TITLE

A REVIEW OF

MASKING LEVEL DIFFERENCE AND ITS CLINICAL APPLICATIONS

CERTIFICATE

This is to certify that the independent project entitled "A REVIEW OF MASKING LEVEL DIFFERENCE AND ITS CLINICAL APPLICATIONS" is the bonafide work in part fulfillment of M.Sc., III Semester, in Speech and Hearing, carrying 50 marks, of the student with Register Number 5.

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CERTIFICATE

This is to certify that the Independent Project entitled "A. REVIEW OF MASKING LEVEL DIFFERENCE AND ITS CLINICAL APPLICATIONS" was done under my guidance.

* * *

GUIDE

DECLARATION.

This independent project is the result of my own work undertaken under the guidance of Mr. M. N. Vyasamurthy, Lecturer in Audioiogy, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier at any University - for any other Diploma or Degree.

Mysore Reg No 5

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CONTESTS

INTRODUCTION

The Audiologist is frequently called upon to make numerous statements of various degress of complexity concerning the hearing of any given patient. Not only must he ascertain the existence of a hearing impairment but he must also make judgements concerning its severity, its influence upon patients life, the locus of lesion or lesions responsible for the pathology of the disorder. Obviously no single test yields sufficient information to answer all of the questions. Some tests are designed specifically to assist in pinpointing the site of the lesion in the system while others have as their primary purpose the determination of existence of an auditory deficit. Thus an extensive battery of audiological tests must be administered in order to fulfil the demands made upon the audiologist. Once the test battery is administered, the audiologist must interpret the raw data and make a statement concerning the meaning of his examination results. It is the audiologists responsibility to summarise his examination findings into a coherant statement of the problem as he sees it. In order to do this he has to look at the information in 2 different ways. First he must examine the results of single tests. Second he must be able to obtain the feeling of the "Gestalt"of entire examinations.

Recent developments in the area of detection and diagnosis represented the efforts of numerous professionals to find more efficient and reliable approaches in assessing the functioning of the auditory system. New techniques have been developed to evaluate the auditory system at various points from the middle ear to cortex.

Considerable progress has been made in the refinement and standardization of diagnostic techniques and procedures as they pertain to adults with auditory problems. However, there has been less progress in developing and

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standardization of some of the diagnostic tests like the masking level difference. The audiologist is capable of making distinctions within the peripheral system and there is ample evidence that he can make distinctions in the central portion as well. Auditory tests can divide pathologic responses into atleast four groups:

Conductive;
Cochlear;
Retrocochlear (nerve VIII and brain stem);
and
Cerebral.

A number of audiological tests have been devised to yield differential information regarding the function of an impaired auditory mechanism. These developments have occurred because the auditory behaviour observed during certain audiologic measurements can be of assistance in localising the site of lesion underlying a hearing disorder.

As mentioned earlier, there are four main types of hearing dys-function.

Conductive assessment: Any dys-function of the outer or middle ear in the presence of a normal ear is termed a conductive impairment of hearing. Here the difficulty is not with the perception of sound but with the conduction of sound to the analyzing system.

Cochlear assessment: The sensory process begins at the cochlear end organ where mechanical energy is translated into bio-chemical energy. Auditory tests relate primarily to the integrity of the structures involved in the bio-chemical transduction and transmission. Here the dys-function is within the sensory process.

Retro-cochlear assessment: Retro-cochlear denotes the auditory system from 8th nerve to brain stem. Marked tonal decay seems to be the most characteristic system of dys-function of the entire retro-cochlear system from 8th nerve to high brain stem level.

Cortical assessment: The lesions within the central auditory nervous system are difficult to detect. It has long been recognized that many central auditory dys-functions will not be demonstrated through the use of conventional audiologic measurements.

The fact that a normal auditory system can make advantageous use of subtle differences in simultaneous acoustic events is well-known.

A number of laboratories have devoted much time and effort to determine to what extent the auditory system can utilise differences in various auditory stimuli delivered to one or both ears simultaneously or almost simultaneously. One such phenomenon is the masking.

(Masking is the process by which the detectability of one sound, the signal is impaired by the presence of another sound, the masker. The effectiveness of a masker and consequently the amount of signal level necessary to be "just detectable" in a constant masking noise is highly dependent on whether the presentation is monaural or binaural and whether its diotic or dichotic. Dichotic presentation permits binaural auditory analysis which can result in detection of signal. Jeffess '72 presented a good example of this effect, supply noise to one ear 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 its just inaudible. Now add the same noise to other ear-phone and signal becomes clearly audible. The signal again disappears when it too is added to the channel for second ear-phone, making the sounds at 2 ears alike. Now if we reverse the conditions 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.

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The Importance of two ears in localising the position of a sound source is obvious. What is equally obvious, especially when one ear is not properly functioning, is that two ears permit selective attention to certain parts of auditory space and thus audiorate the masking effects of distracting noises.

J.C.R. Licklider at the psycho-acoustic Laboratory at Harvard was attempting to improve voice communication over head-phone systems used by pilots in aircraft. The problem was two fold. First, the quality of the voice communication was not the best. Second, the communication was occurring in a very noisy environment. Licklider(1948) found a simple way to improve the pilot's ability to receive and understand messages in the midst of this noise. He merely reversed the wires leading to one ear-phone. This reverses the phase of the signal in the two ears. Thus if one ear-phone diaphragm moves outward causing a rare fraction wave at one ear, then the diaphragm on the opposite ear-phone moves inward causing a condensation wave at the other ear. The efficacy of this procedure rests on the fact that the masking noise is largely external to the ear-phones and produces wave-forms in the same relative phase at the two ears, independent of the polarity of the ear-phone connections. This improvement in the reception of signals when noise and signal are in different phase relations at the two ears has been called the Masking Level Difference (MID). The name is hardly apt because many procedures improve the detectability of signals. Specifying this particular binaural phenomenon by such a general name leads to confusion, both theoretical and empirical. For this reason, the term "binaural masking level difference" is frequently used, but the improvement is only slight

About the same time as Licklider's discovery, Hirsh (1948) started a systematic exploration of the phenomenon at the same laboratory. He used a sinusoid as the

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signal rather than speech. This allowed him to precisely control the frequency contact of the signal.

Definitions: Masking Level Difference is the difference in the signal level required for detection between a reference condition and some other binaural masking condition.

A change in MLD does not indicate in which condition detection has varied, the reference condition, the binaural condition or both conditions. A change in MLD shows only that there was a relative change in detection. MID is defined in terms of detection, not in some other psychological dimension, such as loudness.

A binaural MLD may be defined as the improvement in masked threshold sensitivity for a signal that occurs on transition from a homophasic listening condition to an anti-phasic one. Homophasic listening occurs when each of the 2 stimuli, signal and masker, is either interaurally in phase or interaurally out of phase with itself. Antiphasic listening occurs when either of the stimuli,signal or masker is interaurally out of phase with itself, while its companion is in phase (Olson, Noffsinger and Earhart, 1976).

Thresholds of puretone and complex stimuli presented monaurally or binaurally in binaural phase of the noise. A change in threshold as a result of a shift in the interaural phase of the masker is called MID (Findlay R.C. and Schuchman G.I., 1976). The MLD may be described as the amount in deribels, by which the listners threshold changes, the difference in the signal level required for a given probability of detection, or in the case of a speech signal, by the increase in intelligibility at a given S/N ratio.

MLD as the phenomenon has come to be labelled, is a fascinating example of the advantage of a binaural auditory system over a monaural system. In the antiphasic condition noise and signal are presented to both ears but either the noise or the signal is interaurally 180° out o0f phase while the other is interaurally in phase. The magnitude of the MLD is expressed as the change in dbs between the monaural or homophasic condition and one of the other conditions. A hierarchy of MLD's is recognized. The antiphasic NOSπ yields the largest MLD. HIRSH's MLD is described briefly as follows - Consider a continuous B.B.N. which is presented in phase agreement via ear-phones to 2 ears. A low frequency pulsed sinusoid also in phase agreement at 2 ears, is mixed with noise. The listners task is to adjust the level of the sinusoid to a point where it is just detectable in noise - Now if the sinusoid going to one ear is made 180° out of phase relative to sinusoid at other ear, the signal becomes quite audible and the listner must alternate the signal some 15 dbs to achieve same level of detectability as in in phase condition. That is there is a 15 dbs increase in loudness for out-of-phase signal as compared to the in-phase signal.

The detectability of a tonal signal, presented binaurally in a background of Gattessian Noise is heavily dependent on the interaural amptitude and phase relations of both signal and noise. Experiments have shown that signal detectability is enhanced if the signal and the masking noise are not in the same interaural relation. In some conditions, the detection threshold of a binaural signal can be lowered as much as 25 dbs simply by inverting the signal at one ear (a 180° interaural phase difference). This effect is known as a binaural MLD and was first discovered by Licklider 1948.

The binaural release from masking or MLD, a phenomenon well known to audiologists, occurs when the interaural phase of either the signal or the noise is reversed.

It is now established that performance in a signal detection task is much better with certain dichotic conditions of listening than it is in the monochotic condition. This improvement in performance is typically expressed as a MLD which is the difference in decibels b/w the signal energies required for equal performance in the 2 listening conditions.

MLD's are improvements in detection that occur when the interaural parameters of either signal or mask are varied in a binaural masking experiment. The improvements are measured relative to the socalled homophasic (NoSo) condition in which both noise and signal are diotic. The largest occurs in the antiphasic condition (NoSπ), where the masker is diotie while the signal is reversed in phase interaurally. The MLD for NoSπ , 500 Hz gated tones in a NBN mask is about 15 dbs. Some people have tried to define HLD's in terms of the Time-delay differences than through specified phase shifts.

Lockner and Burger 1961 have emphasized the role of interaural time delays in achieving release from binaural masking for pure tones, pulses, and NB Noises. Concurrently theoretical formulations have appeared that attribute changes of binaural efficiency in separating competing sounds to interaction between externally generated time delays and compensatory normal networks and/or normal delay processes.

The MLD resulting from binaural analysis requires a peripheral mechanism to preserve and transmit the temporal information in stimulus received at each ear and also a central location mechanism where the 2 stimuli interact and are compared. It is this processing of binaural temporal information which allows localization and permits the exceedingly important process of selective listening in noisy environments.

The difference in signal levels required for perception of the signal in the out-of-phase (NoSπ)

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condition described as compared to the in-phase (homophasic NoSo) listening condition can be as much as 15 dbs. This difference in signal levels required for the same degree of detectability is MLD. The MLD is measured and expressed in decibels and is a function not only of interaural phase relations of signal and/or masker but also of various characteristics of signal, masker and psychophysical procedure used.

It's known that due to binaural analysis there is dramatic improvement in detection of dichotic signals.

Binaural analysis is the improvement in hearing that results where there are interaural discrepancies in the signal and masking at the 2 ears. Binaural analysis is an anamolous topic. The basic phenomenon of a binaural analysis experiment is that a signal and a masker are presented to both ears of a listner who adjusts the signal level until it is just detectable. The signal is then alternated 5 dbs. The signal to one ear is then turned off and in certain situations, if the signal is presented to only one ear it can be detected with as much as 10 dbs less signal level than if it is presented to both ears. This rather surprising result is typical of those obtained in the area of binaural analysis.

The binaural analysis experiments demonstrate that vastly superior detection performances is possible in many conditions in which some interaural discrepancy exists between the signals or maskers at 2 ears.

Research in the area of binaural analysis has largely been denoted to investigating those differences in interaural stimulus parameters that lead to improved detection performance. Many interaural differences in the signal 'S' and in masker 'M' have been investigated and a notation has developed. In the situation 'MoSo' the subscript 'o' indicates that there are no interaural different

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between the masker or signal arriving at the ears. In the 'MoSm' since the masker is again the same at both ears (subscript '0') but the signal is presented monaurally (subscript 'm'). These and other symbols are described below:

So = Signal presented binaurally with no interaural difference.

Sm = Signal presented to only one ear.

Mm = Masker presented to only one y ear.

Sπ- Signal presented to one ear 180°, Out of phase relative to the signal presented to other ear.

Mπ Masker presented to one ear 180°. Out of phase relative to the masker presented to the other ear.

Mu = Masker presented to one ear uncorrelated to the masker presented to the other ear.

Any improvement in detection that results from using two ears instead of one is called a masking-level-difference (MID) and is expressed in decibels. When the stimuli to both ears are the same in all respects - level, frequency and phase - the stimulus condition is diotic. The diotic condition is one of the homophasic conditions. Others result from altering both the signal and the noise to one ear in the same way - perhaps by reversing the phase of both, or by delaying both in time by the same amount. If the phase (or time) at one ear either for the signal or for the noise (but not for both) is altered relative to the other ear, the condition is called anti-phasic. If the noise for one ear is independent of the noise for the other (that is, if the noises are uncorrelated), the condition is called heterophasic. Any binaural condition which is not diotic is dichotic. The stimuli may be dichotic in phase, in time, in level, in frequency, and in many other ways.

To make the notations specific and more complete, the following symbols for the various combinations of noise and signal, are adopted, using 'N' for noise and 'S' for signal, π to indicate a phase reversal at one ear relative to the other, 'u' to indicate that the noises at the two ears are uncorrelated (i.e. arise from separate sources), and 'm' to indicate that the noise or the signal is monaural. A number of conditions can be listed.

Monaural(Monotic)

NmSm : Noise and signal both monaured (same ear)

Homophasic

NoSo : Noise and signal both in phase at the ears (diotic)

Nπ Sπ : Noise and signal both reversed in phase at one ear relative to the other (dicbotic).

The remaining conditions are all dichotic.

NoSm : Noise in phase? signal monaured.

NπSm : Noise reversed in phage, signal monoaural.

Antiphasic

NoSπ : Noise in phase, signal reversed in phase (at one ear)

NπSo : Noise reversed in phase, signal in phase.

Hetero-phasic:

NuSo : Noise uncorrelated, signal in phase.

NuSπ : Noise uncorrelated, signal reversed in phase.

Suffice 0π/fd indicates low frequencies in phase, high frequencies 180^{0} out-of-phase; fd is the frequency dividing the 2 bands.

Soπ/250 : Signal in phase for all frequencies upte 250 Hz signal 180^{0} out of phase for all frequencies above 250 Hz.

Nuo/500 : Noise uncorrelated for frequencies upto 500 Hz noise in phase for all frequencies above 500 Hz.

Suffix tx : indicates an interaural delay, x - magnitude of delay in milli-seconds.

S t 1.6 : relative interaural delay of 1.6 milli seconds for the signal (over entire frequency band).

In order to compare detection in one binaural condition to that in another, the data are usually presented as the difference between the signal level required, for detection in a monotic condition and that required in a diotic or dichotic condition and is substracted from the signal level required for detection in the MmSm condition. Such a difference when expressed in decibels is called a Masking Level Difference or a Binaural Masking level Difference.

In most binaural masking experiments a psychometric function is obtained for each monotic, diotic or dichotic condition tested. The psychometric functions relates some measure of the subjects performance to the signal-to-masker ratio. The MLD is simply the separation in decibels between the psychometric functions associated with diotic or monotie and dicbotic conditions.

Green 1966, Egan etal 1969, and Mac Fadde A and Pullian 1971 have shown that the psychometric functions are parallel across the various binaural conditions. Thus the MLD does not depend on the level of a subject performance. In addition, intersubject variability appears to be small in a majority of the MLD studies. Many different psychophysical procedures have been used to measure the size of the MLD, and these estimates are generally in good agreement with one another. Consequently in many conditions the MLD appears to be relatively invariant across subjects, level of subjects performance and psychophysical methods.

The exact value of the MLD depends on a number of factors which will be reviewed systematically later. To provide some typical results and to review how the sise of MLD depends on the various interaural conditions, a situatio

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is considered in which the masker is a load continuous wide band masker such as white noise (spectrum, level 60 dbs or more) and the signal a lew frequency sinusoid (say 500 Hz and presented for a brief duration 10-100 milli-second).

In this situation the following hierarchy of MLDs will probably result*:

Interaural condition compared to MmSm	MLD
MmSm, MoSo, MuSm ..	Odbs
MuSπ ..	3 "
MuSo ..	4 "
MπSB ..	6 "
MoSm ..	9 "
MπSo ..	13 dbs
MoSπ ..	15 dbs

The MLD hierarchy demonstrates for example that when a signal and masker are presented to both ears identically (MoSo) the signal is as easily detected as when the signal and masker are presented to only one ear(MmSm). However, if the interaural phase of the signal is hanged from 0^0 to 180^0 (MoSπ) then the signal is easier to detect by 15 dbs.

Two points regarding this hierarchy should be noted: (1) the MLD is never '-Ve' (2) the MLD for some binaural conditions is zero dbs'. These binaural condition, which yield no MLD are sometimes used as the referant condition for defining the MLD rather than the MmSm condition. In particular/many investigators use the diotic condition (MoSo) as the referent condition. Although there has been a long history of study in the area of binaural interactions of various kinds, MID's for sinusoidal signals were first observed by Hirsh in 1948 and these for speech signals by Licklider in the same year. Since then many investigators have systematically studied the signal and masker parameters involved in MLD. Although this research has indicated many of the conditions required to produce an advantage for binaural listening, no general theory has emerged to produce an advantage for binaural listening, no general thory has emerged to describe all of the data.

CHAPTER - II
SIGNAL PARAMETERS

The emphasis in this Chapter will be on the different stimulus parameters and how they affect the size of MLD.

Throughout the review, the major dependent variable is the MLD; i.e. the difference in the signal level required for detection between a reference condition and some other binaural masking condition.

A change in MLD does not indicate in which condition detection has varied; the reference condition, the binaural condition or both conditions. A change in MLD shows only that there was a relative change in detection. MLD is defined in terms of detection and not in some other psychol-gical dimension, such as loudness. Thus in general the binaural masking literature is an investigation of those parameters and conditions which lead to an improvement in detection due to dichotic listening.

Signal frequency:

The amount of binaural improvement measured in MLD experiments greatly depends on the frequency of the signal. The MLD, an advantage shown by the binaural auditory system over the monaural system when detecting a tonal signal in a background of masking noise, is known to be primarily a low frequency effect.

An MLD of greater than 15 dbs may be obtained for certain binaural masking conditions when the signal frequency

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is 500 Hz. The MLD for the same conditions is not more than about 3 dbs, however, when the signal frequency is above 1500 hz.

Willibanks and Whitmore have shown that as the frequency of the signal is increased or decreased from 250 Hz, the value of the MLD for NoSm decreased. It, therefore, restricts the rate of change in MLD as the interaural condition for noise is reduced from unity. (Any reduction in the size of the MLD can be in interpreted as a reduction in the interaural correlation of masking noise.

Hirsh in 1948 showed in his original experiment that the size of MLD for MoSm and MoSπ conditions diminished at frequencies above about 1 KHZ. His later experiments show that above about 500 Hz, there is good agreement among all of the data. In the MoS and M So conditions, the MLD is large and diminishes to about 3 dbs in the region of 1500 Hz. Above 1500 Hz there is ample evidence that the MLD does not go to zero, but rather remains at a value near 3 dbs. For the other dichotic conditions the MLD reaches an asymptote at or near Odls as the signal frequency increases beyond approximately 1500 Hz.

Schoeny has shown that the magnitude of MLD is minimal above 1 KHz.

Data on the size of MLD at low frequencies are more diverse. It appears from several articles that the discrepancies among the discrepancies among the published values for the MID at lew frequencies below 300 Hz, are almost entirely attributable to differences in the amount of low frequency experiementally controlled noise. One of the best studies on this topic is that of Dolan (1972) who systematically varied the level of experimentally controlled external noise and measured the MID for the MoSπ- condition at 150 and 300 Hz. As the external masking noise increased in level, the MLD steadily increased. And, finally at noise spectrum levels of 50 dbs and above, the MLD is about 15 dbs at both 150 Hz and 300 Hz. Thus the relatively small MLD's measured at very low signal frequencies and with a low level of experimental masking noise are presumably caused by other noises not under the experimenter's control; such as those produced by breathing, heart beat, muscle tonus and room noise. At very low signal frequencies the level of these other noises is sufficient to obscure the low intensity experimental noise introduced via the head-phones. The internal noises at one ear are only partially correlated with those at other ear. Thus they resemble to some degree the Mu condition.Since a condition like MuS produces a very small MLD, there is a small MLD measured for these low frequency signals when the experimental noise is low in level.

Apparently, the only experiment which reports an MID that does not change as a function of signal frequency is one reported by Rabiner, Lawrence and Durlach in 1966.

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In their experiment the MID for an uncorrelated noise (Nu) with either an in-phase signal So or a phase reversed signal (Sπ) was measured relative to NoSo at signal frequencies of 167, 297, 500, 694 and 1040 Hz. Over this region, the MID's for both NuSo and NuSπ appear to remain constant at about 4 dls. This result is inconsistent with earlier studies.

A partial replication of the Rabiner,Lawrence and Durlach experiment was carried out by D.E.Robinson (1971) In that experiment the magnitude of the MLD for the binaural conditions NuSo relative to NmSm was measured at 300 Hz and at 2000 Hz. The results showed that the MLD for NuSo does vary as a function of signal frequency. These results are compatible with the earlier studies, Rabiner, Lawrence and Durlach had pointed out that the EC Model predicted that the MLD for NuSo should change from about 3 dls at 500 Hz to 1.8 dls at 1200 Hz. Robin in his study found an MLD Value of 3.95 dls at 300 Hz and 1.68 dbs at 2000 Hz. Thus these values agree favourably to those estimated.

Mc Fadden in 1968 has investigated the change in MLD at low frequencies as a function of low external noise intensities. The relatively small MLD's obtained were explained by alluding to the effective noise hypothesis of Dicreks and Jeffress in which internal noise interacts with low intensity external noise to produce an effective noise masker. Two sources of evidence support the possibility of effective masking of low frequency signals. First

Shaw and Piercy 1962 have estimated the internal noise under ear-phone cushions to vary between 84 dls SPL at 16 CPS to 0 dbs near %0 CPS. Second the interaural correlation of the effective masker probably varies with the intensity level of the external masker. In this latter case, if its assumed that

a) the interaural correlation of the internal noise is slightly position;
and
b) the interaural correlation of the external noise is +1.00 (No condition),

then when the external noise is fairly intense, the effect of the internal noise would be essentially zero. On the other hand, the external noise intensity decreases the effective interaural correlation begins to decrease from +1.00 due to the relative increase of low positively correlated internal noise. Thus the effective noise correlation would vary from +1.00 to slightly positive as a function of the. intensity of the external noise. By extrapolating from these data it may be argued that as the external masker decreases to a low level there is in/contrast, a frequency related increase in the relative effect of the internal noise. That is the internal noise may conceptually replace the external noise as a masker of low frequency signals. Consequently interesting effects should occur when low intensity external noise, combines with internal noise to form the effective masker.

Dolan in 1968 pointed out the effective noise hypothesis does not amount for all the variability in the data. Jeffress in 1952 found larger MLD's using a 150 milli second signal, he showed a MLD of 13 dbs for a 500 m.sec. signal and 16 dbs for a 25 m.sec. signal. These reulsts at 500 CPS are suggestive of a possible influence of signal "duration on MLD.

The literature thus suggests an examination of MLD's for frequency signals at lew and moderate levels. It was expected that MLD's would decrease as a function, of decreases in external noise intensity and frequency.

Results of the study carried out by David R. Soderquist and Lindsay J.W., where the dependent measure MLD was obtained by comparing the alternator settings for 200 CPS or more mean threshold trials for NoSm relative to N0S0. It should that the MLD for 200 CPS exceeded that at 150 CPS and the extent of the frequency difference depended on spectrum level. The mean difference between the 2 frequencies was small about 1 dbs at the lower spectrum level whereas the mean frequency difference at the 35 dls spectrum level was about 5 dbs.

Extrapolation from the data of Shaw and Piercy 1962 indicates that the internal noise at 150 CPS was approximately 6 to 8 dbs more intense than that at 200 CPS. Accordingly, sore intense internal noise at 150 CPS results in a smaller effective noise correlation at this frequency than at 200 CPS. This smaller effective noige correlation consequently yields a smaller MLD at 150 CPS in contrast with the MLD at 200 CPS.

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The below figure shows the results of several experiments in which the magnitude of MLD for NoS masking condition was measured relative to the NoSo masking condition, at a number of frequencies. The sold curve represents a prediction of the size of MLD as a function of signal frequency based on Durlach's 'EC Mode'. There are atleast 2 areas of discrepancy between the theoretical estimate and the data. First there are variations in data at frequencies below about 300 CPS and only the larger estimates of the size of the MLD at these frequencies are near the prediction. Some investigators obtained estimates more than 10 dls below the prediction. Second at frequencies above 2 K CPS, the estimate approaches 0 dls but the results indicate that MLD never decreases below 3 dbs.

The discrepancy between theory and data at the low frequency end of the function is particularly puzzling. The 'EC Model' assumes a constant time jitter in the binaural processing device that degrades performance. Since the amount of time jitter is constant it should have a smaller degrading effect at low frequencies than at high frequencies. As seen in figure the model predicts an increase in the size of MLD as frequency is decreased.

Results of several experiments in which the MLD at NoSπ relative to NoSo was measured as a function of frequency. The results were obtained exploying different psychophysical methods and spectrum levels of the masker.

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The sold line represents a prediction of the size of the MLD as a function of frequency based upon the 'EC Model' of binaural hearing:

○ = Webster, 1951

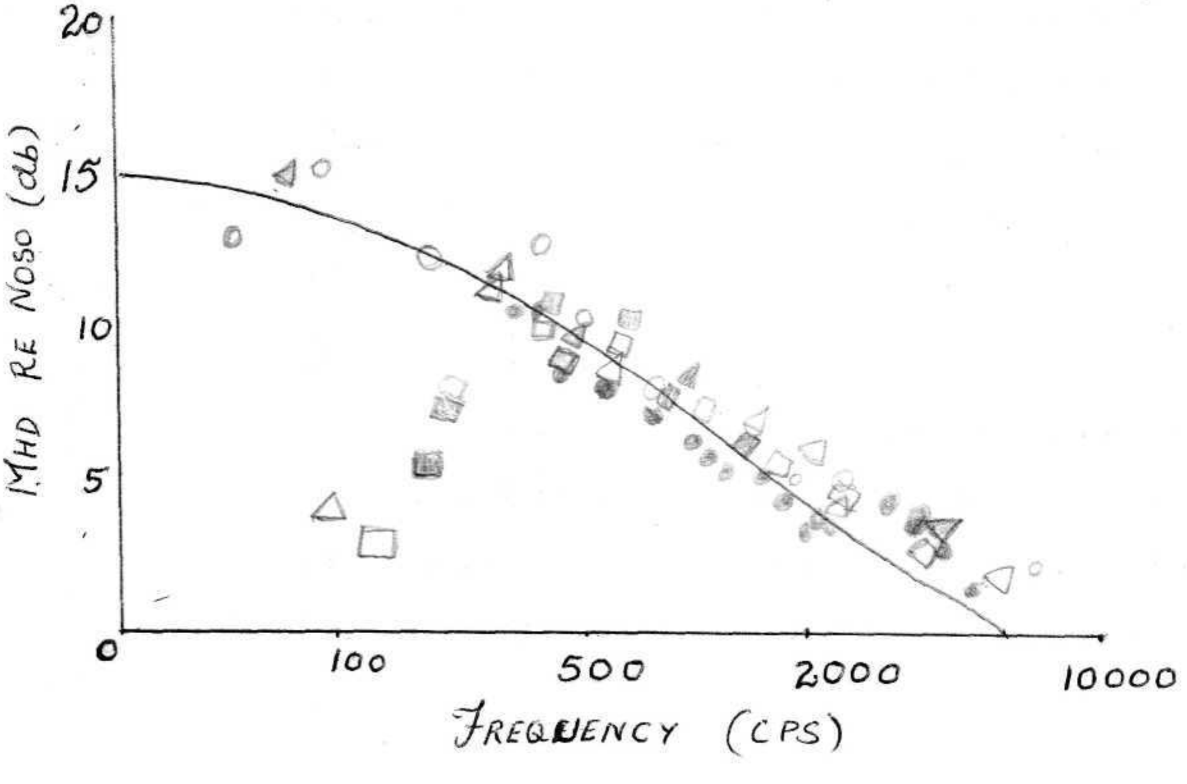
△ = Hirsch, 1948

▨ = Rabiner, Lawrence + Durlach, 1966.

● = Hirsch + Burgeat, 1958

□ = Schenkel, 1964.

▲ = Durlach, 1963.



The Webster--Jeffress time shift model assumes that binaural signal detection is the result of an interaural time shift caused by the addition of signal to joise. The size of the MID should increase as frequency is decreased; then,, since the amount of time associated with a particular phase shift increases with decrease in frequency.

Terrence R.Dolan (1968) took up an investigation designed to re-examine the decrease in the size of MLD at low frequencies and to consider a qualitative explanation of this phenomenon. Dieracks and Jeffress had argued that differences in the absolute threshold for a tone as a function of its interaural phase suggested the presence of an interval noise in auditory system. They estimated the interval noise based upon the size of direction of the threshold shift, to be of low intensity and to have a small positive interaural correlation. They argued that this internal noise may have a significant effect on detection in the absence of an external masker or at low intensities of the masker.

Recent papers have employed this notion to explain binaural masking phenomena that occur when the intensity of the masker is varied. Dolan and Robinson were concerned with the change in size of MID for the NoSm masking condition as a function of the intensity of the masker at the non-signal ear. Several studies have shown that the MLD reaches a maximum when the level of the masker at the non-signal ear is the same as the level of the masker at the

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signal ear, but steadily decreases as the masker at signal ear is alternated.

It's argued that internal noise causes a 'decorrelation' of the external masker, and that the contribution of the internal noise varies with the level of external maskers. At high intensities of the masker the interaural noise contributes very little. As the level of the masker is lowered, the effect of the internal noise increases. Since the lowering the interaural correlation of the external masker causes a decrease in the size of MLD, the explanation correctly predicts a decrease in the size of MLD with a decrease in masker intensity,

The same explanation can be used to account for the discrepancy between theory and data when the size of MLD is measured at low frequencies. It must be argued that the level of the internal noise is not constant across frequencies. Two estimates of the spectrum of Internal noise in the auditory system, support this hypothesis. Shaw and Percy in 1962 measured the acoustiat noise presented in external auditory meatus, and found that the level in a 1/3 octave-band centered at 250 CPS and averaged over 6 subjects was 12 dls SPL. At 120 CPS, the noise level was 34 dbs and continued to increase at lower frequencies.

Franchs and Hood 1967, using a psychophysical procedure, also obtained an estimate of their listeners

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critical bandwidth by assuming that the critical ratio equals 1 and then measuring the amount of signal energy were done in thepresence of a moderate intensity, wide band masking noise at each of several signal frequencies. They had assumed that bandwidth did not change in the absence of masking noise and measured the amount of signal energy necessary to achieve the same performance at each frequency in the quiet. Their results showed that the level is relatively constant above 500 CPS but increases as frequency is lowered. They estimated the level of the noise at 125 CPS to be about 19 dbs greater than the level of the noise at 250 CPS.

To test the applicability of the internal noise hypothesis the size of the MLD for the NoS masking condition relative to NmSm at 150 and 300 CPS was measured at several masker spectrum levels. It was hypothesized that the MLD at both 150 and 300 CPS would increase with increase in the spectrum level of the masker. Further it was argued that the slope of the function relating the size of the MLD to spectrum level would be greater at 150 than at 300 CPS. At high intensity levels of the masker. the size of the MLD at 150 CPS should be atleast equivalent to the size of the MLD at 300 CPS. A study by Canahl and Small 1965 lends some support to the above prediction. They estimated the size of the MLD at 167, 250 and 500 CPS at each of several masker levels and found that the MLD at all 3 frequencies increased as spectrum level was increased. The amount of increase did not,vary systematically with

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frequency.

