A REVIEW ON THE PHENOMENA OF AUDITORY LOCALIZATION AND LATERALIZATION

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An Independent Project Work Submitted as Part fulfillment
For M.Sc., III Semester (Speech and Hearing) to the
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ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE – 570 006

CERTIFICATE

This is to certify that the independent project
entitled:

**"A REVIEW ON THE PHENOMENA OF AUDITORY
LOCALIZATION AND LATERALIZATION"**

has been prepared under my supervision and
guidance.

(GUIDE)

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This is to certify that the independent project

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"A REVIEW ON THE PHENOMENA OF AUDITORY LOCALIZATION AND LATERALIZATION"

is the bonafide work, done in part fulfillment for IIIrd Semester M.Sc., Speech and Hearing, carrying 50 marks, of the student with Register Number 11

Director

ALL INDIA INSTITUTE OF SPEECH AND HEARING

Mysore – 570 006

DECLARATION

This indeTpendent project entitled

“A REVIEW ON THE PHENOMENON OF AUDITORY LOCALIZATION AND LATERALIZATION

is the result of my work undertaken under the guidance of Mr. M.N. VYASAMURTHY, Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore – 570 006, and has not been submitted at any University for any other Diploma and Degree.

MYSORE

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

“While I thus lay in my pit and listened intently, The antlered caribou began to come to me”

- An Eskimo hunting song.

Quoted by, Maurose Bowra, in Hunting Song (Ch.), in prehistory and early man, 1969

The above verse from a Eskimo hunting song epitomizes what man has just had to do – to listen, intently. He did just that and things came to himself. The remarkable ability to locate a sound source has been made possible because of the phenomena of binaural hearing. It has enabled him to locate a prey, dodge aspeeding truck, enjoy the bliss of stereophonic music, and it has enabled him to listen better, even in very difficult situations. Eaves dropping has also been one of its pleasurable, albeit, and often risky uses.

The listeners can locate the sound sources, in free field conditions – usually our daily listening conditions, as well as, while listening through the head phones – usually the clinical experimental conditions. The former condition is usually referred to as localization, and the latter as `lateralization’. With very few exceptions during localization the sound image is formed outside the head and during lateralization, the image is located within the head (Plenge, 1974). These principles applied clinically, are being incorporated among the routine tests of the audiological test battery. These tests are discussed under the general banner of “directional audiometry”. This directional audiometry has been found to be useful in the differential diagnosis of middle ear disorders; in early detection of retrocochlear disorders (Nordlund, 1962, 1963 and 1964); and in diagnosing the central auditory disorders – temporal lobe lesions or lesions around brain stem (Bosatra and Russolo, 1976). These principles and tests are also accounted with increasing importance, in hearing aid selection and fittings for the hearing impaired (Markides, 1977).

The foregoing review is in accordance with above mentioned areas. This vast material has been devided into mainly four chapters; Binaural hearng; localization; lateralization; and their clinical applications. The titles themselves are self explanatory.

Each chapter begins with an introduction. This is to give the reader an overview of the information compiled in that chapter. Also, each chapter ends with a summary, which reviews back in general, the contents of that chapter. It is mentioned here, specifically that the models of binaural hearing are not dealt in this perview.

It is felt necessary to introduce the numbering system, used for each topic here. The first number refers to the main chapter, the second, to the sub-chapter and third to the division of that sub-chapter and it continues likewise. For example: 4.4.2 means, `Lateralization – Masking level differences – masking level differences for tonal signals.

The parenthesis used here also needs a passing

Remark. The names of the authors in parenthesis `(             )' refers that the preceding discussions were ideas obtained by those authors, similarly, author names within a square parenthesis `[   ]', means that, the lines preceding are quoted as it is from their studies, and/or refers that they are the source authors.

As far as possible, an attempt is made to compile the available literature.

