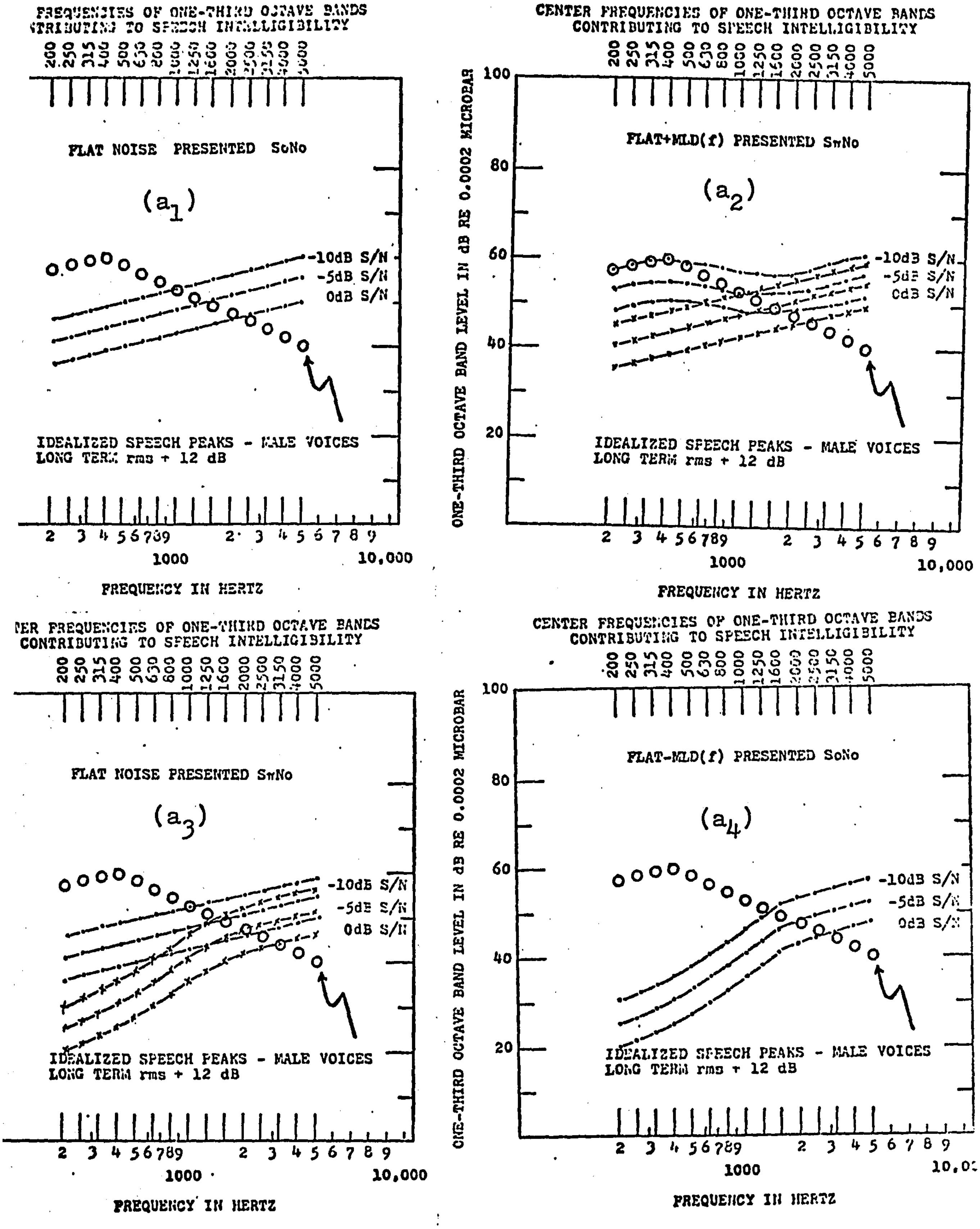


Figure 33. One-third octave band spectra of idealized speech sig and of noise (regular and simulated). Three spectra are shown fc noise corresponding to S/N ratios of 0, -5, and -10 dB. The nois this figure has a flat spectrum.



gure 33. One-third octave band spectra of idealized speech signal, l of noise (regular and simulated). Three spectra are shown for each se corresponding to S/N ratios of 0, -5, and -10 dB. The noise in s figure has a flat spectrum.
]

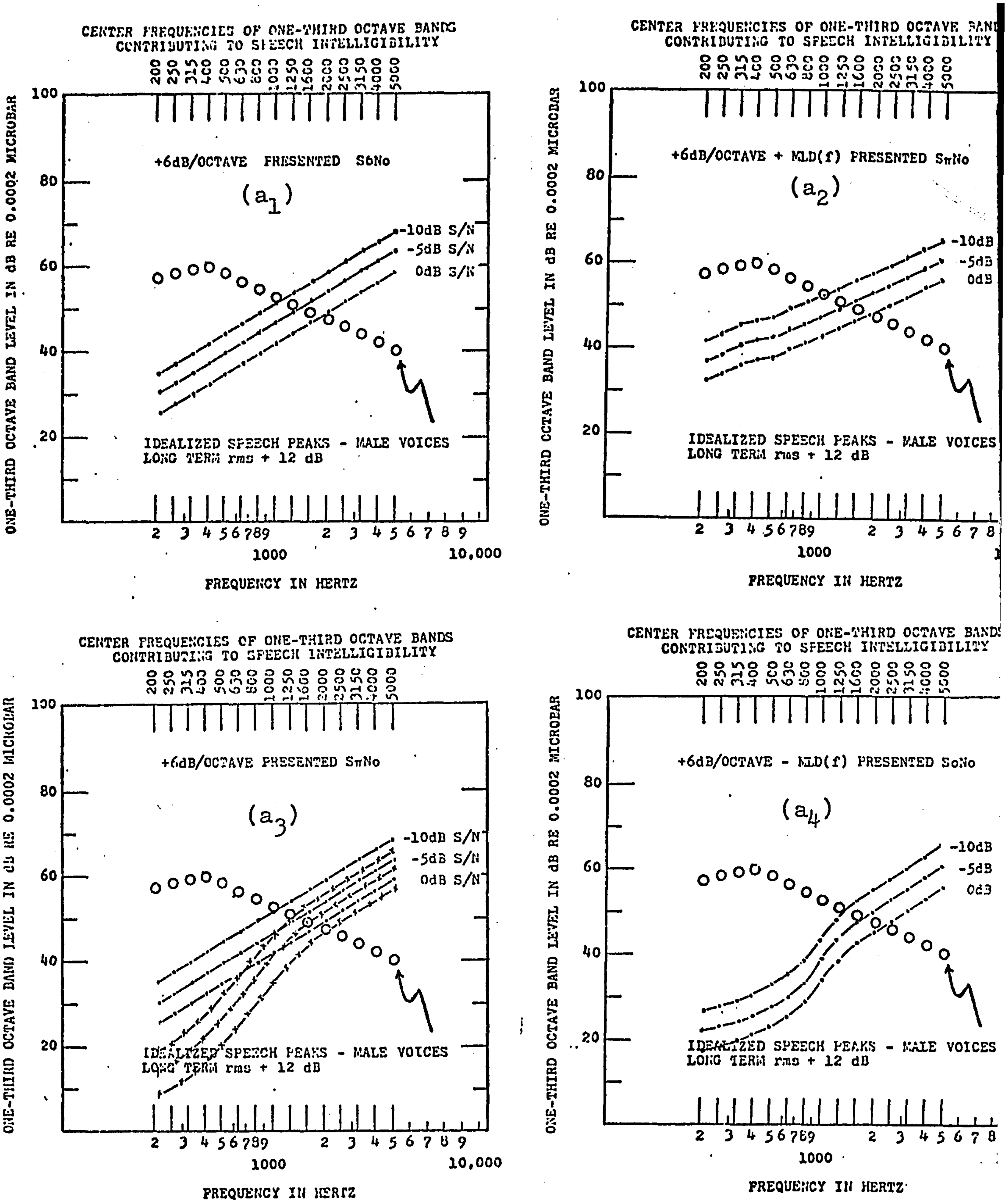
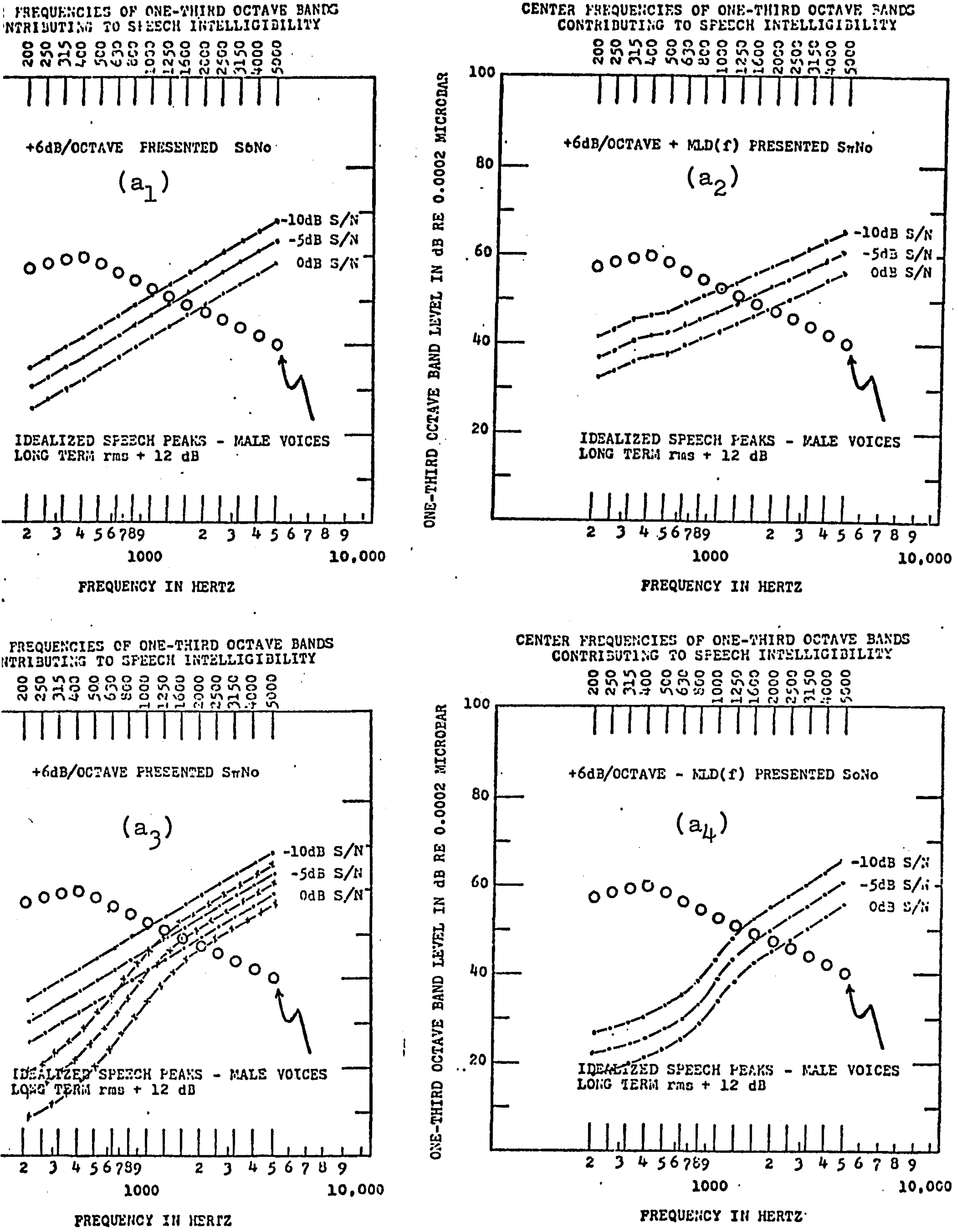


Figure 34. One third-octave band spectra of idealized speech signal, of noise (regular and simulated). Three spectra are shown for each no corresponding to S/N ratios of 0, -5, and -10 dB. The noise in this f ure has a spectrum of +6dB/octave.



e 34. One third-octave band spectra of idealized speech signal, and ise (regular and simulated). Three spectra are shown for each noise sponding to S/N ratios of 0, -5, and -10 dB. The noise in this fig- as a spectrum of +6dB/octave.

considered. Table IX provides qualitative estimates of the gain in the Articulation Index, (Column 2), the corresponding gain in intelligibility (Column 3), the frequency region contributing to the binaural gain in intelliibility (Column 4), and a rough estimate of whether the binaural improvement in discrimination scores would be greater for voiced (V) or voiceless ($\bar{V}$) consonants. Entries in Column 2 were derived by comparing the region between the spectra of speech and noise, respectively, for the SoNo and SπNo conditions. Entries in Column 3 were derived by observing the effect of an increase in the AI on discrimination scores for nonsense-syllables for the AI corresponding to S/N ratio shown in Column 5. The curve used was that in Kryter (1962), which shows that for a low AI a small increment produced a relatively large gain in discrimination scores, whereas at a high AI, the same increment in AI produces a small change in discrimination scores.

In view of the preceding guidelines, the frequency regions contributing to the binaural gain in intelligibility can be read off directly from Figures 32, 33, and 34, where the relative location of the idealized spectrum of speech peaks, and the noise spectra are given. These frequency boundries are determined by the points at which the speech spectrum crosses the noise spectrum, or alternatively when the speech spectrum exceeds the noise spectrum by more than 30 dB. This information is useful in determining whether voiced or voiceless consonants should benefit more the binaural release from masking. It is assumed that if the low frequency region of the speech spectrum plays a role in the release from masking, the voiced consonants will benefit more than voiceless consonants. If, on the other hand, the high frequency region of the speech spectrum plays an important role, the voiceless consonants will benefit from the release from masking. Inspection of Figures 35, and 36 where articulation functions for SoNo and SπNo conditions for voiced and voiceless consonants masked by -6dB/octave, and +6dB/octave noise spectra respectively, are shown, demonstrate the validity of these predictions. In Figure 35 one can see that for downward sloping (-6dB/octave) noise, at -10 dB S/N ratio the size of binaural improvement in intelligibility is substantially larger for voiced, than for voiceless consonants. This is in line with the prediction, since the frequency region where the gain occurs, is primarily in the low frequency region of the speech spectrum. However, at 0-dB S/N ratio where the gain involves all frequencies, binaural improvement in intelligibility is about the same for both, voiced and voiceless consonants. For upward-sloping noise (Figure 36) at -10 dB S/N, binaural improve-

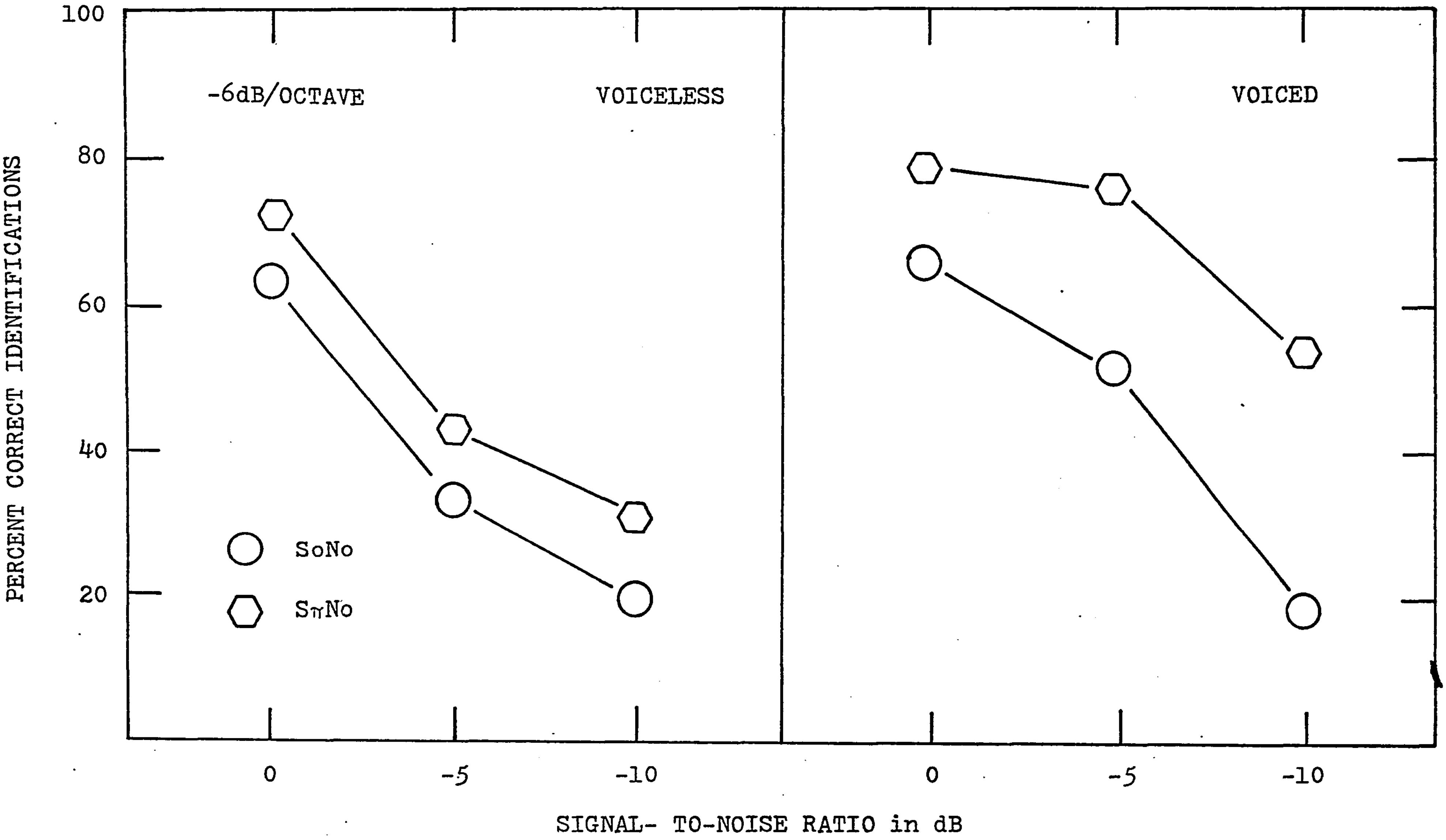


Figure 35. Binaural improvement in intelligibility for voiceless consonants (left-hand panel) and voiced consonants (right hand-panel) presented against the background of -6dB/octave noise. The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

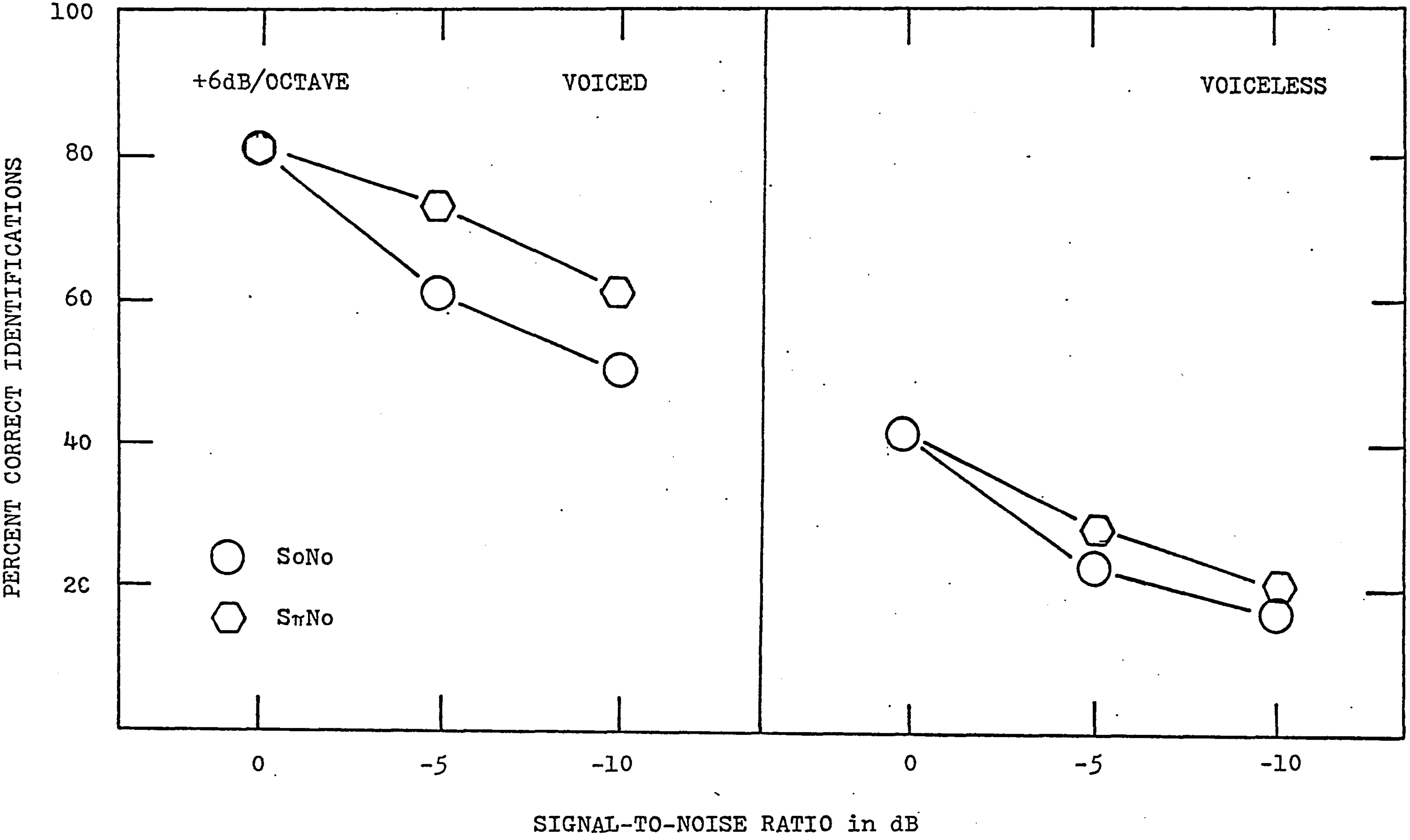


Figure 36. Binaural improvement in intelligibility for voiced consonants (left-hand panel) and voiceless consonants (right-hand panel) presented against the background of upward-sloping (+6dB/octave) noise. The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

ment in intelligibility is greater for voiced than for voiceless consonants, whereas at 0-dB S/N ratio, binaural improvement in intelligibility for both voiced and voiceless consonants is negligible. Comparison of articulation functions for voiceless consonants masked by -6dB/octave, and +6dB/octave noises respectively, as shown in Figure 37, is in line with the prediction made in paragraph (D). As seen in this figure, binaural improvement in intelligibility for voiceless consonants masked by -6dB/octave are greater than those obtained for voiceless consonants masked by +6dB/octave sloping noise at corresponding S/N ratios.