A second aspect of the present experiment concerned the selection of NaSm rather than NoSo as the reference condition in estimating the size of MLD. The data were obtained by measuring the size of MLD at NoS relative to NoSo. The internal noise hypothesis suggests that an external masking noise that is in phase at the ears becomes uncorrelated at low intensities of the masker. Since the binaural masking condition NuSo (noise uncorrelated at the 2 ears, signal in phase at the ears) has an MID of about 3 dls relative to NmSn, it's possible that NoSo will also have a MLD associated with it at low spectrum levels of the masker. This result would contribute to an underestimate of the magnitude of the MID that would vary with both frequency and spectrum level. To ttest this hypothesis, the MLD at NoSo was also measured at 150 and 300 CPS at each of several spectrum levels.

The results indicated that the magnitude of MID at low frequencies is strongly dependent upon the spectrum level of the masker. It shows that the changes in the size of the MLD resulting from changes in those spectrum level of the masker are different at 150 than at 300 CPS. Results have failed to show that the size of MLD at 150 CPS exceeds the MLD at 300 CPS even at high spectrum levels, makes it less than conclusive that a consideration of the spectrum level of the masker will completely resolve

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the discrepancy between theory and data at low frequencies. It may be argued that the results of this experiment closely agree with the prediction of the EC Model, The model predicts the difference in the size of MLD at 150 and 300 CPS to be about 1 dls. The results of the above study showed the size of the MLD at the 2 frequencies was very nearly equivalent at high spectrum levels. On the other hand the results might be used as evidence for the presence of a variable other than spectrum level operating at low frequencies. Although the difference in the size of MLD at the 2 frequencies was small, the average MLD at 300 CPS was greater than the MLD at l50 CPS at each spectrum level studied, A more satisfying result for the internal noise hypothesis would have shown a slightly larger binaural advantage at 150 CPS relative to 300 CPS at high spectrum levels.

There is, however, a troublesome source of difficulty when comparing binaural signal detection at low frequencies. Large changes in interaural intensity and phase can easily occur at low frequencies with slight changes in the position and seal of head-phones on the ears. These changes neeessarily lead to an increased variance and poorer performance as signal frequency is lowered. A more careful investigation of binaural detection at low frequencies would include a capability such as a probe Microphone to make stimulus measurements at the ear at the start of each listening session.

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A possible explanation for the difference in MLD's at different frequencies is to assume an increase in the variability of synchronized neural activity beyond the cochlea as signal frequency decreases. An increase in variability would lead to small MLD's. Hence, the MLD for a 150 CPS signal would be expected to be less than the MLD for a 200 CPS signal given the same masker. However, the explanation is incomplete at this point because it fails to account for data which show that MLD's for low frequencies are essentially the same when the masker spectrum level is above 50 dls. A more comprehensive explanation, therefore, must include reasons for the similarity of MLD's when the external spectrum level is high (50 db and above) as well as for the differences in MLD's at lower spectrum levels. Wilbanks and Whitmore in 1968 have suggested an explanation based on data reported by Teas in 1966, Their suggestion is that synchronization of neural activity makes for easier detection of signal in NoSm condition. When the noise intensity is above 50 db it effectively synchronizes the neural activity for all the low frequencies. Below 50 db the amount of synchronization which occurs depends on the signal frequency. The lower the signal frequency the more intense the external noise must be before it begins to synchronize the neural activity.

Thus, the neural synchronization hypothesis states that when a spectrum level of external noise is below 50 db. it affects the neural synchronization of impulses differentially

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in accordance with the signal frequency. It follows that when 2 different low frequency signals are masked by an identical noise having an intensity below 50 dls, the lower frequency signal will have the larger variability in neural synchronization and therefore, be the least detectable resulting in a smaller MLD.

Binaural masking theory is in like with the reduction in binaural assistance for detection of signal frequencies above 250 Hz. As the frequency of signal is increased, the size of the interaural time shift due to the addition of the signal decreases and therefore, decreases the size of MLD. It's generally presumed that listeners are unable to detect interaural time differences for pure tones above 1500 Hz.

Von Bekesy in 1948 reported that a phase-shifted 1/2 Octave band of noise in the vicinity of 3 KHz can be centered by means of a compensating phase shift. Licklider and Webster in 1950 alternately switched the phase difference of one component of a 2 component binaurally presented tone between 0° and 180° and found that the binaural hearing mechanism was far from phase deaf even when the frequencies of each component were on the order of 8 KHz.

Klumpp and Eady in 1956 report a detection threshold of 62 m.sec. for interaural difference for a 3056 - 3344 Hz band of noise with no audible components below 2 KHz. Leaky, Sayers and Clarry in 1958 employed condition very

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similar to those of Licklider and Webster and found that 4000 - 5000 Hz binaural tones modulated by time-delayed, low frequency tones or noise can be reliably laterized. They concluded that there appears to be a change in the mode of perception of binaural signals according to spectrum below about 1 K - l.5 K CPS, the binaural fusion mechanism appears to be operated directly by the microstructure of the audio-signals, whereas above this threshold, it is operated by the **"summing - averaged envelope of these signals".** In view of these findings interaural time difference need not be abandoned as the physical basis for the MLD's found at high frequencies.

Below 250 Hz the rate at which the size of MLD for NoSm diminishes is quite remarkable. Over a 100 Hz range, these MLD's diminish from about 9.5 dbs to virtually zero. The interesting problem posed by these data is why the binaural mechanism pils to detect the large interaural time difference that is produced, presumably when the 150 Hz signal is added to correlated noise. It is certainly not the case that the interaural time difference resulting from the addition of the 150 Hz signal is too large for the binaural hearing system. Blodgett, Wilbanks and Jeffress in 1956 found that, under optional conditions, listeners can lateraize a 106 - 212 Hz noise on the basis of interaural time difference as large as 20 milli second. Why does the addition of correlated noise at the non-signal ear have virtually no effect on detection at 150 Hz and such a small effect at 200 Hz.

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Jeffress, Blodgett and Deatherage 1962 also report small MLD's for a 167 Hz signal. Hirsch's data and in particular Willbanks and Cummins data on a 150 Hz monaural signal, imply that large MLD's at low frequencies should be obtained if a more intense masker has been used.

Though the failure of No to yield large MLD's at low frequencies can be attributed to the moderate noise level, the problem as to why there should be such a dramatic reduction in binaural assistance below 250 Hz remains unexplained.

The study by Willbanks and Cummins 1966 which shows that the spectral level of the noise must be roughly 20 dbs higher at 150 Hz than at 250 Hz to obtain comparable MLD's, raises the additional question as to why MLD is so dependent on noise level at low frequencies.

The possible explanation for the dependency of MLD on noise spectral level lies in the fact that a considerable amount of masking noise is produced in the ear canal by such physiological actions as breathing. The SPL of the noise generated under ear-phones measured by Piercy and Shaw showed that spectral level of such noise is about 8 dbs at 250 Hz and +25 dbs at 150 Hz. Obviously this noise will add to the noise generated by ear-phones and will affect detection to a greater or lesser degree. It is assumed that the correlation overtime of this body noise is zero, then one would expect this noise to reduce the interaural noise

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correlation from +1.00 for NoSm to +0.98 at 250 Hz and to about 0.86 at 150 Hz. If the condition for NoSm were in fact +0.86 at 150 Hz, then a MID of about 5.5 dls would be expected. The obtained MLD is only about 0.5 dls;while body noise has some effect, it does not tell the whole story.

Teas argues that the lateralization process is best described by the cross correlation function of the neural input to Central Nervous System. The neural input referred to by Teas is the output from each Cocklea and is the synchrony or wave-form of the neural Volley (i.e. neural responses distributed overtime) at the level of 1st order neurous in auditory nerve.

The reduction in binaural assistance below 250 Hz results from less synchronized neural activity at the cocklea for 150 Hz signal than for the 250 Hz signal. According to Willbanks and Cummins 1966 and Hirsh 1948 it would be necessary to maintain that increasing the intensity of Masker noise increases the synchrony of neural volley subsequent to the cocklea.

Teas finds evidence that implicates the speed of propogation of travelling wave as the major determiner of neural synchrony for low frequencies. As the travelling wave along the cocklea partition approaches the apex, its velocity decreases and therefore, decreases neural synchrony. Synchrony is increased with increased stimulus intensity

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because nerve fibres more based to the point of maximal displacement of the cocklear partition are excited. From this view, neural following of low frequency signals is following of the travelling wave rather than of frequency pulse; timing information and therefore MLD depends on the basal spread of neural excitation in the cocklea that exceeds. Some threshold value in Jeffress terminology when represented in the binaural detection mechanism would be called "neural noise".

The cortical potential evoked by sound is without doubt relevant to the process of hearing. A close correspondence in stimulus frequency and intensity exists between that required for behavioural threshold, and that required for the threshold of evoked response. With respect to the evoked response, one might expect a larger response amplitude to S than to So at low frequencies; since S is more easily detected under comparable listening conditions, little or no difference in amplitude would be expected between S and So when the auditory stimuli consist of high frequencies.

The results of the study "The influence of phase Inversion on the auditory evoked response" carried out by R.S.Butler and Klushkens, indicate that response magnitude of the evoked response (Nl P2) is larger for Sπ than for So when the tonal stimulus is 200 Hz, but no differences in response amplitude occur between S and So for a 2000Hz tone. This finding may furnish a lead to the electrophysiological mechanism undulying MLD's; viz. a signal which elicits a greater electrical potential simply requires a correspondingly greater intensity of noise to achieve masking at the neurological level. Working within the framework of MLD paradigm, they reported that the threshold of evoked response to So in presence of noise was inverted, i.e, So N as compared to SoNo. Behavior thresholds were also lower for the SoN condition. No evoked response threshold data, however, were reported for the S No and SoNo listening conditions. Aside from a possible relation to signal detectability, an interesting phenomenological experience is associated with S as contrasted to So at 200 Hz which does not take place at 2000 Hz. Namely, for the former tone, the auditory image resulting from S appears to occupy the entire head, that for So clusters about median sagittal phone. It is tempting to speculate that Sπ at low frequencies activates a more diffuse population of neurous than does So.

SIGNAL BAND WIDTH:

Several experimenters have used clicks (Zertin 1966), short duration sinusoids and pulse trains, as signals in the MLD paradigm. All of these stimuli have energy spread over a wide range of frequencies. In general, the results from these studies agree with those involving long duration sinusoids. The largest MLD's occur when the signals contain energy in the frequency region below 1 KHz

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and when in this spectral region there is an interaural phase reversal of signal but not of masker MoS .

Flanagan and Watson showed that for a pulsed train, the largest MLD's (MoSπ) were related to the fundamental component of the repetition rate. If the fundamental were eliminated by filtering,the MID was generally reduced. This finding agrees well with those involving sinusoidal signals.

SIGNAL SEPARATION:

Rabinson 1971 has investigated the effect of using different frequencies for the signal in the Sπ condition. In general the maximum improvement occurs when the signals are the same frequency (4-00 Hz) and there is a little difference in the Sπ and Sm conditions once the signals are different by 150 Hz; i.e. 400 Hz in one ear/and 550 Hz in the other.

NOISE SIGNALS:

When the noise is the signal as well as a masker, the MLD's (MoSπ) tend to vary over a considerable range 15 30 dls. Rilling and Jeffress argued that a crucial variable in the noise-signal experiments is the phase relation between the signal and masker. If the noige signal and noise masker are from different noise sources, then the phase angle between the masker and signal is random. Jeffress and McFadden were able to control this phase relation by using a noise-signal of the same band-width (50 Hz) as the masker and by using both the masker and signal prove the same noise supply. In this case, the largest MLD's (MoSπ) were found when the phase angle between the signal and masker was less than 90°, the MLD decreased as the phase angle was increased beyond 90°.

By controlling the phase relation between the signal and masker, Jeffress and McFadden also controlled exactly the interaural intensive and temporal differences in the noise wave-forms. The values of these interaural differences agree with those obtained in lateralization and localisation studies. Hence their detection data are compared to the data obtained in a lateralization task.

SPEECH SIGNALS:

A large body of literature concerns attempt to study binaural performance using speech as the signal. The binaural improvement has been measured in 2 ways:

1) the speech signal to masker ratio required to detect the presence of the signal, is measured in the referent and binaural conditions; or
2) the speech signal to masker ratio required to recognize or understand the speech signal is measured in the referent and binaural conditions.

The usual measure of speech recognization is intelligibility the proportion of words correctly repeated or identified from a fixed list of speech signals.

Licklider 1948 was the first to measure the improvement in intelligibility caused by binaural antiphasic listening. His results showed binaural improvements of about 6 dls.

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when the observer is obtaining scores of 20 - 30% intelligibility and practically no improvement at higher signal to noise ratios. Schubert and Sehultz confirmed this basic finding and also found that the most improvement in intelligibility resulted when the masker was the subjects own voice, a reasonable but interesting result. This change in the amount of binaural improvement as a function of signal level is in marked contrast to the results obtained when detecting sinusoidal signals.

During the past few years a substantial amount of work has appeared on MLD's for speech signals. In 1963 Feldman demonstrated that monaurally masked speech discrimination scores were improved when the noise was added also to the opposite ear. He further noted that MLD's can be produced by an interaural time delay of either speech or noise signals. He concluded that the MLD's for speech test signals are dependent on the frequencies below 1200 Hz.

In 1966 Carhart and his associates published the first of series of extensive works on MLD's using speech test signals. In this first study they observed a 4.5 dls release from masking for monosyllable word intelligibility when a continuous noise was made antiphasic (Carhart 1966)

Levitt and Rabiner (1967) investigated changes in the detectability and intelligibility of speech as function of interaural phase. For the No S case they observed an MLD for the detection of single words of 13 dls and conclude

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that the result was determined principally by the frequencies below 500 Hz. This MLD value is quite close to the MLD obtained for the detection of pure-tone test signals in this frequency region. The MLD for intelligibility of single words was 6 dbs and was not so dependent on low frequencies. On the basis of their work and that of others, Levitt and Rabiner (1967) proposed that the binaural gain in intelligibility resulting from binaural listening can be calculated by release from masking for pure-tones produced by the binaural conditions in question. Carhart in 1967 investigated the effects of interaural time delays on the release from masking. The MLD's became greater as the time delays were increased from 0.1 to 0.8 m.sec. It was found that antiphasic intelligibility MLD's were 7 dbs for spondees and 4 dls for monosyllables.

Carhart Etal 1968 observed that the ability to attribute a specific location to a sound is distinct from the capacity to achieve intelligibility for speech under various interaural conditions. In several instances the greatest binaural release was obtained under conditions wherein the subject had the most difficulty in assigning a location to the signal or the noise. This finding is in agreement with the results of Flamagan and Wabson 1966, who used pulse trains as the test stimuli, but in apparent disagreement with some early explanation of MLD's based on apparent locational of noise and test signals.

Carhart Etal (1969) observed that the perceptical

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masking which results when maskers are combined and where atleast one is a speech masker is essentially equivalent in homophasic, anti-phasic and time-delayed conditions; thus supporting the contention that masking involves atleast two essentially independent stages.

In general the same set of parameters has been studied for speech signals and far sinusoidal signals. Since the interest in speech MLD's is ultimately in the improvement of speech intelligibility many different background maskers or distractors have been employed. large MLD's (6 - 15 dbs) have been obtained when the speech signal is in the S configuration and the masker is either a wideband continuous noise, an amplitude-modulated noise, an interrupted noise or a competing speech signal.

If the speech signal is filtered, then the largest MID's (MoS) occur in the frequency region below 500 Hz, sizeable MLD's upto 12 dbs have been obtained by Carhart 1966 when an interaural time delay is introduced between the speech signals arriving at the ears and not between the maskers. Thus, to a first approximation, the MLD's for detection of speech and those for detection of sinusoids seem to vary in the same way as a function of changes in the stimulus parameters.

Thus a number of investigators have shown that the size of MLD is largely independent of the level of detection performance. A reasonable interpretation of this difference is provided by the excellent analysis of Levitt and Rabiner in their 1st paper they explored how the frequency content of the masker and the signal changes the amount of improvement and how time delay of signal influences intelligibility in anti-phasic condition. The second paper is theoretical and attempts to derive the improvement in intelligibility score by treating and attempts to derive the improvement in intelligibility score by treating the anti-phasic condition as if it simply reduced the noise level over that used in the monaural condition. They demonstrated that effectiveness of this scheme by predicting a wide variety of data. The diminishing increase in improvement in the binaural intelligibility score, as signal level increases is predicted on the basis of smaller gains in the articulation index as signal to noise level increases. Levitt H. and Rabiner L.R. (1967) carried out an experiment whose purpose was two fold:

1) The primary aim was to determine whether binaural release from masking for detection of speech (single words) in broad ban Ganssian noise is dependent on factors similar to those for tones and pulses.

   Flanagan and Watson have shown that the release from masking for periodic pulsive stimuli in high level broad-ban ganssian noise is similarly dependent on low frequency interaural phase information. Interaural amplitude differences were not considered in this experiment.

2) A secondary aim was to investigate the relationship between release from masking for detection and the corresponding gain in intelligibility. In particular, it was of interest to compare the relative importance of different frequency regions in binaural unmasking and in improving intelligibility.

   Some work along these lines has been reported by Schubert (1959) and by Schubert and Schultz (1962) who measured the binaural gain in intelligibility of band limited speech in broad-band ganssian noise. The speech was restricted to one of three contiguous bands symmetrically

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> placed about a frequency of 1630 Hz. The results showed that the binaural gain for low frequency band-limited speech was subsequently greater than that for speech band limited to the intermediate or high frequency regions, and almost equal to that for broad-band speech. In the present investigation the speech signal was not band-limited, but portions of the speech spectrum were subjected to a 180° phase reversal. Other stimulus transformations that were investigated included a 180° phase reversal of a band of the noise, decorrelation of a band of the noise, and a large interaural tine delay applied to the speech. In all cases, both the release from masking for detection and gain in intelligibility were measured.

The results indicated that the binaural release from masking (SπNo condition) for the detection of single words in high level broad-ban ganssian noise is on the order of 13 dls and determined primarily by interaural phase opposition in the spectral region below about 500 Hz. This result was in accord with the observations of Flanagan and Watson using pulsive stimuli interaural amplitude differences were not considered.

Binaural intelligibility level differences were substantially smaller than the corresponding binaural masking level differences. Furthermore, it would appear that the gain in intelligibility is not especially dependent on low frequency interaural phase information, but rather on phase opposition over a much larger portion of the spectrum. A simple, approximate interpretation of the data suggests that interaural phase information in different regions of the spectrum contribute independently towards improved intelligibility.

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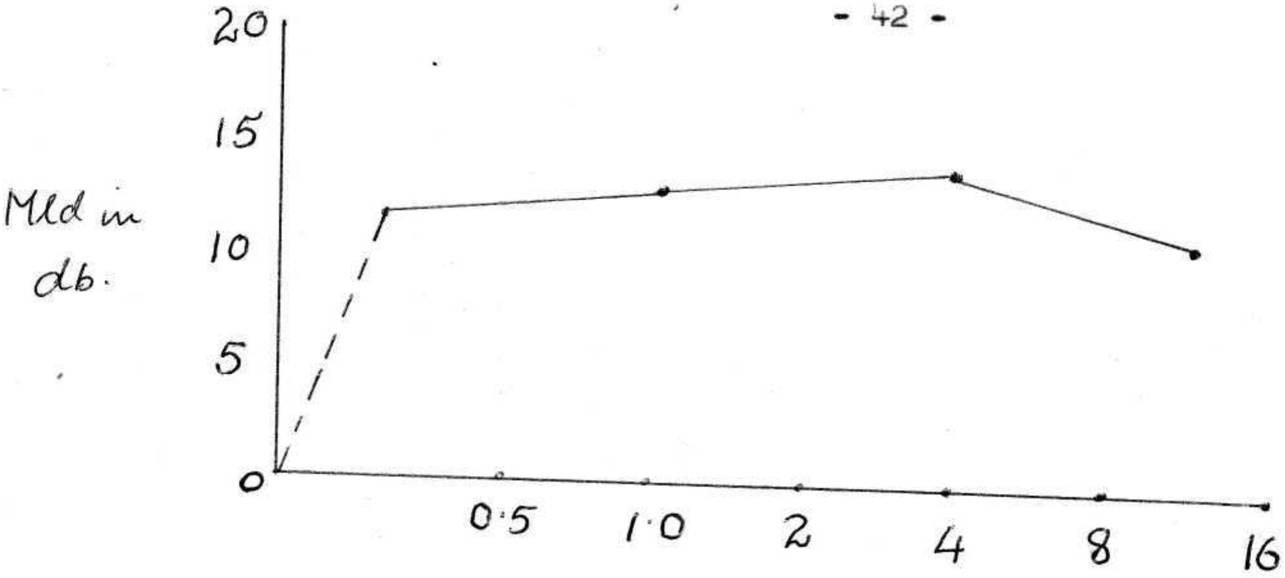
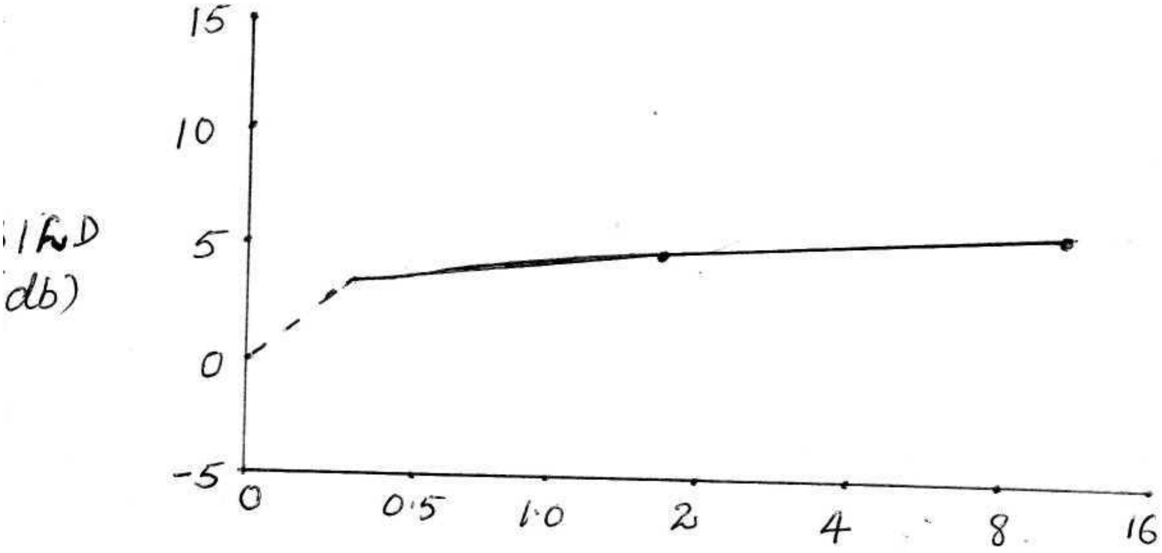
(a) Masking level differences



(b) Intelligibility level differences



Inter aural time delay Δt (Milli seconds)

Figure 2.

Variation of BMLD & BILD with interaural time delay. BMLD'S are shown in the upper figure, BILD'S in the lower figure.

SIGNAL PHASE:

The first systematic study of how signal phase affects the MLD was made by Hirsch who varied the phase of a 200 Hz signal in 30 degree steps in both Mo & Mπ configurations. The effect of interaural signal phase is profound. The largest MLD's appear when the interaural phase of the signal is 180° difference from that of the masker, i.e, when the configurations are MoSπ or Mπ So. Jeffress 1952 and Colburn and Durlach 1965 confirmed these results concerning signal phase using a 500 Hz signal. For an Mo configuration, the effect of signal phase is pronounced, the graph relating detection performance to signal phase angle is a peaked function.

The idea of gating the signal in a binaural detection experiment so as to control (atlast at one set) the phase relation between the signal and a narrow band masker is appealing. If we assume that the phase relation between the masker and the signal changes rather slowly, a short signal gabed coherently should retain its phase relation to the masker for a few cycles. Accordingly, if we gate the signal sothat it and the noise have nearly simultaneous positive going axis crossings at the moment of gating, and if we introduce a phase shifter into the signal channel between the gate and the subjects ear-phone, we can generate any desired phase relation between signal and noise i.e. we can control the value of.

The below **figure 3** illustrates the role of in

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one binaural stimulus condition, NoSm (noise diotic, signal monotic). The coinciding vector Nl and Nr represent the momentary N amplitude (in phase and equal at the ear-phones). S1 represents a signal presented to the left ear, with the phase angle between the signal and the narrow band noise. By gating the signal coherently with the noise (at positive going axis crossing of both, and only when they coincide). We can with the phase shifter in the subjects channel, control the value of angle α, presented to him. By choosing appropriately, it should be possible to exercise some control over both the value of θ and the length of signal noise vector and discover the relative contributions of interaural differences of phase α of level to both detection and lateralization.

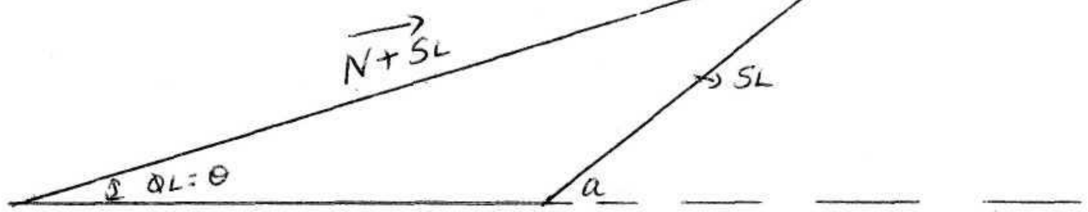

FIGURE 3

A very attractive prospect (vector, phase) 'e representing the NoSm binaural condition is shown. The line N1 = Nr represents a momentary value of Noise (equal to ear-phones), α is the momentary phase angle between NBN and signal.

Two pieces of equipment were constructed to achieve this goal. The first used by Hafter and Jeffress 1962, a primitive device built with vacuum tubes failed to reveal any dependence of MLD's on values selected for α.

The phase shifter following the gate was set so as to make the value of α at onset equal to zero. It will be seen that noise and signal stayed in phase momentarily and then drifted apart. Other samples show a larger stretch of phase coincidence and still others show even shorter stretches.

Reason for failure is it's simply that a narrow filter will not respond to an abrupt change of phase in its input -with an abrupt change of phase in its output. The change requires time. At the beginning of a signal was added in quadratum with a steady sinusoid of equal amplitude and frequency and the combination passed through a filter. The reference trace is the sinusoid without the signal. Examination of the traces shows the filter onput to be in phase with the noise at onset, only after several cycles, have elapsed does it reach the steady state 45° phase difference $\theta = 45^\circ$, $\alpha = 90^\circ$.

The interaural phase effects found by Hirsh were quite dramatic, when a signal and a noise are presented to both ears, and when one or the other is reversed in phase, the signal can be detected at a level on the order of 15 dls

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lower than when both are in phase.

Also the detection of a tonal signal to one ear, partially masked by a noise at the ear can be improved by as much as 10 dls when identical noise is added at the other ear.

In both cases, the signal to which the observer responds its too weak to be detected by monaural means. These phenomena indicate that some sort of binaural detection mechanism, as well as a monaural one, must be involved in hearing.

In addition to the effects of reversing the phase of the signal or of the noise the effects of varying the magnitude of the interaural correlation for noise on the masking of speech, were investigated by Licklider. He found that the advantageous obtained with in-phase and 180° out of phase signals became less and less as the interaural correlation for the noise was reduced by adding uncorrelated noise in the channels to the ears. Robinson and Jeffress 1963 and Langford and Jeffress 1964 have also shown that the magnitude of the interaural correlation for the masking noise is a dominant variable affecting binaural unmasking when a tonal signal is presented to both ears.

The results of study done by Willbanks and Whitmore are in general agreement with the findings of other investigators in showing that the interaural correlation of the masking noise is a dominant variable affecting binaural unmasking and in showing that the maismum MLD obtainable depends

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on the frequency of the signal. The functions obtained with monaural signals showing the course of the release from masking that occurs as the noise correlation is varied between zero (0) and +1.00, are quite similar to those obtained with speech and tonal signals under antiphasic conditions (Sπ). The reduction in binaural assistance found for the detection of signals above and below 250 Hz follows trends established in previous research,

S.E.Gerber investigated difference from 0° to 180° and also the in between frequencies at 40, 45, 50 and 90°, In all experiments the interaural phase relation between the speech signals were always the same as those between the noise signals. Then the speech and the noise were related homophasically but the relations between the 2 ears vary in phase. It is this interaural variance which had been the subject of the study.

Garber in 1967 reported that interaural phase difference have no effect upon intelligibility when the signal to noise is relatively high. The author found marked effects when the signal to noise ratio was very low. This finding is in agreement with that of Licklider who noted "The interaural phase effect is greater at low speech to noise ratio than at high speech to noise ratio". He found no differences among phases when signal to noise ratio was only 0 dls but we did find significant differences at -18 dls. An even more interesting finding is that there were no significant differences among 0°, 90° and 180°; but there was a significant

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difference at 45°. They found that monosyllabic word intelligibility at an interaural phase difference of 45° was significantly higher than any of the others. In 1969 paper, the authors reported no differences among 40°, 45° and 50°. This result was not surprising as they would not have anticipated the intelligibility function to be sharply peaked at any given interaural phase difference. In a further study (Gerber 1978) source of the previous data was confirmed. In that unpublished study the phase shifts employed were in steps of 10° and ranged from 10° to 180°. Two values of interaural phase shift 10° and 50° were of significantly higher intelligibility than no phase shift. That is to say, the intelligibility of isolated words at 0 dls signal to noise was increased by altering the phase relations between the 2 ears by those specified amounts one amount of phase shift, 130° was significantly poorer than no shift. Taking the average word intelligibility over all amounts of phase shift, it was found to be 59.4% which was obviously not different from the intelligibility at 0° which was 60%. On the other hand, these specific values which were significantly different were all somewhat above 70%.

Over these series of studies one finding repeats itself. That finding is that there seems to be an improvement of intelligibility in the neighbourhood of 45° interaural phase angle difference. It has not been easy to find a satisfactory explanation for this result, Gerber and his associates 1970 showed that there is an improvement in threshold for binaurally heard pure tones when there is a

45° phase angle difference introduced between the ears. While that result was satisfactorily significant it was very small < 2 dbs, and varied as a function of frequency. At no frequency was the difference between 45° and 0° any greater than 2 dbs. At frequencies above 1500 Hz there were no differences as a function of phase angle. Perhaps the apparent improvement of intelligibility is in some way related to the improvement in absolute threshold at low frequencies. Perhaps the improvement in intelligibility is a function of speech and is in some way different from the results, one would obtain when using pure tones. It has been shown that the qualitative properties of speech are affected by phase differences. In 1958 Pierce and David stressed that sufficiently great changes or differences in phase can and do alter the quality of a sound, In fact it has been concluded that spectral phase information contributes appreciably to speech quality, particularly when listening over ear phones. And recently timbre judgements have been shown to be influenced by phase alterations. It has also been shown that differences of interaural phase angle are discriminable. The question is "is the apparent improvement in intelligibility a function unique to speech or is it somehow related to a release from making phenomenon". It is a properly peculiar to voicing and would not be found in whispered speech.

Rhyme test lists were used. One is aware that in normal vowels significantly exceeds that of consonant. This is not a property of whispered speech which is of relatively uniform amplitude.