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CHAPTER 2

BINAURAL HEARING

CHAPTER 2

BINAURAL HEARING

2.1 INTRODUCTION

"Binaural" refers to something involving two ears and almost all of us enjoy the advantage of binaural hearing. Hearing with two ears does not provide us just an arithmetical advantage of two ears over one or just a statistical advantage of safety in their chancy world (Mavinakere). Normal listening is almost always binaural.

In evolutionary view point, having more than one ear is a basic property of auditory systems itself. Some properties like localization of a prey or a danger are related to animal survival. Binaural functioning involves spatially segmented sense organs and we see the existence of such spatially distributed sensing elements in all phyla of the animal kingdom and in all sense modalities. Why, even ants have them: (Mavinakere, 1980).

Recent knowledge leads us to believe that binaural hearing has to do something more than just localizing sounds (Markides, 1950). The greatest boon for hearing happiness through the binl fitting of hearing aids has been for teenagers with a severe to profound loss, in particular those who attend a school for the deaf (Lofchie, 1970).

2.2 ADVANTAGE OF BINAURAL HEARING OVER MONAURAL HEARING

2.2.1 Introduction:

Binaural hearing is different, in many ways, from monaural and the auditory system is aware of this fact. The nervous system contains many kinds of cells and some of them especially valuable as participants in binaural analysis (Dattatreya, 1974).

Foregoes a brief discussion of the advantages of binaural hearing over monaural hearing. It is well established that the binaural threshold of hearing is more sensitive than the monaural and the difference being in the range of 3 dB (From Dattatreya, 1974, p.34).

Koenig (1950) asserted that binaural hearing offered the following advantages over monaural hearing:

(a) A remarkable ability to “sqnelch” reverberation and background noises.

(b) The power to select one stimulus from a number of stimuli and as it were to “tune in” to one sound source or one person, the `Cocktail party Effect’ and

(c) To understand speech under extremely unfavorable signal to noise ratios.

Recently (Bergman, 1957; Groen and Hellema, 1960; Mackeith and Coles, 1971) supplemented the above advantages with the following:

(a) Enhanced localization.

(b) Summation of energy both at threshold and at supra threshold levels.

(c) Summation of information content especially when the hearing losses in the two ears are dissimilar in frequency distribution.

(d) Avoidance of head shadow especially when listening with a background noise.

(e) Better discrimination of speech in quiet, and in noise.

(f) Ease of listening, and

(g) Better quality of sound.

We understand these advantages better when we deal with next chapters. Here is a brief discussion of information with speech intelligibility and that on directional hearing.

2.2.2 Binaural enhancement of Speech intelligibility

There is enough evidence to show that one ear can have perfect speech intelligibility (Cherry, 1953; Broadbent, 1954; Bocca and Calearo, 1968). But, in certain conditions, when the second ear is activated, speech intelligibility improves considerably. This improvement can be cumulative of all binaural advantages, summated as binaural summation; facilitation in noise, and integration of incoming stimuli.

2.2.2.1 Summation of incoming stimuli

It is well established that the binaural threshold of hearing is more sensitive than the monaural and the difference being in the range of 3 dB (Feldman, 1967; Bekesy, 1948; and many others [From Dattatreya, p. 34]).

When, two ears are fed with stimuli, at some loudness levels, (not at the same SPLs), It has been established that binaural threshold for speech in quiet, was also around 3 dB more sensitive than the monaural threshold (From Markides, 1977, p. 2). Pollack and Pickett (1958) however, demonstrated that binaural summation of speech in noise can occur, even when signal levels differ by 25-30 dB at two ears. Coles (1968), reported, even with a 40 dB difference, the weaker ear still contributes significant information.

Normals usually listen to speech at levels above their thresholds. Because of this a 3 dB gain may not be significant for them. But, this 3 dB gain may be significant for hearing impaired people.