In conclusion, it may be stated that the observed data in this investigation fit reasonably well the predictions which were based upon the model. More so, the model accounts for many disparities in the results obtained by other investigators. In particular, the model explains the convergence of SoNo and $S\pi No$ intelligibility functions at high S/N ratios (Licklider, 1948; Schubert, 1956; Schubert and Schultz, 1962; Carhart et. al., 1966; and Tobias, 1970), as shown in Figure 6.

In the preceding studies a gain in intelligibility of about 6dB has been reported, however, Kock (1950) reported a binaural gain in intelligibility equivalent to about 13 dB S/N. As seen from Table II, Kock used a single sentence as the speech stimulus. This sentence was repeated over

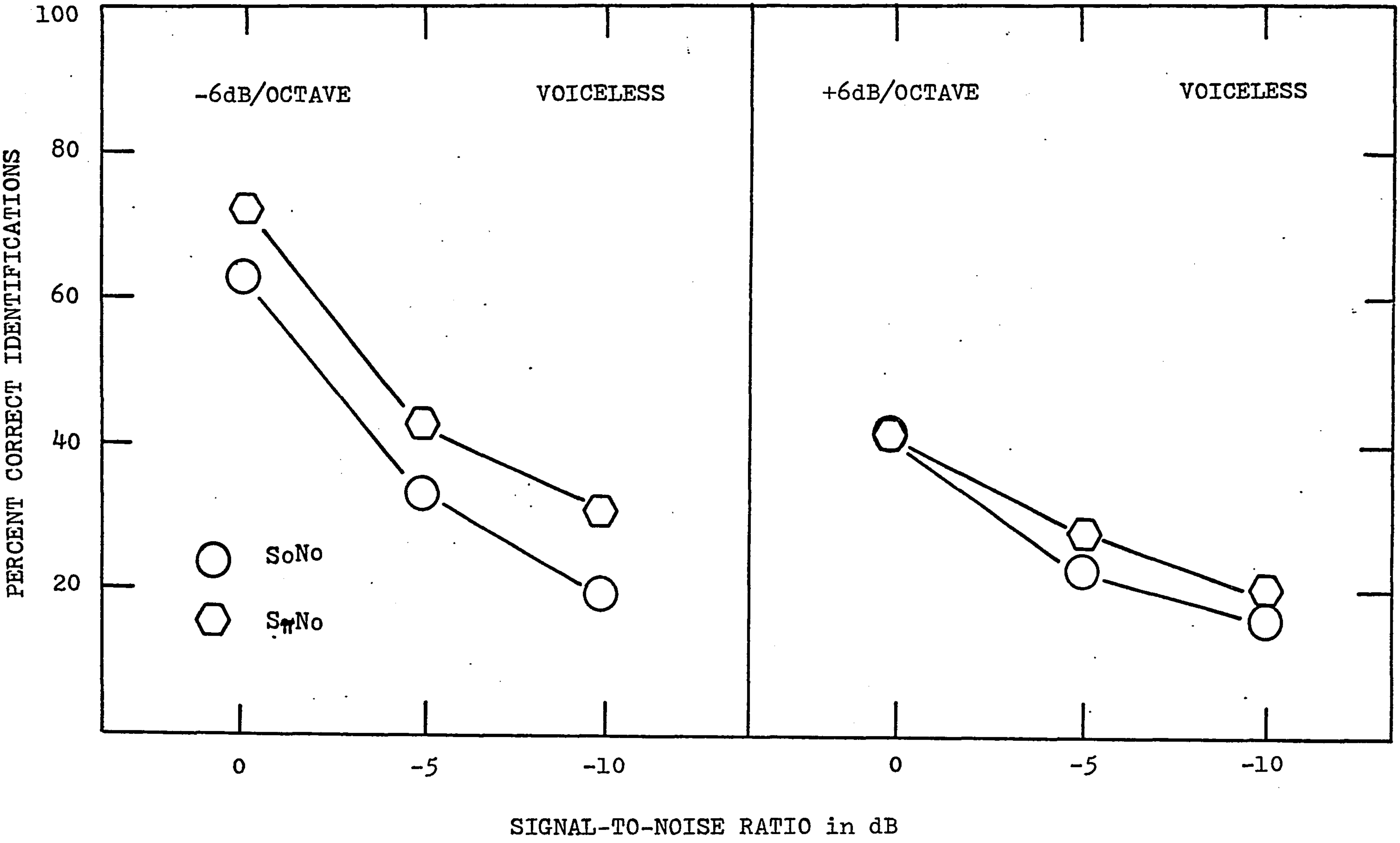


Figure 37. Binaural improvement in intelligibility for voiceless consonants presented against the background og -6dB/octave (left-hand panel), and +6dB/octave sloping noise (right-hand panel). The plotted data have a standard error on the order of 2.9 percentage points (see note on page 56).

and over again, against the background of noise, while the subject was instructed to "detect" this single sentence, a task that is basically different from discriminating between syllables, as was the case in Licklider's (1950), or Carhart et. al., (1966) studies. In Kock's study the subject does not have to understand any new material. Only a narrow band of frequencies, in the low frequency region of the speech spectrum is required to perform this task. Remember that binaural release from masking in this region, 150-400 Hz, averages about 12 dB, hence one may expect a binaural gain of this magnitude.

For experiments where monosyllables were used as speech material, smaller ILD's, on the order of about 6 dB can be predicted in line with the same principle. Monosyllables at very low S/N ratios, when presented against the background of white noise will be identified on the basis of their low- and mid-frequency components. Now, phase reversal of the speech wave, when masked by white noise, the mid-frequencies make their contribution to binaural improvement in intelligibility. As we already know, the ILD in this case is substantially smaller. As listening conditions improve, which can be represented by a higher S/N ratio, discrimination scores for homophasic (SoNo) listening conditions get better. At such levels, improvement in intelligibility depends upon more sublte phonemic discrimination. These subtle discriminations depend upon the high frequency bands of the speech spectrum. Namely, at such high S/N ratios the ILD's depend solely upon high frequency interaural information. In this frequency region release from masking is limited to about 3 dB. In view of the preceding discussion Carhart, Tillman, and Johnson's (1966) results are consistent with predictions made according to the model.

It was also pointed out in an earlier part of this paper when the effect of interaural correlation upon MLD's was discussed, that Robinson and Jeffress (1963) obtained MLD's as large as 13 dB when interaural correlation was changed from -1.0 to +1.0 Licklider (1948), on the other hand obtained under corresponding conditions an ILD equivalent to about 4 dB. However, the basic difference between these experiments was the difference in the signal stimuli used by the investigators. Licklider (1948) used monosyllables, to be identified, whereas Robinson and Jeffress (1963) used a 500 Hz sinusoid to be detected by the subjects, respectively. Again, based upon the model, where detection of a 500 Hz sinusoid is required from the subject, an MLD of about 13 dB is predicted, whereas, for identification of monosyllables (at low S/N ratios, as was the case in Licklider's experiment) one would predict ILD's on the order of about 4 dB, as deduced from this study.

APPENDIX I

SUBTEST #1

	af	aʃ	at	ak	as	ap	aΘ	
af	0.3611	0.0833	0.0972	0.0556	0.0833	0.0	0.0972	REAL SoNo
aʃ	0.2500	0.4444	0.0556	0.0139	0.0833	0.1389	0.0817	
at	0.0566	0.0278	0.4722	0.1389	0.0833	0.0556	0.1250	
ak	0.0833	0.1389	0.0417	0.4583	0.4444	0.3333	0.0972	
as	0.1111	0.0556	0.2222	0.1250	0.1111	0.0556	0.0278	
ap	0.1111	0.2222	0.0556	0.1528	0.1111	0.4167	0.0694	
aΘ	0.0278	0.0278	0.0556	0.0556	0.0833	0.0	0.5417	
af	0.4722	0.1111	0.1067	0.0833	0.1389	0.0278	0.0694	REAL STNo
aʃ	0.3056	0.5000	0.0	0.0	0.0833	0.1944	0.0417	
at	0.0556	0.0	0.7500	0.2083	0.1389	0.0833	0.1111	
ak	0.0556	0.1389	0.0556	0.4444	0.2778	0.2222	0.0139	
as	0.0556	0.0833	0.0139	0.0417	0.1111	0.0	0.0417	
ap	0.0556	0.1667	0.0139	0.1389	0.1667	0.4722	0.0972	
aΘ	0.0	0.0	0.0	0.0833	0.0833	0.0	0.6250	
af	0.3333	0.0556	0.0	0.0278	0.1111	0.0556	0.0278	SIMULATED STNo
aʃ	0.2500	0.5278	0.1111	0.0972	0.1111	0.1667	0.0278	
at	0.1111	0.0278	0.5972	0.0833	0.0833	0.0556	0.0972	
ak	0.1111	0.1389	0.1667	0.6111	0.2778	0.1111	0.0417	
as	0.0833	0.0	0.0417	0.0972	0.1944	0.0556	0.0	
ap	0.0833	0.2500	0.0556	0.0694	0.0833	0.0556	0.0694	
aΘ	0.0278	0.0	0.0278	0.0139	0.1359	0.0	0.7361	
af	0.2500	0.0556	0.0278	0.1111	0.1111	0.0833	0.0972	SIMULATED SoNo
aʃ	0.3611	0.4167	0.0972	0.0972	0.1111	0.0556	0.0417	
at	0.0833	0.0278	0.5000	0.1111	0.1944	0.0633	0.1528	
ak	0.1389	0.2778	0.0972	0.3750	0.2778	0.2500	0.1389	
as	0.0278	0.0278	0.1389	0.1111	0.1111	0.0556	0.0417	
ap	0.1111	0.1667	0.8278	0.1528	0.1667	0.4444	0.0	
aΘ	0.0278	0.0276	0.1111	0.0417	0.0276	0.0276	0.5278	

SUBTEST #2

	uΘ	up	us	uk	ut	uf	u∫	
uΘ	0.4167	0.1667	0.0556	0.0556	0.0833	0.1667	0.1528	REAL SoNo
up	0.0	0.0833	0.0556	0.1111	0.0417	0.0833	0.0556	
us	0.0556	0.0	0.7222	0.0833	0.1528	0.0566	0.1111	
uk	0.0278	0.1944	0.0139	0.2500	0.0278	0.0833	0.0556	
ut	0.1944	0.3056	0.0833	0.2500	0.3611	0.1389	0.3333	
uf	0.0278	0.0833	0.0417	0.1389	0.0972	0.3333	0.0556	
u∫	0.2778	0.1667	0.0278	0.1111	0.2361	0.1389	0.2361	
uΘ	0.6389	0.1111	0.0972	0.0833	0.1526	0.0833	0.0556	REAL STTNo
up	0.0	0.1111	0.0139	0.0278	0.0694	0.0556	0.1250	
us	0.0833	0.0	0.7639	0.0278	0.0139	0.0556	0.0278	
uk	0.0	0.2222	0.0	0.3333	0.0833	0.1389	0.0556	
ut	0.1389	0.2222	0.0	0.2222	0.4444	0.2776	0.4583	
uf	0.0556	0.1944	0.0556	0.2222	0.0556	0.2776	0.0278	
u∫	0.0833	0.1389	0.0694	0.0556	0.1606	0.1111	0.2500	
uΘ	0.3056	0.0278	0.0	0.0278	0.0833	0.0556	0.1389	SIMULATED STTNo
up	0.0278	0.2778	0.0	0.0833	0.0833	0.0556	0.1944	
us	0.1111	0.0833	0.8333	0.0556	0.0556	0.0833	0.0694	
uk	0.0	0.1667	0.0	0.4167	0.0694	0.0556	0.0556	
ut	0.2222	0.1667	0.0276	0.1944	0.2917	0.1944	0.1528	
uf	0.1944	0.1556	0.1250	0.1111	0.2500	0.1667	1.1944	
u∫	0.4722	0.0278	0.0972	0.1389	0.0556	0.0556	0.1806	SIMULATED SoNo
uΘ	0.0278	0.1111	0.0139	0.1944	0.0556	0.1389	0.0972	
up	0.0278	0.1111	0.0139	0.1944	0.0556	0.1389	0.0572	
us	0.0833	0.0833	0.7500	0.0278	0.0833	0.0556	0.1528	
uk	0.0556	0.1389	0.0417	0.1389	0.1250	0.2222	0.0276	
ut	0.1389	0.2500	0.0	0.2500	0.2917	0.2222	0.2222	
uf	0.1667	0.2778	0.0556	0.1389	0.2222	0.1111	0.1389	
u∫	0.0556	0.1111	0.0417	0.1111	0.1667	0.1667	0.1806	

SUBTEST #3

	i∫	if	it	ik	is	iΘ	ip	
i∫	0.1111	0.0	0.0694	0.1111	0.0833	0.0278	0.0833	REAL SoNo
if	0.0278	0.8056	0.0278	0.0556	0.0	0.0833	0.0278	
it	0.1389	0.0556	0.0889	0.8556	0.1389	0.0278	0.0833	
ik	0.1389	0.0278	0.0972	0.3056	0.2917	0.3056	0.1389	
is	0.4722	0.0278	0.3472	0.1944	0.2917	0.2778	0.0556	
iΘ	0.0278	0.0	0.0139	0.0278	0.0694	0.1389	0.0556	
ip	0.0833	0.0833	0.0556	0.2500	0.1250	0.1389	0.0556	
i∫	0.0833	0.0556	0.0694	0.1111	0.0278	0.1111	0.0278	REAL SπNo
if	0.0	0.8333	0.8278	0.0	0.0278	0.0278	0.0	
it	0.1111	0.0	0.3750	0.1667	0.2500	0.0833	0.0278	
ik	0.2222	0.0556	0.1389	0.2778	0.0972	0.3611	0.0278	
is	0.5000	0.0278	0.3056	0.2500	0.4028	0.2222	0.0556	
iΘ	0.0278	0.0	0.0139	0.1111	0.0278	0.0278	0.0278	
ip	0.0656	0.0278	0.0694	0.0833	0.1667	0.1667	0.8333	
i∫	0.1944	0.0278	0.0417	0.1389	0.0556	0.0556	0.0556	SIMULATED SπNo
if	0.0	0.8066	0.0	0.0	0.0139	0.0278	0.0278	
it	0.2222	0.0556	0.1000	0.1111	0.0556	0.0556	0.0833	
ik	0.1111	0.0556	0.0972	0.3333	0.1806	0.3611	0.0	
is	0.3750	0.0278	0.3333	0.2222	0.5278	0.3611	0.0556	
iΘ	0.0278	0.0	0.0276	0.0833	0.0278	0.0278	0.0278	
ip	0.0694	0.0278	0.0	0.1111	0.1389	0.1111	0.7222	
i∫	0.1369	0.0278	0.1111	0.1111	0.0	0.0556	0.0	SIMULATED SoNo
if	0.0278	0.6056	0.0556	0.1111	0.0972	0.0278	0.0556	
it	0.1111	0.0556	0.0889	0.1667	0.2023	0.1111	0.0276	
ik	0.2083	0.0278	0.0833	0.1667	0.1667	0.1944	0.1589	
is	0.3333	0.0278	0.2639	0.2500	0.3333	0.3889	0.0833	
iΘ	0.0694	0.0	0.0278	0.0833	0.0417	0.0833	0.0556	
ip	0.1111	0.0556	0.0694	0.1111	0.1528	0.1389	0.6111	

SUBTEST #4

	ad	at	ad	am	az	ag	an	aj	av	
ab	0.8194	0.0270	0.0	0.0278	0.0833	0.1111	0.0	0.0278	0.0	REAL
at	0.0	0.6111	0.0278	0.0417	0.1667	0.0139	0.3056	0.0	0.0	
ad	0.0	0.0556	0.6667	0.0139	0.0278	0.0	0.0	0.0139	0.0278	
am	0.0139	0.0278	0.0278	0.4306	0.0833	0.0417	0.2222	0,1528	0.0556	
az	0.0417	0.1667	0.1944	0.1111	0.5556	0.0139	0.2778	0.0417	0.0278	
ag	0.0417	0.0	0.0278	0.0139	0.0278	0.6667	0.0278	0.0417	0.0278	
an	0.0278	0.0278	0.0278	0.0278	0.0	0.0139	0.1111	0.0278	0.0	
aj	0.0278	0.0833	0.0278	02917	0.0	0.0833	0.0556	0.6944	0.0556	
av	0.0278	0.0	0.0139	0.0278	0.0556	0.0556	0.0	0.0	0.8056	
ab	0.9306	0.0	0.0	0.0139	0.0278	0.0833	0.0	0.0	0.0	REAL
ad	0.0	0.9722	0.0	0.0	0.3333	0.0	0.4722	0.0	0.0	
ad	0.0	0.0	0.8889	0.0139	0.0278	0.0	0.0833	0.0	0.0	
am	0.0139	0.0	0.0278	0.5972	0.0	0.0278	0.2222	0.0	0.0	
az	0.0	0.0278	0.0833	0.0556	0.6111	0.0139	0.1111	0.0694	0.0278	
ag	0.0139	0.0	0.0	0.0	0.0	0.7917	0.0278	0.0	0.0	
an	0.0278	0.0	0.0	0.0972	0.0	0.0	0.0278	0.0278	0.0	
aj	0.0	0.0	0.0	0.2222	0.0	0.0278	0.0556	0.9028	0.0	
av	0.0139	0.0	0.0	0.0	0.0	0.0556	0.0	0.0	0.9722	
ab	0.9444	0.0	0.0556	0.0	0.0278	0.0139	0.0	0.0	0.0	SIMULATED
at	0.0139	0.8333	0.0278	0.0	0.2500	0.0	0.3611	0.0278	0.0	
ad	0.0	0.0556	0.8056	0.0	0.0	0.0	0.0833	0.0	0.0278	
am	0.0	0.0278	0.0556	0.7500	0.0278	0.0278	0.2222	0.0833	0.0	
az	0.0	0.0556	0.0278	0.0	0.6667	0.0	0.1389	0.0	0.0	
ag	0.0139	0.0	0.0	0.0	0.0	0.9167	0.0	0.0139	0.0	
an	0.0	0.0	0.0278	0.0278	0.0	0.0	0.1111	0.0	0.0	
aj	0.0278	0.0278	0.0	0.2222	0.0278	0.0833	0.8750	0.0	0.0	
av	0.0	0.0	0.0	0.0	0.0	0.0139	0.0	0.0	0.9722	
ab	0.6389	0.0278	0.0278	0.0139	0.1389	0.0556	0.0278	0.0	0.0	SIMULATED
at	0.1111	0.5833	0.0833	0.0278	0.1111	0.0278	0.3889	0.0276	0.0278	
ad	0.0	0.0833	0.6111	0.0972	0.0833	0.0	0.0556	0.0417	0.0278	
am	0.0	0.1111	0.0278	0.5694	0.0278	0.0694	0.2222	0.2222	0.0	
az	0.0417	0.0833	0.1944	0.0278	0.4167	0.0417	0.2222	0.0833	0.1667	
ag	0.0833	0.0	0.0278	0.0139	0.0278	0.6389	0.0	0.0417	0.0	
an	0.0278	0.0556	0.0278	0.0417	0.0278	0.0278	0.0	0.0	0.0	
aj	0.0556	0.0556	0.0	0.1667	0.0278	0.0417	0.0833	0.5833	0.0278	
av	0.0417	0.0	0.0	0.0417	0.1389	0.0972	0.0	0.0	0.7500	