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If we wanted to compare the intelligibility of voice speech in noise with the intelligibility of whispered speech in noise, it would be required that both the voiced and the shispered speech were of similar amplitude. Each of the 20 listeners heard all 250 words of Rhyme test lists both voiced and whispered. Phase angle in multiples of 15° were employed in random order for each listener. The substance of this investigation was that if there were significant differences at any phase angle between voiced speech and whispered speech, then the results are apparently a property of voicing. If there were no differences between voiced and whispered speech then it would have to be assumed that the effect observed in one of release from masking.

Two general results came from this investigation. First was that there were no significant differences between the intelligibility of voiced speech and the intelligibility of whispered speech at 0 dbs signal to noise ratio for any interaural phase angle difference. The result was that the differences as a function of phase angle did not appear as large as they have in the last several studies. Unfortunately there is no sensible answer for this and only say that most of the time it's found that there is improvement in neighbourhood of 45°.

Results showing no difference between voice and whispered speech say that the improvement of intelligibility as a function of interaural phase angle difference is not related to voicing.

It's concluded that there is a release from masking of speech at low frequencies. By altering the phase angle reflection between the two ears, the intelligibility of speech in noise seems to improve. This may be due to interaural phase angle sensitivity at the level of the inferior colliculum. After this level there is no apparent sensitivity to interaural phase shifts for frequencies above 3 KHz. This means that when the two ears are in phase the noise below 3000 Hz masks the speech below 3000 Hz but when the two ears are not homophasically related, then the masking has its primary efferent above 3000 Hz. This frequency in the main is above 3rd formant for most Sp sounds. It can be demonstrated that the first 3 formant out of the noise by phase angle shifts are drawn. This does not explain why the shift in the neighbourhood of 45° to lead to a greater release from masking than the shift at other angles.

ROLE OF NOISE CORRELATION:

Willbanks and Whitmore reported that 2 largest MLD's were obtained for NoSm with signals of 250 and 500 Hz; these MLD's were about 9.5 and 8 dbs respectively. Hirsch and Burgeat also found the greatest reduction in masking at 250 Hz., although their MLD was much smaller.

In accounting for many of the phenomena of binaural unmasking, Jeffress Etal 1950 and Jeffress 1965 theorize that improved detection under NoSm results because of the interaural phase shift between the narrow bands of noise (critical bands) at ears, which occurs when the signal is added at one

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ear. The direction of the interaural difference in random favouring one ear for some additions of the signal and the opposite ear for other additions. The magnitude of the interaural phase shift is determined by both the level of the signal relative to the level of noise and the phase difference between the signal and noise at time of addition. According to this view binaural unmasking occurs when the hearing apparatus detects these sudden changes in the turnings of events at the ears.

As Jeffress 1965 points out, there would be no masking under the NoSm condition if the hearing apparatus were perfect since the transduction of sound is not perfect, there must be some vagueness in the preservation of timing information present in the stimulus. This vagueness or 'neural noise' presumably has the same effect on MLD as a reduction in interaural noise correlation.

Langford and Jeffress 1964 have shown that reducing the correlation of the noise by adding uncorrelated noise at the ears has some effect on MLD as reducing the correlation by introducing time delays equal to integral multipliers of in the channel to one ear. In either case, the detection of the signal is due to the additional interaural time difference that results when the subject is added at one ear. Klumpp and Eady 1956 were found that with an initial zero inter-channel time difference for a 150 - 1700 Hz band of noise listeners can detect a change on the order of 9 m.sec. for a 3056 - 3344 Hz band of noise with no audible components below 2 KHZ, they found a threshold for detection of 62 m.sec., When an inter-channel time difference is readily present a larger change is required for detection. Their results show that the threshold for detection of a change in interaural time difference for noise is increased about 1 m.sec. for every 20 m.sec. of initial difference. When a difference of hundreds of micro-seconds is present, as it's with a reduction in the correlation of noise, the subject must produce a larger time shift to be detected. As the correlation of the noise is reduced from unity a stronger signal is required to produce a detectable change in interaural time difference and therefore, there is less binaural assistance when the subject is added below levels of which it can be detected monaurally. Hence, smaller MLD's should be found as the correlation of noise is decreased from unity.

Robinson Etal 1972 carried out a study on the detectability of a pulsed tone in the presence of a masker with time varying interaural correlation. Detectability of a filtered probe tone (250, 500 or 1000 Hz) was measured in the presence of a narrow band gaussian masker centered at the signal frequency. The signal was interaurally phase-reversed ($S\pi$) and the maskers interaural correlation varied sinusoidally between +1.00 (No) and -1.00 ($N\pi$) at a variable rate. The signal was presented at various points on the maskers modulation cycle. For OHZ modulation (fixed interaural correlation) signal threshold decreased monotomically as the maskers interaural correlation was changed from -1.00 to +1.00 (by a total of 20, 16 and 8 dbs, for 250, 500 and 1 KHZ) signals. For $fm>0$ the function relating signal threshold to the maskers interaural correlation at the moment of signal presentation became progressively flatter with increasing 'fm' for all signal frequencies. For 'fm' = 4 Hz the function was flat, there was no measurable effect of masker interaural correlation on signal detectability. Estimates of minimum binaural integration time based on these data ranged from 44 - 243 m.sec. supporting previous studies which have noted the binaural systems relative insensitivity to dynamic stimulation. Additionally the estimated time constants were approximately twice as large at 250 Hz as at 500 Hz, indicating observers could follow binaural fluctuations better at 800 Hz. The time-constant estimates at 1000 Hz were not sufficiently reliable to permit comparison with lower frequency data.

SIGNAL DURATION:

The duration of the signal changes the MLD very little. As the signal duration is shortened the signal becomes more difficult to detect. This is true for diotic, monotic and dichotic conditions. For very short durations of less than 50 m.sec, the MLD for some conditions may increase somewhat being 1 - 2 dbs larger. This effect has also been confirmed by Green. The shape of the psychometric function, the function relating the percentage of correct detections to the signal level, is approximately the same for many durations and many dichotic and diotic conditions

Donald E. Robinson conducted a study on the effects of signal duration and masker duration on detectability under diotic and dichotic listening conditions. In their study the detectability of a 500 Hz tone of either 32 or 256 m. sec. duration in a broad band 50 dls spectrum level noise was measured as a function of the duration of noise. The noise was continuous or was gated 0, 125 or 250 m.sec, before the onset of signal. For the gated noise conditions, the noise was terminated 5 m.sec. after termination of signal. With a homophasic condition (No - So) the 3 noise condition led to approximately the same detectability as did the continuous masker. In an antiphasic condition (No - Sπ), detectability was poorest when signal and masker began together and improved as the delay between noise onset and signal onset increased. The difference between the simultaneous onset and the continuous noise conditions was about 9 dls for 32 m.sec. signal and about 3 dls for 256 m.sec.

J.Radford Lakey carried out an experiment which was conducted to provide empirical data on the effects of mask duration in relation to temporal masking and temporal MLD's. It was intended

1) to clarify mask duration effects in temporal masking by use of a reliable criterion - free psychophysical technique; and
2) to replicate temporal MLD findings in respect to mask duration.

The results showed that larger mask durations provide more effective masking and larger MLD's in both forward and backward masking. These and other findings yield some insight into the nature of the temporal properties involved in auditory processing.

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Forward masking increases monotonically as the duration of the mask is increased upto 1 second. In contrast to Elliat a larger mask clearly provides greater forward masking. This finding agrees fairly well with the data of Zwisbeki where signal and mask did not overlap; however, it does not agree with those studies which indicate a much shorter limiting value of mask duration.

Backward masking also increases upto 100 m.sec. The lack of a mask-duration is much smaller in backward masking.

Temporal masking is less for No Sπ than for NoSo. This result again confirms the existence of temporarl MLD's first reported by Deatherage and Evans, The MLD's increase as masking is increased whether by smaller signal-mask intervals, longer mask durations or greater mask intensities given a sufficiently long mask duration.

Thus the major findings of this experiment is that both temporal masking and temporal MLD's increase monotonically with longer mask durations. This mask duration effect is more pronounced for forward masking than for backward masking.

The Jeffress monaural model is shown to account for temporal masking and when combined with Jeffress binaural model, partially for temporal MLD's. This synthesis requires that phase information is preserved in each monaural channel.

A second finding is that a short 500 Hz signal without external masking is about 3 dbs more detectable in the So

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configuration than in the Sπ configuration. It's also about 4 dbs more detectable in the Sπ configuration than in Sm configuration.

A third finding is that psychometric functions are generally steeper for detection of an anti-phasic signal than for detection of a homophasic signal in forward masking but not in backward masking. The psychometric functions are also steeper for the S condition than for the So or Sm condition in quiet.

In the study lateralization and detection of noise masked tones of different durations carried out by Dennis McFadden and Kenneth A.Pulliam, the subjects were asked either to detect or to lateralize a monaurally presented signal (Sm) in a binaurally presented noise masker (No). Eight values of signal duration, ranging from 50 to 800 m.sec. were used for both detection and lateralization. The psychometric functions for lateralization and those for detection differed in form, but despite this difference, both were displaced towards greater signal levels at about the same rate as signal durations decreased. That is the difference between lateralization and detection was approximately the same for all signal durations.

Signal : 400 CPS
Masker : WBN, 45 dbs SPL/cycle

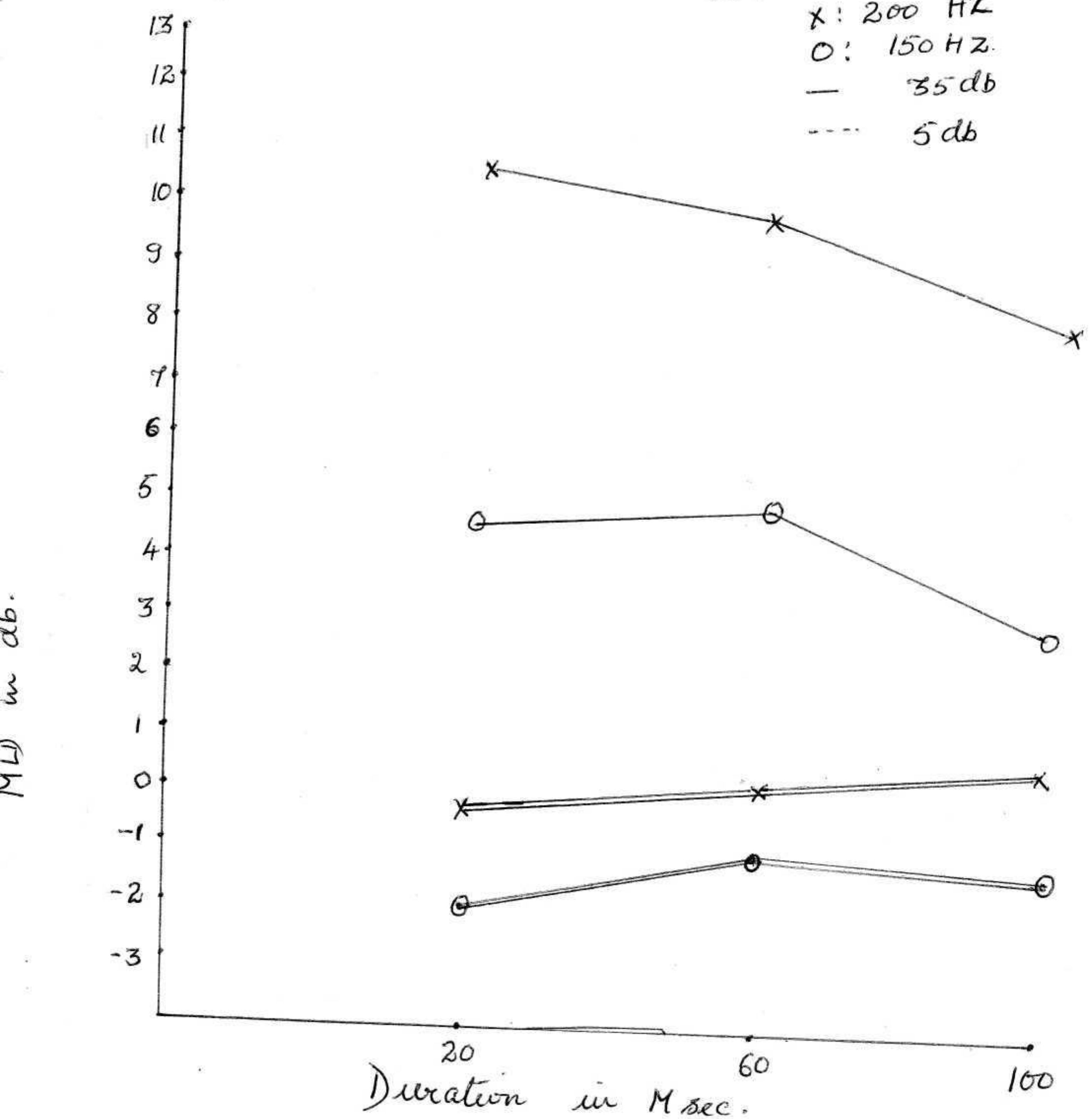
Me are left with the paradox that the psychometric functions for lateralization and detection have different forms and locations and are also affected differently by certain stimulus manipulations - both facts implying that there is something difficult about the signal processing for these two tasks and yet manipulations of signal duration affect the two taks more or less identically. Apriori such an outcome is not impossible, it just seems unlikely. Similar unlikely outcomes have been seen before in-binaural masking experiments however. For example, the forms of the psychometric functions for detection in MID and non-MLD conditions are surprisingly similar, but it is still widely accepted that detection in the MLD conditions is based on an aspect of the input difference from that used in the non-MLD conditions, or on a different means of processing the same aspect.

Since lateralization and detection have proved to be so similar in their responses to changes in signal duration, it may be that the mechanisms for these two types of performance are more similar than persons evidence had indicated. If this is true any model designed to account for detection performance in MLD conditions ought to be able with only minor modifications, also to account for the location and the form of psychometric functions for localization.

D.R.Soderquist and John W.Lindsey (1970) have studied the character of MLD with the different durations. An analysis of variance yielded a non-significant effect for duration. The relationship between the signal intensity and duration shows that the threshold for each condition (NoSo and NoSm) decreases as a function of duration. This decrease in threshold with increases induration was found for all experiemental conditions.

It's shown that the masked threshold decreased 6-10 dbs for both NoSo and NoSm as duration increased from 20 to 100 m.sec. regardless of frequency or masker level. The parallel value of these functions illustrates the non-significant result for duration. That is MLD remained essentially constant as duration varied.

The authors say that the failure to find a significant result for duration clearly suggests that the MLD is not related to this variable at these frequencies and spectrum levels. The relationship between MLD and duration at 150 and 200 CPS and 35 and 5 dbs spectrum level was essentially similar to that reported by previous investigators at different frequencies. The non-significant of signal duration can best be accounted for by noting the negatively sloping functions for NoSo and NoSm listening conditions. The decrease of these masked thresholds with increased signal duration is in agreement with Goerner and Miller 1947 and shows that the advantage for NoSm over NoSo was basically unaffected (MLD was almost constant)



Mean MLD'S as a function of signal duration. Parameters are signal frequency and noise intensity

FIGURE 4

It is clear that the MLD for 200 C/S exceeded that at 150 C/S, and the extent of the frequency difference depended on spectrum level. The mean difference between the two frequencies was small (about 1 dbs) at the lower spectrum level whereas, the mean frequency difference at the 35 dbs spectrum level was about 5 dbs. The figure 5 is representative of the shape of the functions for the individual data although there was considerable variability between MLD sizes obtained at 35 dbs spectrum level.

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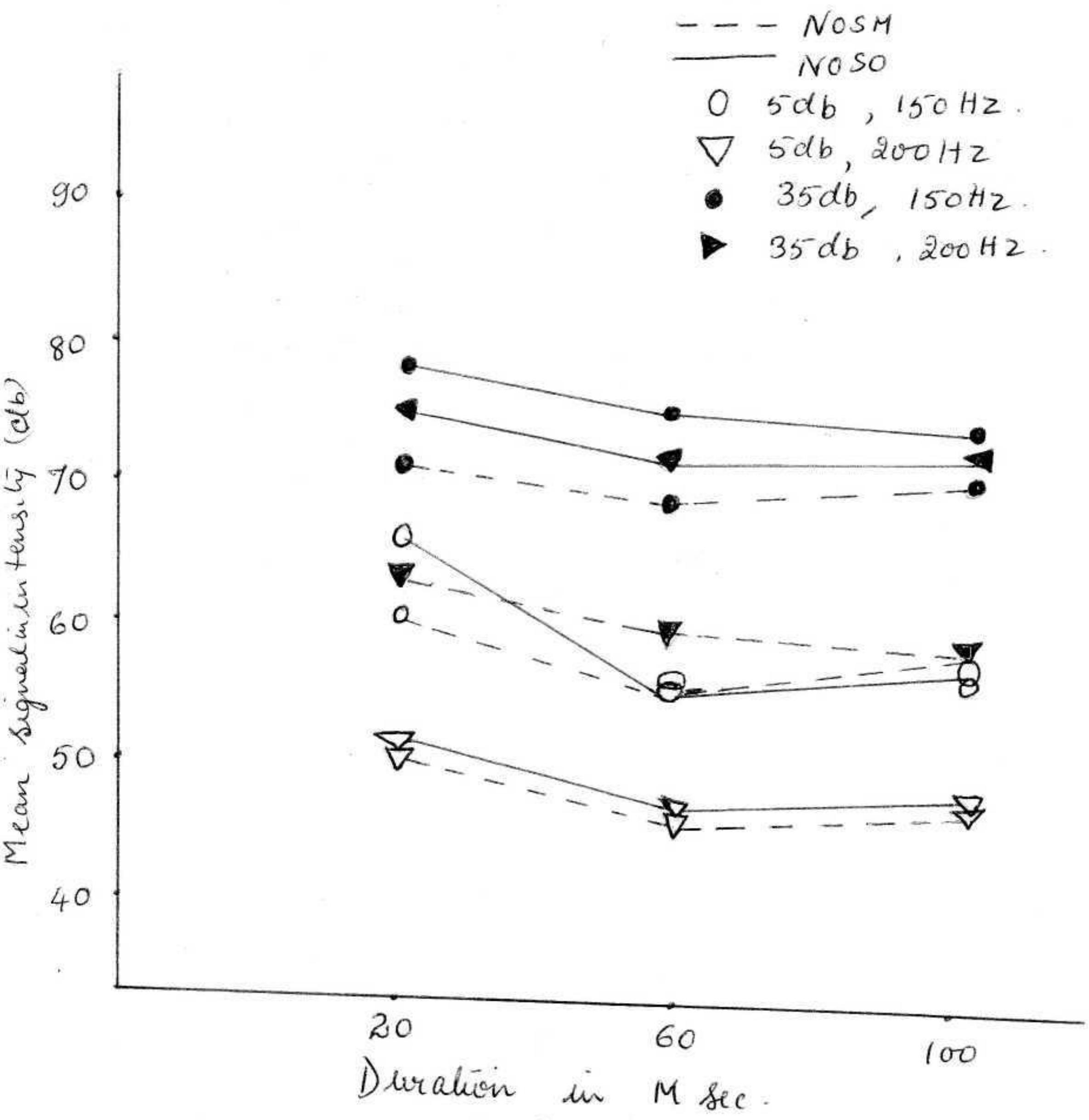

Figure 5

Mean Signal intensity as a function of signal duration. Parameter reflect different signal frequencies, noise intensities and listening conditions.

The relationship between the signal intensity and duration shows that the threshold for each condition (NoSo and NoSm) decreases as a function of duration. This decrease in threshold with increases in duration was found for all experiemental conditions. The negative slope of the functions indicates from 20 to 100 m.sec. regardless of frequency or masker level. The parallel nature of these functions illustrates the nonsignificant result for duration. That is, MLD remained essentially constant as duration varied.

MASKER - PARAMETERS

SIGNAL LEVEL:

Schweny has found that the level of the noise used in the listening condition is also an important variable in determining the amount of unmasking. In general the greater the masker level the large the MLD. There is some evidence that the size of the MLD asymptotes at a noise spectrum level of 40 dbs.

All available research indicates that the size of MLD increases as a function of the level of the masker. Hirsch and Blodgett, systematically investigated this parameter. They showed practically no difference in detection of a signal monaurally (MmSm) and detection of a signal in binaural noise (MoSm) until the spectrum level of the noise exceeded about 20 dbs. From that point there was a reliable increases in the MLD until the spectrum level of the noise was about 40 dbs. Above that level, the MLD also studied the effect of noise level in the MoSπ condition and his results agree with the previous data. The spectrum level of the noise at which the maximum MLD occurs probably depends on the signal frequency. Results of Canabl and Small agree with this.

Diercks and Jeffress found that a binaural advantage exists even in the absence of an external masking noise. The absolute threshold for an So or Sπ signal is lower than that for an So or Sπ signal viz. lower than that for an Sm signal. The lower absolute thresholds for So and Sπ signals

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are predominantly caused by the presence of the interaurally uncorrelated interval noise.

Dolan and Robinson 1967 and McFadden 1968 have investigated the change in MLD at low frequencies as a function of low external noise intensities. The relatively small MLD's obtained were explained by alluding to the effective noise hypothesis of Diercks and Jeffress 1962 in which internal noise interacts with low intensity external noise to produce an effective noise masker. Two sources of evidence support the possibility of effective masking of the low frequency signals. First Shaw and Piercy 1962 have estimated the internal noise under ear-phone cushions to vary between 84 dbspl at 16 CPS to 0 dbs near 500 CPS. Second the interaural correlation of the effective masker probably varies with the intensity level of the external masker. In the latter case if it's assured that (a) the interaural correlation of the internal noise is shorply positive and (b the interaural correlation of the external noise is +1.00 (No condition) then, when the external noise is fairly intense, the effect of the internal noise would be essentially zero. On the other hand, the external noise intensity decreases the effective interaural correlation/begins to decrease from +1.00 due to the relative increase of low positively correlated internal noise. Thus the effective noise correlation would vary from +1.00 to slightly positive as a function of the intensity of the external noise. By extrapolating from these data it may be argued that as the external masker decreases to a low level there is in contrast, a frequency related increase in the relative effect of the internal noise. That is, the internal noise may concepterally replace the external noise as a masker of low frequency signals. Consequently interesting effects should occur when low intensity external noise combines with internal noise to form the effective masker.

INTERAURAL INTENSITY:

Hirsch in 1948 reported that maximum advantage of the binaural system could be achieved when the maskers were equal in level at the 2 ears. Systematic studies of this effect are numerous, all of the results being in very close agreement with one another. Blodgett Etal in 1962 have shown that the noise level is reduced to the non-signal ear in the MoSm condition. The effect upon the size of the MLD is graderal but a reduction is apparent even for a 10 dbs asymmetry in the level of the noise at the 2 ears. Egan in 1965 and Dolan and Robinson in 1967 have replicated these results almost exactly. Binaural improvement approaches a small asymptotic value as the noise is reduced to below its absolute threshold and these results are consistent with the assumption of a small internal noise having a moderate positive correlation. Weston and Miller in 1965 have extended this basic finding with data on conditions where the masker in the non-signal ear is greater in level than the masker in the signal ear. Again the best detection occurs when the maskers are at the same level.

Torrence R.Dolan and Donald E.Robinson (1966) have said that in studies of signal detection in which the external interaural correlation of masker has been varied, the amount

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of internal noise is thought to be small relative to the external noise level. In studies In which the level of masking noise is varied, the contribution of internal noise may become significant as external noise level is reduced. A good example is the condition in which the detectability of a monaural signal is measured as a function of level of external masker at the non-signal ear, while the level of masker at the signal ear remains constant. As shown by Hirsch, detectability reaches a peak when the level of the external noise at 2 ears is equal and steadily decreases as the masker at non-signal ear is attenuated.

It is now possible to estimate the internal noise power. An interaural correlation of 0.90 yields an MID of 6 dbs, for example an interaural intensive relation of about -2Q dbs yields the same MID. Thus it's seen that when the internal noise power is estimated to be 0.0015 for an external noise power of unity, i.e. if the power of noise with zero interaural level difference is one, the internal noise source is adding only 0.0015 - a very small amount.

Relationship between the MLD's obtained as the noise masker is attenuated at the non-signal ear and MLD's predicted by the model - the greatest discrepancy about 1.4 dbs occurs at the 0-40 dbs interaural level difference point.

INTERAURAL CORRELATION:

As the MLD hierarchy shows the maximum advantage of binaural listening depends on the degree to which the noise is correlated at the two ears while the signal is inverted

(Sπ). Generally in most practical situations the ambient acoustic noise is correlated, but the electrical noise containing the signal,when inverted, tends to decorrelate the noise at the two ears. Thus it's an important issue, both practically and theoretically to determine how the degree of binaural improvement depends upon the correlation of the maskers at the two ears.

One of the first to study this phenomenon was Licklider 1948 who used speech as the signal waveform. Licklider varied the correlation of the noise at the two ears by using 3 noise sources. The waveform coming from one source was split and added to the waveforms from the other 2 sources each of which went 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′s results showed that the correlation had little effect until it was greater than about 0.70. Robinson and Jeffress 1963 used Licklider′s technique to study the effect of noise correlation on the detection of sinusoidal signals. Their results showed a systematic change in the size of the MLD (both positive MuSo and MuS conditions) as the correlation was changed from -1.0 to +1.0. Willbanks and Whitmore in 1968 studied the effects of interaural noise correlation for a variety of frequencies ranging from 150 to 4 KHZ. In their discussion they showed how,by means of a single scale, all of the results obtained at different frequencies could be

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reduced to a single function. Their data are consistent with previous investigations of the appropriate frequencies. Egan and Benson in 1966, Durlach in 1964 and Dolan and Robinson in 1967 have also varied the interaural correlation of the noise masker and their results essentially agree with those of Robinson and Jeffress.

These results therefore, tend to confirm the analysis of the effect of over-all level of the masker and the results obtained at low signal frequencies in terms of interual and external noise. In fact, one can employ these data on interaural correlation to estimate the degree to which the internal noise is correlated in absolute threshold conditions (Diercks & Jeffress 1962, Robinson and Jeffress 1963).

Models of binaural processing which lead to the conclusion that the MLD arises from an improvement in S/N ratio are not developed to answer the question of whether detection in conditions leading to MLD will be impaired by simultaneous gating of signal and noise.

On the other hand, models of binaural processing which suggest that the MLD arises from lateralization of noise components surrounding the signal are consistent with the hypothesis that simultaneous gating of signal and noise will impair the detectability of signals in MLD condition. Within the context of the Jeffress lateralization model, McFadden ha

> hypothesized that there is a decrement in NoSπ detecti
> becasue the listener has no change to extablish a cent
> noise image against which he can judge lateral movemen

the signal is gated on simultaneously with the noise, the initial percept already has the spreading due to addition of out of phase signal to noise. A fringe of correlated noise prior to the observation interval facilitates establishment of a centered reference image.

From McFadden's hypothesis one might also predict that a fringe of correlated noise following the signal interval would restore the MID. In this case, the spread image produced by out-of-phase signal plus noise can be perceived to move back to a centered noise image upon signal termination.

Simultaneous gating of signal and noise does more than eliminate an initial centered noise image which provide a reference. It's well documented that the sudden onset of an auditory stimulus is associated with a flung on neural activity. These on effects seem to increase as one ascends the auditory path-way. One might expect on-effects to impair detection when signal and noise are gated simultaneously. But on effects in the auditory system resulting from sudden noise gating at the beginning of the observation interval do not seem to impair detection in non-MLD conditions. However, this does no-rule out the possibility that suddenly introducing a relatively large noise waveform into the auditory system may interfere with binaural timing information about signal onset. The fringe of noise prior to the signal interval may provide temporal isolation for neural events associated with signal onset, thereby separating them from on-effects produced by exposing the auditory system to rapid noise time BBN. If this

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explains why the fringe restores the MLD, then the fringe probably does not have to be correlated noise. Any noise that causes the same neural units the auditory system to be functioning prior to the start of the observation interval,should reduce the presence of on-effects and effectively restore the MLD.

Donald W.Bell 1972 carried out a study whose purpose were

1) to determine if the noise fringe must be correlated noise in order to be effective in restoring NoSπ detection;
2) to examine the effect on detection of gating from uneorrelated to correlated noise prior to signal interval; and
3) to determine if a fringe of correlated noise following the signal interval causes the signal in NoSπ detection to be as detectable as it's when the correlated noise is continuous.

The results indicated the following points:

1) The advantage in detecting out-of-phase sinusoids in correlated noise(MLD) was markedly interfered with by turning signal & masker on simultaneously. This decrement in Sπ detection occurred even though the correlated in-phase noise masker was switched from uneorrelated noise of same level.
2) If the noise was switched from uncorrelated to correlated before the signal interval, the MID tended to be restored. The improvement was a function of fringe duration. This was also true if the fringe of correlated noise followed, rather than preceded, the signal interval.
3) It can be concluded that the fringe must be correlated noise to be effective in restoring MID. This supports the contention that it is interference with establishment of a centered reference image against which to judge signal lateralization that reduces MLD's when signal and correlated noise are simultaneously switched on.

Study done by Carhart, Tillman and Dallos (1968)

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indicated that when two wideband, continuous and uncorrelated; white noises were used as maskers, the introduction of paralleted and of opposing time delays produce essentially equivalent patterns of escape from masking by pure-tones. This parallel pattern would be predicted from the fact that these two conditions of time delay produce similar interaural correlations of masker complex, and that the size of the MLD at a given frequency may be expected to vary with interaural correlation.

INTERAURAL PHASE:

Jeffress and McFadden (1969) have stated that by employing the same narrow band of noise (50 Hz wide, centered at 500 HZ), as both masker and signal and by introducing a phase shifting network between the masking and signal channels, it's possible to control the phase angle 'α' between the two. For a given signal to noise ratio, controlling the phase angle 'α' controls the shape of vector 'es and hence determines the relative magnitudes of interaural phase differences and the interaural difference in level between the stimuli at two ears. When 'α' lies between 0° and 90°, and when the signal is reversed in phase at one ear relative to the other, the interaural time and the interaural level difference favour the same ear. When 'α' is between 90° and 180°, the ear that leads in phase or time will receive the weaker stimulus, thus putting time and intensity in opposition as was to the lateralization of stimulus. Data were obtained at a variety of values of'α' both for detection and for lateralization. On the basis of these data the following conclusions appear to be justified:

1) Large MLD(s can be obtained for all values of 'α', even for 'α' = 0°. Previous experiments using a continuous tonal masker, have failed to find an appreciable MLD at 'α'= 0°.
2) Neither interaural time differences nor interaural level difference can be considered the sole basis for detection in an MLD condition. If either were the sold basis, detection at 30° would be the same as for 150° and that for 60°, the same as for 120°. The data showed neither of these statements to be true.
3) Substantial detection scores and substantial MLD's can be obtained at values of 'α' where the ability to lateralize falls to chance.
4) Chance performance in lateralization is due to a confusion between the two cues, time and intensity, not to a true cancellation of one by the other.
5) There are significant individual differences in the response to the 2 m.sec. time and intensity. One subject may be more dependent upon time in both his detection and his lateralization performance while another may show a similar dependence upon the interaural difference in intensity.
6) The results are in general agreement with those of Hafter and Carrier who employed a pulsed tonal masker.
7) The 2 cues, time and intensity, combine their influence on detection in a complicated manner. Under some condition they appear to support each other even when in opposition under other conditions they appear to interfere. Neither simple addition nor algebric addition can account for their influence on detection.
8) The data on detection fail to support the EC Model of binaural detection. According to this model, detection should be independent of the value of 'α'.
9) The data appear to support the hypothesis that there are 2 mechanisms involved in detection and lateralization one is virtually independent of interaural differences in level and depends upon cycle-by-cycle difference in time. The other is much more affected by level differences. One appears to be responsible for the 'time image' of earlier studies, and the other for the intensity image'.