Hirsh (1950) has reported, on binaural summation of loudness. Pure tone measurements show that, binaural sounds are louder than monaural sounds, by 3 dB to a maximum of 6 dB at a sensation level of 35 dB (Hirsh and Pollock, 1948; Reynolds and Stevens, 1960; Scharf, 1968) [From Markides, 1977, p. 3]

Bocca (1955),Groen and Hellema (1960), Lochner and Burger (1961) using speech discrimination procedures, showed that binaural and monaural curves run parallel to each other. And the monaural curve, required ahigher level, to achieve the same articulation score as for binaural listening. This horizontal shift was of the magnitude of 3 dB (Markides, 1977, p.3). Although, these studies used PB mono syllabic lists, with connected speech this difference can be very substantial.

Aniansson (1973) found binaural intelligibility of PB words, in everyday listening conditions with 63 normals and patients with bilateral sensory neural losses. He reported that S.n. loss patients had 25-45% lesser scores than normals. In quiet, the difference was 5 to 15%. This again substantiates above findings.

2.2.2.2 Facilitation of speech in noise

Interaural Phase: The difference in phase between signals presented to the two ears is called as interaural phase. This is known to have an effect on masked threshold of tones (Hirsh, 1948; Hirsh and Pollack, 1948; Jeffress, Blodgett and Wood, 1958) [From Markides, 1977, p.3].

A tone is more detectable when its interaural phase is different from the interaural phase of the masking noise (heterophasic condition) or opposite to it (anticiphasic condition). While when the interaural phase of the tone and noise are the same (homophasic condition), detectability is poorer.

The difference between homophasic and heterophasic thresholds is often referred to as `Masking Level Difference (MLD)' or Binaural release from masking', or `Unmasking' (Markides, 1977). Though the advantage of listening binaurally when attempting to attend to a given voice in the presence of others, or against a competing noise, is quite dramatic subjectively, and was so reported by `Koenig'. It measures only a few dB in most laboratory studies. But MLD's for certain non contextual signals may be as high as 22 dB (Schubert and Shultz, 1962). Although the studies vary considerably, because of their procedural differences, all point to an improvement in speech discrimination, due to MLD.

This particularly refers to interaural phase differences and are obtained through ear phones. In true free field listening, however, interaural differences in intensity and acoustic spectra occur simultaneously with interaural phase differences. So, only IPD's cannot be related to enhancemet of speech intelligibility in a free field situation (Markides, 1977).

The Squelch Effect: Koenig (1950) observed a remarkable binaural ability to select and attend at will to any single sound from a complex auditory environment. This ability to `tune in' to a particular signal and at the same time to minimize the interfering effects of unwanted background noise, is referred to as `Squelching' (Markides, 1977).

Studies of speech intelligibility in noise with normally hearing people (Nordlund and Fritzell, 1963; Harris, 1965; Carhart, 1965) it has been found that binaural reception was improved over monaural near ear listening (ie., listening with the ear on the same side as the speech source), as much as if the background noise in the near ear had been reduced by 3 dB. Carhart termed this reduction the `binaural squelch effect' (Markides, 1977). Studies report squelch of 0 to 4 dB, and the difference between different studies are rather small and can be attributed to different speech materials employed (Markides, 1977). When a 3 dB squelch can be combined with head shadow effect, it might became significant.

The head shadow effect: A signal coming from the right side of a person will be louder in his right ear than in his left ear and vice versa. This reduction in loudness, at the far ear, is obviously due to intervening head. The effect is referred to as the `head shadow effect' (Markides, 1977). These interaural intensity differences, are reported to vary with frequency, maximum effects are seen when head was fully interposed between sound source and the test ear (Sivian and White, 1933; Weiner and Ross, 1946; Weiner, 1947; Nordlund and Liden, 1963; Shaw, 1966) [From Marides, 1977].

Similar results were reported when effect of head shadow on speech intelligibility was studied (Markides, 1977).

The effects varied from 5 to 7 dB on spondee thresholds of normal listeners (Olsen, 1965. [Markides, 1977]. In a situation where a single ear is unfavourably placed in relation to the wanted sound, the head shadow effect can be translated into a binaural advantage of 13 dB (Markides, 1977). But, in most of the daily listening situations, always one of the ears is placed favourably to sound source, so head shadow is largely ineffective.