SUBTEST #5

fa	ta	pa	ha	θa	tʃa	sa	ʃa	ka	
0.5556	0.0278	0.1389	0.3889	0.0417	0.0	0.0417	0.0	0.0278	REAL SoNo
0.0139	0.0333	0.0	0.1389	0.0	0.1111	0.0	0.0270	0.0	
0.1667	0.0	0.3889	0.0	0.0833	0.0556	0.1944	0.0	0.2222	
0.0139	0.0	0.0278	0.2222	0.0278	0.0139	0.0556	0.0556	0.0556	
0.0278	0.0278	0.0556	0.0833	0.1528	0.0556	0.1250	0.0556	0.1389	
0.0	0.0833	0.0	0.0	0.0278	0.4306	0.0	0.1944	0.0278	
0.1250	0.0	0.3889	0.0833	0.5972	0.0833	0.5694	0.0	0.2500	
0.0278	0.0278	0.0	0.0278	0.0	0.1944	0.0139	0.6667	0.0	
0.0694	0.0	0.0	0.0556	0.0694	0.0556	0.0	0.0	0.2778	
0.7361	0.0556	0.0556	0.4167	0.0278	0.0139	0.0	0.0278	0.0278	REAL SπNo
0.0	0.0611	0.0	0.1667	0.0	0.0556	0.0139	0.1111	0.0278	
0.1389	0.0	0.5556	0.0556	0.1944	0.0270	0.0833	0.0278	0.1389	
0.0139	0.0	0.0	0.222	0.0694	0.0556	0.0278	0.0	0.0278	
0.0278	0.0	0.0278	0.0	0.1250	0.0	0.0833	0.0	0.0556	
0.0	0.0556	0.0278	0.0278	0.0	0.7500	0.0	0.0556	0.0	
0.0833	0.0	0.2500	0.0	0.5000	0.0	0.7083	0.0	0.4444	
0.0	0.0278	0.0278	0.0278	0.0139	0.0972	0.0	0.7778	0.0	
0.0	0.0	0.0556	0.0833	0.0694	0.0	0.0833	0.0	0.2778	
0.8472	0.0	0.1111	0.3889	0.0278	0.0	0.0	0.0556	0.0	SIMULATED SπNo
0.0	0.8889	0.0	0.1389	0.0	0.0417	0.0	0.0833	0.0278	
0.0556	0.0	0.5000	0.0833	0.2222	0.0	0.0417	0.0	0.0833	
0.0278	0.0556	0.0	0.3056	0.0694	0.0417	0.0139	0.0278	0.0278	
0.0	0.0278	0.0278	0.0	0.1944	0.0278	0.0556	0.0	0.0556	
0.0	0.0	0.0	0.0	0.0	0.6667	0.0278	0.1389	0.0	
0.0417	0.0	0.2500	0.0	0.2778	0.0278	0.8194	0.0	0.4444	
0.0278	0.0	0.0278	0.0278	0.0417	0.1944	0.0278	0.6667	0.0	
0.0	0.0278	0.0833	0.0556	0.1667	0.0	0.0139	0.0278	0.3611	
0.7083	0.0	0.0833	0.2778	0.0972	0.0	0.0833	0.0	0.0566	SIMULATED SoNo
0.0139	0.8333	0.0278	0.0833	0.0	0.0972	0.0	0.0833	0.0278	
0.1389	0.0	0.5556	0.1111	0.1250	0.0417	0.0972	0.0556	0.1667	
0.0556	0.0556	0.0278	0.2222	0.0	0.0278	0.1111	0.0278	0.0833	
0.0	0.0278	0.0556	0.1111	0.1389	0.0694	0.0278	0.0556	0.0278	
0.0	0.0	0.0	0.0556	0.0417	0.6389	0.0	0.2222	0.0556	
0.0278	0.0556	0.2222	0.0278	0.4722	0.0	0.5139	0.0556	0.3056	
0.0	0.0278	0.0278	0.0278	0.0694	0.1111	0.0278	0.5000	0.0278	
0.0556	0.0	0.0	0.0833	0.0556	0.0139	0.1389	0.0	0.2500	

SUBTEST #6

	la	ba	da	ga	ra	ja	dza	da	
la	0.6389	0.0	0.0278	0.0	0.0	0.0	0.3611	0.0	REAL SoNo
ba	0.0	0.6250	0.0833	0.0556	0.0	0.2222	0.0	0.0	
da	0.0	0.0278	0.5833	0.0	0.0	0.0278	0.0417	0.0	
ga	0.0	0.0972	0.0278	0.9167	0.0	0.2222	0.0417	0.0556	
ra	0.0278	0.0278	0.1111	0.0278	0.9444	0.0	0.0278	0.2500	
ja	0.0	0.2222	0.0556	0.0	0.0	0.5278	0.0	0.0	
dza	0.2776	0.0	0.0556	0.0	0.0417	0.0	0.5000	0.1944	
wa	0.0556	0.0	0.0556	0.0	010139	0.0	0.0278	0.5000	
la	0.8056	0.0	0.0278	0.0	0.0	0.0	0.3333	0.0	REAL STNo
ba	0.0	0.7222	0.0833	0.0	0.0	0.0833	0.0	0.0556	
da	0.0	0.0	0.7500	0.0	0.0	0.0	0.0139	0.0	
ga	0.0	0.0556	0.0278	1.0000	0.0	0.1111	0.0	0.0	
ra	0.0556	0.0	0.0	0.0	1.0000	0.0278	0.0417	0.1389	
ja	0.0	0.2222	0.0833	0.0	0.0	0.7778	0.0	0.0	
dza	0.1389	0.0	0.0	0.0	0.0	0.0	0.5833	0.1389	
wa	0.0	0.0	0.0278	0.0	0.0	0.0	0.0278	0.6667	
la	0.7778	0.0	0.0556	0.0	0.0	0.0	0.3333	0.0	SIMULATED STNo
ba	0.0	0.7361	0.0	0.0	0.0	0.0833	0.0	0.0	
da	0.0278	0.0	0.9167	0.0	0.0	0.0	0.0	0.0	
ga	0.0	0.1111	0.0	1.0000	0.0	0.0278	0.0	0.0	
ra	0.0556	0.0	0.0	0.0	1.0000	0.0	0.0	0.1389	
ja	0.0	0.1528	0.0	0.0	0.0	0.8889	0.0	0.0	
dza	0.1111	0.0	0.0278	0.0	0.0	0.0	0.6667	0.1944	
wa	0.0278	0.0	0.0	0.0	0.0	0.0	0.0	0.6667	
la	0.7500	0.0	0.0278	0.0276	0.0556	0.0	0.2222	0.0278	SIMULATED SoNo
ba	0.0	0.5833	0.1111	0.0	0.0	0.1111	0.0278	0.0278	
da	0.0	0.0417	0.7500	0.0	0.0	0.0278	0.0	0.0556	
ga	0.0	0.1111	0.0	0.9444	0.0	0.1111	0.0556	0.0556	
ra	0.0833	0.0	0.0556	0.0	0.9167	0.0276	0.0972	0.1389	
ja	0.0	0.2639	0.0278	0.0	0.0	0.6944	0.0	0.0278	
dza	0.1111	0.0	0.0278	0.0278	0.0278	0.0	0.5556	0.0556	
wa	0.0556	0.0	0.0	0.0	0.0	0.0278	0.0417	0.6111	

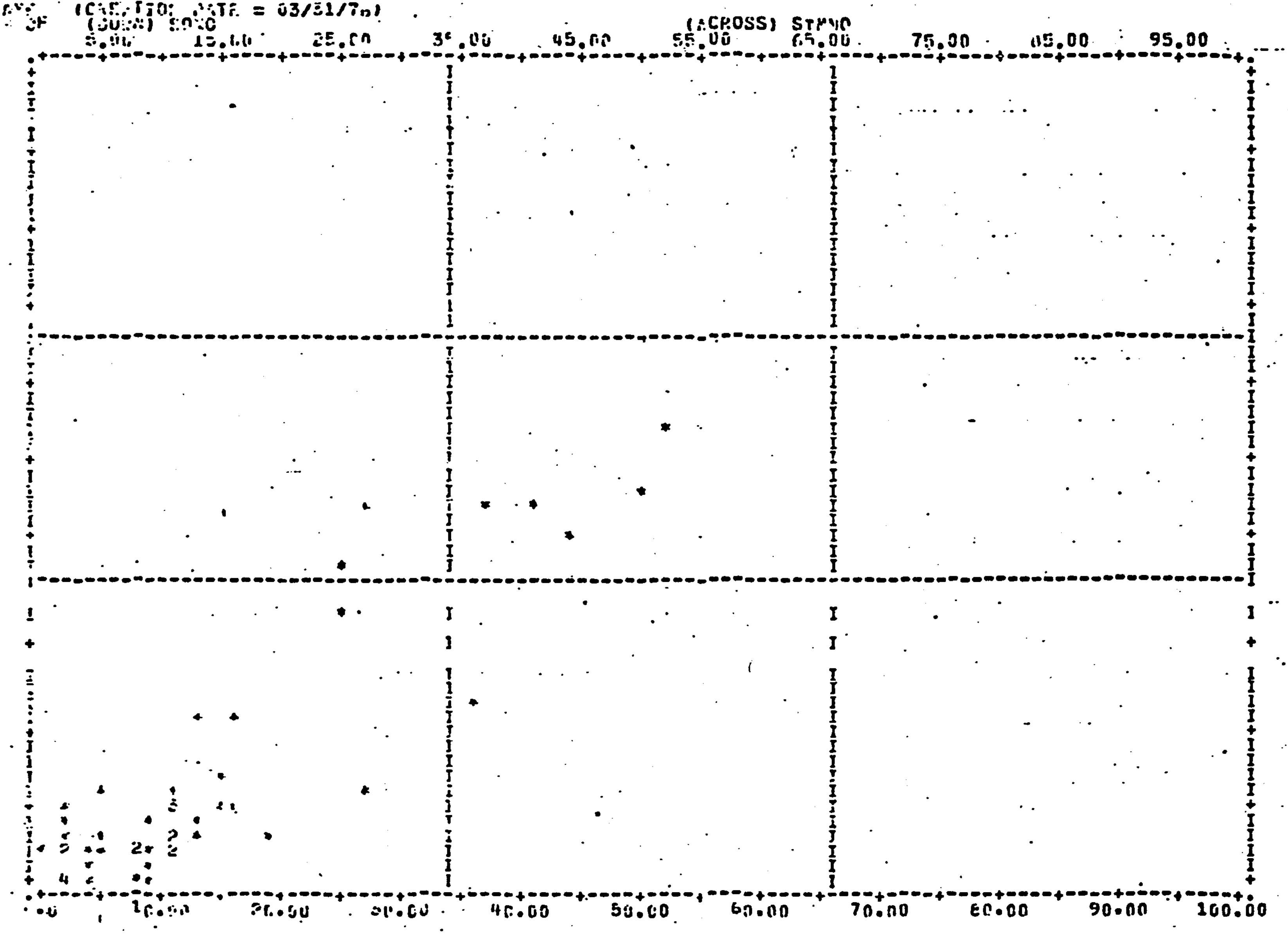
SUBTEST #7

	/na/	/va/	/ma/	/za/	/ga/	/ba/	/ta/	/da/	
na	0.2361	0.1944	0.0	0.0139	0.0139	0.0278	0.0278	0.0278	REAL SoNo
va	0.2639	0.4722	0.0	0.0	0.1806	0.0	0.0	0.0	
ma	0.0278	0.0556	0.6944	0.0417	0.0833	0.0278	0.0	0.0	
za	0.0972	0.1389	0.0833	0.6806	0.3611	0.0833	0.4444	0.0139	
ga	0.2917	0.1111	0.0833	0.0972	0.2639	0.0273	0.0556	0.0694	
ba	0.0139	0.0	0.0278	0.0556	0.0139	0.8056	0.0	0.0833	
ta	0.0694	0.0278	0.0833	0.1111	0.0556	0.0278	0.4444	0.0278	
da	0.0	0.0	0.0278	0.0	0.0278	0.0	0.0278	0.7778	
na	0.4167	0.3333	0.0	0.0	0.0169	0.0	0.0	0.0278	REAL SπNo
va	0.2083	0.4722	0.0	0.0	0.0972	0.0	0.0278	0.0	
ma	0.0417	0.0278	0.3333	0.0	0.0278	0.0	0.0278	0.0	
za	0.0417	0.0278	0.0556	0.8194	0.2222	0.0556	0.3611	0.0278	
ga	0.2639	0.1111	0.0833	0.0278	0.4722	0.0	0.0	0.0	
ba	0.0	0.0	0.0	0.0278	0.0	0.9444	0.0	0.0	
ta	0.0278	0.0278	0.0278	0.1250	0.1828	0.0	0.5833	0.0	
da	0.0	0.0	0.0	0.0	0.0139	0.0	0.0	0.9444	
na	0.4722	0.2500	0.0	0.0	0.0556	0.0	0.0	0.0	SIMULATED SπNo
va	0.1667	0.5000	0.0	0.0	0.1250	0.0	0.0	0.0	
ma	0.0	0.0	0.9167	0.0	0.0278	0.0	0.0	0.0	
za	0.0972	0.0	0.0	0.8333	0.2639	0.0278	0.3333	0.0	
ga	0.2361	0.2222	0.0556	0.0	0.4167	0.0	0.0		
ba	0.0	0.0	0.0	0.0	0.0	0.9722	0.0	0.0	
ta	0.0278	0.0278	0.0278	0.1667	0.1111	0.0	0.6667	0.0	
da	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	
na	0.1944	0.2500	0.0	0.0	0.0417	0.0556	0.0	0.1667	SIMULATED SoNo
va	0.3333	0.3611	0.0	0.0556	0.0417	0.0	0.0	0.0278	
ma	0.0833	0.0833	0.6111	0.0278	0.0833	0.0	0.0556	0.0	
za	0.0139	0.0556	0.1944	0.0556	0.3194	0.0278	0.3889	0.0	
ga	0.2222	0.1389	0.1111	0.0556	0.3472	0.0556	0.0556	0.0556	
ba	0.0139	0.0556	0.0	0.1111	0.0833	0.8333	0.0	0.0	
ta	0.0533	0.0278	0.0556	0.1667	0.0833	0.0278	0.6000	0.0	
wa	0.0556	0.0278	0.9278	0.0276	0.0	0.0	0.0	0.7500	

APPENDIX II

03/31/76 PAGE 5

FILE [illegible] (CREATION DATE = 03/31/76)
SCATTERGRAM OF (DOWN) [illegible] (ACROSS) [illegible]



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ILE    SCHAPE    (CREATION DATE = 03/31/76)
CATTERGRAM OF    (DOWN) SOXO                                     (ACROSS) STPNO
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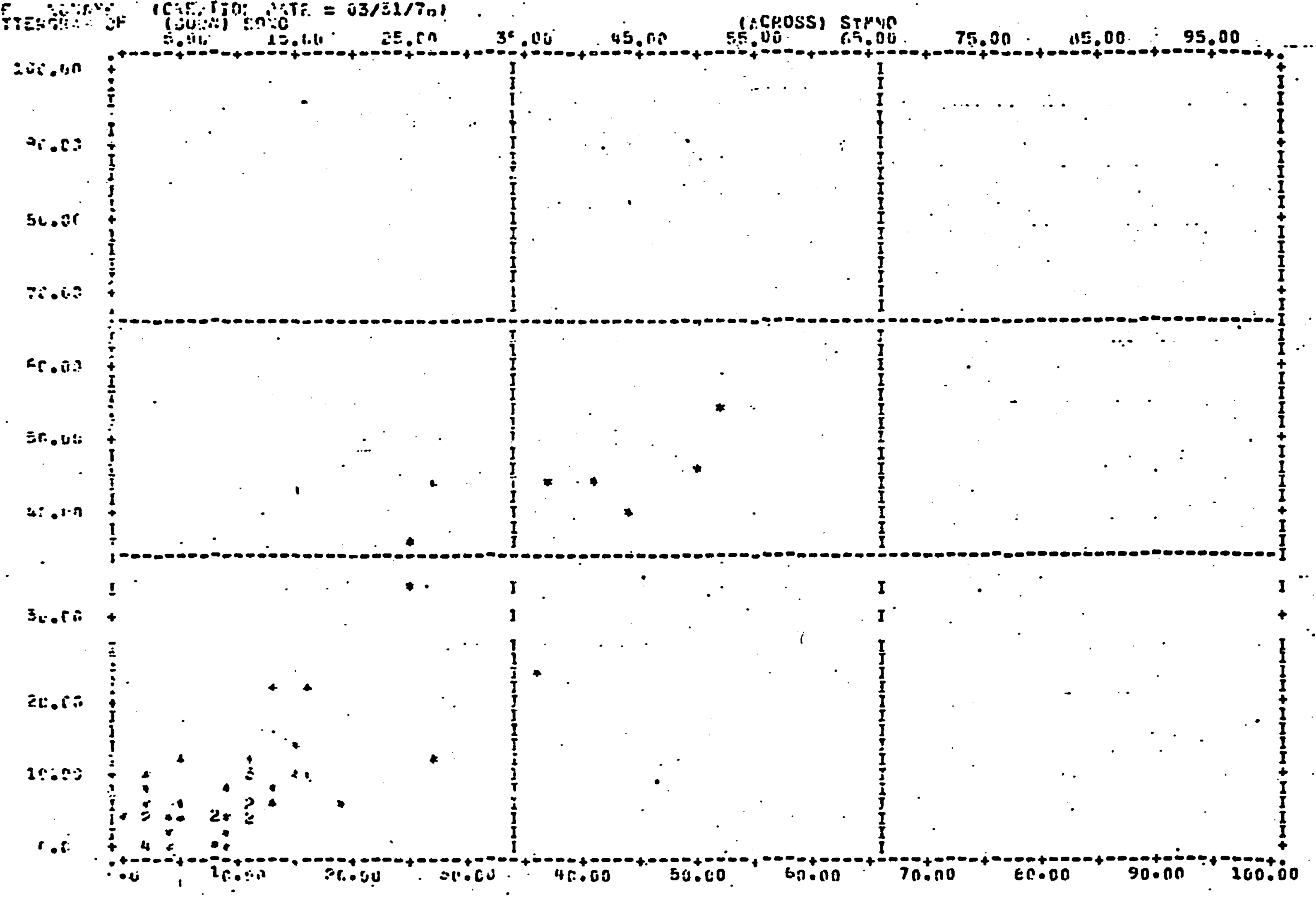

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                                                    03/31/76        PAGE    6

STATISTICS..
  CORRELATION (R)-      0.90437       R SQUARED     -      0.61735     SIGNIFICANCE   -      0.00001
  STD ERR OF EST -      6.15223       INTERCEPT (A) -      0.31593     SLOPE (B)      -      0.97861
  PLOTTED VALUES -      45            EXCLUDED VALUES-     0           MISSING VALUES -      0

          ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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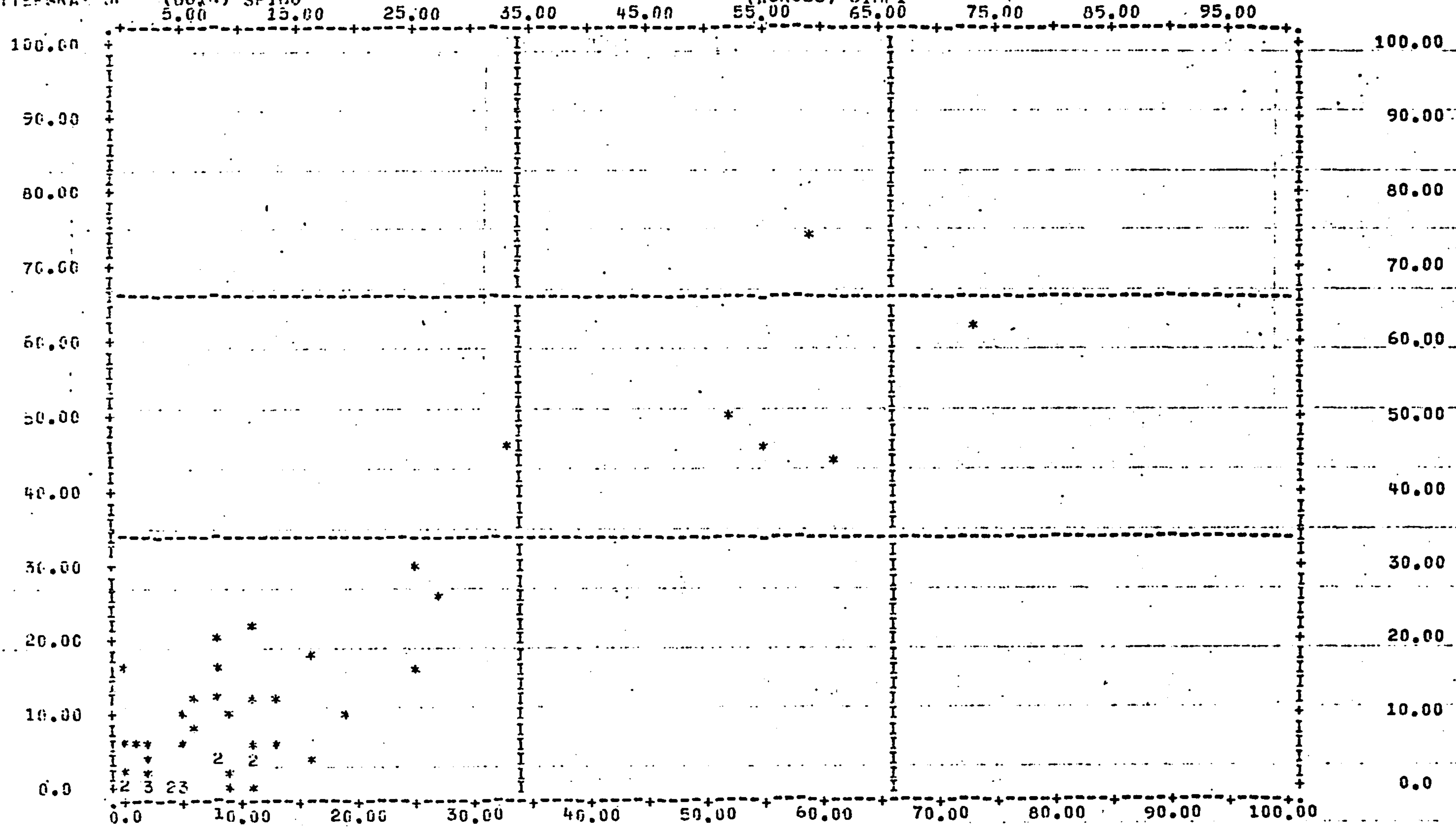
FILE NONAME (CREATION DATE = 03/31/76)
SCATTERGRAM OF (DOWN) SPIUO (ACROSS) SIMPI



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FILE    NONAME    (CREATION DATE = 03/31/76)
SCATTERGRAM OF    (DOWN) SPIUO                         (ACROSS) SIMPI
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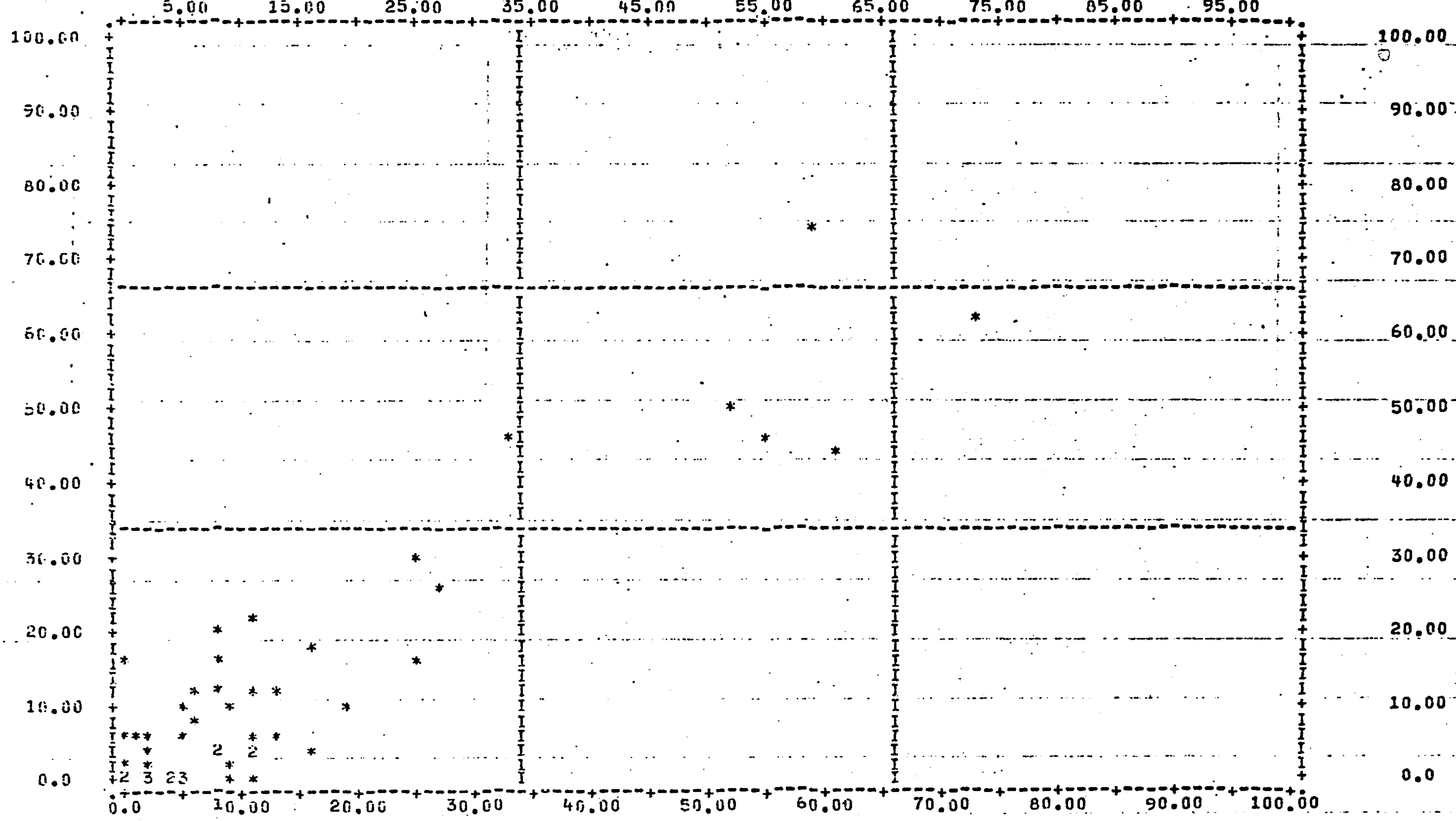

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STATISTICS..
  CORRELATION (R)-        0.91137     R SQUARED       -       0.83060     SIGNIFICANCE   -       0.00001
  STD ERR OF EST -        7.15917     INTERCEPT (A)   -       1.49520     SLOPE (B)      -       0.89636
  PLOTTED VALUES -       49           EXCLUDED VALUES-        0           MISSING VALUES -       0

               '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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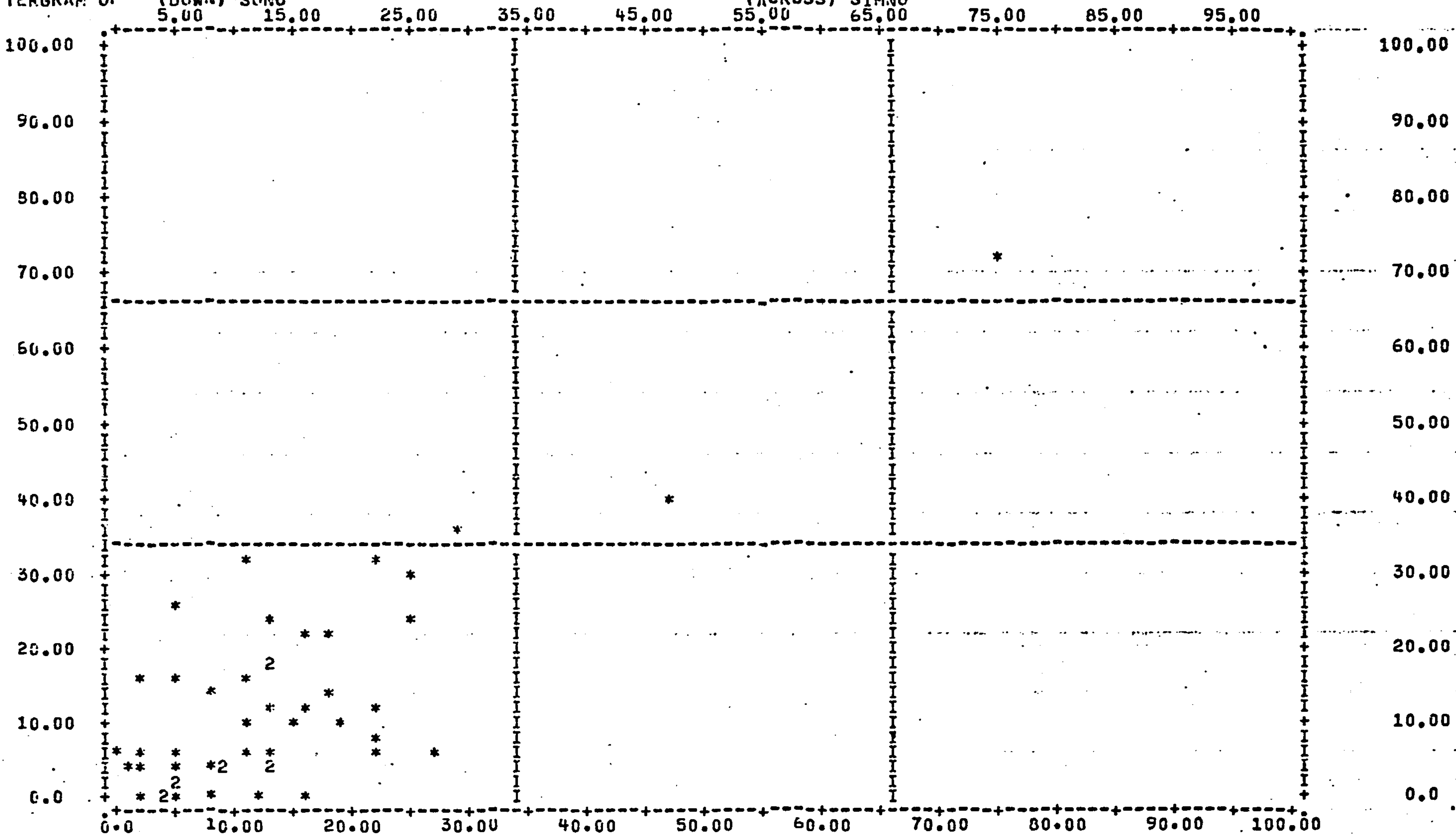
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SONO (ACROSS) SIMNO



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FILE   NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SONO                                          (ACROSS) SIMNO
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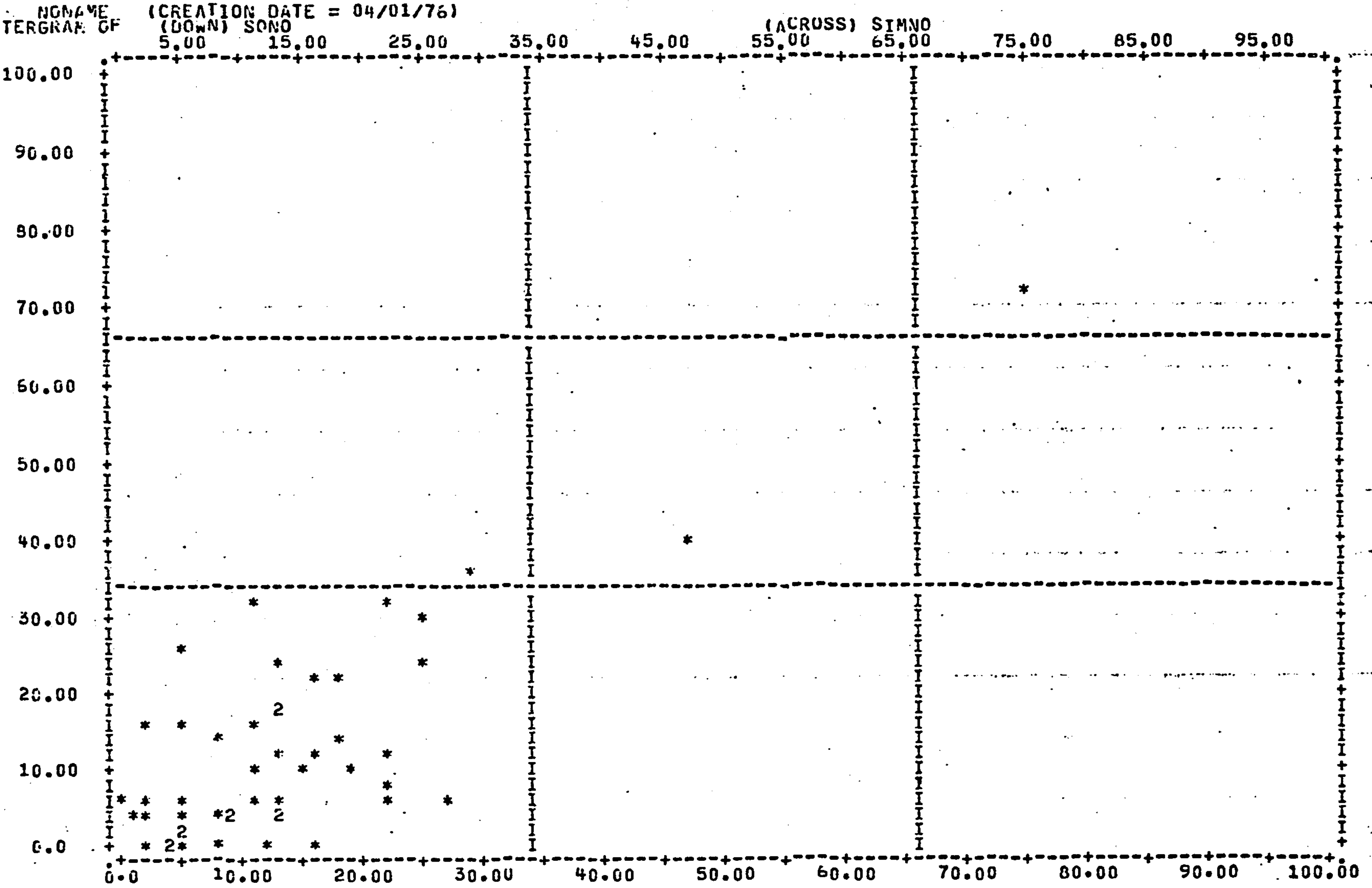

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MODULE TWO                                                      04/01/76        PAGE    6

STATISTICS..
  CORRELATION (R)-          0.78328       R SQUARED        -          0.61353        SIGNIFICANCE   -         0.00001
  STD ERR OF EST -          8.35171       INTERCEPT (A)    -          2.49863        SLOPE (B)      -         0.82306
  PLOTTED VALUES -         49             EXCLUDED VALUES-            0              MISSING VALUES -         0

                  '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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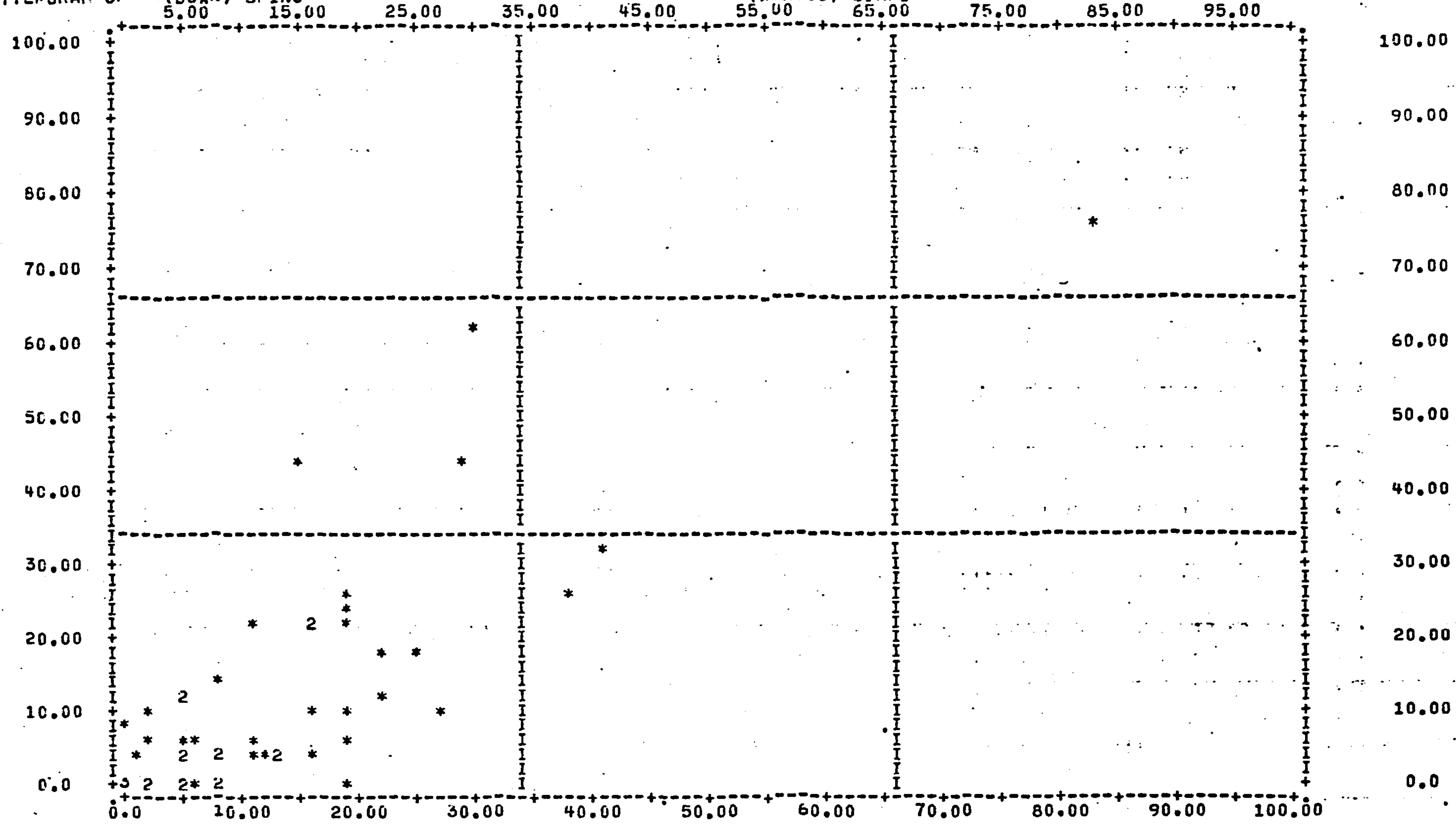
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SPINC (ACROSS) SIMPI



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FILE   NONAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF   (DOWN) SPINO                                       (ACROSS) SIMPI
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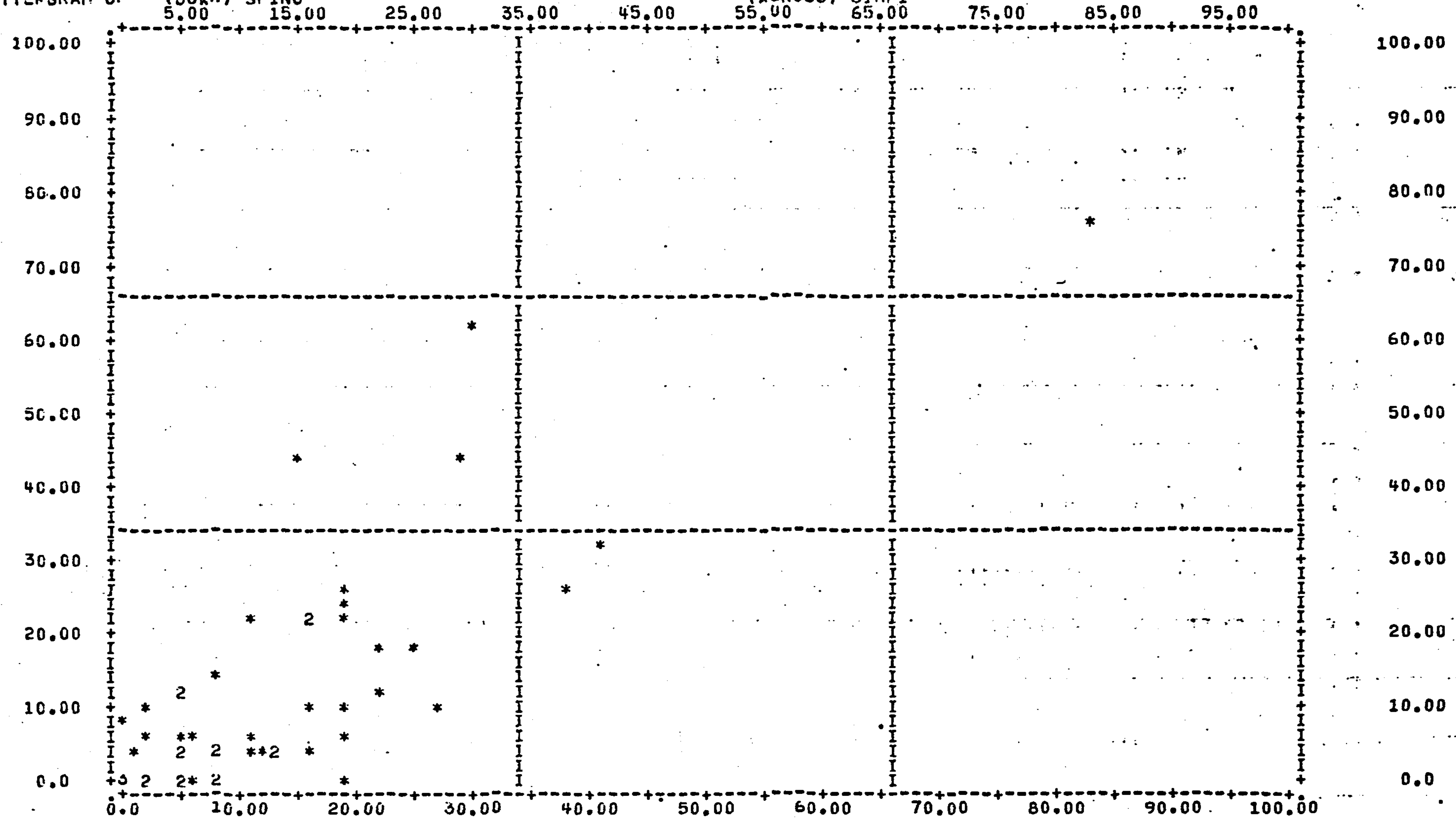