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In another study conducted by McFadden, Jeffress and J.R.Lakey, detection and lateralization performance were measured using as a signal the same NB of noise that served as the masker. The centre frequency of noise band was either 1000 or 2000 Hz in different experiments. Both diotic (NoSo) and dichotic (No Sπ) data were taken at both frequencies. By varying the signal-to-masker ratio and the angle 'α' at which the signal is added to the masker in the NoSπ condition it's possible to control the magnitudes of 2 binaural cues- interaural time differences and interaural level differences. The outcomes at 1000 Hz support and the findings - subjects differ in their sensitivities to the two cues, and the cues do not cancel perfectly when the task is detection. At 2000 Hz even relatively large interaural time differences were of little or no benefit either for detection or lateralization and interaural level differentiation was the primary binaural cue. At 1000 Hz, sizeable MLD's were observed for all subjects at all values of 'α '. At 2000 Hz the MLD's were large at α'=0°. However, detectability was essentially the same in the conditions No S ,'α'= 90° and No So, 'α' = 90° implying that in both of these conditions performance was based on the increment in level that occurred with signal onset.

It is clear that subjects differ greatly in their sensitiveness to the 2 interaural cues that are available in most dichotic listening conditions and this is true whether the signal is centered at 250, 500, 1 K or 2 KHZ. At 2 KHZ detectability in the No Sπ conditions was not very different from that in corresponding No So conditions, except for the very smallest and the very largest value of 'α'. That is, at 2 KHZ there was a dichotic advantage only when sufficient interaural level information was available for processing the interaural time information available at the intermediate values of 'α' was of little benefit for detection or lateralization at this high frequency. It's important to note that the values obtained at 2000 Hz for No Sπ , 'α'= 0° are substantially larger than MLD's typically obtained with tonal signals of this frequency in presence of wideband and maskers.

We have once again obtained data that are incompatible with the EC model of Durlach 1963 as well as with the recently proposed model of Osmens 1971. At neither 1000 Hz nor 2000 Hz is detectability independent of 'α', as these models predict but instead both detection performance and lateralization model has little difficulty dealing with detection data from 'α' = 0° and 'α' = 90°, but it's unable to account for the data obtained when the 2 interaural cues are in opposition. So there is the existence of 2 relatively independent binaural mechanisms; one of these is concerned with interaural differences in time and is important only at low frequencies, the other is concerned with interaural differences in level and is operative over a larger frequency range than is the time mechanism. All subjects have both mechanisms, however, they differ in their reliance on each of the two. Also the information contained in 2 mechanisms does not combine in a simple algebraic manner, there is no simple trade of time for intensity.

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INTERAURAL TIME:

The role of interaural time delays achieving release from binaural masking for pure-tones, pulses and narrow band noises has received substantial attention in recent years. Various experimental studies, some specifying time-delay differences overtly and others achieving such differences with puretones through specified phase shifts have measured the MLD's. Concurrently theoretical formulations have appeared that attribute changes of binaural efficiency in separating completing sounds to interaction between externally generated time delays and compensatory neural networks and/or neural delay processes.

In reviewing the history, the first point is that short interaural time delays do not appear to have any important influence on the reception of speech heard in a quiet environment. It is seen that MLD's produced by varying the interaural produced by varying the interaural timing of either the masking sound or the speech signal became larger or the speech signal became larger as the time differences was increased from 0.1 to 0.8 m.sec. but that they are always smaller than the MLD's achieved during antiphasic listening.

Jeffress Etal in 1952 were the first to investigate how the MLD depended on a time delay between the noise masker at the 2 ears. The signal in their study was a 500 Hz tone. They found that as the noise was delayed, detection performa improved to about 10 dbs until the delay reahced the about 1 m.sec. half the period of 500 Hz tone. From t

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detection performance deteriorated, until the delay was 2 m.sec., at which point the results were essentially the same as those obtained with no delay. Continuing the amount of the delay produced another maximum of about 8 dbs at 3 m.sec. and another minimum at 4 m.sec. The same authors in 1962, studied a delay in the noise when the signal was 167 Hz. The results are quite different for as the delay increased at 167 Hz, the MLD increased slightly to a value *of* about 4 dbs at 1 m.sec. and remained there for all longer delays. In a later study, Langford and Jeffress in 1964 studied the effects of delay as long as 10 m.sec. This study which is interpreted in terms of an auto-correlation model showed that performance oscillated with a period equal to that of the signal as might be expected but that improvement in detection diminished gradually as longer and longer delays occurred.

Lockner and Burger in 1961 compared discrimination for monosyllables received in phase at the 2 ears, via ear-phones with discrimination when the signal on one side lagged upto 0.6 m.sec. They found efficiency was unchanged to any significant degree. This relation will not always be as immediately apparent during sound field listening. Here the azimuth changes, that yield interaural time differences simultaneously, produce head shadow effects that modify both interaural intensity and spectral balance. Further when interaural time differences are made grossly longer than encountered in everyday listening, i.e. 8 to 15 m.sec. the perception image is split and binaural fusion is disrupted.

random noise. Here too, the criterion of intelligibility was the percentage of words identified correctly in 3 ways, 200 - 1600, 880 - 2200 and 1660 - 6111 Hz. In all 3 instances performance during the anti-phasic and 0.5 m.sec. delay conditions were nearly identical with the latter being slightly poorer for the 200 - 1600 Hz, filtering and superior for the l660 - 6100 Hz filter. The major difference between filterings is found in degree to which homophasic reception was inferior to other 2 models of presentation. This disadvantage was 4-5 dbs with the low frequency speech 2 dls with the middle frequency speech and almost lacking with the high frequency speech. It is clear from these several results that only when speech was subjected to low frequency band pass was its MLD behaviour fairly similar to that which Schubert had observed for broad range speech. The beneficial influence of both anti-phasic presentation and interaural time delay is sharply curtailed when one must depend for understanding on only the higher frequency segments of speech spectrum.

Feldmann in 1965 undertood a study of binaural intelligibility in which he performed 7 experiments employing interaural time delays ranging from 0.1 144 to 0.648 m.sec. During these experiments Feldmann measured discrimination with the paired numbers form of Freiberg speech tests which he says rise from 0% to 100% intelligibility in a span of 20 dls of intensity change. Masking was produced by correlated broad band noise. Both speech and noise were delivered homophasically except when time delay was employed or when 1 signal was eliminated.

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Feldman reported his results as mean percentage of test items heard correctly under various experimental conditions, He evaluated the effects of time delay in terms of shift in this percentage. This method of viewing the findings does not directly report the MLD's brought about by interaural time delay. But MLD's may be estimated from Feldmann's data by using the slope of intelligibility function of Freiberg numbers last as given by Hablbrock to translate from percentage shift in discrimination score into the decibel change in effective masking. Such a procedure is an approximation but gives the order of magnitude of MLD's involved.

It's seen that even the largest MLD's reported are substantially smaller than can be achieved through interaural time delay with low frequency pure-tones. None of the studies has undertaken extensive exploration of time discrimination for speech as measured with monosyllabic word lists.

Carhart, Tillman and Johnson in 1966 undertook 3 experiments in which spondees and monosyllabic words were presented binaurally at several signal to noise ratios. Continuous noise, modulated noise and connected speech were used as maskers. Homophasic and anti-phasic presentation was compared with conditions involving various interaural time differences of the noise and/or the speech. These interaural time differences ranged from 0.1 to 0.8 milli second.

Main results are -

1) Antiphasic thresholds for spondees were about 7 dls better than their homophasic counterparts, whereas this advantage dropped to less than 4 dls for monosyllabic words.

2) MLD's arising from interaural time difference were never suprior to MID's for antiphasie listening and usually were appreciably poorer.
3) MID's became greater as interaural time differences of the masker were increased from 0.1 to 0.8 milli second.
4) As gauged by performance with 0.4 and 0.8 mill! second interaural time delay, release from masking as it is manifested in discrimination for monosyllabic words is the same when the time difference operates on masking signal as when it operates on speech.

and

5) Opposing interaural time differences (masker leading in one ear and speech in the other) do not achieve MLD's greater than does antiphasic reception even though the aggregate timing discrepancy between the two signals is 1.6 m.sec.

Based on these experiments the following two conclusions can be drawn:

1) The observed magnitudes of MLD's for speech are consistent with MID's for the sinusoidal stimuli that lie within the frequency range essential for success in the perceptual task assigned the listener.

and

2) Interaural time differences produce lesser MID's for speech than antiphasie presentation does because no single interaural time difference can bring about the maximum interaural phase differences for all the component frequencies that antiphasic presentation does.

INTERAURAL PHASE:

Since noise is composed of many frequencies a phase shift in the noise produces differential time shifts in the components at the different frequencies. The first to systematically study the effects of phase-shifting the noise interaurally were Jeffress Etal (1952). In their study the signal was a 500 Hz sinusoid. The noise was shifted in 30, 6 degree

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steps from 0 to 180°. Results best performance occurred when the noise and signal were 180° out of phase from one another and worst performance resulted when both signal and noise were in phase at 2 ears. An interesting result obtained in this experiment was the so-called 'flattening effect'. The flattening effects refer to a graph relating detection performance and the interaural phase of the signal or the noise. Changes in the interaural phase of the signal, holding the phase of the noise constant, produce a much more pronounced peak in performance than comparable conditions in which the interaural phase of the noise is varied and the phase of the signal is held constant. This same effect was observed by Metz in 1967 who studied a 250 Hz sinusoid using both a very narrow band (4.2)Hz and a wide band noise (250 Hz), Their data show very clearly the flattening effect for both bandwidth of the noise.

The interaural phase effects found by Hirsch were quite dramatic.When a signal and a noise are presented to both ears and when one or the other is reversed in phase, the signal can be detected at a level on the order of 15 dls lower than when both are in phase (Blodgett, Jeffress and Taylor 1958). Also, the detection of a tonal signal at one ear, partially masked by a noise at the ear, can be improved by as much as 10 dis when identical noise is added at the -other ear. In both cases, the signal to which the observer responds its too weak to be detected by monaural means. These phenomgnan indicate that some sort of binaural detection

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mechanism, as well as a monaural one must be involved in hearing.

The **effects of interaural phase** on the detection of auditory signals have been under investigation for sometime (Thompson 1887, Hirsch 1948, Licklider 1948). The general result in detection experiments is that signals are detected at lower signal-to-noise ratios when they are presented with different interaural phase from that of the background noise against which they are to be detected.

A study was carried out by G.Bruce Henning (1973) whose purpose was to find the way in which frequency and amplitude discrimination are affected by interaural phase relations. The first experiment of his was a detection experiment demonstrating the magnitude of the interaural phase effect in detection.

Two observers were tested simultaneously in a sound attenuating chamber using a standard two alternative forced-choice experimental procedure. The signal was a burst of a 250 CPS sinusoid presented binaurally in a background of continuous Ganssian noise having a uniform average spectrum level of 30 dls. The signal was 250 m.sec. long, gated on and off at a zero axis crossing. In each trial, two 250 m.sec. observation intervals, separated by a 600 m.sec. pause, were defined for the observes by lights, one interval contained the signal and noise, the other interval contained noise alone. During a 750 m.sec. interval following the two observation intervals, the observes indicated whether the first or the second interval

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had contained the signal. Lights indicated to the observers the onset and duration of the observation and answer intervals. Lights also indicated the correct response to each observer. The background noise was identical at the two ears but the sinusoidal signals were in-phase in one condition and 180° out of phase in other.

Cross talk was measured with the signal for one ear at a voltage corresponding to 102 dbs SPL and the channel for the other ear attenuated from that level by 110 dbs. The resulting electrical signal in the 'off' channel was measured through a six cycle filter set at the signal frequency. The cross talk induced signal in the 'off' channel was atleast 70 dbs below the level of signal in the 'on' channel. The figure 6 shows the effect of interaural phase on the detection of a 250 CPS signal. The percentages of correct responses in 200 trials obtained by each observer are plotted as a function of the ratio of signal energy to noise-power density. Following Jeffress Etal (1956) the symbols NoSo are used to indicate the condition in which both the noise and the signal are in-phase at the ears while the symbols NoS indicate the condition in which the noise is in-phase but the signal is 180°, Out-of phase at the ears. The figures indicate for both observers that the out-of-phase signals are approximately 12 dbS easier to hear in that any given performance level may be achieved at a 12 dbs smaller ratio of signal energy to noise-power density in the NoSπ condition. This is the usual case in detection experiments with the level of noise used here.

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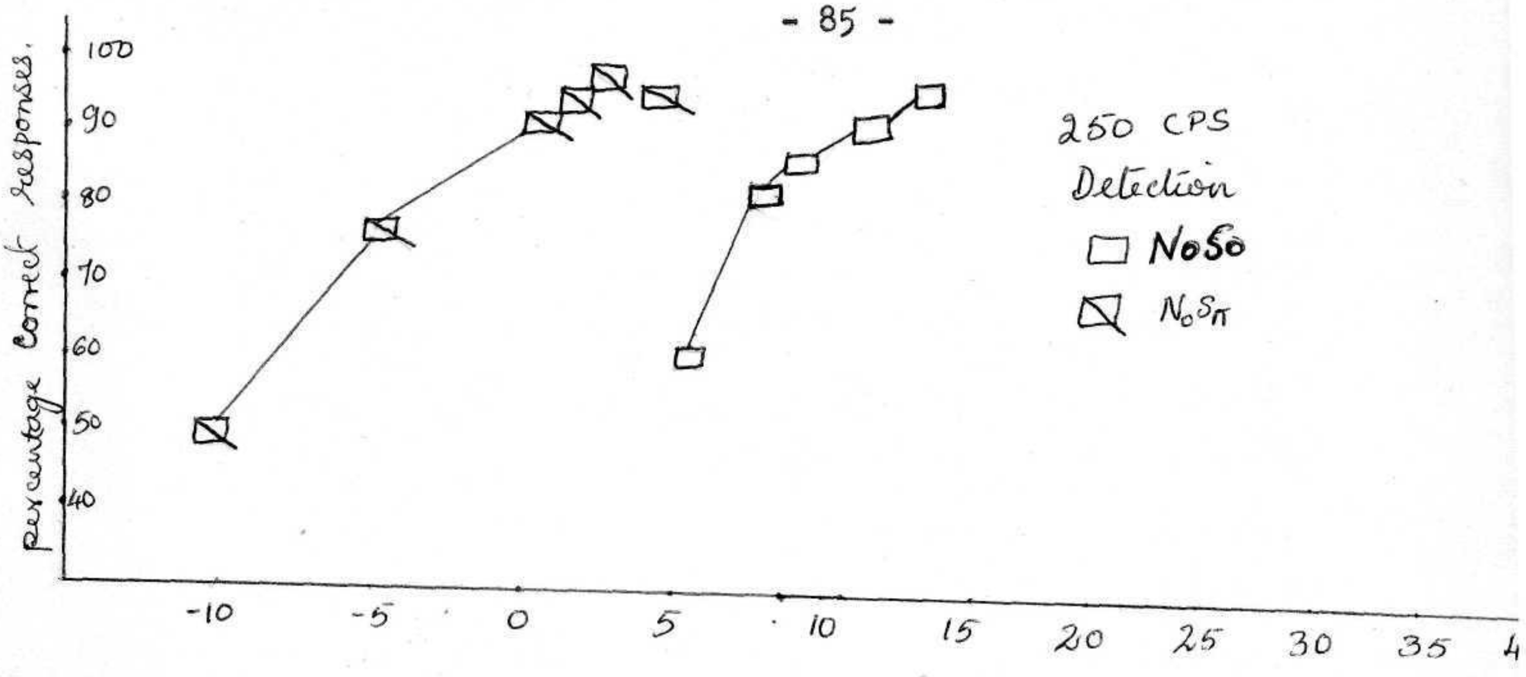

Figure 6.

The percentage of correct detections of a 250 m.sec. burst of a 250 CPS sinusoidal signal as a function of the ratio of signal energy to noise power density. The spectrum level of the noise was 30 dbs. The slashed symbols indicate performance in conditions in which the signal was presented 180° out-of-phase at the ears while the other symbols represent the conditions in which the signals were presented in-phase.

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FREQUENCY DISCRIMINATION:

The same two observers were tested in a standard two-alternative forced-choice frequency discrimination experiment. The signals were bursts of equal amplitude sinusoidal signals presented binaurally in a background of continuous white gans-sian noise having an average spectrum level of 30 dbs. The signals were 250 m.sec. long gated on rectangularly at a zero axis crossing. On each trial a signal of one frequency was followed 600 m.sec. later by a signal of a slightly different frequency. During a 750 m.sec. interval following the two signals, the observers indicated whether the first or the second tone had been higher in frequency. The signal and answer intervals as well as the correct responses were indicated to the observers by lights as in the detection experiment. The background noise was identical at the two ears but the signals to be discriminated were presented in phase ia one condition and 180° out-of-phase in the other.

The signal frequencies were centered about 250 CPS and the observers made 100 judgements at a given frequency separation and ratio of signal energy to noise-power density before the ratio of signal energy to noise-power density was changed. The functions relating discrimination performance to the ratio of signal energy to noise-power density were obtained in both conditions of signal phase to noise-power density were before the value of the frequency separation was changed. Two sets of 100 trials were given at each value of signal-to-noise ratio making 200 observations per data point per observe

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In all four different frequency separations were used.

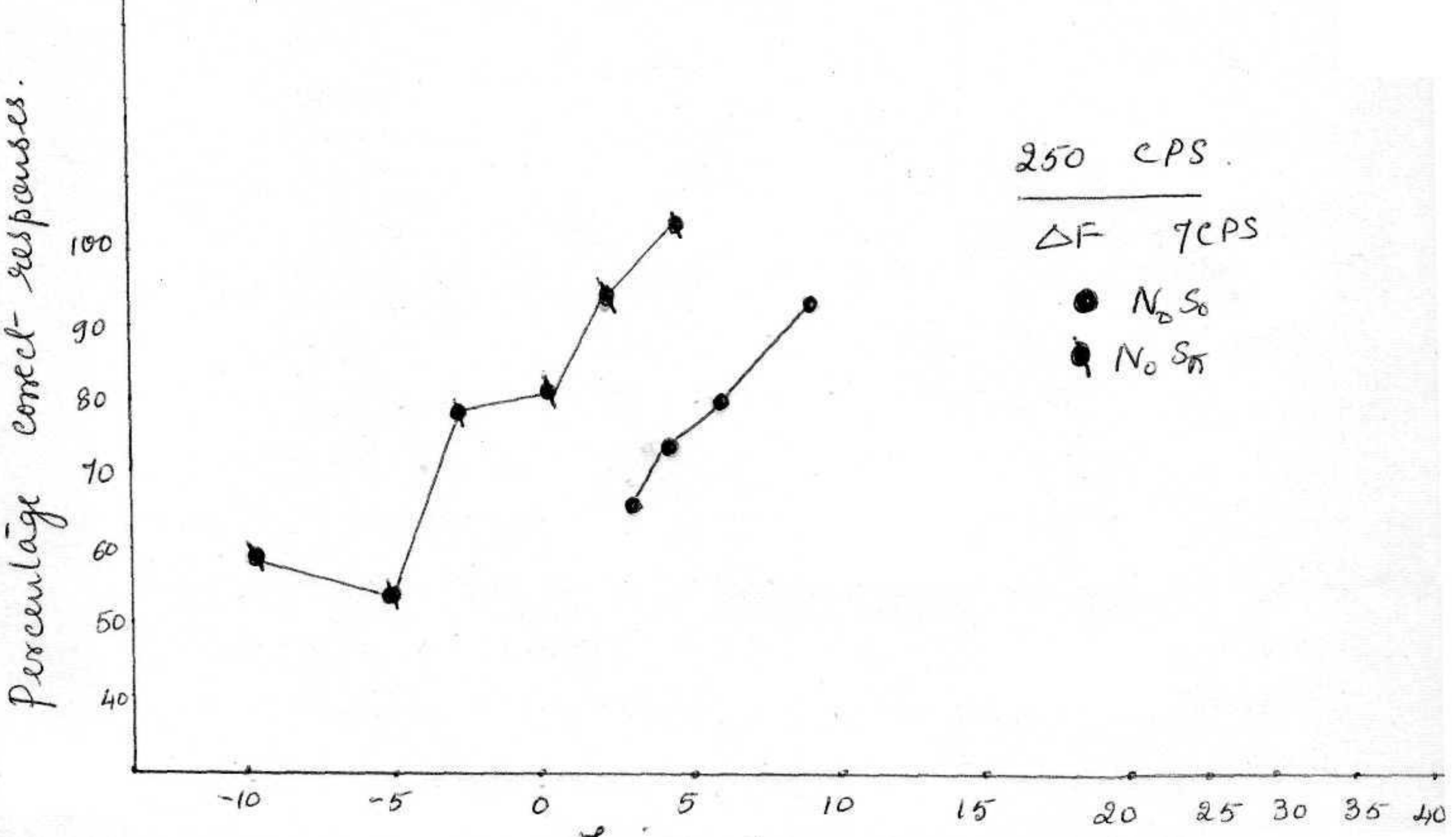

Figure 7.

The percentage of correct frequency discriminations as a function of the ratio of signal energy to noise-power density. The signals were 250 m.sec. bursts of sinusoids 7 CPS different in frequency centered about 250 CPS. The spectrum level of the background noise was 30 dbs. The slashed symbols represent data from the conditions in which the signals were both 180° out-of-phase at the ears while the other symbols represent the in-phase conditions.

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The figure shows the effect of interaural phase on frequency discrimination performance for different values of frequency separation. The figure shows the percentage correct frequency discrimination for each observer as a function of the ratio of signal energy to noise-power density for a frequency separation of 7 CPS. This frequency separation is relatively large and the effect of the signal phase reversal on discrimination is large - a level of 75%. Correct responses is achieved at a ratio of signal energy to noise-power density approximately 11 dls lower in the out-of-phase case than in the in-phase case.

AMPLITUDE DISCRIMINATION:- III Experiment:

A two alternative forced-choice procedure identical to that employed in the previous experiment was used to measure amplitude discrimination. The signal frequency was kept constant at 250 CPS and amplitude discrimination performance was measured as a function of the ratio of the energy of the higher amplitude tone to noise-power density. Again, two experimental conditions were used, one in which the signals to be discriminated were in-phase at the ears and one in which they were 180° out-of-phase. On each trial a 250 m.sec. burst of a sinusoidal signal was followed 600 m.sec. later by a second 250 m.sec. burst of the same frequency, but different amplitude. The observers were required to indicate which of the tones had been of higher amplitude. Cueing lights, answer, the feed-back intervals were the same as those used in the frequency-discrimination experiment. On each set of 100 trials

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a constant-amplitude ratio (En/El) was maintained between the signals to be discriminated. Data were obtained relating the percentage of correct responses to signal-to-noise ratio at four different relative amplitudes and in each condition of interaural signal phase.

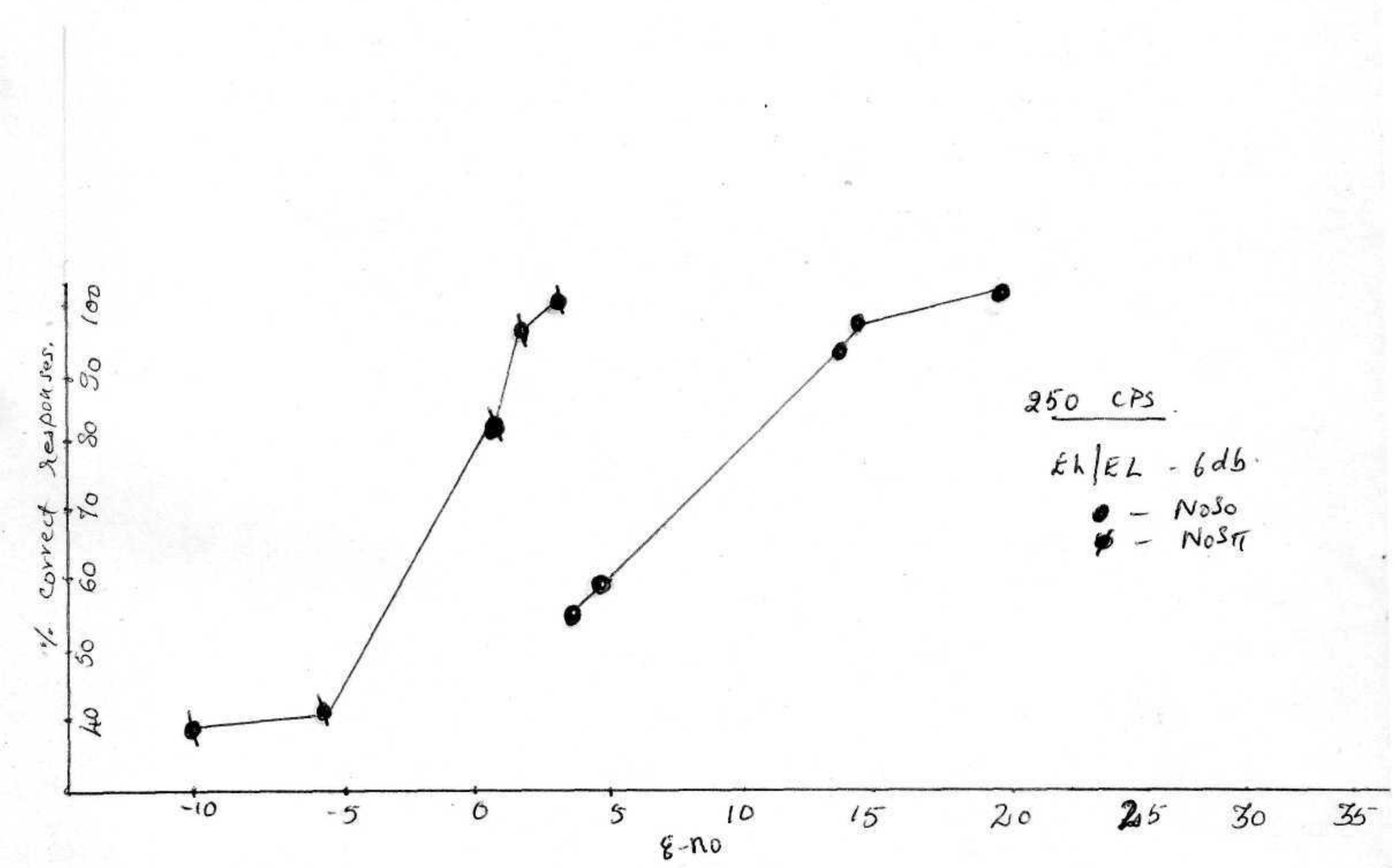

Figure 8.

The percentage of correct amplitude discriminations as a function of the ratio of the signal energy to noise-power density of the higher amplitude tone. The signals were 250 m.sec. bursts of a 250 CPS sinusoids with an energy ratio (Eh/El) of 6 dbs.

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The figure shows the result of several values of the relative amplitude of the tones to be discriminated. There is a sizeable release from masking when the amplitude ratio to be discriminated is large, but the effect becomes much smaller as the amplitude ratio to be discriminated decreases and larger ratios of signal energy to noise-power density are required to achieve any given performance level.

CONCLUSIONS:

1) It's clear from the data that both frequency and amplitude discrimination in noise are improved at low signal-to-noise ratios by presenting the signals out-of-phase. From this it seems reasonable to conclude that the information in stimuli necessary for frequency and amplitude resolution is preserved beyond the low at which information from each ear may be combined. The fact that improvement with out-of-phase signals occurs only at low signal-to-noise ratios indicates that resolution of frequency and amplitude differences is not limited by the external noise at high signal to noise ratios but by some features of the auditory system. In most psychophysical models of the ear, internal noise of some sort is postulated as producing the resolution limits.

2) The operations suggested by the Webster-Jeffreas model for discriminating binaural signals in the NoSπ condition do not predict the performance obtained by observes in frequency-discrimination tasks. Modifications of the model to include the effects of interaural amplitude or wide-band processing capable of using many independent samples of

interaural delays do not appear to lead to better predictions than those based only on interaural phase. It may be possible, however, that assumptions about the model other than those used in the present paper will lead to adequate predictions.

3) For the 250 CPS signals used in the present study, a modified version of the equalization and cancellation model of Durlach predicts the families of detection and amplitude discrimination data for both NoSo and NoS with the selection of one number - the variance of the equalization device. Frequency discrimination data may be predicted, but not with the same accuracy with the additional assumption of an initial filter with a steep attennation characteristic.

4) It is difficult even in the face of the failure of the Webster-Jeffress model to predict the release from masking in frequency resolution, that binaural masking phenomena and sound localization are unrelated.

EVOKED……POTENTIAL CORRELAIES OF INTERAURAL PHASE RBVERSALS:

The MLD is based on a behavior measure. Recently, computer averaged auditory evoked potentials (AEP's) produced by acoustic signals presented in the context of an MLD experiment have been reported. Edwards found that the amplitude of N1 P2 component of auditory evoke potential reflected the MLD at threshold. N2 P2 was largest for N So, followed by NoSm and NoSo. Butler and Klusken's 1971 reported that in the absence of a noise masker N1 P2 was about 18% larger in $S\pi$ condition than in the So condition, for a

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200 Hz, 82 dbs SPL tone. For a 2 KHZ no differences in N1 P2 were found since N1 P2 amplitude is usually larger for louder signals, one explanation for the N1 P1 differences observed by Butler and Kluskens may be that S signals sound louder than So signals. However, Butler and Kluskens showed that there were no differences in behaviourally measured loudness between the So and S conditions for the moderately intense 200 Hz tones. In the absence of a noise background, Diercks and Jeffress 1962 showed that only a 1 dls difference in "absolute detectability" exists for So and Sπ tones. However, in the presence of a noise masker No, Hirseh and Pollack demonstrated that there are loudness differences between So and Sπ tones at and slightly above masked threshold supported by Townsend and Goldstein 1972. Therefore, the Butler and Kluskens finding that N1 P2 amplitude is larger for S signals than for So signals for low-frequency tones does not appear to be related to loudness for there was no background noise and the signals were well above threshold. Edwards(1971) finding is that relatively larger N1 P2 amplitudes are evoked in the antiphasic N So condition may be related to loudness since she presented tones against a noise background and the observation were made at threshold.

An experiment was designed by David C. Tavis and Donald C.Teas (1974) to complement the finding of other investigators by exploring the effects of interaural phase reversals on amplitude of evoked potential in a variety of stimulus configuration. A further experimental objective was to determine

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whether the stimulus conditions which produce loudness differences also produce larger AEP amplitudes. Results indicated that interaural stimulus phase differences are reflected at the level of the diffusely-generated potential recorded at the vertex. In the presence of noise M1 P2 amplitudes vary with stimulus conditions as do loudness estimates provided the range is restricted to low S/N ratios. Thus N1 P2 amplitude seems to be an appropriate physiological correlate of loudness over the stimulus range from near detectability upto about 20 dls above that level. At high S/N ratios or in the absence of an external masker, however, there is a fairly constant difference between N1 - P2 amplitudes in homophasic and antiphasic conditions a finding not predicted by the resuits of psychophysical studies of loudness. Loudness is not the only response continue which varies with interaural stimulus conditions. There are other perceptual qualities that practised observers may detect in binaural stimuli. Location in the right-left dimension also depends heavily on interaural phase differences and is thus correlated with the loudness dimension, atleast at low S/N ratio. Though loudness differences may not be apparent at high S/N ratios, phase-reversed stimuli are easily discriminated from in-phase stimuli.