Most studies used speech, were delivered through ear phones only recently (McKeith and Coles, 1971) that binaural and monaural listening have been compared for conversational levels of speech in a free field situation against a background of noise over a considerable range of sources. They found that binaural listening was better than partial monaural near ear listening for all speech and noise orientations, except when the noise came directly opposite to one ear and speech directly opposite to the other ear, although some of the advantage did not yield statistical significance (Markides, 1977).

Hirsh (1950) suggested that directional hearing facilitates the intelligibility of speech, especially in the presence of noise and that slightly head movements give sufficient localizational cues to a monaural listener, thus eliminating the advantages of the binaural squelch and head shadow effects. But Olsen (1963), criticized, Hirsh's monaural condition, as infact binaural, as Hirsh failed to adequately masked the other ear. So, even it is not totally binaural condition (From Markides, 1977, p.7.). Olsen's investigations, appeared to point out that head movement can alter the head shadow and squelch effects slightly; but even substantial head movement, cannot fully overcome these effects on speech. Same conclusions can be drawn by Mackeith and Coles (1971) study (Markides, 1977).

Therefore, a binaural listen can cope up with difficult listening situations, because of two factors – 1. He always has one of his ears exposed to wanted sound source (16 dB advantage) and 2. Squelch effect gives an additional advantage of 3 dB. When both effects are additive, a 19 dB binaural advantage can be obtained (Markides,1977). This is even supported by Schubert and Schultz, (1962).

2.2.2.3 Cross correlation of incoming stimuli.

Several lines of evidence points to the binaural system as a detector of the instantaneous correlation of wave forms delivered through ears separately (Pollack, 1971).

This cross correlation facility enables a binaural listener to use interaural signal differences in temporal and intensity characteristics, in binaural reception especially in presence of noise (Cherry and Sayers, 1956, 1957, [From Markides, 1977, p. 8]). Also, it enhances speech intelligibility, when in complete auditory patterns each ear (Fletcher, 1953, Bocca, 1955), Ofcourse such an ability has its limits.

Perrott and Barry (1969) determined the binaural fusion limit on 7 young adults using dichotic pure tones. They found limits range from OHz difference at 250 Hz to 640 Hz at 8 KHz. It can be deduced from this that, by stimulating second ear of hearing inpaired people, speech intelligibility may be enhanced.

2.2.3 Directional hearing

2.2.3.1 Introduction and Factors in Directional hearing

The notion that auditory localization, is better under binaural conditions than under monaural is being opposed by researchers recently and evidence can be found in even older studies (Angell and Fite, 1901; Jongkees and Veer, 1957; Vlehweg and Campbell, 1960; Fisher and Freedman, 1968; Butler, 1969; Butler and Planert, 1975; etc.). Still two ears are better than one (Markides, 1977).

Since the beginning of this century many workers have studied the physical phenomena governing directional hearing. From a physical view point, directional hearing can be explained by the effects of the interposing head and the distance between the two ears. This involves differences in intensity, differences in phase, differences in time of arrival, differences in spectral composition and multiple changes in these differences due to head movement and the reflective properties of the environment. The interpretation of these differences is influenced by learning and past experience, as shown by Pierce 1901; Hirsh, 1952 etc. (Markides, 1977). A description of all these factors and studies done on them can be found in next chapters.

The importance of directional hearing is well known. The need to locate the source of sound is necessary not only from survival point of view, but also for communication.