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MODULE TWO                                                        04/01/76        PAGE   9

STATISTICS..
  CORRELATION (R)-          0.79699       R SQUARED       -         0.63520       SIGNIFICANCE  -          0.00001
  STD ERR OF EST -          9.70332       INTERCEPT (A)   -         1.37639       SLOPE (B)     -          0.89743
  PLOTTED VALUES -         49             EXCLUDED VALUES-          0             MISSING VALUES -         0

                      '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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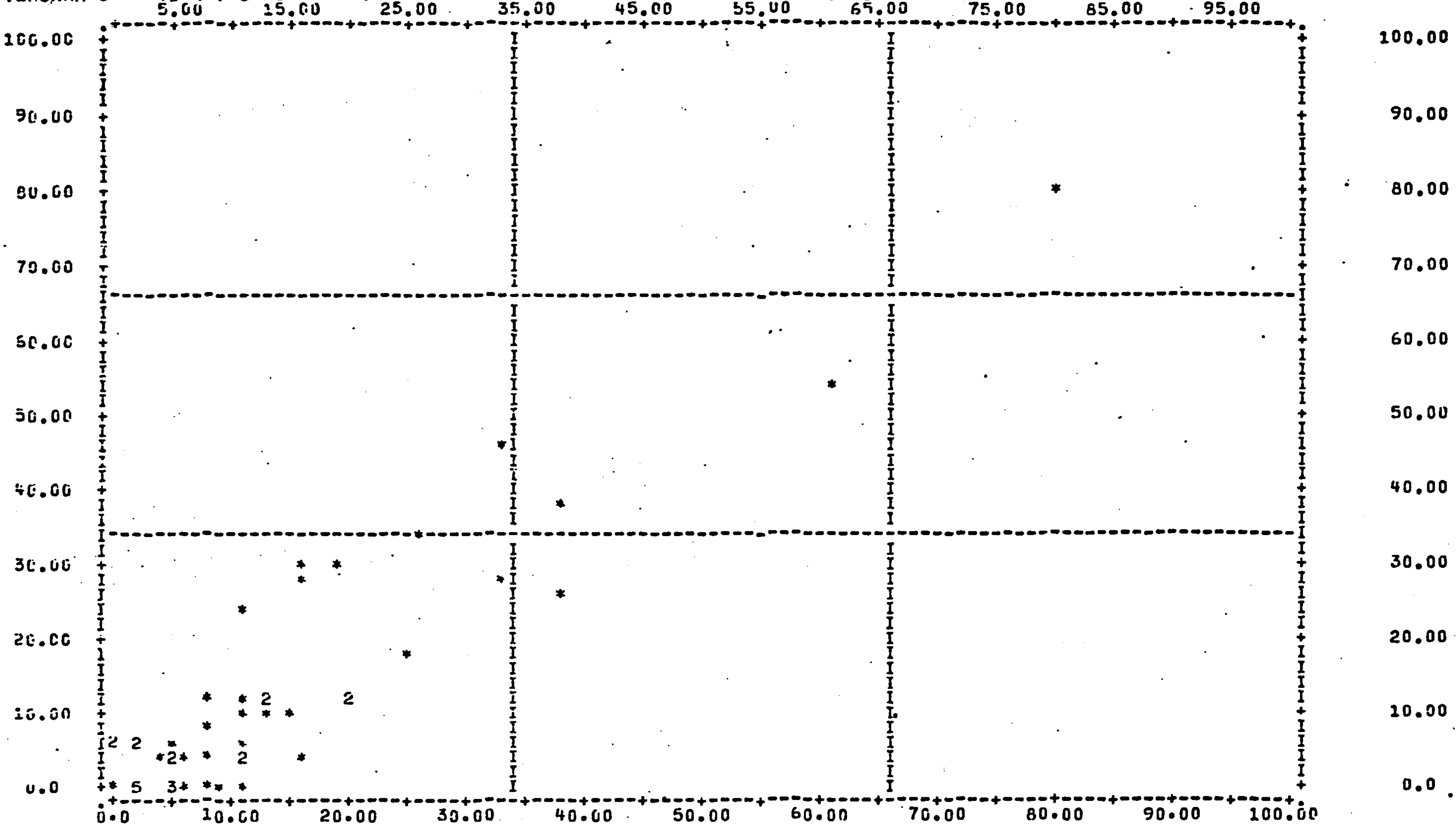
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SONO (ACROSS) SIMNO



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FILE    NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SONO                                    (ACROSS) SIMNO
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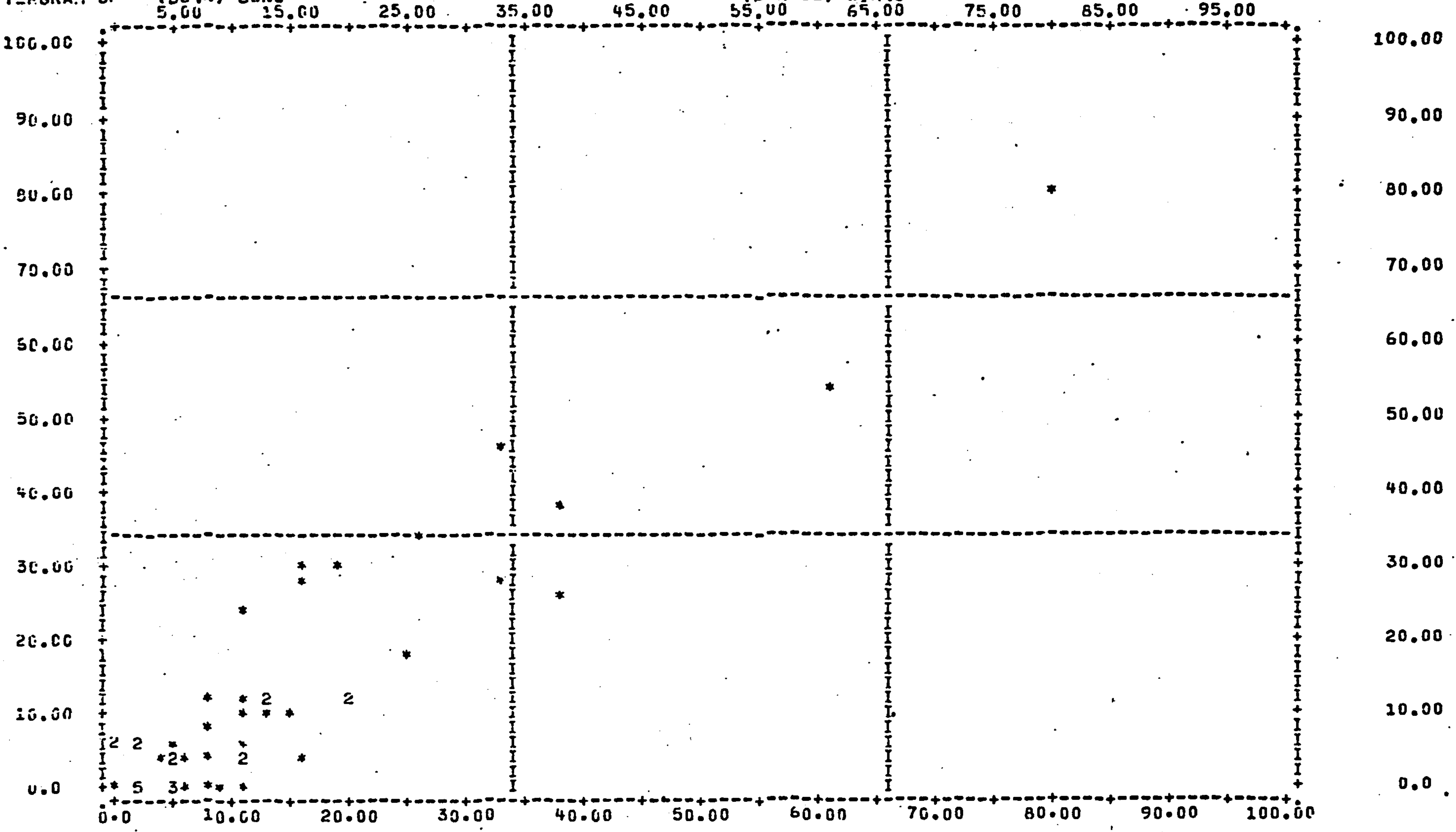

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STATISTICS..
  CORRELATION (R)-        0.91827     R SQUARED        -       0.84322     SIGNIFICANCE    -       0.00001
  STD ERR OF EST -        6.40637     INTERCEPT (A)    -       0.60234     SLOPE (B)       -       0.95614
  PLOTTED VALUES -       49           EXCLUDED VALUES-         0           MISSING VALUES  -       0

              ********* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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FILE    MCNAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF   (DOWN) SPINO                                    (ACROSS) SIMPI
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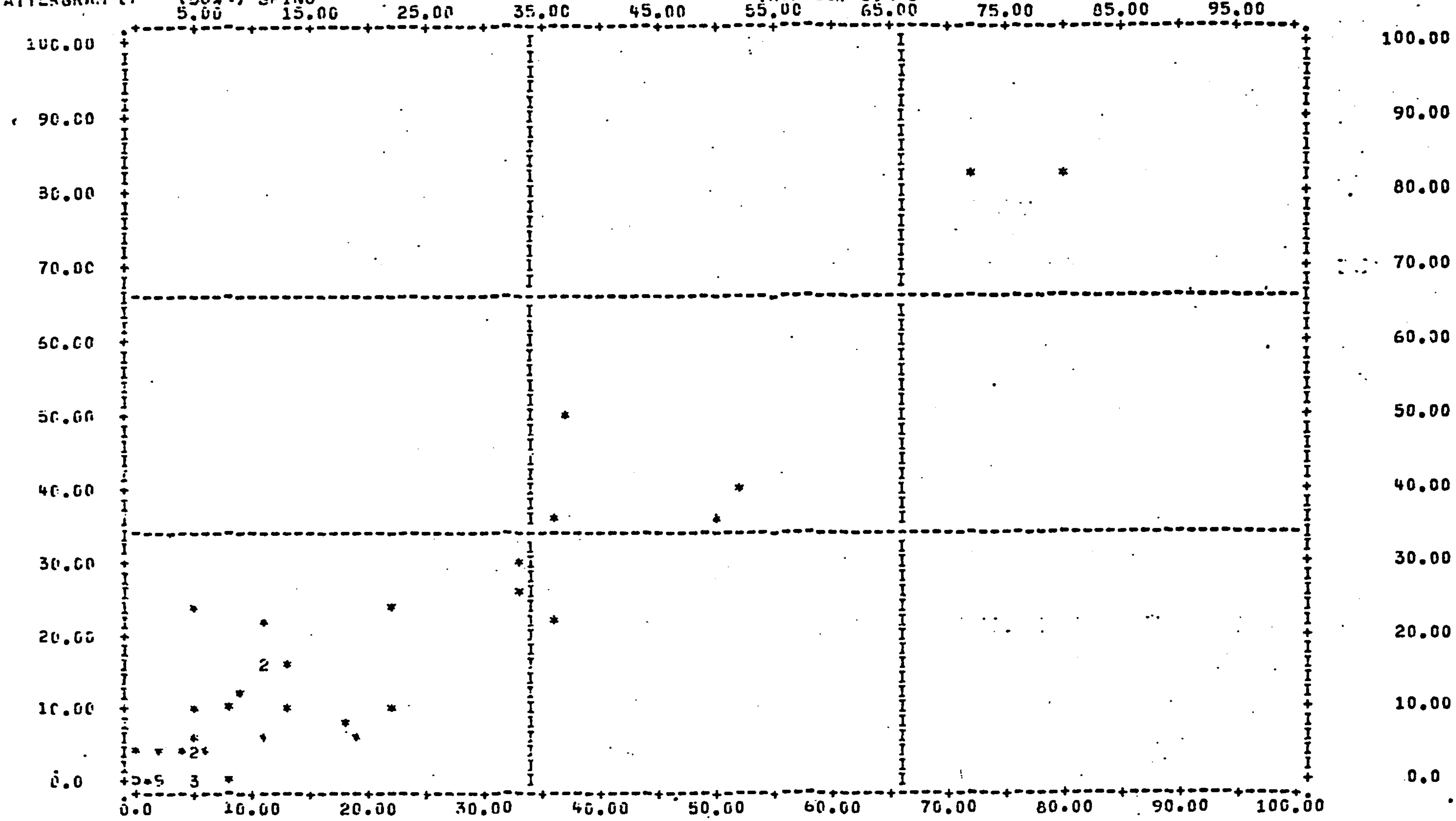

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MODULE THREE

FILE   MCNAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF   (DOWN) SPINO                                        (ACROSS) SIMPI
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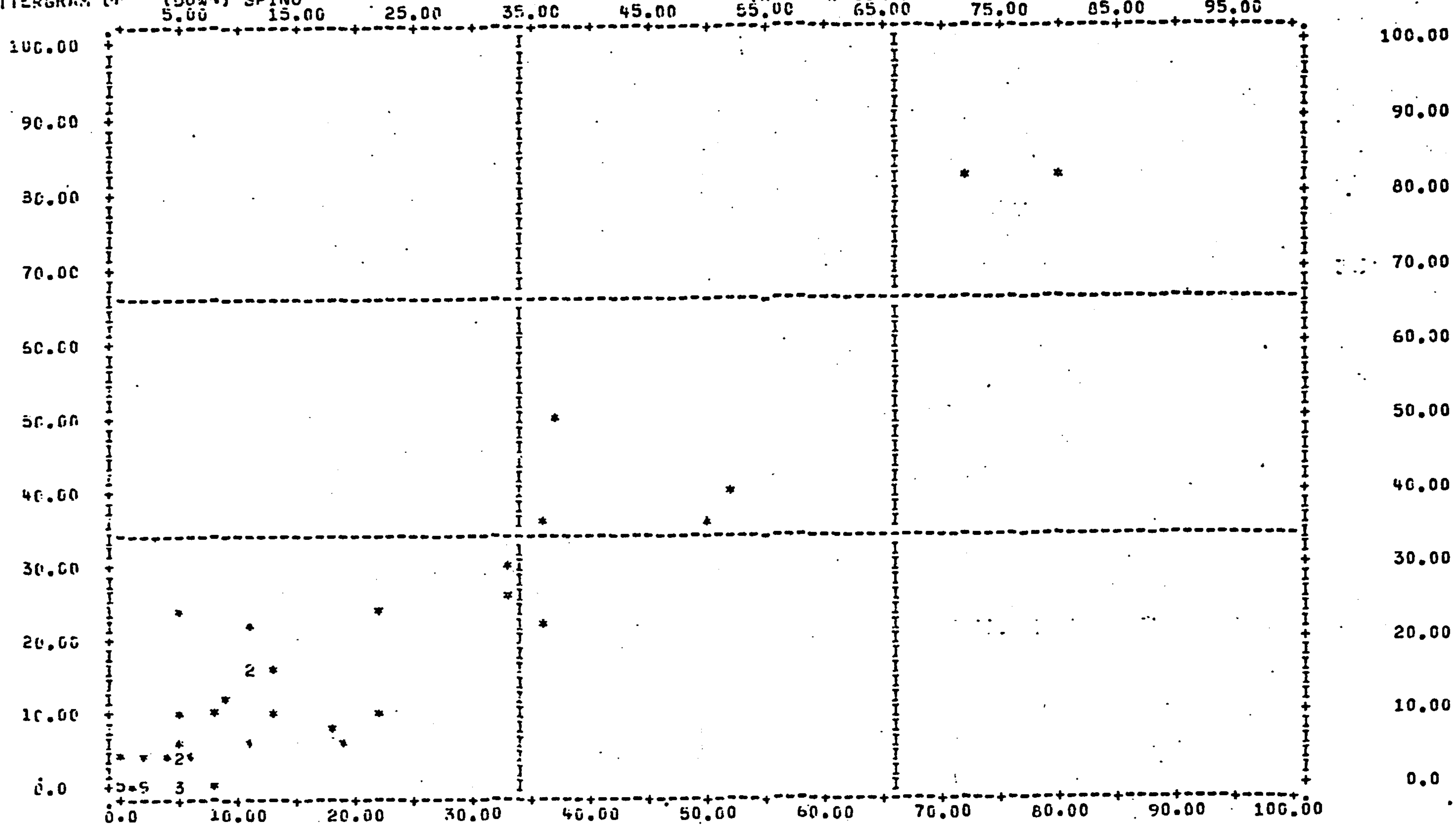

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MODULE THREE                                                      04/01/76        PAGE    9

STATISTICS..
  CORRELATION (R)-        0.94069      R SQUARED        -     0.88489      SIGNIFICANCE    -      0.00001
  STD ERR OF EST -        6.44406      INTERCEPT (A)    -     0.69161      SLOPE (B)       -      0.95133
  PLOTTED VALUES -       49            EXCLUDED VALUES-       0            MISSING VALUES  -      0

           ********* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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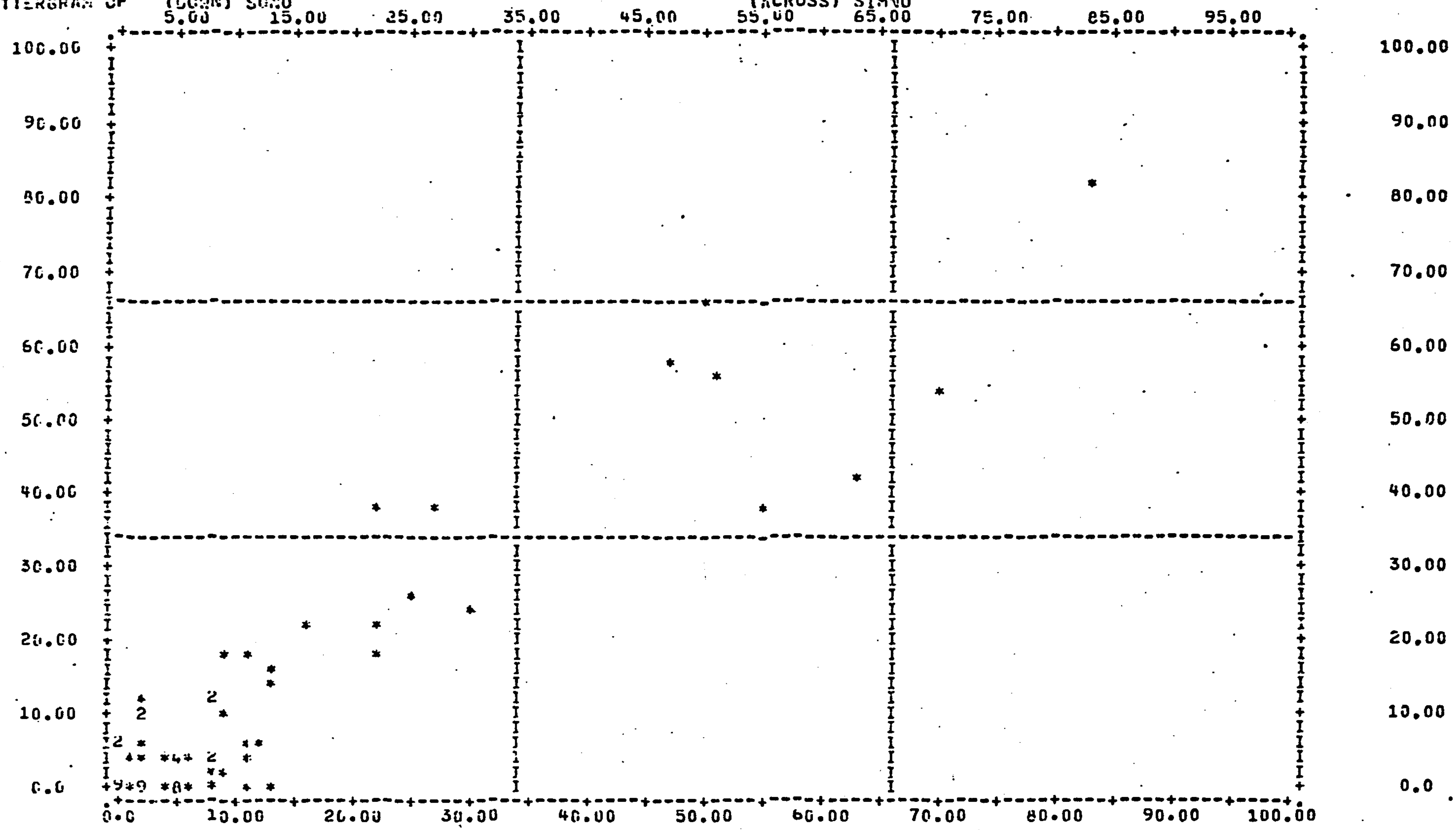
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SGNO (ACROSS) SIMNO