Therefore, for low frequency signals presented in a background of noise (No), both loudness and lateralization vary with interaural phase, antiphasic stimuli produce the loudest, most lateralized images produce the loudest, most lateralized images also produce the largest vertex responses. However, the N1P2 difference persists for signal energies well above those producing MLD's or loudness differences. It's tempting to attribute the larger N1P2 responses produced by antiphasic stimuli to the synchrony of the group of nerve impulses produced by the signal. It is not implied, however, that the AEP is the primary electrical sign of that neural activity. Rather, the AEP must reflect some later set of events that depend upon the earlier temporal relations among discharging cells. The more central synchrony may occur because of temporal relation between nerve impulses produced by noise and those produced by signal in more peripheral pathways. Assuming that the two ears and their neural pathways are similar, then the noise events which produce neural activity are the same in the right and left pathways and at some location in the system, must be coincident. However, volleys of neural activity produced by the out-of-phase signals to the two ears are uniquely displaced in time with respect to those produced by the noise. For any other interaural phase relation, the signal produces volleys of nerve impulses that correspond more closely to the neural activity produced by the in-phase noise. According to this hypothesis the AEP's should increase monotonically with increasing interaural phase upto 180° and then decrease as interaural phase approaches 360°. In preliminary -work using in-phase noise, the authors have detected increments in N1P2 at 45° and 90°, for a 250 Hz tone but were not able to attribute a quantitatively reliable function to magnitude.

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BANDWIDTH:

The size of MLD depends upon coherence in the masker at two ears. For a wide band noise, one might suspect that only a narrow region of the spectrum located near the signal frequency is actually responsible for binaural improvement in detection. It's confirmed by Mulligan 1967. There is one methodological problem. As the noise is filtered the overall level of the masker decreases and it's known what the size of the MLD depends on the level. An ingenious way to overcome this difficulty was utilized by Sonelli and Guttman (1966) They used digital filtering to remove a nearly rectangular band of the noise spectrum. They could systematically vary the width of this noise band and by inverting this band before adding it to the two ears, they could manipulate the interaural phase relations. The remainder of the noise spectrum from which the band was taken was presented in phase at two ears. Thus in the M So condition only a narrow band of noise centered about the signal frequency was anti-phasic (Mπ), the rest of the noise was homophasic (Mo). The signal frequency was 250 Hz. Sondhi and Guttman showed that a 15 dls MLD would result as long as the width of this band was approximately 150 Hz wide. Using the equalization and cancellation model, they estimated that the width of the critical band for MLD experiment is approximately 125 Hz at 250 Hz center frequency.

Another set of experiments involving masker bandwidth and the MLD involves simply narrowing the band of noise present

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about the signal and determining the MLD that results when the interaural phases are reversed, varies with the noise bandwidth. The general result seems to be that the narrower the bandwidth of the noise, the larger the MLD. This effect was first observed by Bourban and Jeffress (1965) and has been confirmed in later experiments by Metz Etal (1967) and Wightman (1971). For a narrow band of noise, about 4.2 Hz wide, Metz Etal reported a MLD (MoSπ) of almost 25 dls, compared with the MLD for wideband noise of about 15 dls. Wightman made systematic study of how the MLD changes with bandwidth for a signal frequency of 800 Hz. He found that the resulting MLD (Mo Sπ) depends heavily upon how one has filtered the noise and signal. He advanced the hypothesis that energy splattered by gating the signal changes considerably the size of MID. He also obtained a sizeable MID (MoSnr) larger than 20 dig for a very narrow (about 3 cycles) band of noise.

Mhen langford and Jeffress (1964) tried to compare the reduction in MID magnitude caused by 2 techniques for reducing the masker correlation, they found equal reduction in MID occurred only if they assumed a wider bandwidth of effective masking noise for the antiphasic listening conditions. langford and Jeffress 1965 noted that a narrow band masker 50 Hz was 10 dbs less effective them a broad band noise in masking a NoSπ condition but just as effective in masking a No So condition. He argued that since narrowing the masker bandwidth did not alter the homophasic threshold but significantly improved the antiphasic threshold, the band width involved in the antiphasic detection must be considerably wider than 50 Hz. A subsequent hand-narrowing experiment by Bourbon and Jeffress 1965 revealed no improvement in NoSo detection until the bandwidth was reduced to less than 150 Hz. However, for the NoS condition, masker bandwidths narrower than 300 Hz created substantially improved thresholds.

The use of a phase splitting technique by Sondhi and Guttman 1966 lent further support to the hypothesis. Their procedure permitted the phase inversion of an inner band of noise surrounding bands or the overall amplitude characteristics of the masker. With this technique a very small homophasic inner band caused a rapid decline in the magnitude of the MLD. However, a much wider antiphasic inner band was required before any appreciably release from masking was obtained.

Motivated by the belief that changes in effective, antiphasic band-width would be reflected in frequency discrimination behavior, Robertson and Goldstein (1967) investigated, binaural masked frequency discrimination. They reported larger absolute difference timers at 300 Hz for the antiphasic listening condition at low sensation levels in a 55 dls spectrum level masker.

A similar finding was reported by Henning. Be used a 250 Hz sinusoid with a 30 dls spectrum level noise and charted psychometric functions for fixed frequency separations from 15 to 0.5 Hz. under both NoSo and NoSπ configurations. Substantial binaural advantages in S/N ratio required for equal performance levels were noted for large frequency separations from 15 to 0.5 Hz, under NoSo and NoS configuration. Substantial

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binaural advantages in S/N ratio required for equal performance levels were noted for large frequency separations and the psychometric functions resembled detection function in shape. However, as the frequency separation decreased requiring a greater signal to noise ratio to accomplish the task, the slope of the psychometric functions changed differentially, for the 1 Hz separation condition, the functions were 5 dls apart at relatively low signal to noise ratios while for larger signal to noise ratios the two functions merged.

GATED MASKER:

In practically all detection experiments the masker is continuous and the signal a gated sinusoid is added to the noise. MeFadden (1966) was the first to use a procedure in which the masker as well as the signal was turned on only during the observation interval (125 m.sec). The use of gating procedure produces essentially no change in detection for the MoSo condition but a worsening of detection, about 4 - 6 dbs in MoSπ condition. McFadden also investigated how long the noise had to be turned on prior to the signal before detection performance returned to that obtained with a continuous masker. His results showed that presenting the noise about 600 m.sec. before the onset of the signal was equivalent to a continuous masker.

TONAL MASKER:

A number of investigators have used a tone as the masker in studies of the MLD. As was the case with noise signals, the phase relation between the signal masker at each ear can be controlled with the use of a tonal masker of the same frequency and duration as the signal. When the interaural stimulus configuration is MoSπ, the MLD increases from 0 to 3 dbs at a signal to masker phase angle of 0° to 25 - 30 dbs at a phase angle of 90°. When the phase angle between the signal and masker is greater than 90°, the MLD decreases.

In the MoS condition, variation in the phase angle of addition between the signal and the masker will result in changes in the relative magnitudes of the interaural aplitude and temporal differences in waveform at the two ears.

INTERAURAL FREQUENCY DIFFERENCE:

Egan (1965) called attention to the fact that binaural beats are more easily heard in a noise background than in the quiet. In the case of binaural beats in the quiet, most listeners report that the sound image seems to move from side to side within the head or that the sound appears to rotate about the head. This observation leads to Von Bellesy's more descriptive name for the phenomenon 'rotating tones'. In noise as Egan observed, these same condition lead to the perception of a tone which becomes alternately more and less detectable, without any noticeable movement.

It is wellknown that a low frequency tone in a noise background can be made considerably more detectable by manipulation of the interaural phase relations of the tone and noise i.e. MLD interaural phase angles between 180° and 0° result in intermediate values for the MLD. Thus the same variable interaural phase that determines lateralization in the quiet determines detectability in noise.

Thus Egans' observations about binaural beats in noise may be interpreted as he pointed out as an example of a MLD, occurring as the tones at ears vary in interaural phase.

The fact that binaural beats became increasingly difficult to hear as frequency is increased is also in agreement with binaural masking data since the magnitude of the MLD has been shown to decrease at high frequencies. Both of these observations may be understood by noting that as frequency is increased the interaural time differences resulting from interaural phase difference decrease.

In order to understand the results of varying interaural frequency differences it's assumed that there are two filters, one in each monaural channel. Further it is assumed that these filters are not independently variable in either bandwidth or centre frequency. The outputs of these 2 filters are the inputs to a binaural processing device. It's also assumed that for the interaural signal frequency difference (f) conditions, the observer centers the filters at the frequency which yields the highest detectability under binaural listening conditions.

These assumptions lead to the following expectation:

1) For small interaural frequency differences the system will perform better, than under NoSm with the 400 Hz signal, since for brief periods the stimulus may be considered to be No = Sπ, For f = 6 Hz, the condition will be S six times

per second. However, the detectability will be poorer than for No s s with the 400 Hz signal, since by the same argument, the signal will be No - So six times per second, i.e. the interaural phase differences will vary at a rate of 2πf to an MLD, performance will be better than under No - So at 400 Hz.

2) As f is increased, the higher frequency signal will be attenuated according to the shape of the filter centred at 400 Hz. The effects of attenuating the signal at one ear are known from the work of Egan and of Golburn and Durlach (1965). As the dichotic signal is attenuated at one ear, the MLD decreases, when the signal in one ear is turned off, the condition is NoSm. Thus as f is increased, the expectation is that the MLD will gradually decrease until the filter completely attenuates the signal high frequency channel. At that point the MLD should be the same as that for NoSm at the low frequency (400 Hz) and maintain that value thereafter.

The data reported by Donald E.Robinson (1971) indicate that if the observers maintained their filters at the lower frequency, the function relating MLD to f may be considered a first approximation to a portion of filter characteristic for 400 Hz channel. Only the portion of the characteristic above 400 Hz was obtained in their experiment, since using a frequency lower than 400 Hz would have led the server to shift

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the centre frequency from 400 Hz to the lower frequency, i.e. he would move to the frequency having the greater MLD.

The data indicate that the presence of the higher frequency tone is continuing to have an effect on the MLD until f is atleast 100 Hz. This value is considerably larger than similar estimates made in the absence of noise. Penott and Nelson (1969) report that binaural interaction cease to occur when the separation between the 2 tones is about 25 Hz. Whether the large discrepancy is due to the difference in task or because of presence of noise is not known.

EFFECTS 0F EAR DOMINANCE:

In the light of accumulating evidence which indicates a right ear superiority on verbal tasks with contralateral competition, one might anticipate a difference in MLD depending on which ear receives the NmSm condition. Licklider 1948 noted that in combinations of monaural speech signals and binaural noise higher mean intelligibility scores were associated with right ear. Although the overall intelligibilty scores were less than 32% the mean right ear advantage varied from slightly less than 5% in NmSm condition. Weston replicated Licklide's study but found that only in the NoSm condition were means right ear scores greater than left ear scores by more than 6%.

Since the MLD has been proposed as a potential tool to assess the integrity of the central auditory nervous investigation of the effect of subjective variables on the

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MLD seems appropriate. Recent studies comparing discrimination of speech in noise by right and left ears have demonstrated no consistent interaural differences. Jokiner measured discrimination of speech presented with ipsi lateral white noise among subjects aged 20 - 70 years and found no significant right-left differences at any age level. Marston and Goetzinger using low-pass filtered monosyllabic word lists presented with a competing message masker in contralateral ear, found no significant ear asymmetry in young or older adults.

Morales - Garcia and Poole (1912) presented monosyllables and ipsilateral competing white noise to right and left handed adults subjects and found for both groups a slight right ear advantage at S/N ratio above 6 dbs.

Robert C.Findley and Gerald I Schuman (1976) conducted a study on the effect of ear dominance and age on MLD for speech. Purpose of the study was to compare right and left ear discrimination of monosyllables presented with competing 'cokktail party* noise in NmSm and NoSm conditions. These conditions were compared in listeners of 3 age levels 5-6, 18-24 and 66-76 years. The results indicated the superior discrimination performance of the right ear for the adult age groups mainly as a result of the right ear advantage in NmSm condition. When the condition of presentation was changed to NoSm, a MLD occurred for right and left ears; but interaural performance difference almost completely disappeared.

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The present results are somewhat in contrast to those of 2 earlier investigations. Morales - Garcia and Poole 1972 reported slight right ear advantage for discriminating monosyllables in ipsilateral competing white noise with S/N ratios of +5 to +10 dbs, but not with ratio of -5 or -10 dls. Johiner 1973 found no interaural difference among adult subjects for discrimination of speech in ipsilateral competing white noise at S/N ratios between -3 and +22 dbs. Thus it may be hypothesized that in young adult listeners superior speech discrimination by right ear is more likely to occur when signal and noise do not differ significantly with respect to frequency phase or temporal characteristics, anyone of which would allow separation of signal and noise at a brainstem level. When signal and noise can be differentiated precortically whether on the basis of frequency or phase difference the speech signal may be extracted and directed to the left, speech dominant hemisphere. Without intervention by brainstem, separation of speech signal and speech noise may occur only in the cortex. Since in the study of Pindlay (1976), signal and noise were both speech stimuli, sharing common frequency and temporal properties, separation may not have been possible at a brain stem level. Recognition and extraction of the speech signal may have been an exclusively cortical activity. The right cerebral hemisphere may be less proficient at this task than left hemisphere and so superior right ear discrimination scores would result. Within this model, however, it remains to be determined why among children, in whom the MLD is already quite apparent these does not take

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place a right-left ear differences similar to that of adult listeners. One possible explanation is that central dominance for language may not be firmly established by age 6 but may occur only in later childhoods.

The magnitude of MLD for right and left ears of each age group can be described by examining the comparative performance of the ears in the two noise condition. Among the young adult, listeners are interaural difference in favour of right ear, occurred in the NmSm but not NoSm. The left ear was more affected by the ipsilateral competing noise and demonstrated a system and release from masking. The data is difficult to speculate whether condition is peculiar among the older listener. In the case of the 5 and 6 year olds no interaural difference occurred in either noise condition and thus the MLD's for the children were approximately equal for right and left ears.

Bocca and Calearo have described the suitability of using materials with reduced informational content when testing for lesious of the central auditory nervous system. The results of present study with adults and children in a moderately difficult speech S/N task indicate considerable variation of scores in NmSm conditions and NoSm condition and of magnitude of MLD. The correlations between right and left ear MLD magnitudes for individual listeners were insignificant at all age levels. But if a measure of MLD is to be incorporated into the test battery for central auditory lesious the use of either PB words or speech. Bubble noise should be questioned.

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MLD's IN FORWARD AND BACKWARD MASKING:

The release from masking brought about by a shift in the interaural phase of either signal or masker in a binaural listening situation is an intriguing phenomenon.

Small, Boggess and Klich (1972) carried out an experiment that dealt specifically with whether MLD's conventionally defined, be absent in backward and forward masking conditions.

They used a masker, wide band noise, 500 m.sec. of 46 dls and the signal consisted of a 250 Hz sinusoid. Data were gathered for NoSo, NoSπ and So, Sπ with no noise. Five normal hearing listeners acted as subjects. Results indicated that the MLD is nearly proportional to the amount of masking produced. MLD was present and was equal in forward and backward masking. The magnitude of the MLD produced in the simultaneous masking condition, 10.5 dbs is somewhat less than would be expected based on earlier studies under similar conditions.

These results have several implications for mechanisms underlying the MLD phenomenon as well as those responsible for backward and forward masking. It has been suggested that backward and forward masking are reflections of fundamentally different processes. Forward masking is often thought of as originating in the peripheral portion of auditory system while backward masking is generally considered to be central in origin. Other data suggest that forward masking is mediated in part atleast centrally.

But the above study results go a step further. Not only do they support the idea that both backward and forward masking are largely central in origin, but they indicate that these 2 forms of masking may be the result of similar processes. However, the various aspects of the stimulus may be represented neurally than binaural interaction produces the same result on MLD whether the signal precedes or follows the masker.

Many investigators have shown that the NoSm condition yields approximately a 15 dbs MLD - the Nπ - So correlation approximated a 12 dbs MLD and NoSm condition approximately a 9 dbs MLD when the signal and masker occur simultaneously.

William A.Yost and Joseph Walton carried out a study whose purpose was to compare the hierarchy of MLD's obtained in the following conditions -

Simultaneous masking
Forward masking,
Backward masking, and
Combined forward-backward masking.

The results indicated that the hierarchy of MLD's is the same in simultaneous and temporal masking, however, there are differences in the amount of additonal masking obtained across monaural and binaural conditions in the combined forward-backward masking procedure. These results were viewed as indicating that the temporal (phase) and intensive information associated with temporary separated maskers and signals combine within the nervous system differently for binaural processing them for monaural processing.

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CHAPTER - III

THEORIES OF MID

Certain theories try to explain as to why binaural listening improves the detection of signals in certain dichotic conditions. The oldest is the webster-Jeffress hypothesis which dates from Webster's initial observations 1951 of the MLD phenomena. The theory was adapted and elaborated by Jeffress 1956 in seme detail and is known as 'The Vector Model' or the 'θ Model'.

In about 1960 a relatively formal and mathematical theory was advanced by Durlach 1963 based upon ideas and concepts from radar analysis.

WEBSTER-JEFFRESS HYPOTHESIS:

This assumes that binaural detection is better than monaural detection because the interaction of signal and the noise at the two ears produces a time difference in the waveforms arriving at the two ears. To compute the magnitude of this time difference one needs to make certain assumptions concerning the representation of the signal and the noise. The most popular assumption is that because only a narrow band noise is effective in masking the signal, the noise can be treated as a slowly changing sinusoidal proces. The signal when added to such a noise, produces a change in the resulting sinusoid that can be analysed according to the familiar vector diagrams (Figure 9). Computing the magnitude and phase of the vectors at the two ears, one can calculate a phase angle difference between the sine-waves

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at the two ears, and hence a temporal delay in the waveforms at that frequency. It is this delay that is presumably responsible for the enhanced detection. Without the signal, there is no delay in the Mo condition or a 180° phase delay in the Mπ condition. When the signal is added to the masker, the delay is systematically altered, it is this change in delay that makes the signal easy to detect.

In 1950's Jeffress imbedded this general notion within a theory of localization. He suggests that in some binaural conditions localization cues allow separation (in perceptual space) of the signal plus noise stimulus from the noise alone stimulus. This separation is presumed to improve the detectability of the signal, resulting in MLD. Jeffress noted that the MLD is largest for signal frequency below about 2 KHZ where the most salient localisation cue is interaural phase difference. Thus he suggests that the important cue for detection of binaural signals is interaural phase difference. In conditions where there are no interaural phase differences the system is presumed to operate monaurally.

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$S_0 M_0$ conditions

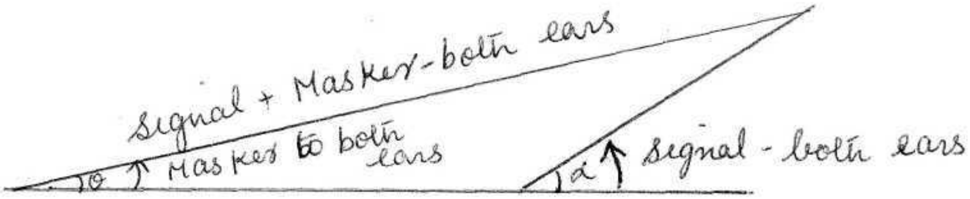

Figure 9 a.

$S_\pi M_0$ conditions

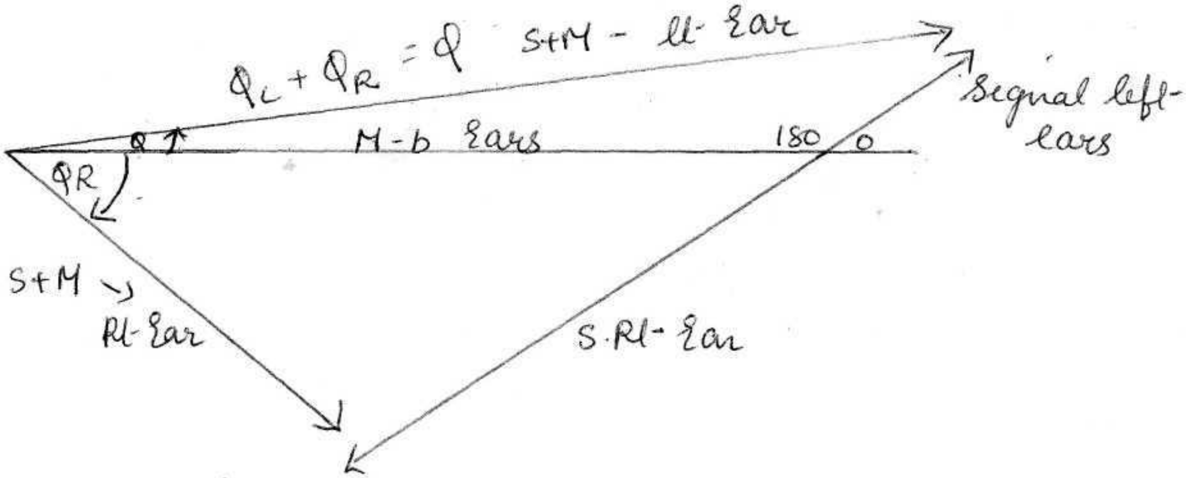

Figure 9 b.

A vector representation of Stimulus condition The Signal and Masker are Sinusoids shown here as vectors.

The above figure represents some of the details of Jeffress model. The two typical conditions of an MLD experiment are represented with vector diagrams. The noise masker is shown in both conditions as a single vector, since it is the same in both ears. Because the masker is noise, the instantaneous length of the vector is a random variable and is assumed to be 'rms' amplitude of the noise at the output of some internal filter, such as the critical band. The upper diagram represents the condition in which both signal and noise are in phase at the two ears (NoMo). The signal is added to the masker in random phase (angle α) producing a resultant signal plus-masker complex that is the same in both ears. The lower diagram shows the condition in which the signal has been inverted at one ear (SπNo). In this case, the resultant signal-plus-masker complex is not the same in both ears; there are interaural differences in both amplitude and phase. Jeffress proposes that the basis of binaural detection is the interaural phase difference represented in figure (9-b) by the angle Q ($Q = \theta_L + \theta_R$). Thus, the detectability of signals in any binaural condition is determined by the average value of θ in that condition. If $\theta = 0^0$ as in the SoMo condition, the binaural system is assumed to be operative and signal detectability is determined only by monaural parameters (such as signal energy).

Jeffress envisions two filter systems at the two ears representing the mechanical and neural analysis of the signal, both of which are known to be frequency-independent. After this filtering operation, a hypothetical axon extends towards the other ear and towards the corresponding filter on opposite side. Thus there is a matrix of hypothetical axons reaching towards each other. Each of these axons carries a signal representing the amount of energy in the acoustic wave at that particular frequency. Collaterals from these axons converge on higher order neurous located at various distances between the two ears. If the waveforms were identical at the two ears, the delay in each axon from each side of head would roughly be the same and the higher order neurous in the middle of this matrix would be stimulated. As delay is introduced, the neuron impulses meet off center, either to the 'left or right, depending upon which ear is leading or lagging. Consequently both localization and improved detection can be deduced from this model.

The model proposed by Jeffress is able to account for many of the data obtained on MLD's. It's important, therefore, that the weaknesses of this model be closely examined, for it's possible that with minor modification the model would be able to account for even more data. But until detailed information is available on the inadequacies of the model, in its present form, the nature of such modification will not be obvious.

An experiment was carried out by Dennis MacFadden to investigate one of the weaknesses of Jeffress model. The purpose and the outcome of that experiment is briefly summarized. When interpreted strictly, the vector model

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proposed by Jeffress implies that the magnitude of MLD will be independent of any interaural disparities in masker intensity as long as equal S/N ratios are maintained in two ears. The data indicates that the auditory system is able to tolerate interaural disparities in masker intensity of about 10 dbs before detectability is affected and only with larger disparities ia there a gradual decline in the magnitude of MLD. But Blodgett, Jeffress and Whitworth 1962 reported that when the interaural difference in noise spectrum level was 6 dbs, the MLD for No-Sm was about 2 dbs smaller than it was with equal noise levels in 2 ears. Other investigators have obtained similar results but the listening conditions employed have always been those of binaural noise and monaural signal, condition which produces a relatively small MLD. In the experiment carried out by Dennis MacFadden contamination by monaural detections was minimized by using the interaural condition that leads to the largest MLD NoSπ . The fact that the results of the present experiment differ from those of previous experiments implies that the range over which the vector model holds is different for different interaural conditions. In this particular experiment, the range was approximately 10 dbs, for previous studies the range was apparently much smaller.

A finding that deserves some emphasis is that masking increased linearly with noise level for Nm Sm conditions. Due primarily to the data of Hawkins and Stevens 1970 which are like those for NmSm in this experiment masking has generally been regarded as a process that increases by an amount equal to the increase in masker level. Apparently this 'dbs for a dbs' relation dees not hold for NoSπ and if so, this difference between the MLD and the non-MLD conditions might be viewed as further support for the view that detection is based upon a different aspect of acoustic input in 2 types of conditions.

The results of this experiment can be explained by assuming that there is an internal noise component that adds to the neural activity caused by the external masking noise. As the intensity of external noise is decreased the relative contribution of internal noise is increased until some point at which external noise ceases to be effective and the internal noise becomes the primary masking component. Implicit in this view is the assumption that determinations of 'absolute sensitivity' are actually determinations of masked sensitivity; where the masker is the 'internal noised' Dierck's and Jeffress 1962 have presented data to support this assumption. Since the results of this experiment were in good qualitative agreement with an internal noise hypothesis, an attempt to make quantitiative predictions seemed justified. The procedures and results of such an attempt are presented here.

It's assumed that in the auditory channel serving each ear there is some ongoing neural activity called the internal noise, the statistical characteristics of which are identical to the neural activity produced by external noise source. The level of this additional activity is presumed to be relatively constant and independent of external noise.

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The correlation between the internal noise and the external noise is assumed to be zero, but it is assumed that there is a small +Ve correlation between the internal noise in the two auditory channels. In other words, the internal noise proposed here is analogous to having added additional noise sources externally. Indeed, it may be that part of this 'internal noise' is due to the physiological noise measured in the external ear canal by Shane and Percy 1962.

The assumption of a small '+Ve' correlation between the internal noise in the two channels is in accordance with an argument made by Dierecks and Jeffress 1962. These investigators showed that the changes that occur in the hierarcy of detectability of Sm, So and S signals as the noise level is increased could be nicely explained by making this assumption. For moderate and high levels of No noise, the hierarchy is So, Sm and Sπ where So requires the most intense signal and S the least intense. With small noise spectrum levels and at 'absolute threshold' however, the hierarchy is Sm, So, Sπ . Dierecks and Jeffress assumed that even the measurements made 'in the quiet' were masked thresholds due to the presence of internal noise. They pointed out that if the correlation of this internal noise were zero (Nu) then the hierarchy with small noise levels and at 'absolute threshold' would have been Sm, Sπ, So. The fact that So requires a slightly more intense signal than Sπ with small noise levels and at'absolute threshold' led Dierecks and Jeffress to conclude that the interaural correlation of the internal noise is not zero, but is

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slightly +Ve. The same hierarchy reported by Dierecks and Jeffress at 'absolute threshold' was obtained here. The difference in MLD's for So and S was smaller than that obtained for Dierecks and Jeffress, but it was in the same direction. So their argument, which was made from data collected at 250 CPS is constant with the present data obtained with a 400 CPS signal.

The relative contribution of internal noise to the total noise level in a channel is obviously negligible when the external noise is large relative to internal noise. When the external noise is small, the internal noise makes a relatively large contributions to total noise level. Since the internal noise is assumed to be uncorrelated with the external noise, the effect of increasing the proportion of internal noise is to change the effective interaural correlation. The direction of change depends upon the interaural correlation of external noise, the value towards which the effective correlation will tend as the level of external noise in both channels approaches zero is the value of the small '+Ve correlation' between the internal noise in the two auditory channels.

Thus the assumption of a small and relatively constant amount of internal noise has led to the conclusion that lowering the external noise level will produce a change in the effective interaural correlation. The question of interest is that 'what effect do changes in interaural correlation have on detectability?'. The answer is provided in the data of Robinson and Jeffress 1963 who measured the detectability

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of a tonal signal as the noise correlation was varied from +1.0 to -1.0. The data most relevant here are those obtained with an Sπ signal. The result was that the MLD was maximum with a correlation of +1.0 (i.e. No Sπ), it declined rapidly with small decreases in the correlation and then it declined gradually as the correlation was further reduced -1.0 (Nπ Sπ). That is reducing the interaural correlation from +1.0, resulted in a decline in the magnitude of the MLD, precisely the effect observed in this experiment, when the level of external noise was reduced. Quantitatively then, **The Internal Noise** hypothesis provides a reasonable explanation of present data.

LATERALIZATION THEORY:

The generic term "lateralization" characterises a number of specific theories that have evolved since the binaural masking level difference was originally discovered. The specific theories differ in detail and emphasis, but all agree that the increased detectability observed in these binaural experiments arises because mechanisms like those used in localization, lateralise the noise and signal in different places. The original models emphasised temporal cues. The signal has different interaural temporal properties than the noise. These differences are assumed to account for its improved detectability. The formal statement of the model was first made by Webster 1951 and was considerably elaborated by Jeffress, Sandel and Wood 1956. Jeffress 1972 basic assumption is that the binaural improvement in detection occurs because the addition of the signal to the noise

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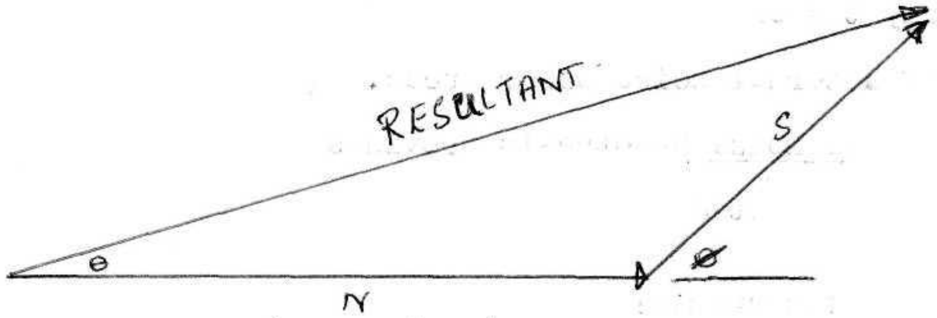

Figure '9c'

Vector Diagram illustrating how adding a signal S added at angle φ to noise Component produces a phase change θ. The resulting interaural phase Cue, θ, or its temporal equivalent is the basis of detection in this lateralization model.

causes a relative change in the time that the waveforms reach the two ears. To understand this model we must first all that a sinusoid can be represented by a rotating vector. The instantaneous amplitude of the sinusoid is the projection of this vector on the vertical axis. The frequency of the sinusoid is the projection of this vector on the vertical axis. The frequency of the sinusoid is determined by the angular velocity of rotation. The phase of the sinusoid is given by the orientation of the vector with the time of projection at time zero. In some narrow band of frequencies, noise can also be represented by a vector, but there are differences between a vector representing a sinusoid and a vector representing noise. A sinusoidal vector has constant amplitude and angular velocity. A noise vector changes both in amplitude and velocity. The rate of change of these quantities depends on the bandwidth of the noise. The central assumption of these binaural theories is the treatment of noise as a slowly changing sinusoidal process. The noise waveform at any instant is represented by a vector of fixed lengths as in fig.9c For the N_o condition, except for errors i processing, the interaural phase of the noise should be zero. Since the waveform arrives at the same time at the two ears, the binaural image should be lateralized near the center of the head. Next, consider the results of adding a signal, say to one ear, since this is the simplest case. This causes the resultant vector representing the waveform in that ear to move relative to the vector for the opposite ear. The parameter θ is the phase angle between the signal

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and the instantaneous phase of the noise and the relative amplitude of S and N in the figure are the relative amplitudes of noise and signal, respectively. The effect of adding a signal to the noise at one ear produces a phase change between the S plus N vector that ear and the noise vector in the other ear. Adding the signal thus changes the interaural phase or interaural time, and this is the cue for detection. For example, by adding a signal to the noise the resultant is moved 10° that is $\theta = 10^\circ$. If the signal frequency is about 360 Hz, then a change of 1/36 of a period, or about 77 m.sec. has been produced between the two ears.