2.2.3.2 Pysiological explanation of directional hearing

Experiments of Skinner and Skimota, 1972, have shown that binaural hearing is neurogenic in origin. But the exact neurology is least understood. On the basis of anatomical evidence and electro-physiological evidence, Galambos, et. al, (1959), Von Bergeijk (1962) proposed a model of binaural interaction for the accessory nucleus. Current evidence indicates that superior olivary complex is the center of the auditory nervous system, in which the first interaction of nerve impulses from the two ears takes place (Rassmussen, 1946; Galambos, Schwartz, Korff and Rupatt, 1959; Hilali and Whitefield, 1952; Stotler, 1953). Though the mingling of homolateral and contralateral fibers from the ochleat nuclei is complete by the time superior olivary complex and lateral leminsci have been reacted. The exact place of occurance of binaural interaction is not yet known [Dattatreya, 1974]

Matzker (1959) attempted to explain the existence of a directional perception in binaural hearing of slight time differences as resulting from centrifugally coursing inhibitory impulses in the auditory path ways of brain stem. These centrifugal path ways have already been demonstrated anatomically as well as electrophysiologically. The importance of central inhibitory pathways in the organized completion of the hearing act becomes obvious. But the exact mechanism underlying, it is yet to be understood.

2.3 CONCLUSIONS

Binaural hearing has been assessed advantageous over monaural hearing. The advantages can be summarized as follows:

1. Enhancement of speech intelligibility.

2. To understand speech under extremely unfavourable signal to noise ratio.
3. Enhanced localizing ability.
4. To select stimuli in a complex `Cocktail party Effect'.
5. A remarkable ability to `Squelch' reverberation and background noise.
6. Summation of energy both at threshold and at supra threshold levels.
7. Summation of energy, especially when the hearing losses in the two ears are dissimilar in frequency distribution.
8. Avoiding head shadow, when listening with a background noise.
9. Ease of listening and better quality of sound.

We discussed briefly the binaural enhancement of speech intelligibility and directional hearing. The foregoing Chapters deal with localization ability and lateralization abilities in detail.

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CHAPTER 3

AUDITORY LOCALIZATION

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3.1 INTRODUCTION

From stand point of survival, the two most important things to be known about a source of sound are what it is and where it is. Knowledge about the former depends upon the remarkable ability of the hearing mechanism to discriminate subtle differences in the composition of the sound; the later is the function of localization ability of the human auditory system (Jeffress, 1975).

The location is far more important; it dictates the direction for visual contact, and it offers the directions for flight (From Foreward, for Chapter 8 "Auditory Localization" in Tobis, 1972, p. 301).

Spatial relations do not impinge upon each ear as they do upon each eye. Light from different directions fall upon different parts of the retina, but sounds from all directions stimulate a common membrane extended in frequency rather than in space. Visual localization may work by directions, but auditory localization must by indirections find directions out (Mills, 1972).

Both the localization of signals in auditory space and detection of signals in backgrounds of interference are severly degraded, when stimulus is restricted to one ear. From evolutionary point of view for the predator's in order to catch the prey localization is important. For many normal hearing listener's in a noisy environment, each ear not only receives signals from many sources, but it receives the signal from a given source over many paths of reflections. Somehow the listener transforms this hodge podge of a stimulus into a clear and distinct perception of various acoustic properties of the room in which the sources are located. Even though monaural hearing would bring about most of the characteristics, binaural hearing has a larger role to play.

The most characteristically binaural of all auditory phenomenon is localization. The process by which a listener reports distance and direction of the apparent source of sound. If a sound source is very close to the listener, the sound coming directly from the sources will be much greater than sound reflected by any near by walls. Converse is true for distant sources.

It has been already pointed out that, although there are evidences to show that only one ear is needed for processing information given by acoustic stimulation, there is no doubt that the second ear improves the ability to localize and to discriminate speech. It is also pointed out that two ears determine effectively the distance and position in both the azimuth and elevation of the sources.

The circular plans formed around the head is that is created by the emission of sound in the free field, is called azimuth. The distance between the centre of the head and the source of sound is called the range (Yost and Nielson, 1977).