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FILE    NONAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SGNO                                    (ACROSS) SIMNO
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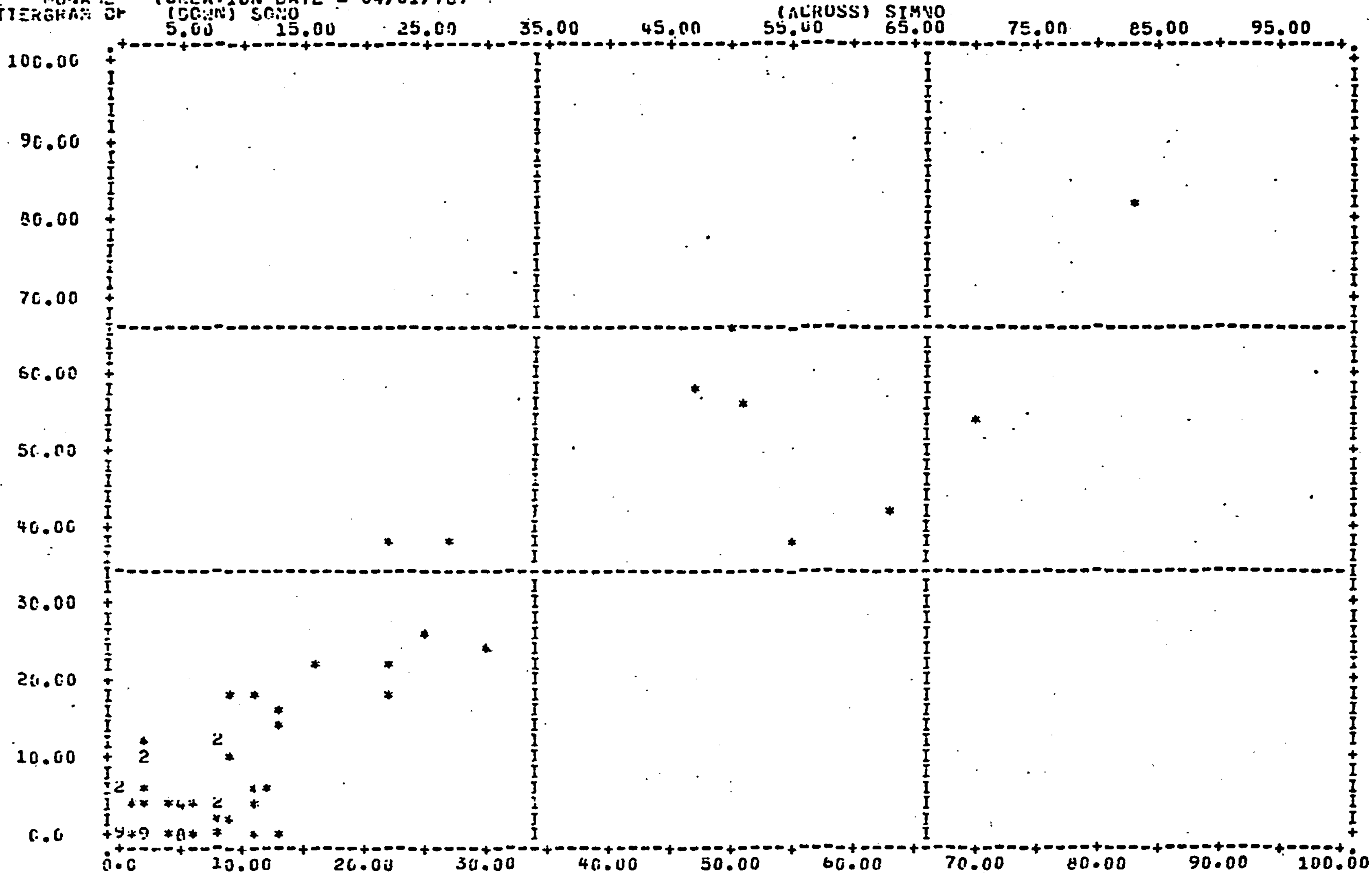

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MODULE FOUR                                                             04/01/76        PAGE    6

STATISTICS..
  CORRELATION (R)-        0.93065      R SQUARED        -       0.86611     SIGNIFICANCE    -       0.00001
  STD ERR OF EST -        6.28273      INTERCEPT (A)    -       0.71252     SLOPE (B)       -       0.93559
  PLOTTED VALUES -        81           EXCLUDED VALUES-         0           MISSING VALUES  -       0

                  '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

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MODULE FOUR                                                          04/01/76        PAGE    8

FILE   NONAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF   (DOWN) SPINO                                  (ACROSS) SIMPI
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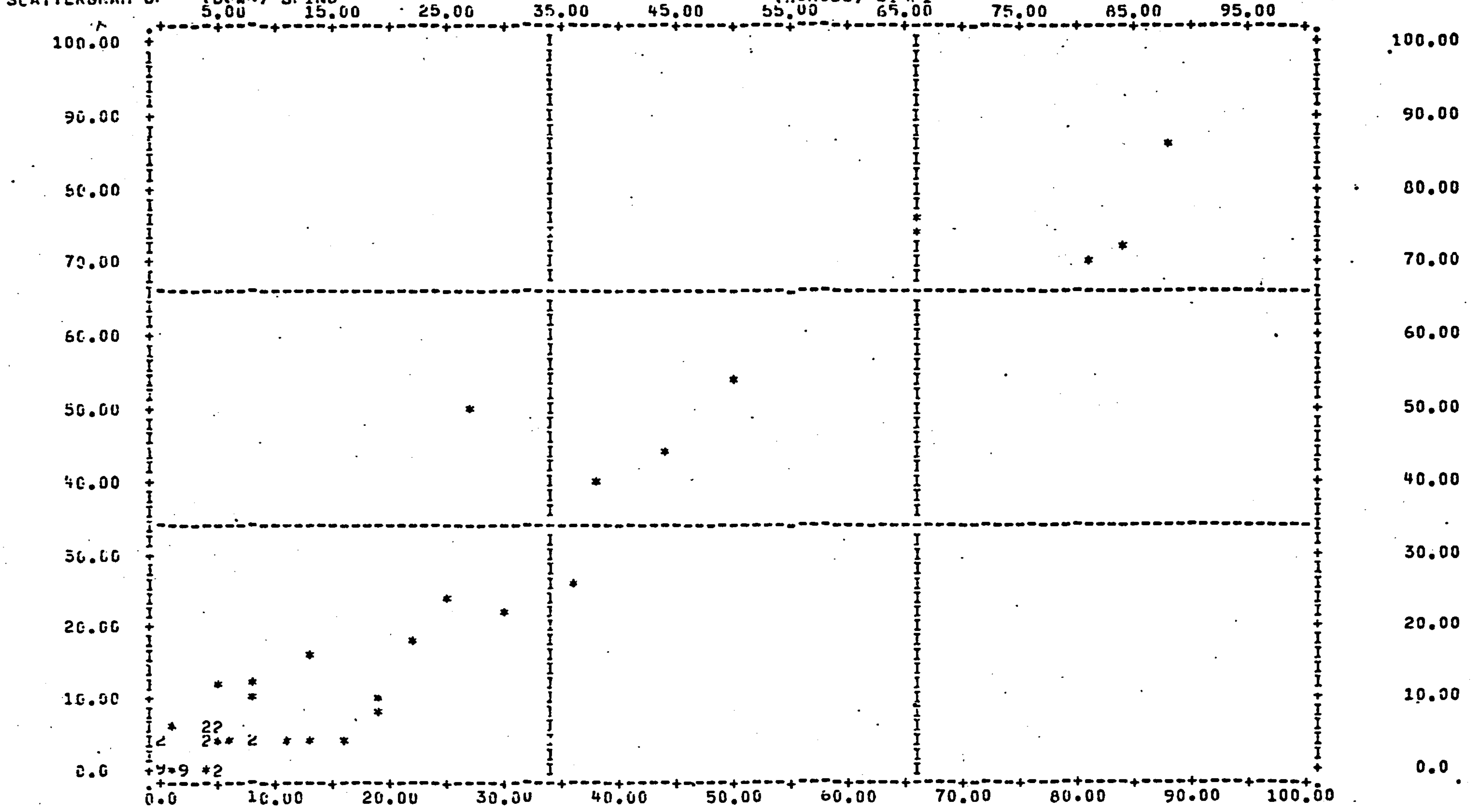

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MODULE FOUR                                                          04/01/76        PAGE    9
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FILE   NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SPINO                                    (ACROSS) SIMPI
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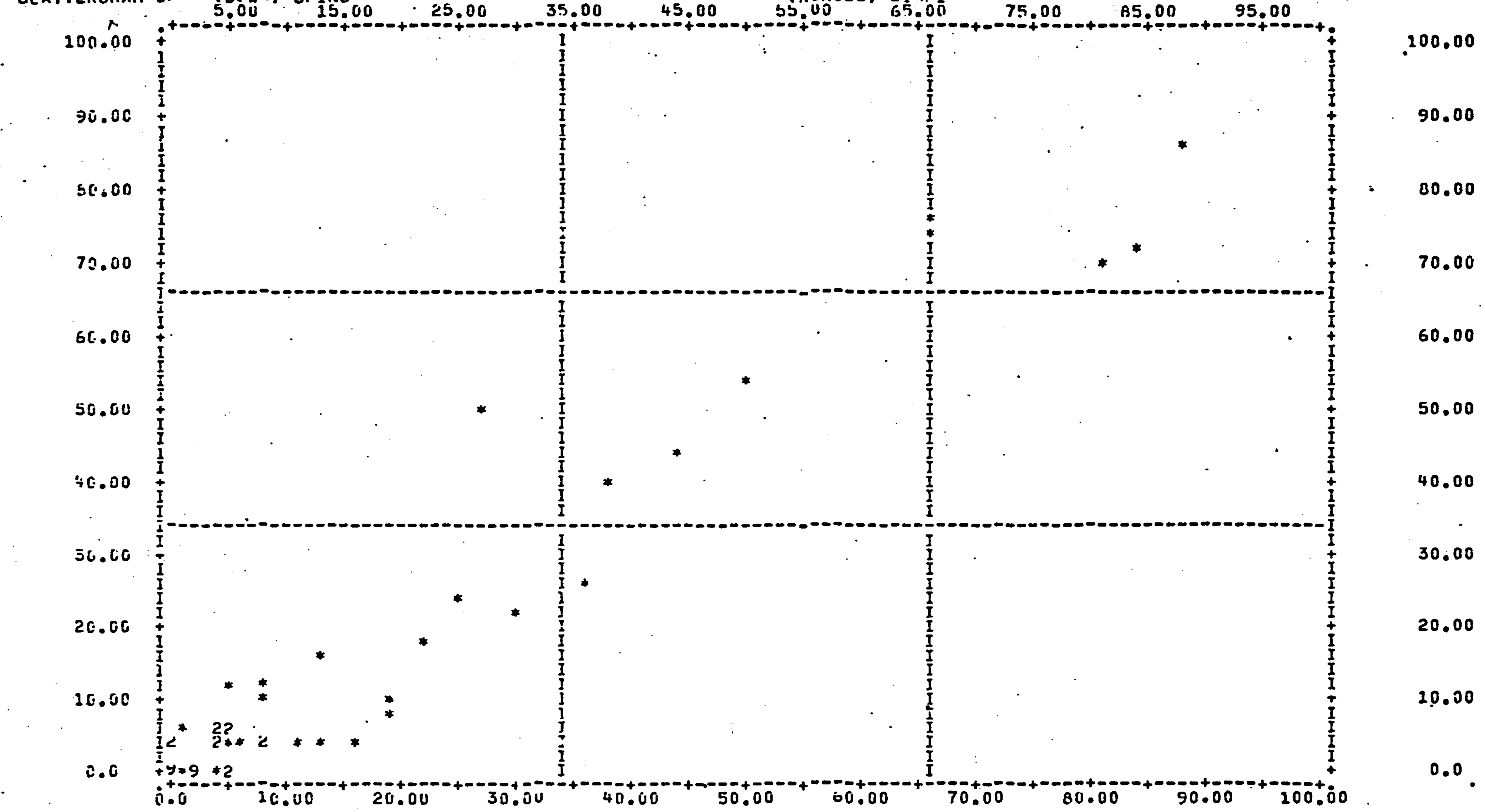

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MODULE FOUR                                                            04/01/76        PAGE    9

STATISTICS..
  CORRELATION (R)-         0.97097        R SQUARED        -          0.94279        SIGNIFICANCE    -         0.00001
  STD ERR OF EST -         4.87507        INTERCEPT (A)    -          0.27543        SLOPE (B)       -         0.97321
  PLOTTED VALUES -        81              EXCLUDED VALUES-           0               MISSING VALUES  -         0

                         '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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FILE   NONAME   (CREATION DATE = 04/01/76)
SCATTERGRAM OF   (DOWN) SCNO                    (ACROSS) SIMNO
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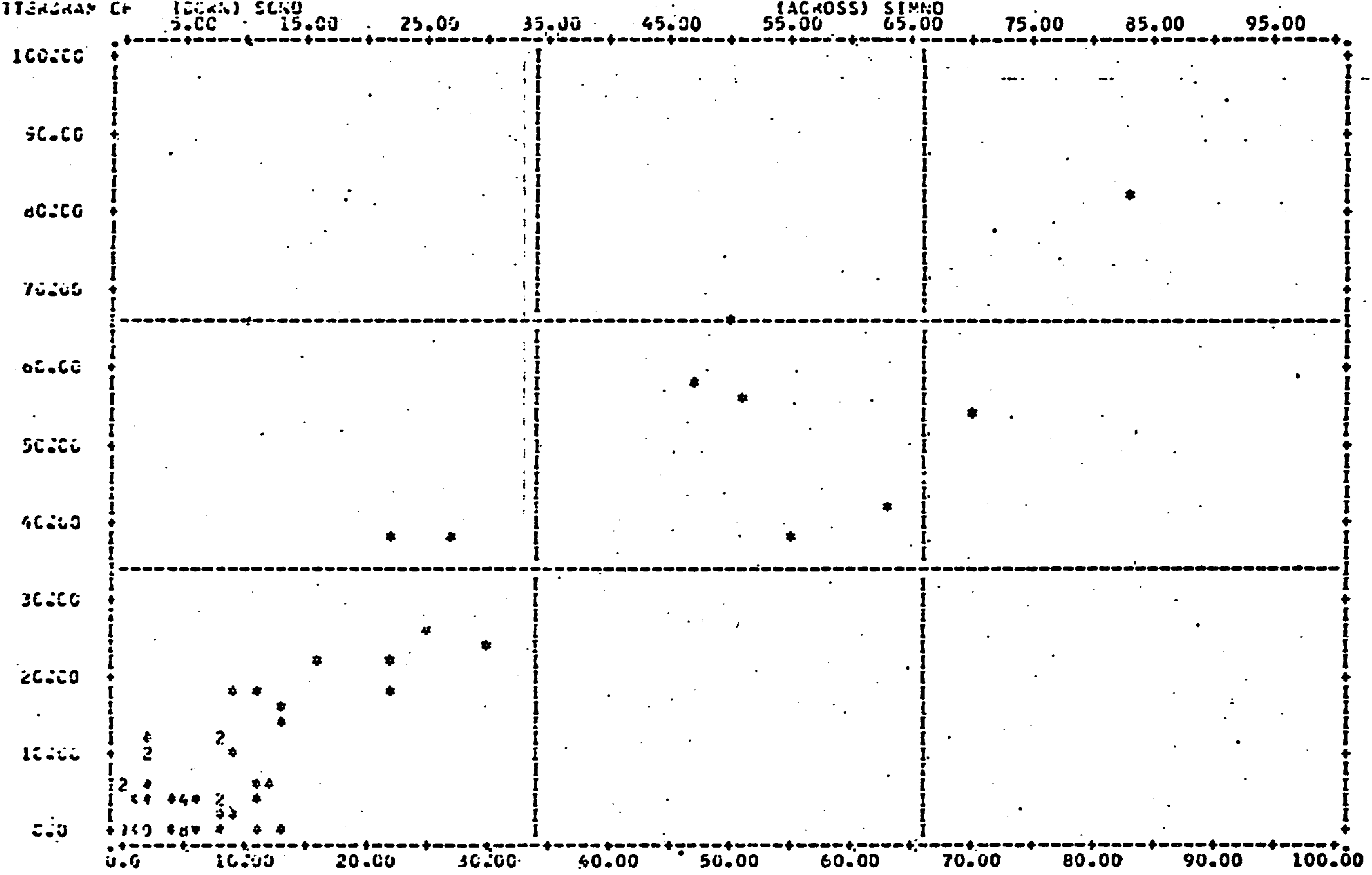

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FILE   NONAME   (CREATION DATE = 04/01/76)                              (ACROSS) SIMND
SCATTERGRAM OF   (DOWN) SCND
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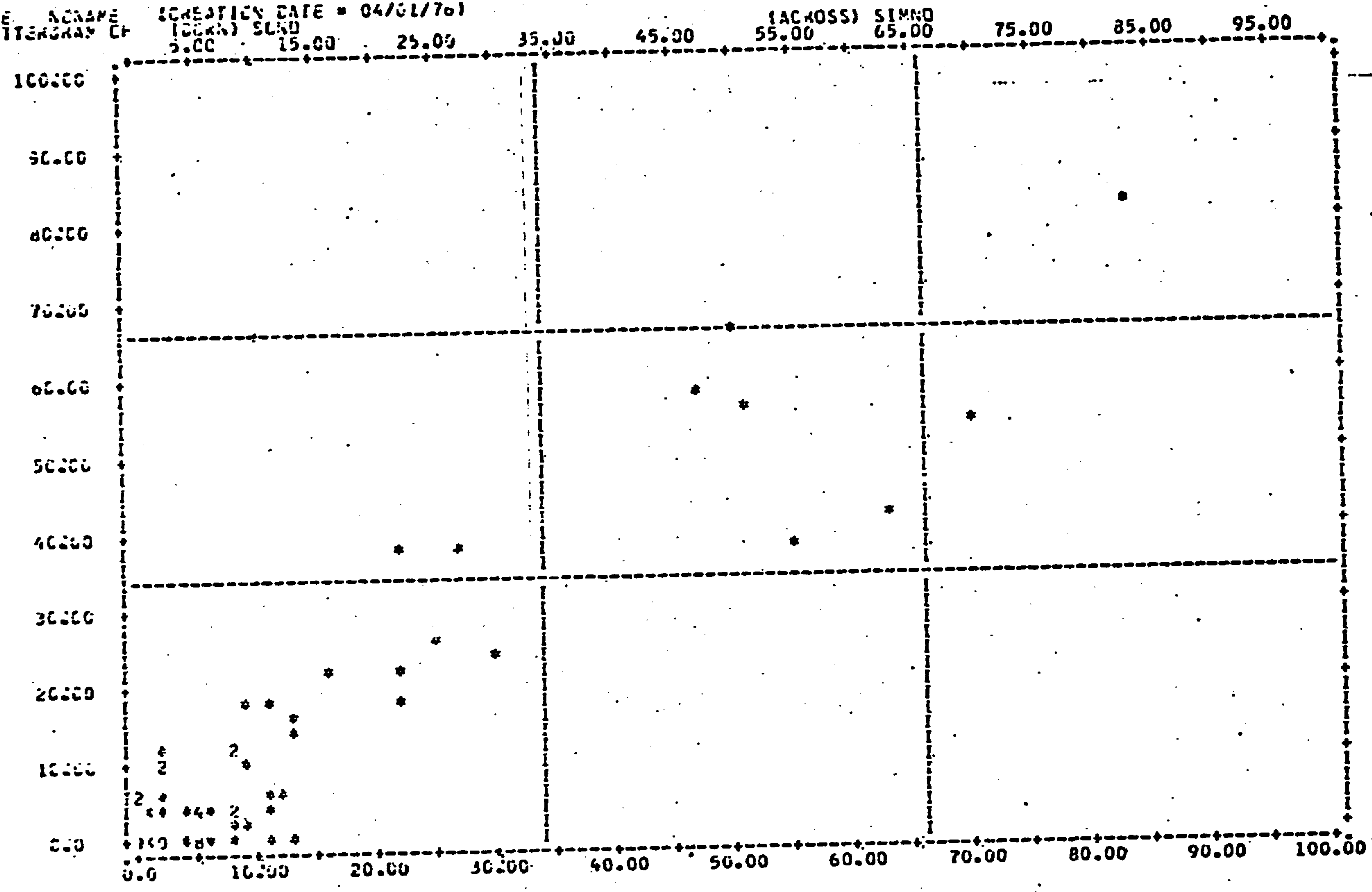