This interaural time difference calculated from the interaural phase angle, is the crucial variable according to this theory. One would like to calculate its average value exactly. The value of θ depends on the amplitude of the vectors N & S and the value of θ . The amplitude of the Signal S is 'straight forward. The amplitude of the noise vector is more complicated. Its average value grows with noise level, in fact, it is proportional to root mean square (rms) value of the noise. It is also dependent on the assumed bandwidth of the auditory filter or critical band. The phase angle between S & N should be a random variable with all possible values of θ equal likely. Thus, the value of will be a random variable with some distribution of possible values, depending on N, S & θ . Henning 1973 has worked out mathematical expressions and the relevant distributions can be computed to make specific predictions for this model.

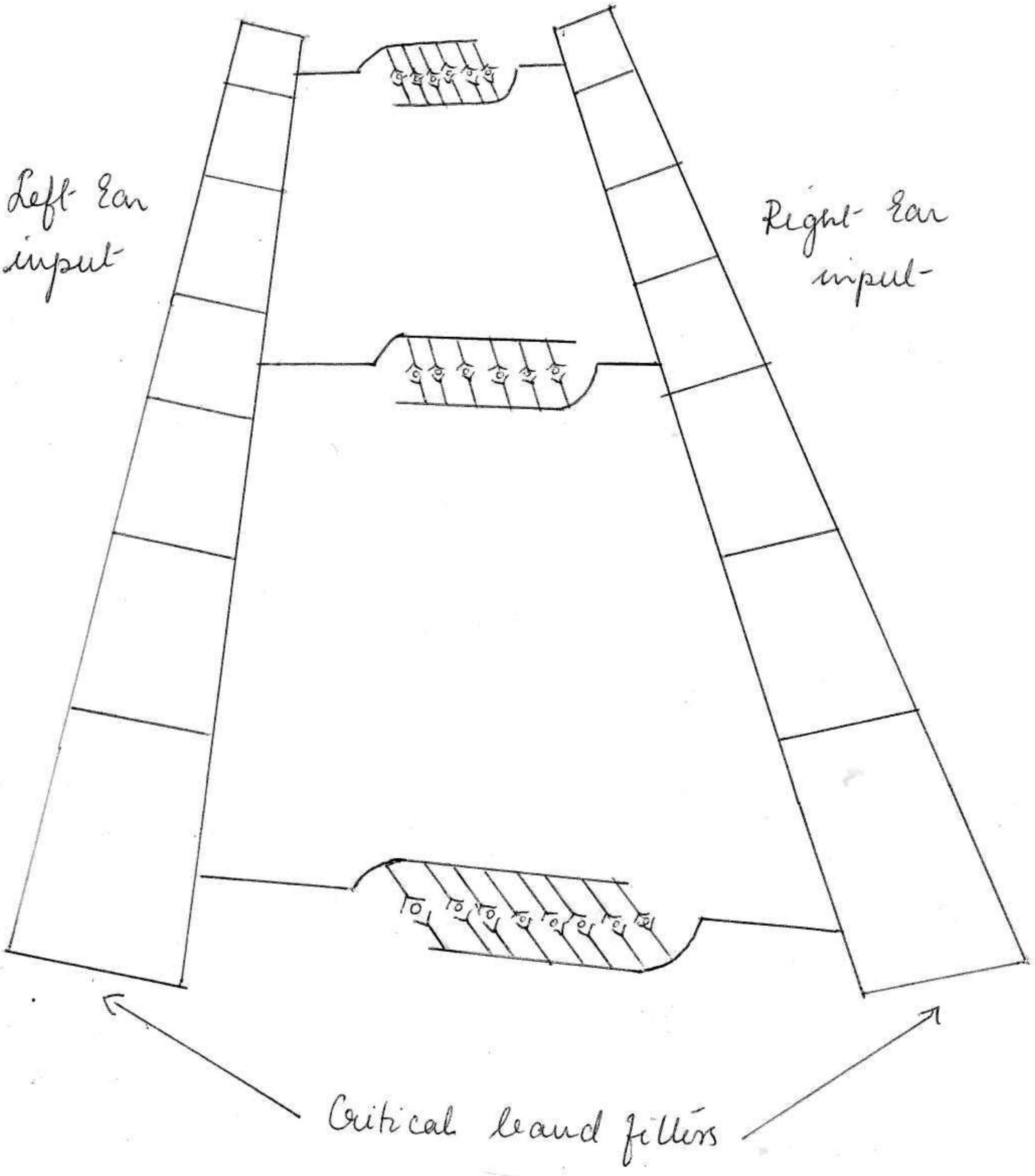

Figure 9 d. An illustration of Jeffress's hypothesis, of the physiological mechanism responsible for the interaural time cue. Signal is 1st filtered by critical bands & initiates neural impulses that travel on fibres extending toward the opposite ear. Each fiber sends off collaterals to a cell body indicated by a small circle. If the signal is delayed to left ear, the finite velocity of neural transmission will cause the impulses generated in each ear to arrive simultaneously at a cell body located on left side of the diagram.

An appealing aspect of this general approach is that it has been embedded in a physiological model for the mechanism that detects these time differences. This idea is illustrated in figure 9d. First as the two sides of the figure indicate, the incoming sound is filtered by critical bands. The output of the filter feeds a hypothetical axon extending into the brain stem. In some central network the axons send off collaterals that converge on cells along with collatuals from the axons coming from the corresponding filter in the other ear. Each axon carries an impulse caused by the acoustic input from the respective ear. If the anatony and impulse velocity are suitably arranged, the cells at which these two impulses converge simultaneously will indicate whether the waveform in the left or right ear ear occurred first. The higher order neuron represented by a circle in the middle of the figure detects this coincidence. If the waveforms are in-phase at the two ears, then neural bursts will be initiated at roughly the sametime. If the delays (i.e. propagation velocities) are similar for the two sides, the nervous located near the center of the diagram would be stimulated. If the waveform is delayed in the right ear the burst will start later and coincidence will move towards the left side of the diagram. Thus the phase of coincidence codes interaural delay. Licklider 1959 has elaborated an extension of this general coincidence model. In fact, this general idea is the basis for Colburn's recent theory. This physiological model and the lateralization model of Webster and Jeffress suggest a strong link between

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mechanisms for localising a sound and lateralization cues responsible for MLD.

Several studies have explored the link between the MLD and the process of lateralization. Based on these studies Hafter has come forth with the lateralization model. In its basic form, the model states that signal plus noise is assigned a lateral phase in the subjective space by a weighted combination of interaural parameters, time and intensity, and that binaural detection is then of the difference 'between the lateral phase of signal plus noise and that of noise alone. The simultaneous contributions of time and intensity lateralization are combined through weighted summation into a single interaural parameter.

An MLD occurs only when there are interaural differences in the waveforms arriving at the ears. The interaural differences can be either in amplitude in time or in both. Hafter has shown that an observers ability to detect the signal.

Several studies have explored the link between the MLD and the process of lateralization. Among the more ingenious experiments is one by Hafter, Carrier and Stephan in which the MLD's for individual subjects were predicted from the subjects lateralization responses. The first part of the experiment consisted of teaching the subjects to map, with a simple scale, the apparent location of the sound image. One end of the scale represented the left ear, the other end of the scale the right ear, and the center values the middle of the lead. If SmNo is compared with SoNo, then the lateralization judgement tends to distribute about centre in the SoNo condition and cluster towards the side containing the signal in the SmNo condition. From these reponses a computer calculates the likelihood ratio of each lateralization judgement and tabulates the distribution of the particular likelihood ratio, given the two hypothesis (So No and Sm No). Using a theorem of signal detection theory, the computer predicts the percentage of correct responses the subject should achieve in the binaural masking task, in which he must detect the signal in one of two temporal intervals. For atleast four of the five subjects the percentage of correct detections was successfully predicted from the lateralization judgements with an accuracy of about ±1 dls. These and other similar experiments provide support for the thesis that binaural masking phenomena and the lateralization phenomenon are simply different manifestations of similar; if not identical processes. The change in locus of the lateralized image is clearest in the Sm No condition. The lateralization image in the S   condition is not at either ear but somehow different in form from the So or No image. Adherents of lateralization theory would still maintain that the detection cues and lateralization changes are intimately related.

An apparent exception to this relation between lateralization and binaural MLD's are waveforms having energy only in the high frequency regions (above 2000 Hz). Such stimuli, either narrow bands of noise centered at high

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frequencies or amplitude modulated sinusoids, can be lateralized if the stimulus is delayed at one of the ears. In fact, the abilities to alteralize a 300 Hz pure-tone and a 3900 Hz carrier amplitude modulated at 300 Hz are nearly identical (Henning 1974). Henning showed that a delay of about 70 m.sec. in either the complex or simple stimulus can be detected about 75% of the time in a 2-internal forced-choice procedure. Despite this ability to lateralige the envelope of the complex signal does not improve its detectability in noise. Wightman and Green 1971 found similar results when they delayed a high-pass filtered pulse train by half the period of the fundamental. This signal was clearly lateralized but showed essentially no MLD. These results indicate that timing information contained in the envelope of the waveform is available to the binaural system for lateralization and localisation judgements but it is not available to improve the detectability of such signals in noise.

HAFTER'S MODEL: derives mainly from his work with tonal maskers and the MLD. He has shown that both the interaural amplitude and interaural delay add in a linear fashion to produce a change in the lateral position of an image. This movement results in detection of, the signal in a binaural masking experiment. Although the model does not predict the difference in detection between the referent and binaural conditions MLD it does predict the possible changes in detection for a dichotic condition. Thus the model realtes the binaural masking data to the data obtained from lateralization and localisation studies.

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DURLACH'S EQUALIZATION AND CANCELIATION THEORY 1963:

Durlach pointed out that many binaural masking results can be predicted from simply assuming that it was possible to add or substract the output of the two ears, stated more formally, he assumed that the binaural system can perform simple linear operations of addition or substraction after the outputs of the two ears are suitably scaled in magnitude. The assumption of a scaling operation is necessary because we know that the noise level at the 2 ears does not have to be equal to create a large binaural advantage. Figure (9c) presents the essentials of the theory. The waveform in each ear passes through a filter - the critical band and then through a variable gain amplifier to scale the output for maximum cancellation. The two channels are then combined, either being substracted (L - R) or added (L + R) in the cancellation device. The decision device operates so that the masked threshold is inversely proportional to the signal to noise ratio, that is, the ratio of signal power to noise power at the input to the detection device. The ability to switch from a binaural to either manaural channel is assumed because the signal to noise ratio in either ear alone might be better than that provided by the binaural processor. In this case only the monaural information would be used by the decision device.

Consider how the system provides better binaural signal to noise ratio in a typical condition such as Sπ No. In this case the cancellation device would subtract the

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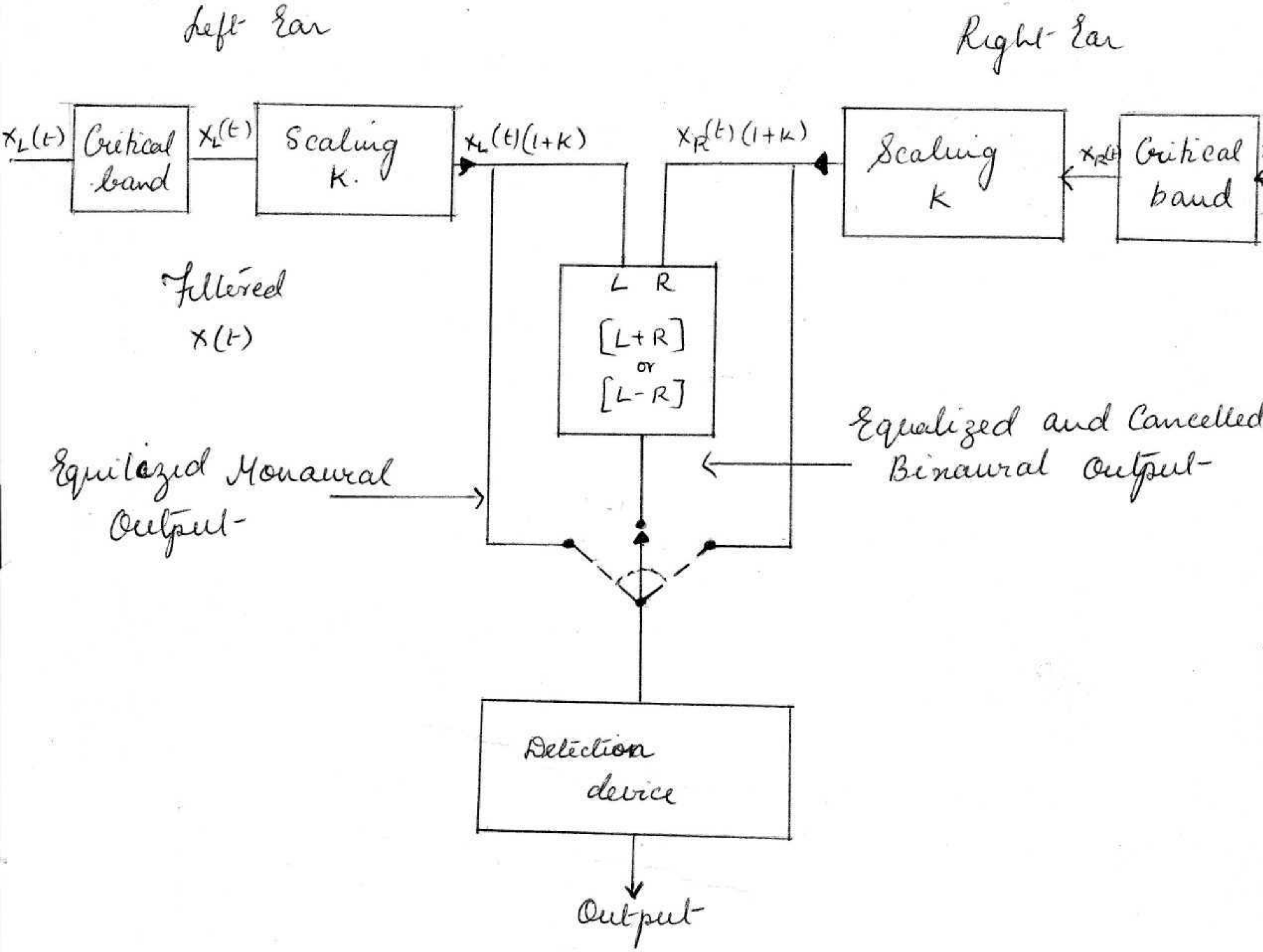

Fig 9.E

Durlach's Equalization and cancellation model. The operations of the model are indicated by the boxes. The detection device will select either ear or the binaural interaction to maximize the signals detectabilit outputs of the two ears, after suitable scaling. Since the signal is out of phase at the two ears, it doubles after subtraction. The noise, on the other hand, will be reduced to zero, What then limits the detectability of the signal? The theory assumes, there are small errors in timing and scaling. These errors prevent even identical noise waveforms at the two ears from exactly canceling.

The assumption of a timing error makes the cencellation process frequency dependent. A timing error plays no role as long as it is small compared with the period of the signal. However, as the frequency of the signal increases, the effect of timing error becomes appreciable. Eventually, as the period of the signal nears the size of timing error, practically no binaural advantage accrues from using the cancellation device. At this point detection of the signal should be no better than either ear alone.

By the same token, we must expect better and better cancellation at lower and lower frequencies, but this is not the case. Thus in addition to the timing error, the model assumes some sealing error. The model has only these two parameters, the size of the sealing and timing errors. Remarkably the model can predict most of the binaural results using only these 2 parameters. The standard deviation of the scaling error is 0.25 for a unit input and a timing error of T = 150 m.sec. Neither value is unreasonable in terms of general auditory abilities. One can center a click with an error of about 25 m.sec. and although this is a factor of five less than l50 m.sec., one must probably use a number different critical bands in the centering task. Similarly,

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one can detect a change in intensity of about one or two dls which corresponds to amplitude changes of about 0.12 to 0.26.

Durlach assumes that either addition or subtraction occurs at the waveforms. By applying these operations, the signal is extracted from the noise. Before the linear operator is applied, two aspects of the process must be considered. First the waveforms at the two ears must be equalized so that they have the same aplitude. Secondly it is assumed that each waveform undergoes some temporal jitter. The failure to achieve perfect equalization explains why in an No S condition, the signal does not become infinitely more detectable since without the amplitude error the noise would be completely cancelled. The temporal jitter provides an easy way to account for decreases in MLD at higher frequencies. Once the period of the waveform exceeds the range of the jitter, then (on the average) no cancellation is achieved.

A further assumption of the model is that if the equalization and cancellation processes cannot yield detection better than that achieved by the monaural mechanism, it will not be used. Thus the model predicts small +ve MLD's for some conditions but never '-ve' MLD's.

The equalization - cancellations steps in the model have lead to its label: "the E-C Model". Although the model does not describe any physiological mechanism, it has been highly successful in accounting for a large portion of the

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MLD literature, other investigators have used the idea of E.C. Model in proposing other models of MLD. In general those models offer prediction for some conditions, not accounted for by the Durlach model although they risk losing the generality of Durlach's Model. According to Durlach binaural signals are processed in three stages, initial filtering, equalization - cancellation and decision. After initial filtering signals are fed to the inputs of both EC and decision mechanisms. Monaural processing is represented by two inputs to the decision device that bypass the EC mechanism. This device combines signals from the two ears and provides a single binaural input to the decision mechanism. The EC mechanism first transforms the two input waveforms in such a way that the masking components of the two are exactly the same (the equalization process), then subtracts one waveform from the other (cancellation). The decision device functions as a signal detector and operates only on the input with the largest S/N ratio.

The EC mechanism will improve the S/N ratio whenever signal and masking noise are not in the same interaural relation. In these conditions the cancellation process tends to eliminate the masker and leave the signal readily detectable. If signal and maskers are in the same interaural relation however the EC mechanism will not improve the S/N ratio. The equalization process would equate both signal and masking components of input waveforms

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and cancellation would thus eliminate the signal and masker. If the binaural processing could be carried out with perfect precision, the E-C mechanism would improve the S/N ratio an infinite amount. In order to predict quantitatively realistic detection performance, Durlach assumes that the precision of E/C is limited by small random errors, with this single limitation, Durlach's E-C model can successfully account for most of results from MLD studies.

The results of a study done by P.J.Metz, Gvon Bismarck and Durlach on binaural unmasking and the E-C model are presented on binaural unmasking of tones masked by noise as a function of the interaural phases of the tone and noise and the bandwidth of the noise. It's found that

1) for a tone of 250 Hz, the binaural unmasking increases by 10 dls as the bandwidth is reduced from 250 Hz to 4.2 Hz.
2) The functional form of the dependence on interaural phase is independent of bandwidth.
3) Reducing the bandwidth increases the amount of unmasking at all frequencies.
4) previous versions of E-C Model are inadequately for describing the results.

and

5) the data can be described by assuming that the error factor K in the EC model depends on the bandwidth W and interaural phase of the noise according to a relation of the forms

$$K = 1 + k\ (W)\ Kz\ (\theta_n)$$

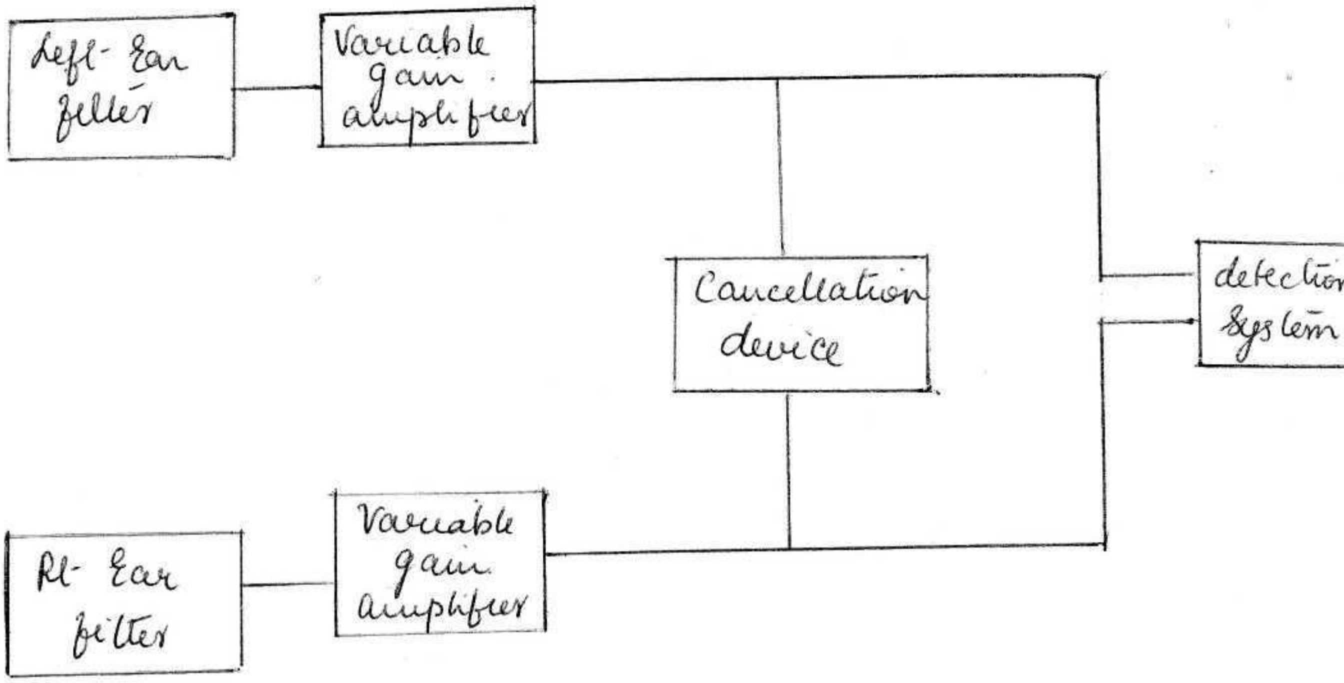

Figure 10

A schematic diagram of Durlach's E-C model for MLD - signals entering the right and left ears are filtered and adjusted in gain to equalize the level of the masker at the two ears. The equalized outputs of the two channels are either added or subtracted in order to cancel the masker as much as possible and allow the signal to be detected.

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The synchrony of neural impulses in response to low frequency sinusoids is described for auditory medullary neurons. The results are summarized as follows:

1) In general, neural synchrony is found to improve with increases in intensity and frequency of stimulation for both monaural and binaural neurous when measurements are made in absolute time.
2) An analysis of our population of neurous implies that 2 separate mechanisms are responsible for the decrease in synchrony found in many neurous as compared to primary like neurous with high locking ability. The two mechanisms are convergence of mistimed impulses and electronic changes which occur in dendrites.
3) An analysis of binaural vector strengths as a function of interaural time and reveals the effects of mistimed convergence upon neural synchrony.
4) In contrast to the inferior colliculus, when the nerous discharge best with contralateral leads in time, superior olivary neurous exhibited no such preference. Some discharge best to ipsilateral while others to contralateral leads. This comparison reveals a striking difference in the coding characteristics of medullary and inferior colliculus neurous.

A correlation model of binaural masking level differences:

(By Eli Osman).

Here the receiver is presumed to behave as if it

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computes a statistical decision variable equivalent to a linear combination of three quantities, the energy levels at the channels deriving from the two ears and the inter-channel cross-correlation where the co-efficients are dependent on the interaural noise cross and the interaural amplitude a ratio for noise but are completely independent of signal parameters. Additive internal noise is assumed. Equations for BMLD's are derived with the restriction of equal noise levels at the two ears.

CHAPTER - IV

METHODOLOGY

Masking is the process by which the detectability of one sound, the signal, is impaired by the presence of another sound, the masker. The effectiveness of a masker and consequently the amount of signal level necessary to be just detectable in a constant masking noise is highly dependent on whether the presntation in monaural or binaural and whether its diotic or dichotic. Dichotic presentation permits binaural auditory analysis which can result in dramatic improvement in detection of signal. Jeffress presented a good example of this effect, first supply noise to one ear at a confortable listening level, then add a signal consisting of a 500 Hz tone interrupted every quarter of a second and adjusted in level until it's just inaudible. Now add the same noise to other earphone and signal becomes clearly audible. The signal again disappears when it too is added to the channel for second earphone, making the sounds at two ears alike. Now if we reverse the conditions 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.

The difference in signal levels required for perception of the signal in the out-of-phase (NoSπ) condition described as compared to the in-phase (homophasic NoSo) listening condition can be as much as 15 db. This difference in signal levels required for the same degree of detectability is MLD. The MLD is measured and expressed **in decibels** and the methodology adopted to measure MLD by different investigators vary.

The following chapter gives the Methodology adopted by various investigators in their study of MLD on different persons with different auditory pathology.

The methodology adopted by the following investigators are presented here:

1) Levitt and Rabiner (1967)
2) carhart Etal (1969)
3) Schoeny & Carhart (1971)
4) Quaranta & Cervellera (1974)
5) D.P.Goldstein & Stephens S.D.G.(1975)
6) E.Bocea & A.R.Antonelli (1976)
7) Wayne 0. Olsen & D.Neffsinger (1976)
8) James H. Stubblefield & D.P.Goldstein (1977)

There are atleast two ways in which improvements in intelligibility may be quantified. 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 used by Levitt and Rabiner (1967) in their study of binaural release from masking for speech and gain in intelligibility.

The investigation was carried out in two parts. In the first experiment, detection thresholds and 50% intelligibility levels were measured for the SoNo, Sπ 0/500 No, Soπ/500 No, So Nπ o/500, SoNu 0/500, S t 1.6 No S t 10 No & Sπ No conditions. In the second experiment, the measurements were repeated for the SoNo, Soπ /250 No, Sπ/250 No, Sπ /1000 No, Sπ 0/1000 No, S t, 0.5 No, S t 5.0 No and SoNu conditions.

A block diagram of the apparatus is shown in figure 11 . The test material was recorded on magnetic tape and played-back through an ampex PR10 recorder. The signal was passed through an automatic recording attenuator and then routed via switch S1 either to the spectrum shaper or directly to the subjects headphones. The recording attenuator was controlled by the experimenter. The masking noise was produced by a noise generator and its output could similarly be routed via switch S to either the spectrum shaper or directly to the headphones. The noise was bandlimited to 4800 Hz and presented at a pressure spectrum level of 49.5 dbs.

The spectrum shaper consisted of two matched channels. Bach channel consisted of two complementary high pass and low pass filters. Each filter was made up of two Allison type 2 BR units in cascade yielding an attenuation rate approaching 7-2 dbs/oct in the stop band. The output of the high pass filter in channel 1 was reversed in phase and added to the output of the low pass filter in that channel. Since the pass bands of the two filters are contiguous, the amplitude spectrum for the channel is reasonably flat (within ± 1.5 dls).

Lay out of equipment. Each Spectrum shaper consists of high pass & a low pass filter pair. The output of the high pass Section can be reversed in phase prior to being added to the Output of the low pass section. In channel 1 the combined Output can also be reversed in phase or delayed as required.

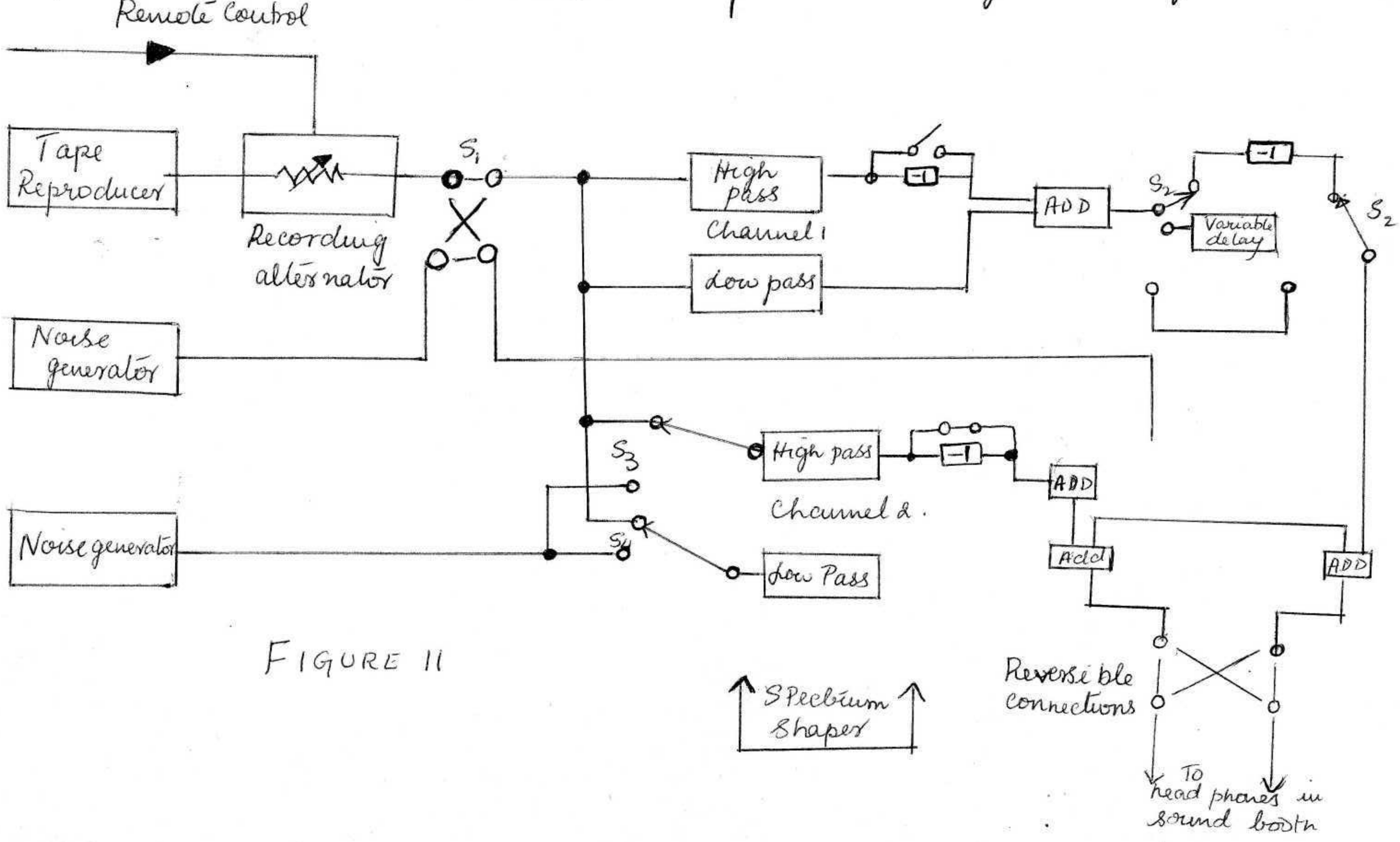

FIGURE 11

The phase response of the channel however undergoes a sharp 180° transition at the dividing frequency fd. The output of channel 1 could also be delayed or subjected to abscond phase reversal. Two audio precision model DL - 0470 - 400/125 delay lines were used in series. Each delay line provided a maximum delay of 5 m.sec. with a frequency response flat within I ± 1 dbs upto a frequency of 5000 Hz. Channel 2 was identical to channel 1 except that the outputs of the two filters were added directly without phase reversal, i.e. the operational amplifier was by-passed. Since the experiment is critically dependent on interchannel differences, the two channels are carefully watched. Interchannel amplitude differences were within ± 1.3 dbs in the vicinity of fd and within ± 0.1 dls elsewhere.