According to Carhart (1958), the ability to localize sounds depends on the fact that the two ears are separated by the head. In consequence, the listener achieves what he calls, an `auditory triangulation', on every sound. The sounds will result in identical excitation of the two ears only if the source is directly in front or directly at the back, or in the mid saggital plane. If the position of the source is deviant with respect to this plane, the acoustical excitation becomes dissimilar i e., the sound will be different at two ears, in one of the following dimensions (1) intensity (2) time of arrival (3) phase, or (4) spectrum. And these factors are influenced by many other factors such as, head movements, eye movements body tilt and posture, Aging, pinna position and action, other sound reflections, other physiological systems in body etc. These factors will also be discussed in this chapter in detail.

To localize a sound it is necessary and sufficient to determine the curvature of the on coming wave front and to establish a perpendicular to it. The fact of having two ears, led to the finding the azimuth of a source of sound – and upon two measurements – interaural differences in intensity of the sound and interaural differences in time at which it reaches the ears (Mills, 1972).

Interaural time and intensity differences are explained in duplex theory of sound localization (Lord Rayleigh, 1907). This widely cited theory asserts that the auditory system uses interaural time differences to localize only for frequencies below about 1200-1500 Hz; and at higher frequencies it can only use the gradually increasing interaural level differences (McFadden and Pasanen, 1976). But this theory has been criticized and many additions and modifications are brought about.

This part hopes to give some basic understanding of auditory localization, and also hopes to aid in reading, next topics, where all these factors would be highlightened.

3.2 LOCALIZATION AND LATERALIZATION COMPARED

The study of cooperation of both ears in aural perception is partially facilitated, when the ears receive the sounds separately, usually by the use of ear phones. This is an advantage, in that, the whole scale of differences between the signals coming to the ears, the Interaural Time Difference and Interaural Intensity Differences can be manipulated separately and individually. When listening through ear phones, the sound source is inside the head. Consequently, this intracranial localization (inside head localization, IHL) is called lateralization, as opposed to localization (outside head localization, OHL) according to direction and distance (Plenge, 1974).

Schirmer (1965) and Tool (1970) hypothesize that, if concomitant changes due to head turning are prevented during listening to a sound source far away from the listener in free space, an intracranial localization of sound image has to be expected. This did not happen in Plenge's experiments.

But, while listening through ear phones to sound signlas (conveyed by an artificial head) extra cranial localization of sound image occurred. This did not depend upon head movements, as changes in sound signals were not noticed, and therefore head movements may render a more likely confusion (Plenge, 1974).

Some researchers (Ebata and Nimusa, 1968) concluded bone conducted sound leads to OHL. Many have contradicted this hypothesis.

Many have proved that sound coming from loud speaker to ear, can lead to IHL (Inside head localization) (Sandel, et al. 1955, Fedderaar, 1955 etc.) (From Plenge, 1974). Jeffress and Toyler (1961) concluded that “Apparently whether we should speak of localization or lateralization depends on what we ask the subjects to do, rather than how we present the sound to them”. They also warrant in making this statement by their results that suggest, localizing sounds coming to ears via ear phones is essentially the same task as localizing an external sound.

Both the small Initial Errors, which were about the same in magnitude as those reported by stevens and Newman and lack of any great improvement with practice, in this direction. This may also suggest that, a subject can learn if adequately trained to correlate certain acoustic stimuli. These do not agree with other results, if extra cranial localization, so, difference is agreed usually between localization and lateralization (Jeffress and Toyler, 1961) [Qoted by Plenge, 1974]

In the study by Plenge, (1974) the assumption was a basic difference between out of head localization (OHL) ad inside head localization (IHL) with ear phones. Results indicated that OHL also occurs when the signals at both ears stimulated by an external source sufficiently alike, although those sound events are conveyed through ear phones. According to author, these results prove that, the question of whether OHL or IHL occurs does not depend upon any kind of electro acoustic transmission.

According to methods on binaural recording and reproduction with dummy head, directional information is the original sound field is believed to be reproduced faithfully with head phone listening and the problem of out of head localization has been reported in some literature (Gotoh and others, 1975). Gotoh and other (!975) performed experiments taking the acoustic energy density ratio of reflected sound to direct sound (Ar) as one of the factors that affect subjective distance as for as a sound source is concerned. It was also assumed that `Out of head localization' n binaural hearing through head phones depends on the case, when the subjective distance is very large. He also reported methods of ranging value of Hz and the experimental results of making a close examination of `Out of head localization' in binaural hearing relative to different sound directions around the listener.