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                                                              04/01/76        PAGE    6
FIGURE FIVE

STATISTICS..
  CORRELATION (R)-       0.93065      R SQUARED       -        0.86611      SIGNIFICANCE   -       0.00001
  STD ERR OF EST -       6.28273      INTERCEPT (A)   -        0.71252      SLOPE (B)      -       0.93559
  PLOTTED VALUES -       81           EXCLUDED VALUES-         0            MISSING VALUES -       0
             ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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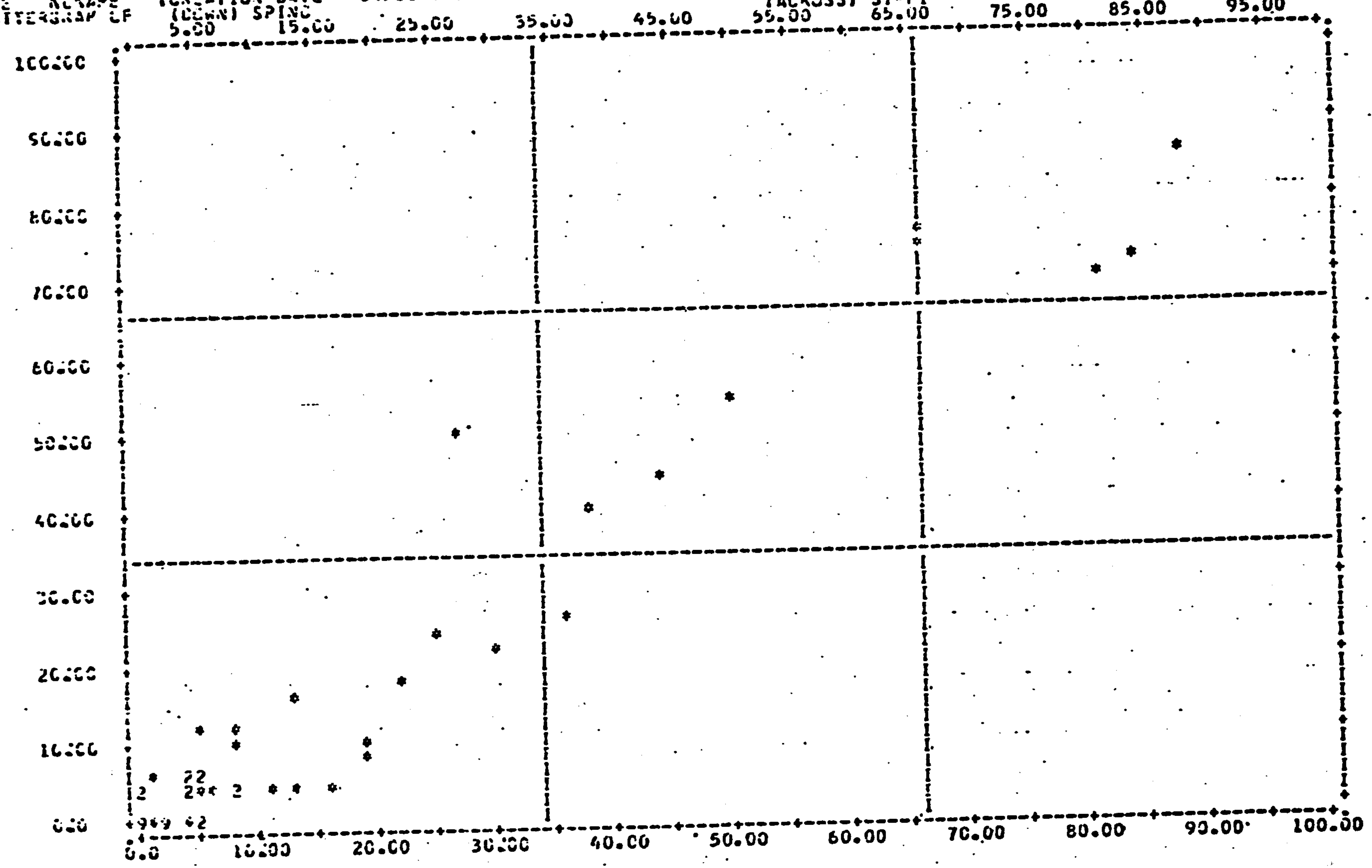
MIDDLE FIVE

FILE NONAME (CREATION DATE = 04/01/76)

SCATTERGRAM OF (DOWN) SPINC (ACROSS) SIMPI



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MODULE FIVE                                                        04/01/76        PAGE    8

FILE    NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SPINC                              (ACROSS) SIMPI
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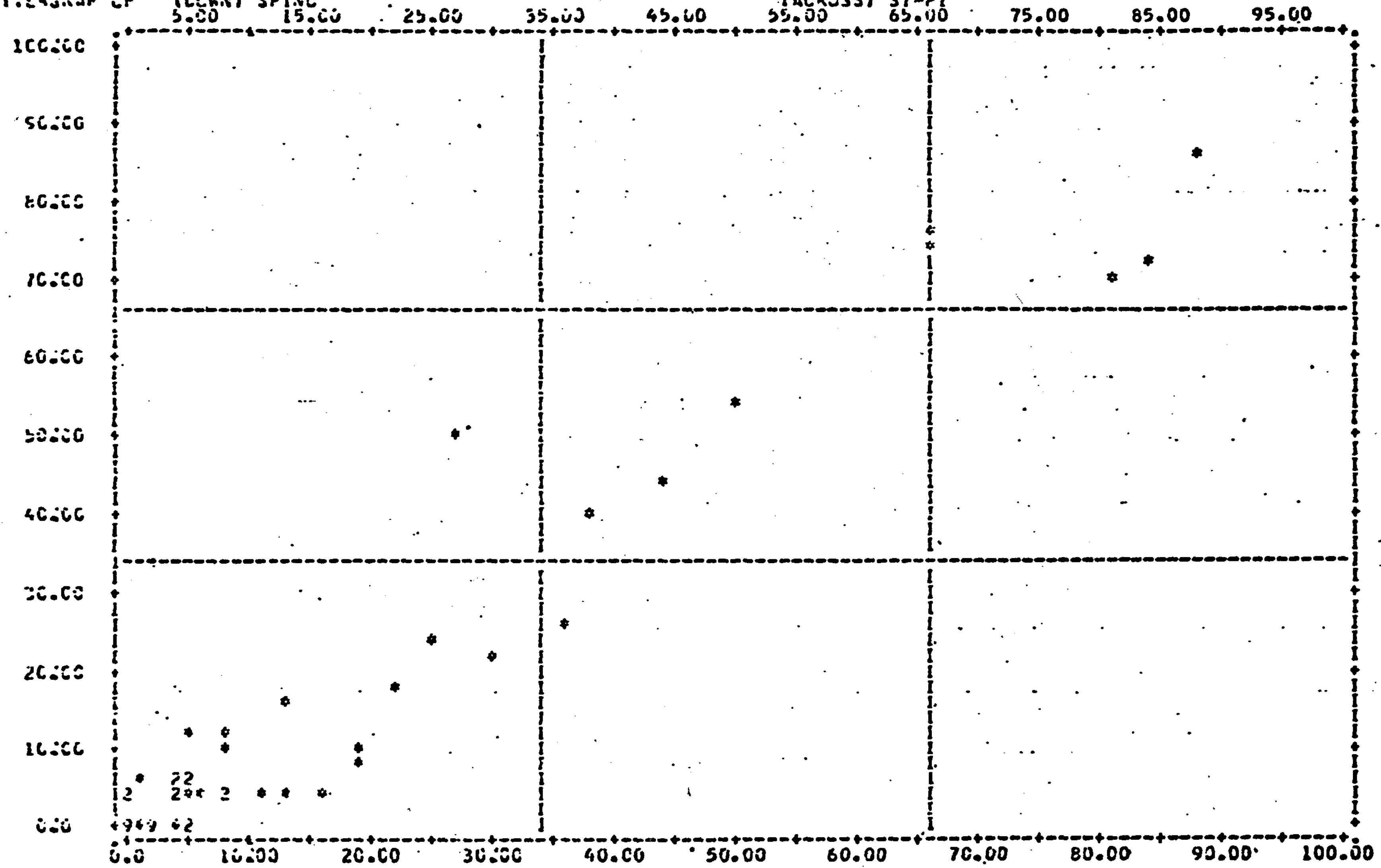

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MODULE FIVE                                                        04/01/76        PAGE    9

STATISTICS..
  CORRELATION (R)-        0.97097      R SQUARED       -        0.94279      SIGNIFICANCE     -        0.00001
  STD ERR OF EST -        4.87507      INTERCEPT (A)   -        0.27543      SLOPE (B)        -        0.97321
                                                                             MISSING VALUES   -        0
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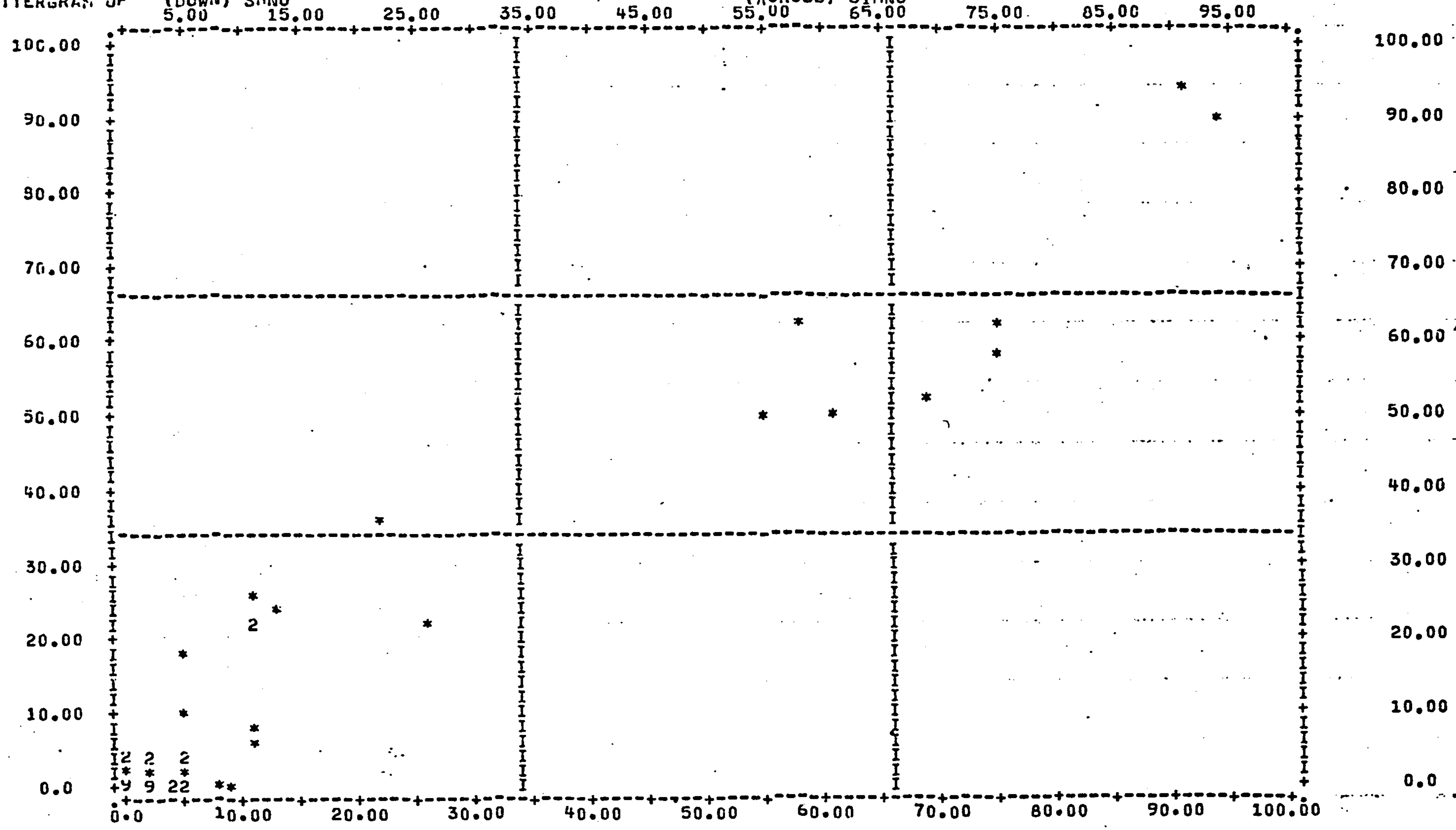
FILE NONAME (CREATION DATE = 04/01/76)

SCATTERGRAM OF (DOWN) SONU (ACROSS) SIMNO



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SCATTERGRAM OF    (DOWN) SONU                        (ACROSS) SIMNO
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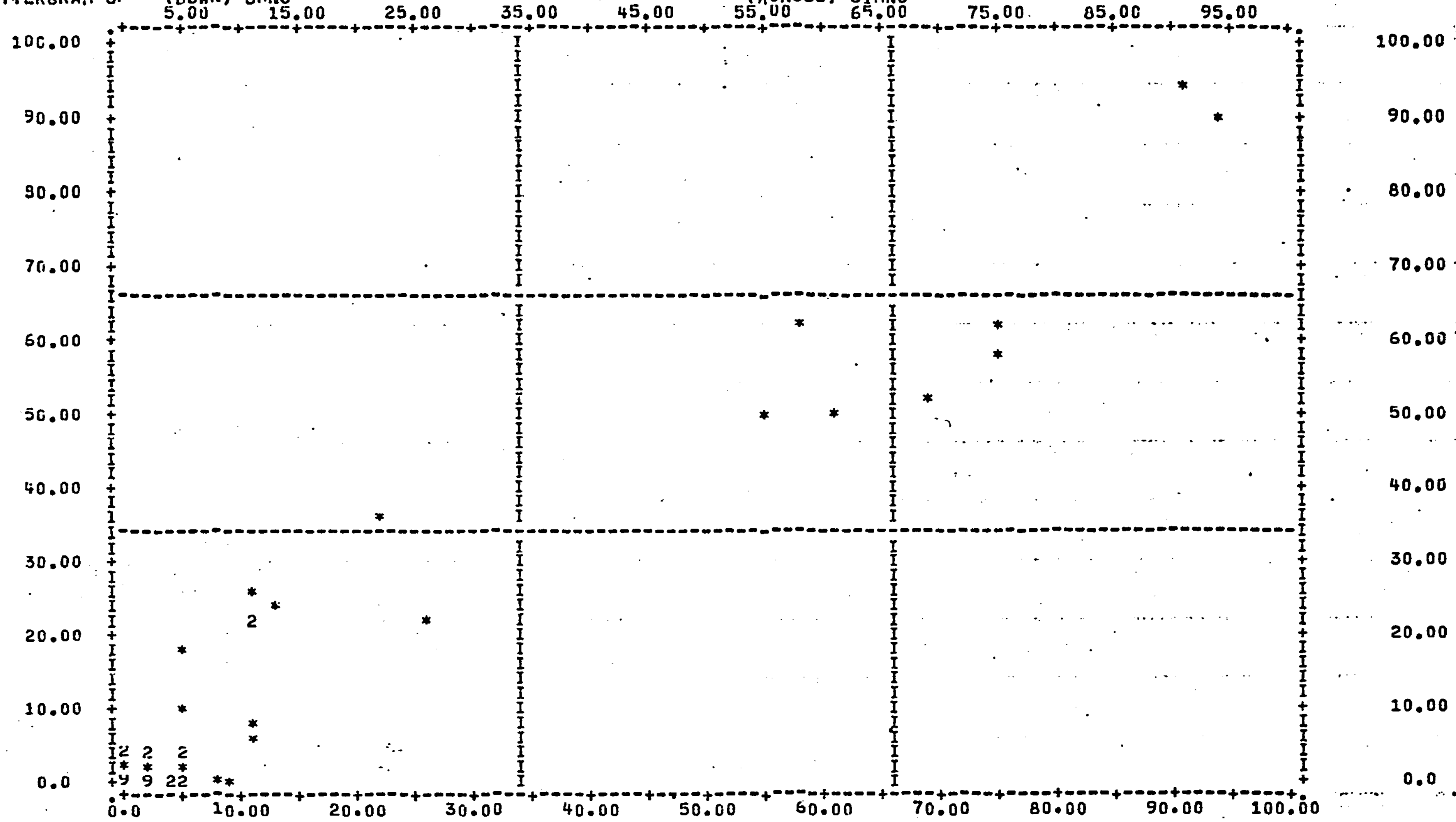

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MODULE SIX                                                        04/01/76        PAGE    6

STATISTICS..
  CORRELATION (R)-        0.96856       R SQUARED       -        0.93810       SIGNIFICANCE    -        0.00001
  STD ERR OF EST -        5.59960       INTERCEPT (A)   -        1.20384       SLOPE (B)       -        0.90379
  PLOTTED VALUES -       64             EXCLUDED VALUES-         0             MISSING VALUES  -        0