Roughly 90% of the 180^{o} phase reversal takes place within a band from approximately 0.8 fd to 1.3 fd (i.e. within 1/3 Oct above and below the dividing frequency).

The interchannel phase response using the spectrum shapers without phase reversal shows a peak approaching 45% in the region of fd.

By permutations of switches S1 S2 S3 and S4 it was possible to set up any of the desired experimental conditions. For the case of uncorrelated noise, a second noise generator of the same type was used and its output was routed through channel 2. The uncorrelated noise was routed through only the low pass section of this channel for the SoNuo/fd condition.

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Two lists of 50 single CNC words were recorded by a male speaker. The words were adjusted in level to a rectified average value of 103 dbs SPL measured over the duration of the word. The adjustment process was carried out by digital computer. For each test 75, words selected at random from the ensemble of 100 were used. The words were presented at three-second intervals. For the intelligibility measurements, the subject was required to repeat each word immediately on hearing it, scoring only for correct repetitions. For the detection threshold measurements, the subject was required to state whether or not a word had been presented during a specified 2 second observation interval. Warning lights were used to prepare the subject and to mark out the observation interval. Control presentations with No signal present were made in order to estimate the false alarm rate.

In both the detectability and intelligibility trials, the signal level was controlled by the experimenter according to a simple sequential stragegy. The purpose of the stragegy were two fold: (1) to estimate the 50% level of the response curve rapidly and efficiently; and (2) to restrict data to the symmetric region of the response curve. The latter requirement was of particular importance for the intelligibility measurements since the intelligibility function tended to flatten at high S/N ratios, seldom exceeding 80% intelligibility.

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Four subjects were used, with three replications per condition. Measurements were carried out in random order to protect against learning effects or other regular trends. Within each experimental condition, the tests were recorded in sequence thus allowing a subsequent check for possible learning or other time order effects. The reference SoNo condition was repeated for both experiments.

3) Z.G.Schoeny and Raymond Carhart adopted the following procedure in their study of MLD in Meniere's diesease.

The instrumentation permitted the controlled presentation of a pulsed 500 Hz pure-tone signal to each ear separately or to both ears, either alternately or simultaneously. The 500 Hz signal had a duration of 250 m.sec., 25 m.sec. rise/fall time and a 50% duty cycle. The intensity level of the signal was controlled by the subject, once the experimenter adjusted the equipment for the test condition of the moment. Recording attenuators provided a graphic write-out of the intensity change required by each subject while performing the experimental tasks.

The narrow band masking noise, 400 Hz wide with the center frequency at 500 Hz, could be presented to each ear separately or to both ears simultaneously. Switching was provided to permit the convenient selection of any combination of signal and noise as required. Additional switching was used to attain the interaural phase relations of So and Sπ for the signal and No and Nπ for the masker. Also, it was possible to present noise bands to each ear with random

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interaural phase Nu by using two independent noise sources.

It was ascertained empirically that the instrumentation possessed the interaural matching of stimuli, the flexibility and the stability required for the investigation. The effective isolation between the channels to the 2 ears was greater than 52 db for both types of stimulus. The frequency responses of the two TDH.39 ear-phones did not differ by more than 0.5 db in the range from 300 to 700 Hz, within which range both the pure-tone and the bands of masking noise fall. The acoustic output at each ear-phone agreed very precisely with the output levels which the system was expected to provide. The mean day to day variation in stimulus level was less than 0.1 db during the course of the study. The electrical output of the system was continuously monitored throughout the period when data were being collected so as to assure that proper interaural intensity levels and the requisite interaural signal conditions were achieved. Lissajous patterns produced on a Cathoderay oscilloscope were used to check interaural phase relations.

Each subject was seen in a single experimental session that lasted about 3 hours. A brief history was taken, and pure-tone thresholds in quite were measured by conventional audiometry. Then every subject performed three sets of auditory tasks, using 500 Hz as the test stimulus. First he did alternate binaural loudness balancing (ABLB) and simultaneous binaural median place localization (SBMPL). The loudness balancing was done to assess supra threshold

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asymmetry between ears, while the intracranial localization task was done to assess possible interaural imbalance per supra-threshold localization. Second, he undertook a series of monaural threshold trackings via each ear in the presence of 4 arrangements of masking. SmNm, SmNu, SmNπ and SmNo. Finally, he carried out a series of binaural threshold trackings in the presence of six conditions of masking: SoNo, Sπ Nπ, Sπ Nu, SoNu, SoNπ and Sπ No. All measures were repeated to yield retest data. The several procedures within each of these three sets of tests were counter-balanced, but the identical sequence was used for a given subject during his retest session.

The subject was instructed to carry out the loudness matching procedure by varying the stimulus intensity in the variable ear so as to make it subjectively louder and softer until he perceived it to be equal in loudness to the stimulus fixed at 70 dbs SPL in his other ear. The subject was able to control the intensity of the bursts reaching his variable ear by means of a three-position switch which permitted him to increase the intensity level of these bursts, to decrease them, or to hold them constant. A recording attenuator plotted the changes he invoked in the burst level. He was given sufficient practice to ensure complete understanding of the task required and he was asked to pass the point of equal loudness two or three times before making his final judgement. Three repetitions of this loudness balancing were averaged to obtain the measure of the interaural loudness disparity for that run. The measure of interaural disparity for this study was taken to be the difference in intensity obtained as above when the pathological ear served as the fixed ear.

The technique for administering the SBMPL test was identical to that used for the ADLB test, except that now the stimulus bursts reached both ears simultaneously. The burst level remained constant at 70 dbs SPL in the subjects fixed ear. He was instructed to change the intensity of the burst level in the other ear so that the sound image moved back and forth several times in the intracranial space and then to center the perceived sound image in this space. The results of three repetions of such centerings with the pathological ear fixed were averaged. These computations yielded the measure of the interaural difference in signal intensity required by the subject for centering of the image to be experienced.

After completion of the balancing tasks, the eight monaural and six binaural masked thresholds for 500 Hz were measured. The masker consisted of a band of random noise 400 Hz wide with the center frequency of 500 Hz. It was present at an overall intensity level of 80 dbs SPL, which gave a spectrum level of 54 dbs. In order to achieve the SmNu condition, it was necessary to feed a second noise band, uncorrelated with, but otherwise identical to the first band, as the subjects second ear.

A Bekesy tracking procedure was used to obtain each threshold. The subject was instructed to increase the intensity of the 500 Hz tone until it was just audible over

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the masker and then decrease the intensity until the tone became audible. His tracking pattern was plotted with a recording attenuator. Each tracking was continued until the peaks of each pen excursion were within 2 db of each successive peak for a minimum of 5 complete excursions. These five excursions were considered the stabilized level. The threshold was defined as the SPL of the average of the mid-points of these five excursions.

Tillman, Carhart and Nicholls (1973) in their study of MLD in elderly patients have used the following methodology.

The equipment and test materials employed in gathering the data were those described by Carhart Etal (1969), except that only one modulated white noise was included as a masker stimulus. This noise was pulsed to a depth of 10 dls, four times a second (50% duty cycle). The notation N has been adopted for this noise. The 2 other masking stimuli (designated C^1 and C^2) were sentences spoken by adult males. The spondees (S) were spoken by a third adult male. Spondee thresholds were measured in the presence of each masker alone and in combinations consisting of the noise with each talker alone, Both talkers without noise, and all three signals combined.

Each of the 4 types of signal was recorded on a separate channel of a 4 channel magnetic tape, so as to yield spondees that were time locked with each of the three maskers. This study used 197 test stimuli produced by

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recording the same block of 36 spondees in different random orders.

By reproducing the test tape on the same instrument used for recording, the experimenter was able to produce the masker complex required at the moment and to select the appropriate one of our listening modes. **Table-1** shows the various masker conditions in each of the 4 listening modes, the first of which was homophasic. There were seven masker conditions in this mode, wherein all signals were presented in-phase (for example - CoNoSo). In this mode the subject tended to perceive both signal and masker as a phantom image localized in the mid-line. The second listening mode was anti-phasic. Here the signal remained in-phase while the masker was given an interaural phase difference of 180° (CπNπSo). In this condition the typical listener perceived the spondees as being in the mid-line and the masker as intracranially diffuse. The third listening mode has been labelled parallel time-delay. Here the masker whether comprised of a single or multiple signals, was delayed 0.8 m.sec. in one ear, with respect to the other (for example C^1. 8, N^2.8, So). This yielded a perceptual experience wherein the spondees were localized in the mid-line and the masker in the ear when the signal was leading. Incidentally the delay time of 0.8 m.sec. was chosen since it corresponds roughly to the time required for an acoustic signal to travel over the head from one ear to the other. Finally, the fourth listening mode was designated opposed time delay. This condition was created by delaying one signal in the masker complex in one ear and the remainder of the masker complex to the other ear (for example C.8, N.8,S). In the example shown here, the typical observer localized the C^1 masker in one ear, the N^2 masker in the other ear and the spondees in the midline. The negative sign associated with the noise signal in the notation $C^1.8,N^2.8,So$ is meant to indicate that the 2 signals were delayed in opposite ears, albeit by the same duration. It should be apparent that for a condition to be designated opposed time delay, the maskers had to consist of two or more signals. Thus in **Table-1** and subsequent tables there is no entry under 'opposed' for the three single maskers.

Each masker, whether presented singly or in combination with one or both of the remaining maskers was presented to each listener at 80 db SPL specified in terms of an equivalent 1000 Hz tone, that is, a tone that produced the same meter deflection as the 3 masker signals. Because the frequency response characteristics of the ear-phones were more restricted than those of the transmission system that preceded them, this method of equaling the signal electrically with a 1000 Hz tone resulted in a noise signal whose overall acoustic intensity, when measured directly, was 78 dts rather than 80 db SPL. listening was done under TDH = 39.

Two sets of subjects were used. One group consisted of 10 young adults (five men and five women) with normal hearing, between the ages of 18 and 27. This group was included to furnish reference data to evaluate performance

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of the second group, composed of 23 women between the ages of 70 and 85 years and 22 men between the ages of 63 and 88 years. None of these individuals had a spondee threshold in the poorer ear that exceeded 30 dls hearing level, that is 50 dls SPL. The mean spondee threshold hearing levels for the better and poorer ears of this group were 8 and 10 dls respectively.

LISTENING MODE **TABLE - 1**

Homophasic	Antiphasic	Parallel	Opposed.
$N_0^2 S_o$	$N_\pi^2 S_o$	$N_{.8}^2 S_o$	–
$C_0^1 S_o$	$C_\pi^1 S_o$	$C_{.8}^1 S_o$	-
$C_0^2 S_o$	$C_\pi^2 S_o$	$C_{.8}^2 S_o$	-
$C_0^1 N_0^2 S_o$	$C_\pi^1 N_\pi^2 S_o$	$C_{.8}^1 N_{.8}^2 S_o$	$C_{.8}^1 N_{.8}^2 S_o$.
$C_0^2 N_0^2 S_o$	$C_\pi^2 N_\pi^2 S_o$	$C_{.8}^2 N_{.8}^2 S_o$	$C_{.8}^2 C_{.8}^2 S_o$
$C_0^1 C_0^2 S_o$	$C_\pi^1 C_\pi^2 S_o$	$C_{.8}^1 C_{.8}^2 S_o$	$C_{.8}^1 N_{.8}^2 S_o$
$C_0^1 C_0^2 N_0^2 S_o$	$C_\pi^1 C_\pi^2 N_\pi^2 S_o$	$C_{.8}^1 C_{.8}^2 N_{.8}^2 S_o$	* .

Masker condition designations for the 27 binaural masking conditions in the various listening modes. The spondee signal (So) was always presented in-phase. The opposed time delay condition cannot exist for the 3 conditions that involve a single masker. In addition, the three possible opposed time delay conditions * for the 3 masker situations have been combined for convenience.

4) Quaranta and Gervellera (1974) have used the following Apparatus and procedure in their study of MLD in normal and pathological ears.

Apparatus:

The signal provided by an automatic audiometer (Rudmose AR J 5) was 500 Hz with a duration of 250 m.sec. a rise - fall time of 250 m.sec. and a duty cycle of 50%. The audiometer fed a phase shifter (Grason Stedler Model E 3520 B) the reference output of which was led to a mixer and headphone. The adjustable output was led to the other. By setting the phase shifter to either 0 or 180°, homophasic or anti-phasic stimulation could be obtained; these settings were monitored using a dual-beam oscilloscope (Dumont type 322-A). The left and right ear signals were passed through separate attenuators (Hewlett - Pack and Model 4436 - A) to the left and right mixer amplifiers (Geloso model 300 V and 240 Hf). The noise generator (Mercury M 132) produced a continuous wide-band thermal noise signal reasonably flat from 350 to 20000 Hz. The noise was led separately to both left and right mixer amplifiers. Masking noise output power could reach 126 dls SPL corresponding to a spectrum level of about 83 dls. The ear-phones were telephonies model TDH - 39. The masked thresholds were recorded in a silent room.

Testing procedure:

The procedure adopted by Quaranta and Cervellera can be summarized as follows: Signal and noise thresholds were recorded separately for each ear. The noise was presented

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at 60 db sensation level in the more affected ear, and the subject then adjusted the intensity in the better ear until the sound was centered on his medium place. Next, the masked thresholds for each ear were determined for the pulsed signal in the continuous noise (Nm Sm).

The right and left masked thresholds were presented simultaneously in homophasic condition (NoSo), and the subject was invited to say whether the perceived sound image (noise + pulsed tone) was centered under binaural hearing. If the sound image was now lateralized, the procedure was repeated until the subject reported that the sound was centered.

The recording of the binaural masked threshold lasted 3 minutes. The examination changed the interaural relation of tone every 30 seconds, back and forth between NoSo and NoSπ. This procedure was repeated three times and between each session, there was a rest period lasting no less than 1 hour. The initial interaural phase condition was homophasic on some runs and antiphasic on others.

5) D.P.Goldstein and S.D.G.Stephens (1975) give the following methodology.

MLD's were determined as the difference between the homophasic condition, NoSo and the antiphasic condition NoS . All measures were made in a background of white noise at a level of 80 dls SPL. Seven measures were obtained. Three were under ear-phones for the sinusoids of 300, 500 and 1000 Hz. Speech MLD's were measured with a consonant rhyme test.

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A binaural percentage improvement in intelligibility was derived for each type of list first under ear-phones and then with the listener seated in the sound field listening to the words coming from loudspeakers. In this way four additional measures were obtained making a total of seven MLD's.

6) E. Bocea and A.R.Antonelli (1976) in their study of the MLD in peripheral and cortical defects have used the following instruments.

The instrumentation used (Amplaid speech audiometer, Model 500) allowed the presentation of the speech signals to each ear separately or to both ears. Speech signals could be delivered to the ears either alternately or simultaneously; this feature was especially important whenever it was required to perform alternate binaural loudness balance (ADLB) and simultaneous balancing medium plane localization (SBMPL) procedures.

The speech material (five-word meaningful sentence in ten sentence lists) was taped and played back from a two-track tape recorder. Each track was fed into one of the four channels of the speech audiometer used. Different sound pressure levels could be obtained for the signal for each ear. The other two channels of the speech audiometer were used to control separately for each ear the sound pressure levels of the masking signal. The masking noise used was a broad band noise (frequency spectrum from 10 to 20000 Hz) filtered (3 dbs/oct. rise from 250 to 1000 Hz, and 12 dbs/Oct, fall from 1000 to 4000 Hz.).

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The headphones and the ear-muffs were arranged so that the attenuation between channels for the two ears was greater than 70 dls far both types of signals. A two-channel delay unit incorporated in the speech audiometer ensured transient-free interaural time delay. It consisted of a passive network employed to delay the speech signal from 0 to 1 m.s. in 50 m.s. steps.

7) Wayne O.Olseny Douglas Noffsinger and Raymond Carhart (1976) have in their study of MLD in clinical populations have used the following methodology.

The techniques for measuring MLD's were, selected on the basis of their feasibility in a clinical setting, that is, economy of time and ease of administration, points that are important in a clinical setting in which patients undergo a number of tests and are usually seen only once.

MLD's were derived by measuring masked thresholds for either 500 Hz or spondees (or both) under one homophasic and two antiphasic conditions. These conditions were the following:

1) Binaural homophasic with signal and masker each in phase with itself at the 2 ears (SoNo);
2) binaural antiphasic with signal 180° out of phase and noise in phase at the two ears (SπNo); and
3) binaural antiphasic with signal in phase and masker 180° out of phase at the 2 ears (So Nπ).

The 500 Hz signal was initiated by a Bekesy audiometer operating in a standard pulsed mode of stimulus presentation; (50% duty cycle; 2.5 interruptions, 25 m.sec. rise - fall time and 2.5 dls/s attenuation rate). A narrow band-noise

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generator developed the masking stimulus, which was a 600 Hz band of noise centered at 500 Hz and set to an overall level of 80 dbs SPL. Both signals were fed to a network that allowed their being mixed in a pair of ear-phones housed in cushions. The network also allowed phase reversal of either the noise or the test signal in one ear-phone. Subjects traced their thresholds by operating a standard Bekesy audiometry switch for atleast 1 minute under each of the test conditions. All head previously completed Bekesy tracings in quiet and were given practice in one of the masking conditions (SoNo) before MLD data were collected. Masked thresholds for spondees were measured under each of the three listening conditions. The speech signal was reproduced by a tape recorder and transmitted via one channel of a speech audiometer to the mixing and phase control network. The masker in this situation was white noise for which the band width was determined by the ear-phone characteristic 11 dbs, 20 - 2000 HZ, +5 dbs resonance peak at 3000 - 4500 Hz, 10 dbs/Octave roll-off above 5000 Hz). The overall level delivered by the ear-phones was 80 db SPL. Speech reception thresholds were determined with the descending approach described by Tillman and Olsen (1973), the signal being attenuated in steps of 2 dbs. Two words were presented at each level. All subjects were familiar with the 36 spondees and the SRT technique because speech reception thresholds in quiet had been obtained previously for each ear. One practice speech threshold in noise (SoNo) was obtained before data were collected.

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The size of the MLD's (in dbs) was defined as the difference between the threshold obtained in the SoNo condition and the threshold for the same test stimulus in an antiphasic condition. (SπNo or SoNπ).

8) The methodology adopted by James H.Stubblefield and David P .Goldstein (1977) will be briefly described:

The experimental factorial design with repeated measures required that each subject was tested in four experimental sessions (yielding 640 masked thresholds from which 320 MLD's were computed). Each session was separated by a period of 3 days to minimize the effects for an interupted 500 Hz sinusoid and for spondee speech reception threshold (SRT) was obtained at each session with the homophasic (NoSo) and antiphasic (NoSπ) listening conditions being alternated as the first presented to distribute possible order effects in determination of the MLD for the 500 Hz pure-tone stimulus and different randonization of the CID auditory Test W-l were used for each determination of spondee SRT's. Since masked threshold values vary over a much wider range than do MLD's for both within subject and across subject measurements and since the MLD's for the antiphasic (NoSπ) versus the homophasic (NoSo) conditions yield the largest consistent effects, it was these MLD's which were compared for test-retest reliability.

Masking level differences for the 500 Hz target signal were obtained by presenting 65 dls SPL continuous narrow-band noise (180 Hz wide, 42,5 dls spectrum level) binaurally and

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interaurally in phase (No), then determining the amplitude level of the 500 Hz signal required for detectability when the signal was interaurally in-phase (So) and when the signal was interaurally out-of-phase (Sπ). The difference is decibels between the required amplitude levels for detectability.

Figures of Apparatus on page 154 and 155.

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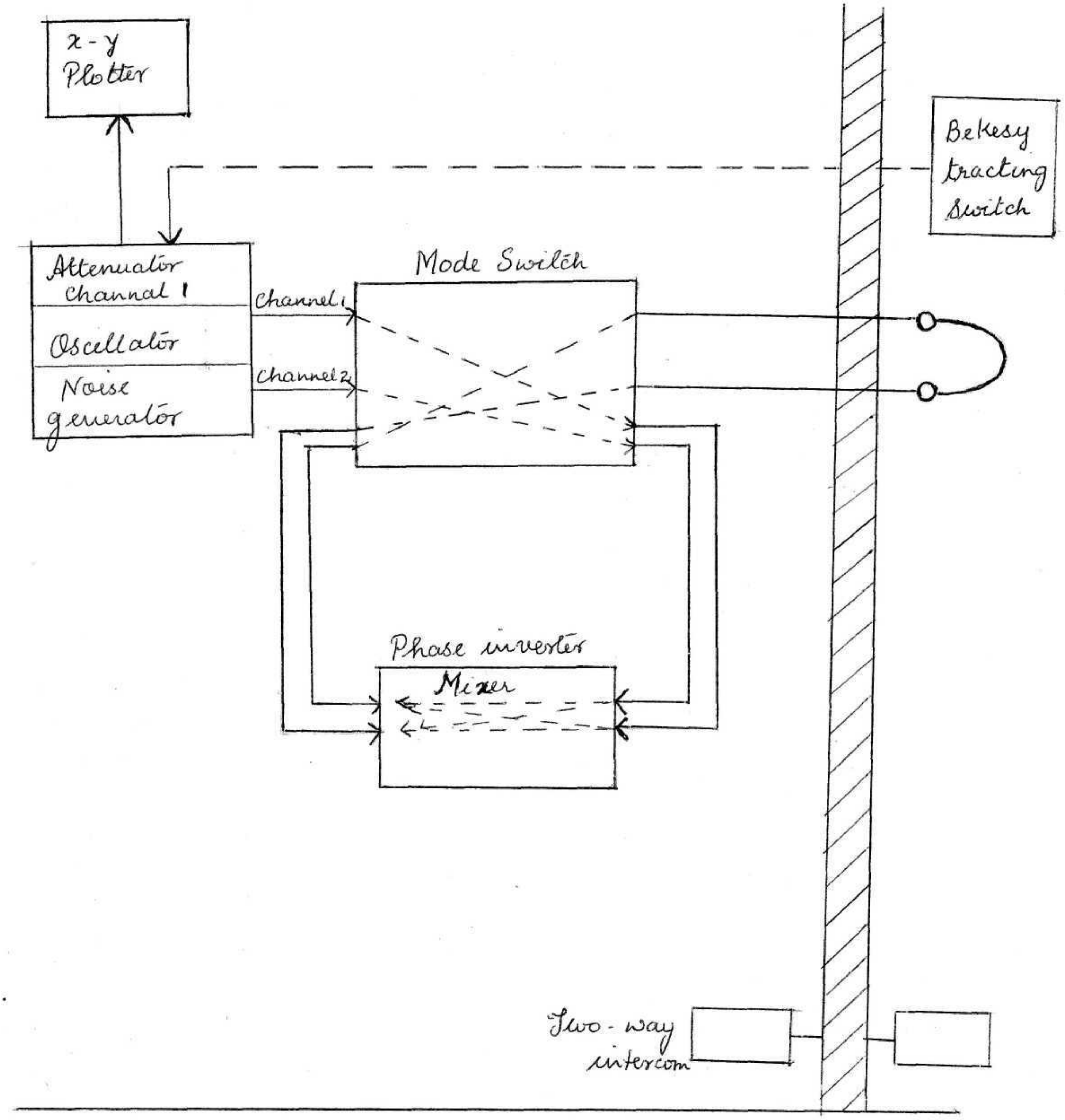
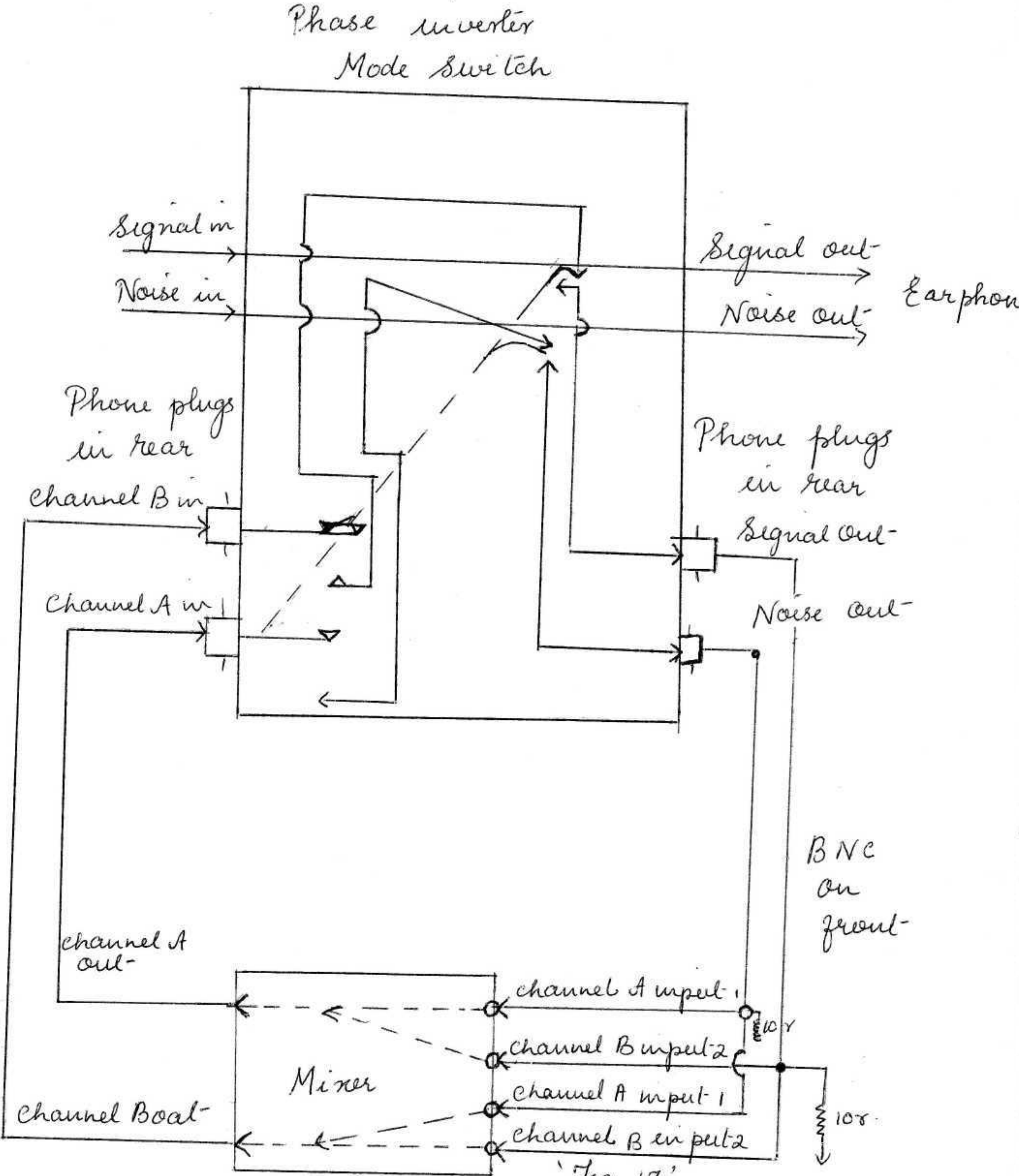


Simplified block diagram of instrumentation

'Fig 12'

Fig 13



'Fig 13'

Simplified diagram of routing of Signal and Noise through the mixer and phase inveter. The arrangement is Shown for the 'normal operation' where Signals and noise do not go through the mixer and phase inverter.

CHAPTER - V

CLININAL APPLICATIONS OF MLD

Introduction: The masking level difference is a consequence of complex binaural auditory behavior. It's natural that this psychoacoustical phenomenon should be evaluated with hearing impaired patients, to determine its clinical usefulness. One of the first such reports was by Jerger & Jerger '65.

In addition to focusing on the MLD as a possible clinical tool, there is a need to understand binaural signal processing capabilities. Development of a profile of normal binaural auditory processing abilities would serve several, purposes. Included among these would be increased insight into normal audition as well as a greater understanding of the subtle ways in which persons with hearing loss are handicapped.

The MLD has been studied in patients with auditory impairments for a dual purpose, to obtain data for the interpretation of the unmasking effect and to develop a test useful in audiologic diagnosis.

Research in MLD is characterized by a marked dichotomy between experiments involving speech and experiments involving mathematically well defined stimuli such as tones or pulses. The reason for the dichotony are obvious: the problem is to find valid and useful relationships between the 2 bodies of data.

The tonal MLD clinical studies (Noffsinger 1972, 1975, Olsen Etal 1976, Quaranta and Cervellera 1974) began in 1971 by Quaranta, Cassairo and Cervellera in Europe and by Schoeny and Carhart 1971 in USA.

Recently speech MLD has been extensively used among the clinical population by various researchers like Antonelli, Schuchman, etc. Since the values of tonal MLD decreases as the frequency increases from 500 Hz, greater interest has been shown in measuring MLD's for speech by using spondee stimuli; than monosyllables.

A. MLD IN NORMALS:

In order to have an increased insight regarding MLD's in normal subjects many studies were carried out.

Dierecks and Jeffress 1962 on the basis of their own work and earlier studies presented hierarchy of MLD conditions in the order of increasing signal detectability in normals. The 3 conditions that produce the poorest detection are Nπ sπ , No So and NmSm. These were reported to produce about equal masked thresholds and are used as the reference conditions in most MLD studies. The best detection is obtained in the anti-phasic condition

Figure 14 reproduces a figure first presented by Durlach 1960 which summarized several studies on antiphasic MLD's along with a prediction based on Durlach's E-C model. The general size of the antiphasic MLD is about 15 db at low frequencies, decreasing in size, through the mid-frequency range.

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Figure 8 (refer to p. 21 fig.1) shows the effects of noise corre size through the mid-frequency range in phase and for signal out of phase. These data are from Robinson and Jeffress 1963. Noise correlation is a concept which needs explanation. When a noise from a single source is split and led to ear-phones on the two ears, the noise at the 2 ears is in perfect +Ve correlation, if in phase, and in perfect '-Ve correlation' if out-of-phase. The noise at the 2 ears is completely uncorrelated if a separate noise source supplies the noise for each ear. When a combination of uncorrelated and perfectly correlated noise is desired, 3 noise generator can be used, one going to both ears and one of each of the others going to one ear. The extent of the noise correlation is determined by the relative levels of the correlated and uncorrelated noise signals. Another method is to send one source to both ears and a second noise source to one ear, The formulas needed to calculate the correlation for each of these cases and their derivation were given by Jeffress and Robinson 1962. In their study done in 1963, Robinson and Jeffress in order to facilitate the comparison, they reversed the abscissa for the So conditions so that the 2 curves approximately parallel each other in the figure rather than crossing. The MLD extended from 0 dbs with Sπ and noise at -1.0 correlation (which is equivalent to Nπ) to about 12 - 15 dbs with the noise at +1.0 correlation (or No), With So the same results were obtained but in reverse with respect to the noise correlation. Note that there was only about a 3 dls difference

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between Sπ Nu and Sπ Nπ. It's also noted that the MLD decreased very quickly as the noise correlation was reduced from 1.0 or -1.0.