                         '*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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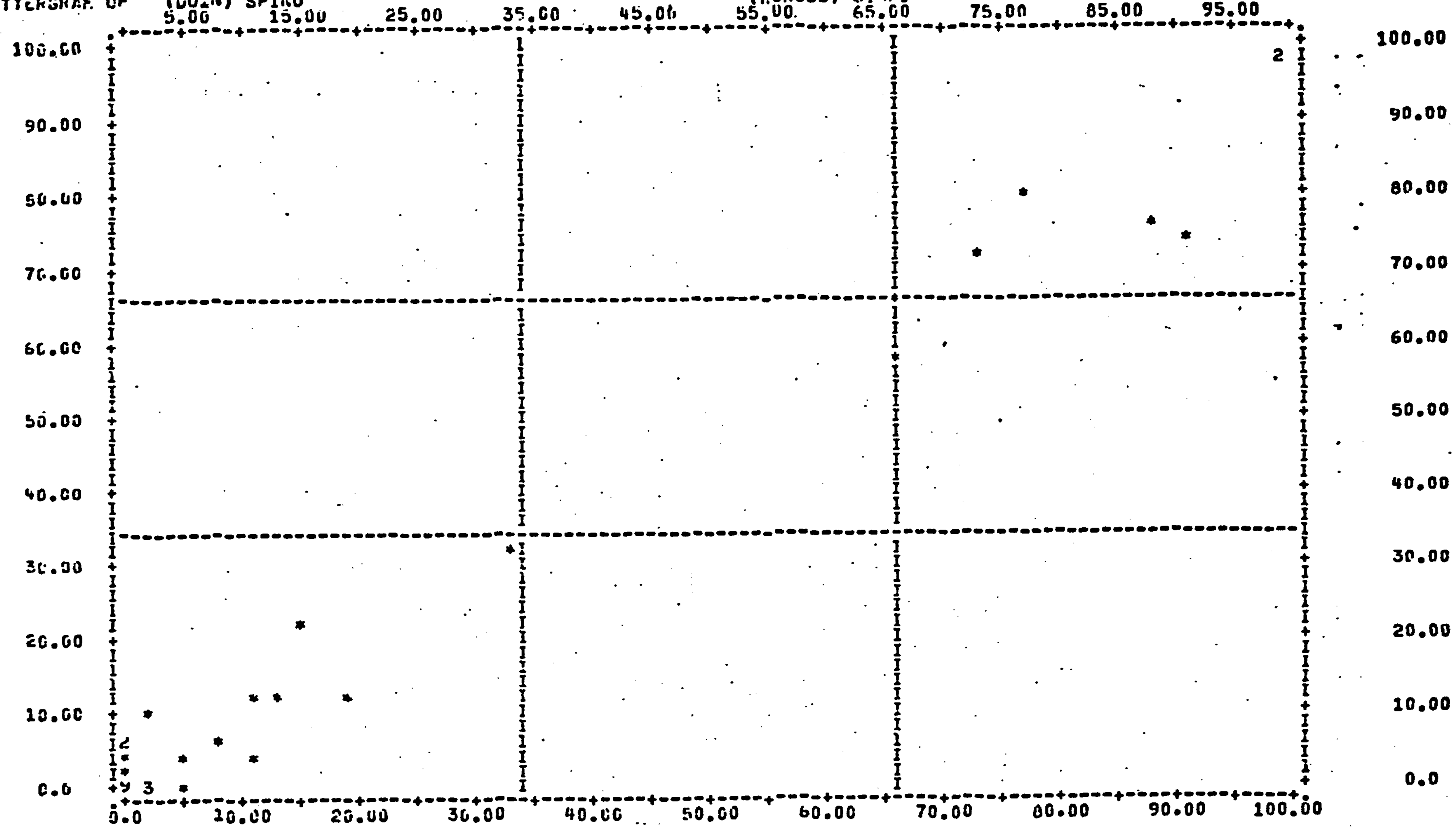
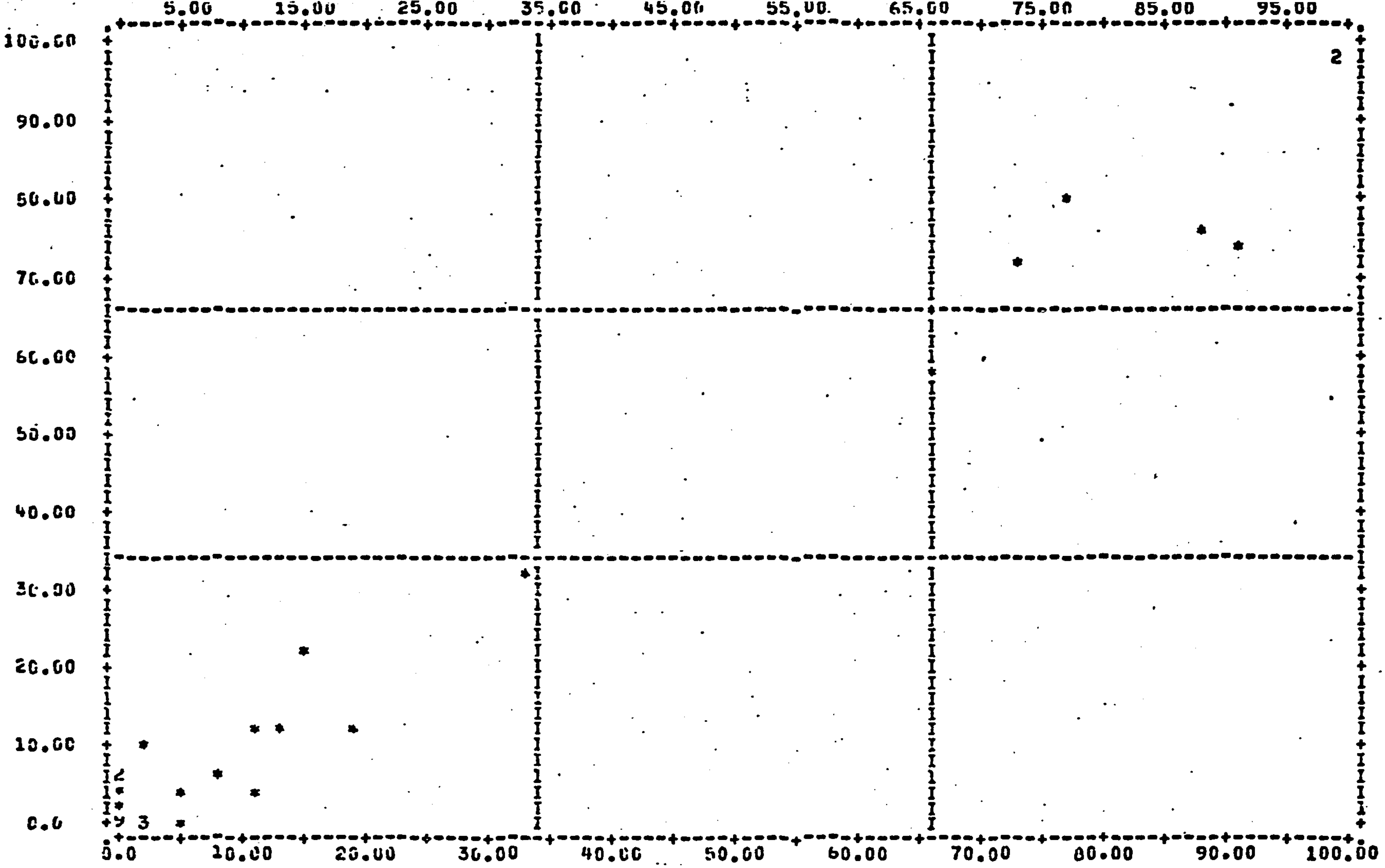
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SPIRO (ACROSS) SIMPI



STATISTICS



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MODULE SIX                                                   04/01/76        PAGE   9

STATISTICS..
  CORRELATION (R)-          0.99192      R SQUARED        -        0.98391      SIGNIFICANCE   -        0.00001
  STD ERR OF EST -          3.35384      INTERCEPT (A)    -        0.69207      SLOPE (B)      -        0.94118
  PLOTTED VALUES -         64            EXCLUDED VALUES-          0            MISSING VALUES -        0

                         ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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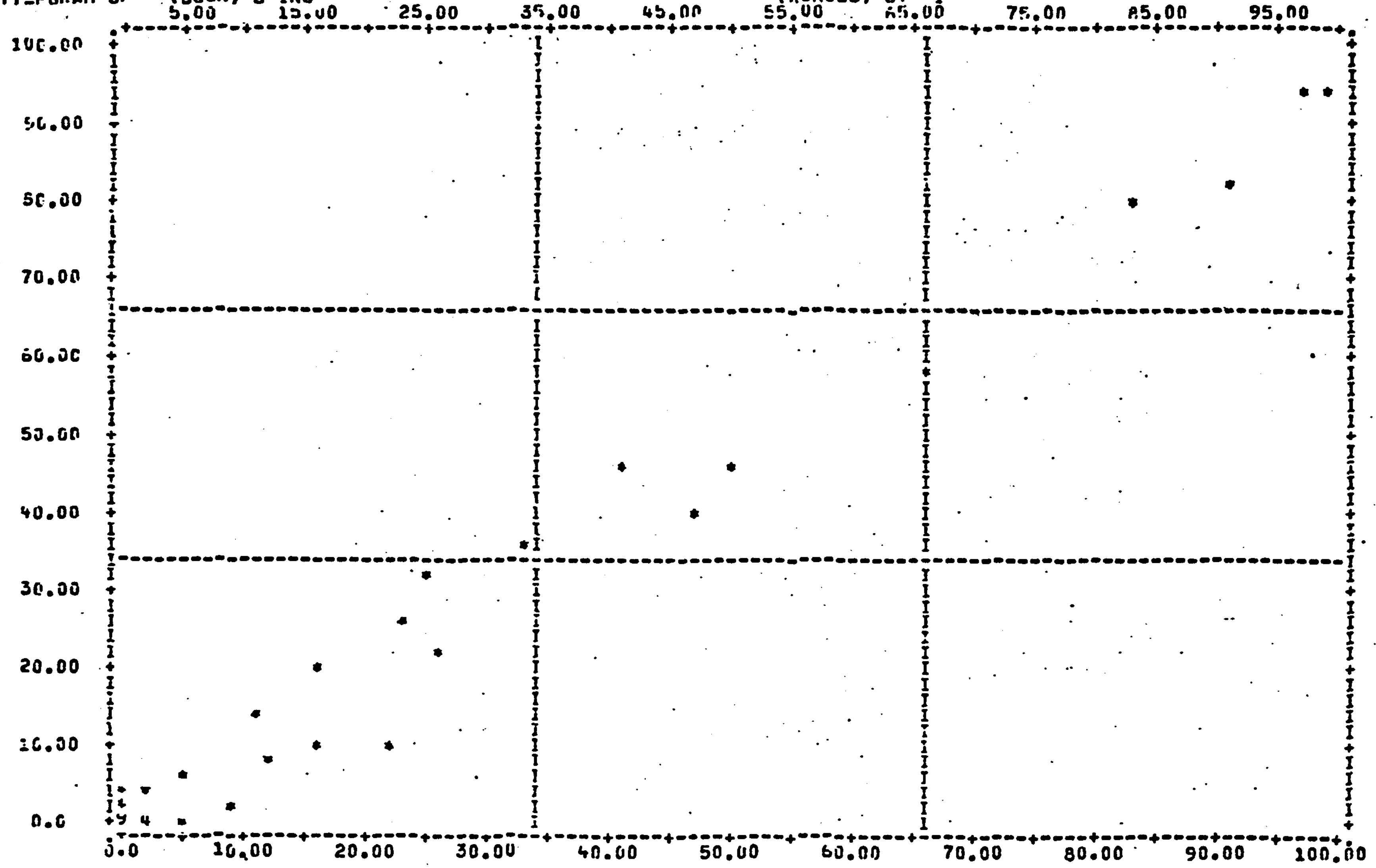
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SPINO (ACROSS) STMPI



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SCATTERGRAM OF    (DOWN) SPINO                                    (ACROSS) STMPI
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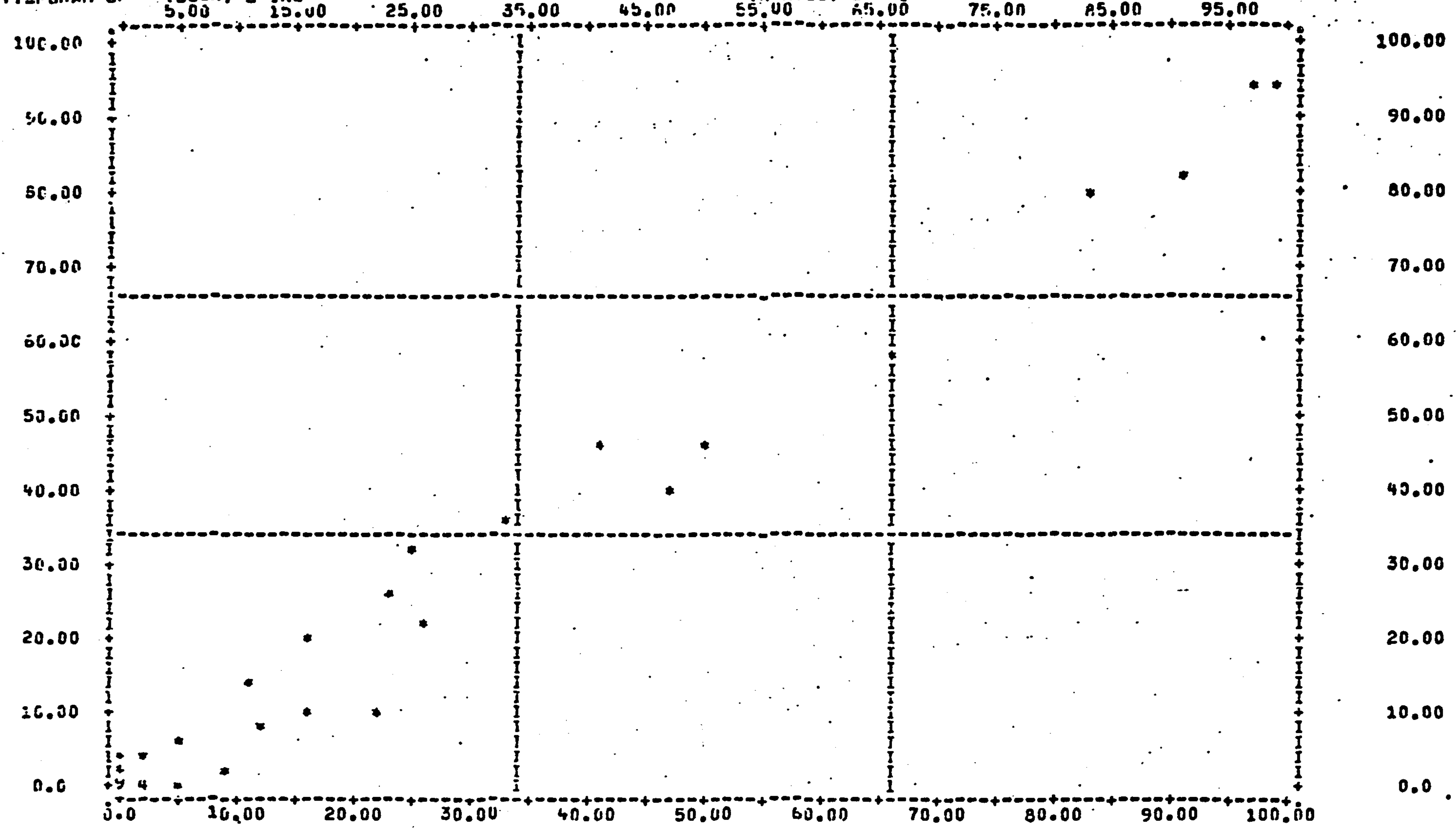

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MODULE SEVEN                                                          04/01/76          PAGE    9

STATISTICS..
  CORRELATION (R)-         0.99273      R SQUARED       -        0.98550      SIGNIFICANCE   -        0.00001
  STD ERR OF EST -         2.09178      INTERCEPT (A)   -        0.62782      SLOPE (B)      -        0.94132
  PLOTTED VALUES -        64            EXCLUDED VALUES-         0            MISSING VALUES -        0

                   ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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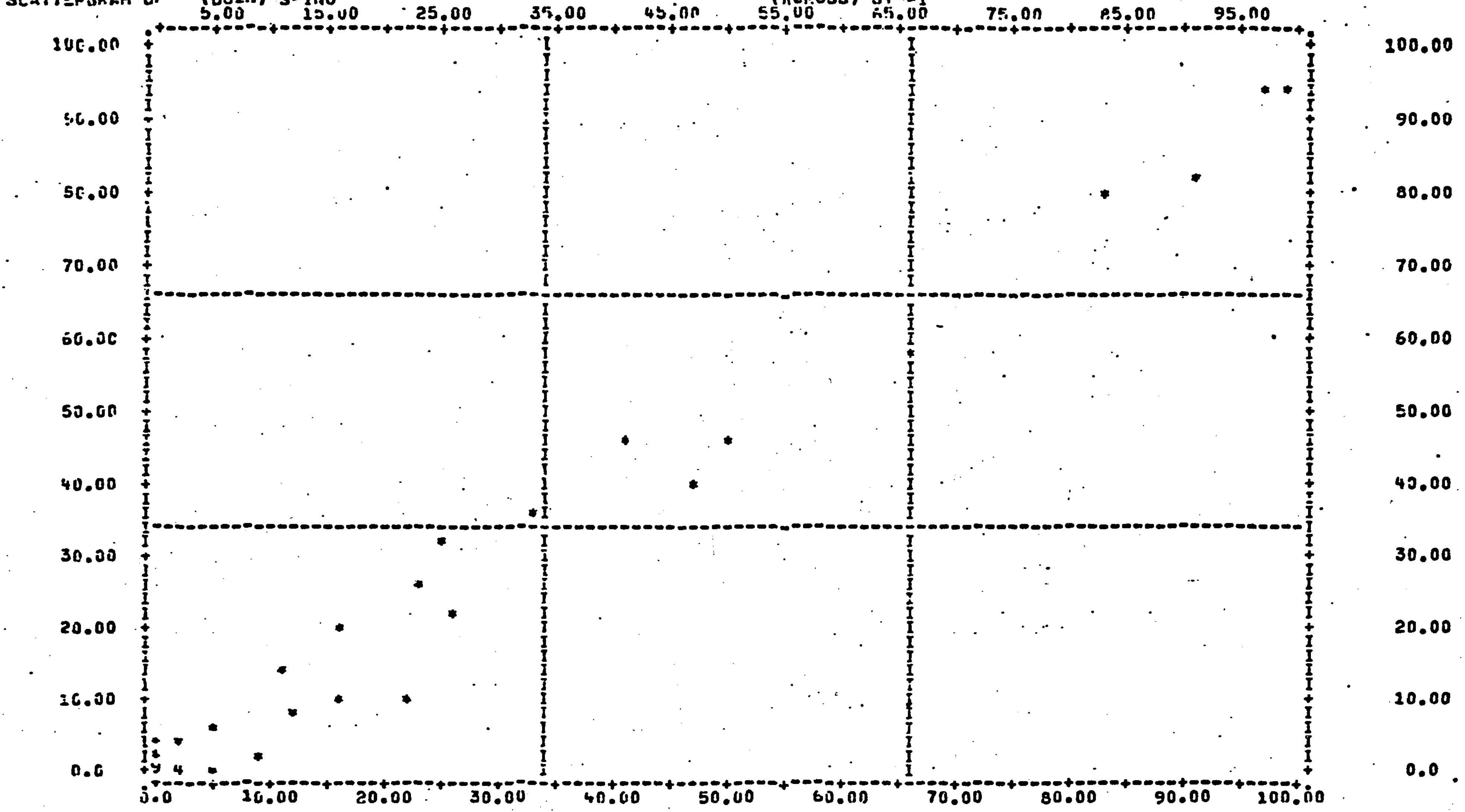
FILE NONAME (CREATION DATE = 04/01/76)
SCATTERGRAM OF (DOWN) SPINO (ACROSS) STMPI



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FILE   NONAME    (CREATION DATE = 04/01/76)
SCATTERGRAM OF    (DOWN) SPINO                                    (ACROSS) STMPI
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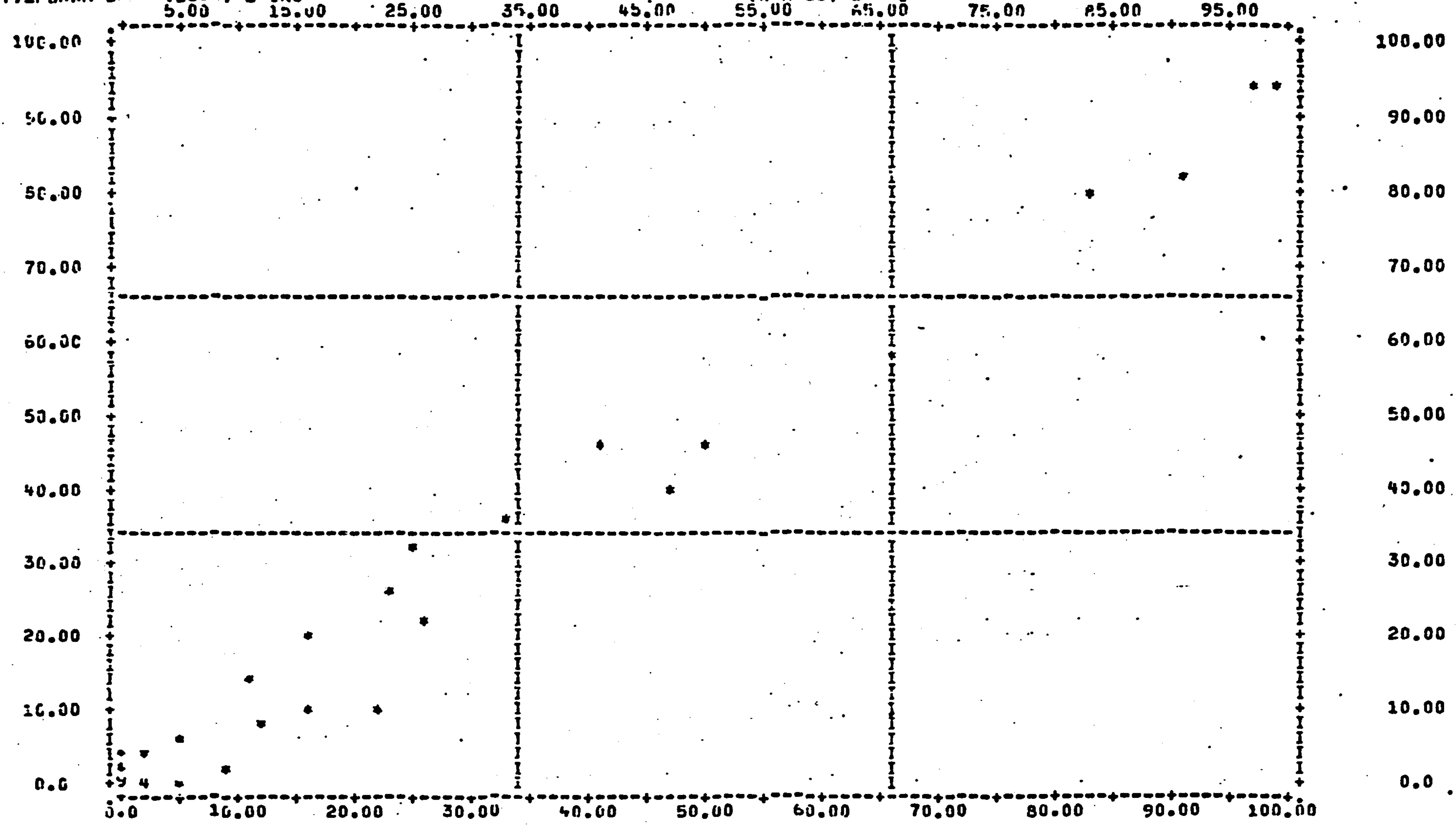

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MODULE SEVEN                                                           04/01/76         PAGE    9

STATISTICS..
  CORRELATION (R)-         0.99273       R SQUARED        -         0.98550       SIGNIFICANCE   -        0.00001
  STD ERR OF EST -         2.09178       INTERCEPT (A)    -         0.62782       SLOPE (B)      -        0.94132
  PLOTTED VALUES -        64             EXCLUDED VALUES-           0             MISSING VALUES -        0

                   ********** IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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