Longford and Jeffress 1964 studied the effect of 'cross correlated' noise on the masked threshold. Noise cross correlation was accomplished by time delaying the noise going to one ear relative to the noise from the same source (correlated) going to the other ear. Figure 9 reproduces a Longford and Jeffress figure showing the MLD for in-phase and out-of-phase signals as a function of the noise interaural delay. The alteration of the 2 curves is very evident. At 0 m.sec. delay the MLD for the So condition was 0 dbs and for the Sπ condition the MLD was about 14 dbs because the noise was perfectly correlated, which is equivalent to No. It was hypothesized that only the components in the noise around the frequency of the test tone (500 Hz) are influential and that this narrow band influences the auditory system as would a pure-tone located at the center of the band. When delayed the components in the 500 Hz centered NB are put out of phase with respect to each other at the two ears. Assuming the NB behaved like a pure-tone, a half period delay; because the half period of 500 Hz is 1 m.sec., the results for this frequency should reverse in 1 m.sec. intervals.

In a study of interaural time delays, Zerli A (1966) concluded that the MLD increases with interaural delay time in a manner similar to that for analogous interaural phase difference. Rilling and Jeffress 1965 in a comparison of

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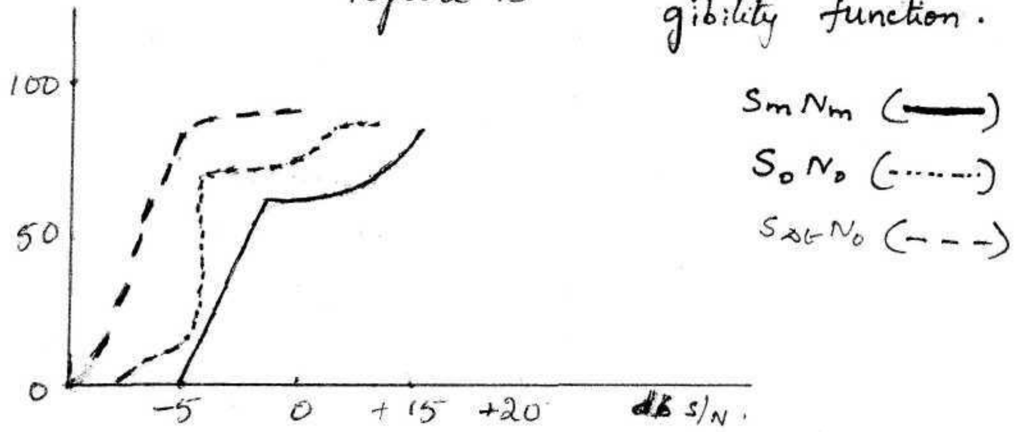
interaural phase and time delays using tones and NB's as test signals observed that when the signal noise had an independent source that tones and NB noise showed the same MLD's as a result of temporal delays and concluded that there is essentially no difference in detectability between a given phase shift for the central frequency of a NB of noise and a corresponding time delay. The MLD is generally assumed to be produced by a narrow band within the broad band masking noise immediately surrounding the frequency of the test tone. Langford & Jeffress 1964 estimated the band to be about 100 Hz wide at 500 Hz. Sondhi and Guttman found the bandwidth to be 133 Hz at 500 Hz and 90 Hz at 500 Hz. Sondhi and Guttman 1966 obtained effective bandwidths of 200 Hz at 500 Hz, 125 at 250 Hz which are considerably wider than the earlier estimates. Mulligan 1967 reported a study which demonstrated that only a NB around the frequency of the test tone is effective in producing the MLD's were obtained with a medium band noise (3100 HZ wide) a narrow band noise (1600 Hz wide) and a medium band noise with a hole in it although a critical bandwidth wide and centered at the test tone frequency. When set a equals spectral levels the 1st, 2nd noises produced equal MLD in spite of the different overall levels. The third noise produces much smaller MLD's. Mulligan Etal 1967 concluded that the MLD depends upon the relative levels, phase and correlation of the paired critical bands of two ears.

Quaranta and Cervellera (1973) in their study with different groups of subjects namely normals, conductive symmetrical, conductive asymmetrical, SN hearing loss, mild and severe Meniere's disease found a MLD value of 8.2 dls in normals which was taken as reference and the results of the pathological group were compared with that of the normals.

Study done by Quaranta,Cossero and Cervellera (1974) to investigate the clinical value of the tonal MLD examined 184 subjects among which normal subjects were 20. Average MLD obtained for normals was 8.2 dbs and the range was 7 to 9.3 dbs. Bocea and Antomelli (1976) have studied the intelligibility function for normally hearing subjects under the 3 conditions SmNm, SoNo and S t No with t = 0.8 m.sec. interaural delay.

Figure 15

Figure shows the intelli gibility function.



Wayne O.Olson and Douglas Noffsinger and Raymond Carhart (1976) encountered MLD's in clinical populations. The results of investigation into MLD's for 500 Hz and spondees among those with normal hearing in this investigation are similar to results reported by numerous other investigators. The value of MLD was found to be 8 dls in this study in normals.

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B. MLD IN SYMMETRICL CONDUCTIVE HEARING LOSS CASES:

Quaranta and Cervellera (1974) found that a similar MLD average was obtained for symmetrical conductive hearing losses i.e. 8.1 to ± 2 dbs, as seen in normals.

In the study done by Bocea and Antonelli (1976) where a group of symmetrical conductive hearing loss were tested, they found that MLD size in this group was the same as that of the control group which consisted of normals.

C. MLD IN ASYMMETRICAL CONDUCTIVE HEARING LOSS CASES:

In 1971 Olsen reported the results of 118 patients with various types of hearing loss, grouped into 6 hearing loss categories and he found that MLD's were least reduced for patients with asymmetrical conductive hearing losses and labyrinttine otosclerosis.

Quaranta, Cassaro and Cervellera (1974) studied MLD in 15 cases with chronic otitis media and found average MLD to be 7.9 dbs, and the range was from 5 to 10.8 dbs, they also took up 12 cases with otosclerosis and found MLD of 7.2 dbs and the range was from 5 to 8.8 dbs Earlier they had found MLD in normals to be 8.2 dbs. They found out that only if MLD as less than 7 db it was considered to be pathological. So they concluded that binaural unmasking is normal in patients suffering from symmetrical and asymmetrical conductive impairment.

Bocea and Antonelli (1976) in their study reported that MLD is significantly reduced in asymmetrical hearing loss cases when compared to normals especially when the good ear is leading and the poor ear laggings Olsen, Noffsinger

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and Carhart (1976) In their study have found that 2/5 of patients with conductive hearing lass yielded Sπ No MLD's at 500 Hz, smaller than that found in normals i.e. 8 db. All of these patients had thresholds at 500 Hz in one ear of 50 dbs Hz and hearing within normal limits at 500 Hz in the other ear. A comparable percentage 50% yielded Sπ No MLD's smaller than 6 dbs for spondees and all of them had SRI poorer than 25 dbs in one ear and an interaural disparity in speech reception thresholds exceeding 15 dbs. These findings suggest that the reduced MLD's in this group are attributable to interaural differences in the signal and noise levels reaching the cochlea. The detrimental effect of large interaural difference on MLD size has been demonstrated for normal hearers also.

D. MLD IN SENSORI - NEURAL HEARING LOSS CASES:

Study done by Quaranta and Cervellera (1972) of MLD in Sensori - Neural hearing loss patients revealed a smaller MLD than that obtained for normal subjects. They found a MLD of 5.7 ± 2 dbs in SN loss cases.

Quaranta, Cassaro and Cervellera 1974 collected 50 cases with SN loss and their MLD value was found to be 5.2 db and ranging from +1.8 to +10.2 db, and so they concluded that binaural unmasking was significantly reduced in patients with SN lesions.

But Jerger and Jerger in 1965 tested in a series of 3 patients with SN hearing loss and it was shown that the MLD was not significantly different from that found with normally hearing subjects.

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Results of study done by E.Bocea and Antonelli (1976) indicated that MLD is small in SN unilateral deafness when good ear is leading.

E. MLD IN NOISE INDUCED HEARING LOSS CASES:

Olsen and Noffsinger and Carhart (1976) found MLD,s for 500 Hz and for spondees. Their results indicated that the behavior of patients with NIHL was unique, because the MLD's for 500 Hz were usually normal, whereas a substantial fraction of the spondee MLD's were smaller than normal.

In evaluating these findings one must first consider that each of the 50 patients in the NIHL group had 500 Hz thresholds in quiet of 25 db HL or better and essentially equal hearing sensitivity bilaterally. Normal MLD behavior would be expected of these patients but they attained a speech SπNo MLD smaller than that achieved by 94% of normal sample. There is a possible explanation for this paradox. Levitt and Rabiner and Carhart have suggested that MLD's for spondees can be predicted from the average of MLD's at 500 and 1 KHZ. If so, those with NIHL who showed small MLD's for spondees in this study probably would have a very small MLD's for 1 KHZ and hence, would have a reduced 500 Hz to 1 KHZ average that matched the MLD for spondees. It's question for future research. For the time being, in instances of NIHL, normal release from masking at 500 Hz may fail to lower its counterpart when spondees are test stimuli.

F. MLD IN MENIERE'S DISEASE CASES:

An extensive study on Meniere's diseases cases has

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been reported by Zahrl G.Schoeny and Raymond - Carhart 1971. Their study tried to explore the effect of unilateral hearing loss due to Meniere's disease on MLD, The purposes were to ascertain whether persons with this type of affliction achieve MLD's which are different from those yielded by normal hearing subjects under the same listening conditions and if so to observe the relationship between shifts in MLD and 4 variables:

1) amount of hearing loss in affected ear
2) Interaural threshold difference
3) Interaural loudness
4) Interaural timing difference.

There ware several reasons for choosing Meniere's disease subjects:

1) subjects with 1 good ear are obtainable.
2) It produces low frequency loss where MLD in normals is large.
3) Air and bone conducted sounds are equally involved thus assuming that one is not dealing with the effect of unilateral middle ear pathology.
4) Recruitment is characteristically present in affected ear, thus allowing exploration of difference in effect on MLD between interaural threshold disparity and loudness disparity.
5) Meniere's disease produces diplacens is and there is the prospect that the nature of diplacensis may affect release from masking.
6) Meniere's disease is manifested by an increase in volume of Enddymph which produces hearing loss by virtue of mechanical changes within the cocklea rather than by virtue of degenerative changes in sense organs. Thus we have a condition in which irrevocable damage to SN system is not a primary feature, atleast in early stages.

The authors selected 12 normal subjects and 12 Meneire's disease patients.

As a frame of reference for comparing the MLD's for two groups, it's helpful to look at the absolute values of

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the mean thresholds these groups obtained under various masking conditions.

Monaural MLD's were computed for SmNu, SmNπ and SmNo conditions by subtracting the mean thresholds for these conditions from mean thresholds for SmNn. It's seen that the controls achieved some release from masking during all 3 conditions and that their MLD's increased in the progression from SmNu to SmNo. By contrast the experimental group failed to achieve appreciable MLD's via the poor ear in any condition and via the good ear in SmNu condition. Samll MLD's did appear when the signal was in the good ear provided the binaural masker was correlated. Stated differently subjects with unilateral Meniere's disease could take modest advantage of correlated noise added via affected ear when the 500 Hz signal went only to good ear, but adding correlated noise to the good ear was of no benefit when the signal was in the poor ear.

The control group exhibited the expected pattern of release from masking, to wit none for SπNπ, moderate amounts in uncorrelated noise and more substantial amounts in the two antiphasic conditions (with more release during SπNo than during SoNπ). The experimental group obtained a similar patterning in MLD's except for the absence of the difference between antiphasic conditions exhibited by the controls. However, the magnitude of the groups MLD's were reduced being only a little more than 1 db in uncorrelated noise and less than 4 dbs in correlated noise.

Unilateral Meniere's disease disrupted stimulus transduction to central nervous system enough so that release from masking did not occur to the normal degree in the several listening conditions employed here. It becomes pertinent to inquire whether the sizes of MLD's of individual subjects were systematically related to their amounts of loss for 500 Hz in poor ear to their magnitudes of interaural threshold differences to degree of their interaural loudness discrepancy, or to the extents of their interaural timing differences.

Subjects were listed in terms of increasing loss at 500 Hz in poor ear. It formed 3 sub-categories. A trio of subjects exhibited hearing levels of 15 db or better. They obtained average MLD's of 2 dbs or better in 6 conditions of masked listening, with the average being highest for the SoNπ and Sπ No conditions. Five other individuals had hearing levels between 30 and 50 db. They obtained mean MLD's of less than 2 dbs except during SoNπ and SπNo where the values were 4.3 db and 4.5 db respectively. The remaining 4 subjects had thresholds at 55 or 60 db HL. Their average MLD's were less than 1.2 dbs for all listening conditions and in only 2 instances was the individual MLD greater than 2 dbs. Thus there was a clear trend for MLD's for 500 Hz to become smaller with increased hearing loss at that frequency.

An analogous relationship is apparent when magnitudes of MLD are compared to interaural differences in threshold. Spearman rank order showed an inverse correlation between these 2 variables at the 5% level of confidence for SmNo (poor ear), SmNπ (good ear), SmNo (good ear),SoNu, SoNπ, and Sπ No listening condition. It's also seen that smaller MLD's are associated with greater threshold differences. MLD's were highest for the 2 subjects with less than 10 db interaural threshold difference fairly uniform for the intermediate 7 subjects and essentially zero for 3 persons with threshold differences greater than 40 db.

An event less definitive inter-dependence emerged between MLD's and interaural loudness differences. In only 2 instances, SmNπ (good ear) & SoNπ did spearman's correlation bespeak a inverse correlation at 5% confidence level. The MLD's ranged fairly nondescriptively from 2.5 to 8.4 db for 9 subjects whose interaural loudness differences were less than 17 db, but were essentially zero for the 3 persons whose differences exceeded 25 db.

The subjects with greatest losses in poor ear tended to be those with the greatest interaural threshold differences and greatest interaural loudness differences. To the degree that these 2 types of differences are dependent upon the severity of impairment in poorer ear, the magnitude of this hearing loss would seem to be the variable among these three that is most intimately related to reduction in MLD size.

Wayne Olsen and D.Noffsinger and Carhart 1976 studied MLD in 12 unilateral Meniere's disease cases. Their results are as follows:

MLD for 500 Hz SπNo was 4.8 and SoNπ 2.9
MLD for spondees SπNo was 3.0 & SoNπ 2.9

More than 50% of the merniere's disease group had small MLD's for 500 Hz and all but 15% of them had abnormally reduced S No speech MLD's. Mean MLD's for the patients divided on the basis of magnitude of interaural disparity revealed somewhat larger mean MLD's among those with similar thresholds bilaterally than among those with 500 Hz thresholds that differed by more than 15 db at the 2 ears. Thus the MLD's were larger for those with essentially equal hearing bilaterally but still were smaller than normal. The fact that MLD's obtained for speech were smaller than usual in both of these subgroups suggests that interaural threshold disparity is not the sole factor in Meniere's disease to reduce MLD's. The reduction is an outcome of distortion in signal transduction occurring at the cocklea on affected side.

A Quaranta, P.Cassaro and G.Cerveliera studied MLD in 27 Meniere's disease cases and found average MLD to be 3.7 db and the range to be 0 to 7 db.

In their earlier study they have reported an unmasking effect in patients suffering from serious and advanced disease to be 1.2 db but a MLD average of 5.2 in cases of mild and recent illness.

Bocea and Antonelli 1976 found that for Meniere's disease group, MLD was very small when the good ear was leading. MLD effect disappeared when the poor ear was leading.

Thas it is seen that binaural release from masking was reduced considerably for the group of patients having unilateral Meniere's disease. It is apparent that low frequency SN loss such as associated with unilateral Meniere's disease does alter the input from one side sufficiently to diminish release from masking.

G. MLD IN VESTIBULAR NEURINITIS CASES:

Quaranta and Cervellera in 1974 studied MLD in 6 cases of vestibular neuvinitis and found an average MLD to be 4.6 db and the range was 5 to 9 db.

H. MLD IN 8th NERVE TUMOR CASES:

Carhart,Olsen and Noffsinger (1976) have reported reduced MLD's for 500 Hz and speech among the 20 patients with 8th nerve tumor dispite the findings that 13 of them had normal hearing sensitivity at 500 Hz and bilterally interaural threshold difference of greater than 15 db. The mean SπNo speech MLD's were 3.1 and 3.2 dbs. The average SoNπ MLD's for 500 Hz and for spondees were larger for those with 15 dbs or greater interaural disparities. The fact that 500 Hz and spondee MLD's were reduced for most of the patients with 8th nerve tumor is evidence that unilateral involvement of auditory nerve can reduce the size of binaural MLD's. Because patients with Meniere's disease often show the same combination of results, lesions of either cocklear or 8th nerve on one side evidently can alter coding of auditory information or its transmission to central auditory nervous system in such a way that the normal advantage associated with antiphasic over homophasic listening condition is lost.

Quanranta, Cassaro and Cervellera (1978) tested 5 cases with acoustic neuroma and found that average MLD was 2.7 dbs, range extending from 1.2 to 4.5 dbs.

I. MLD IN BRAIN STEM LESION CASES:

Douglas Noffsinger took up brain stem lesion cases

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and administered 4 tests which involved binaural comparison or interaction in which MLD was one of them.

Speech MLD's and MLD at 500 Hz were measured. The MLD at 500 Hz was measured in following fashion, threshold for 500 Hz tones presented to both ears in phase was determined in the presence of narrow band noise. The noise centered at 500 Hz and 80 db SPL was presented to both ears in phase. The tones were then put out of phase by 180° and a second masked threshold was determined. The difference between the 2 thresholds was MLD. Normals had a shift of 11 db and these patients had shift of only less than 6 db.

Speech MLD's were measured in the same manner and MLD for normals was 9 db, and in brain-stem lesion cases it was less than 4 and sometimes 0.

A year later Noffsinger along with Olsen studied MLD in 12 brain stem lesion group and found that 500 Hz MLD was about 2 db smaller than those of normal group. This difference is not large but the fact that there was a difference at all is of interest. There is a reduction of speech MLD also. But the reduction in MLD size for these patients cannot be attributed to hearing loss since their SRT and 250 - 4000 Hz thresholds were normal. Therefore, reduced MLD for these patients is more logically tied to some disruption in central auditory nervous system integration of binaural input than to peripheral auditory image.

Olsen, Noffsinger and Carhart (1976) have reported that the average MLD in 12 central nervous system disordered patients was 9.8 in SπNo and 7.3. in SoNπ for MLD at 500 Hz

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and for spondees was 5.0 for SπNo and 3.8 for SoNπ.

Of the central nervous system patients only the patients with an inflamatory lesion of the pons attained reduced MLD for 500 Hz. These patient 4 of 9 multiple sclecrosis patients and patient with ongoing degeneration of cerebellum and adjacent nervous tissue also obtained reduced MLD for speech, the incidence of reduced MLD atleast for speech are seen. The other patient who had reassumed nearly normal neurological status at the time of testing attained 8 dls of binaural release from masking for speech for the SπNo condition and 5 dbs for the So Nπ condition.

In 1974 Quaranta, Cervellera and Cassaro found average MLD to be 6 dbs and the range is from 2 to 10 db in 29 cases of central nervous system. Thus there is a reduction in tonal MLD. So it's hypothesized that in such cases the centers reponsible for the cross-correlation are directly impaired.

Thus the tonal MLD may be used as a test for the diagnosis of central auditory lesions but only in normally hearing patients. Indeed in subjects with SN hearing losses the tonal MLD loses its diagnostic value because lesions of peripheral auditory system disrupt binaural release from masking.

J. MULTIPLE SCLEROSIS AND MLD:

Noffsinger, Olsen and Carhart (1976) studied the effect of multiple sclerosis on the size of MLD. Subjects were 61 patients with multiple sclerosis age 20 to 64 years.

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They reported that the heterogenity of past findings regarding the auditory responses of multiple sclerosis patients is undoubtedly due partly to differences in the sites and extents of lesions produced by the disease and partly to the variety of hearing tests employed.

Neurological and audiological evaluations were made. Among the audiological tests MLD was one.

Speech MLD test was administered because its outcome clearly depends on the adequacy of binaural neurological interactions which are central. This special speech test measured the MLD for spondees. Spondee thresholds in the presence of BBN at 80 db SPL were determined under 2 binaural listening conditions namely the homophasic and the antiphasic. The mean spondee MLD for normal hearers is 8.7 dls and 95% achieve spondee MLD's of 8 or more dbs with the mean 500 Hz MLD being 11.2 dbs.

23 out of 61 patients with multiple sclerosis had MLD's at 500 Hz of 7 dbs or less. These results must be judged as abnormal since 95% of the 50 normals had MLD's of 8 dbs or more.

42 subjects took the spondee MLD test. 5/7 ths of them achieved MLD's of 5 dbs or less. These MLD's must also be considered abnormally small since 95% of the control population obtained MLD's greater than 5 db. Therefore, the 2 MLD's proved to be items on which unusual auditory performance was quite consistently exhibited by the multiple sclerotic subject under study.

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Northworthy is that almost all of the persons yielding small MLD's had bilaterally normal thresholds for 500 HZ and for spondees. For this reason it seems safe to assume that 2 potential sources of decreased release from masking, namely end organ pathology and 8th nerve damage were absent in a preponderance of these subjects. This interpretation leads to the assumption that the reduced MLD's exhibited by this population were the result of lesions in central nervous system.

One might presume that the proper functioning of cross-correlational mechanisms at the medullo-poretine level are particularly critical in achieving normal MLD's - example that the initial separation of signal from background occurs in the centers where binaural stimuli are first mixed. However, when one considers the results in relation to the inferred sites of neurological lesions in our population one finds that the incidence of reduced MLD's was as great in those cases where the brainstem was not involved as in those cases where only the brainstem was involved or where the midbrain was affected along with the brainstem. Thus it would appear that MLD performance is sensitive to pathology throughout much of the central auditory nervous system. Moreover the fact that MLD tests yielded such a high proportion of abnormal responses suggests that this test is quite sensitive to the lesions which multiple sclerosis produces.

One must remember that normal release from masking (large MLD's) can occur only if cross correlational mechanisms are interrelating binaural stimulus trains properly.

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It appears from the present study that the critical cross-correlational processes are not limited to the brainstem. One may speculate that a possible source of disruption in cross-correlation function may be a change in neural teansmission engendered by partial or complete demyelinization within the auditory tracts which disrups the synchrony and completeness of nerve impulse trains reaching correlational centers at more than one level in the central auditory nervous system.

The same authors i.e. Olsen, Noffsinger and Carhart measured MLD's at 500 Hz and for spondees with 290 subjects, 50 persons with normal hearing and 240 patients with various diseases and among them were cases with multiple sclerosis. They found the average 500 Hz MLD's were small - 7.4- dbs for SπNo and 5.7 dbs for SoNπ . A total of 47% of patients had SπNo MLD's that were smaller than 8 dbs, and 42% had SoNπ MLD's smaller than 5 dbs the limits used. Their SπNo speech MLD's averaged 4.9 dbs and 58% of group yielded MLD's of 5 dbs or less. The mean SoNπ speech MLD for group with multiple sclerosis was 4.4 db and 41% of them yielded masking releases of 3 db and smaller. Finding a high incidence of reduced MLD's in a group of patients with multiple sclerosis is particularly important because of the known predilections of such lesions for paraventricular areas of central nervous system including those in brainstem and mid-brain.; They conclude from their data that many of the patients with multiple sclerosis had normal peripheral auditory function but had lesions that interferred with central binaural processing as revealed by MLD.

K. MLD IN CORTICAL LESION CASES:

Noffsinger and Olsen (1971) studied MLD's in a series of 2 hemispherectonized patients and achieved large MLD's. Cullen and Thompson (1971) and Olsen (1973) have also reported patients with cortical lesions who achieved large MLD's.

Bocea and Antonelli (1976) carried out MLD tests on a group of patients with unilateral cerebral lesions of vascular origin and apparently normal puretone audiograms. He found whilst the PTA was within normal limits on both sides, a tendency with interaural delay to produce larger MLD when the ear leading in time was ipsilateral to the normal hemisphere.

Carhart, Noffsinger and Olsen (1976) in their study of 290 subjects found that MLD's were not affected by cortical lesions. Findings sgggest that unmodified participation of both cortical hemispheres is unnecessary for normal release from masking and therefore that MLD's are mediated at levels below the auditory cortex. Hence reduced MLD's with normal hearing is indicate of damage at lower levels of central auditory nervous system and small MLD's in multiple sclerosis patients implicate lesions in brainstem or midbrain or both.

L. MLD IN APHASIC CHILDREN:

Rosenthal and wohlert 1973 explored the MLD in developmentally aphasic and normal, age matched children. The aphasic children showed slight but consistently lower puretone MLD's than normal children.

M - MLD IN PRESBYAMSIC CASES:

Carhart, Tillman and Greetis studied the MLD's for spondee words that were obtained for young adults with normal hearing while exposed to a variety of maskers presented antiphasically and with interaural time delay. They observed that MLD's were largest during antiphasic presentation and slightly larger during parallel time delay than during opposed time delay (entire masker complex given 0.8 m.sec. lag to 1 ear) (opposed time delay - part of the masker complex given the lag to one ear and part of 2nd ear). Antiphasic MLD's varied from 4.5 dbs when 2 talkers comprised the masker. When noise was a component of the masker, the antiphasic MLD's ranged from 4.8 to 6.8 dbs.

In a recent study of masking of speech by others speech, they found that clinically normal but elderly individuals showed a pattern of interference from complex maskers that differed from that observed in normal young adults. This observation led to the authors to hypothesize that in the elderly subject, the MLD for speech would be reduced relative to that observed in normal young adults. Since the mechanism for the release from masking which constitutes an MLD must reside in central nervous system such a finding would suggest that the elderly subject has undergone some subtle if not detectable, deterioration in the CNS which

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interfers to some extent with the binaural signal processing that produces the MLD. This study was designed to test this hypothesis.

The elderly men and women in this study exhibited release from masking of spondees that was in general to the behavior of young adults. Their mean MLD's during antiphasic listening were sizeable and followed the general pattern of the control group. These MLD's differed somewhat for both groups as the masker complex was changed, being largest when 2 talkers were included in the background. Another feature common to the 2 groups was the reduction in MLD size when the masker complex was given parallel time delay rather than made antiphasie. One may conclude that the elderly individuals maintained their capacity to use interaural relations to improve their senstivity for speech in thepresence of competing sounds. However, the performance of the elderly subjects deviated from that of young ones in two ways.

For one thing, the elderly systematically obtained smaller MLDs for the same condition. The elderly as a group were somewhat less efficient than the normals in achieving release from masking. Their deficit in MLD averaged 1.8 dbs during antiphasic and 2.2 db during opposed time delay listening while the mean deficit was only 0.8 db for the remaining time delay conditions.

The grand mean of the foregoing deficits was 1.5 dbs. A drop of this magnitude, while very modest numerically is nevertheless a sizeable fraction of the overall average of release from masking (5.9 dbs) achieved by the young group. To the degree that this trend is representative, it may be taken as revealing one of the ways in which age reduces hearing efficiency. In this regard it's particularly important to remember that a deficit of this kind is not apparently through ordinary hearing tests and that it represents a dis-advantage in the great exacting type of every day listening task, namely abstracting a desired message from among several competing sounds which are on the verge of masking and desired message.

The second deviation in the behavior of the elderly is related to the 2.2 dbs deficit in MLD's they exhibited with respect to the normals during opposed delay. This deficit must be evaluated in light of the fact that the average MLD obtained by the young group during the opposed delay was only 4.5 dbs. Here the elderly appear to have exhibited a note-worthy added inferiority in performance dropping 5 to mean MLD of only 2.3 dbs. This drop was not a general feature of their response to time delay, since their MLD,s during the remaining time delay condition averaged 4.3 dbs as opposed to 5.1 dbs. for the younger subjects. The differences for like masker condition between opposed and parallel time delays were significant at 1% level for the elderly. The interesting thing about unusual reduction in release from masking during opposed time delay is that it occurred during the listening mode wherein an auditor can most clearly assign the difference competing signals to

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separate source location in subjective auditory space. Thus, multiple maskers presented so as to be subjectively separable were more confusing to the elderly than when source location was not so definitive.

To the extent that such behavior is typical of older persons, we may expect such listeners to benefit less in everyday situations than do their younger comparisons from adjustments is complicated sound environments that give each component a distinctive point of origin. Younger people appear capable of coping with the extra complexity posed by this crispness of identity without much change in release from masking, whereas the elderly for whom release from masking is preserved in simpler backgrounds are not able to do as well here. The differences while not large numerically, are important because they represent another way in which the effects of age probably reduce hearing efficiency in complex listening situation. In this regard it should be remembered that while the experimental group in this study was composed of elderly individuals they did not as a group manifest clinical symptoms of hearing impairment. The deficits which they showed in binaural signal processing may well be exaggerated by hearing loss and this possibility deserves attention.

Bocea and Antonelli 1976 studied effect of MLD in a group of presbyousis cases found that whilst under SmNm and SoNo conditions, intelligibility was definitely poorer than in the central group, but MLD obtained under binaural conditions with interaural delay reaches the same values as in control group.

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Olsen Noffsinger and Carhart 1976 in their study of 290 subjects found spondee MLD's smaller for elderly subjects than for normals. Schuknecht has documented the fact that sensory or neural changes in auditory system occur with ageing.

Quaranta, Cassero and Cervellera tested 20 cases of presbycusis and found average MLD to be 7 dbs and the range 5 - 9 dbs.

Tillman have suggested that the smaller MLD's for elderly listeners may be related to increased (difficulty separating signal and noise in intracrucial space, possibly as a result of CNs degeneration.

The below table gives a summary of the results of masking level differences in normals and in each of the pathological conditons. Here the average MLD in each of the pathological group is compared with the MLD obtained in normals and the results are categorized into 3 subgroups.

1) Normal MLD value - Denoted by the letter 'N'
2) Greater MLD - " 'G'
3) Lesser MLD - " 'L'.

	Categories	Results	Average MLD - in dbs
1.	Normals ..	N	7 to 15
2.	Symmetrical conductive hg. loss cases	N	8.1
	Asymmetrical conductive "	N	7.2
3 4:	SN loss cases ..	L	5.7
5.	Noise induced hearing loss cases	L	-
6.	Meniere's disease cases	L	3.7
7.	Vestibular neurinitis cases	L	4.6
8.	8th nerve tumor cases	L	2.7
9.	Brain stem lesion cases	L	4
10.	Multiple sclerotic cases	L	5
11.	Cortical cases	G,	-
12.	Aphasic children	L	-
13.	Presbycusic cases	L Less	- than 7 dbs.

SUMMARY

In this paper 'Review of Litereature regarding masking level difference and its clinical applications' I have tried to include almost all available information regarding masking level difference.

At first there is a small bit of an introduction, than a few definitions of MLD are quoted. The next chapter is mainly concerned with the signal and masker parameters that affect the size of the binaural masking level difference. The third chapter deals with the various theories which contribute to a better understanding of the mechanism involved in the binaural unmasking phenomenon.

The next two chapters are purely concerned with the clinical application of MLD, in that the IV Chapter gives the Methodology adopted by various investigators.

The V chapter gives the result of MLD in various pathological groups namely MLD.

A) In Normals
B) In symmetrical conductive hearing loss cases
C) In asymmetrical conductive hearing loss cases
D) In SN hearing loss cases
E) In NIHL cases
F) In Meniere's disease cases
G) In Vetibular Neurinitis cases
H) In 8th nerve tumor cases
I) In brain-stem lesion cases.
J) In Multiple sclerotic cases
K) In cortical lesion cases.
L) In aphasic children.
M) In presbycusic cases.

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Many a times we have come across studies carried out on a group with some pathology but the obtained results being highly contradictory, and so its extremely difficult to come to any conclusion based on the available studies and so I recommend that a highly controlled study with large number of subjects in the normal group and in the pathological groups be studied, only then it will help us in differential diagnosis.

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