3.3 FACTORS IN LOCALIZATION

3.3.1 Interaural Time Differences (ITD)

This refers to the difference in time of arrival at the two ears of the start of the sound on any of the transients of the complex sound. Blauret (!972) suggests at least two mechanisms for evaluations of interaural signal differences, one, the time difference of sound signal; two, the time difference of the sound envelope as well as interaural level difference.

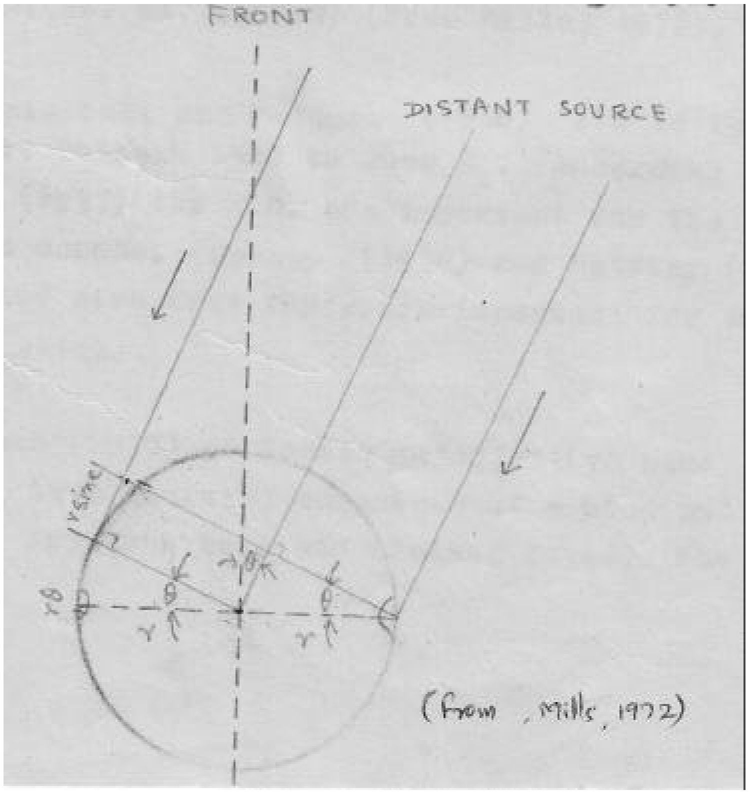
The waves from different directions impinge upon the tympanic membrane. If the sound arrives at the two ears at different instances, then it is localized towards the side from which the first impulse was heard. The speed of air is constant and is independent of frequency. Thus the interaural temporal difference for any frequency is same for a particular stimulus location, whereas interaural phase difference will vary according to the frequency of the stimulus ie., If a

1000 Hz tone, (period of 1 m.sec.arrives in the right ear .5 m.sec. after it has reached the left. The tone at the right ear is half a period (180^0) out of phase with the tone at the left ear. If a 500 H$_z$ sinusoid (a period of 2 m.sec.) arrives this same 0.5 m.sec. late at the right ear than at the left ear, there is only one quarter period phase difference between two ears (90^0). Thus two different tones (1000 H$_z$ and 500 H$_z$) having 0.5 m.sec.interaural time difference produce different interaural phase differences (Yost and Neilson, 1979).

Mills (1972) gives a model to explain interaural time differences. For a moment regard the ears as a pair of holes separated by a spherical obstacle. If a sound source is to one side of the head, the sound reaches the farther ear about 29 M.sec. later for each additional centimeter it must travel. For a sound lying in front of the interaural axis and far enough away to produce a plane wave front, the difference between the shortest distances to the ears 4d is given by

$$?d= r(? + \text{Sin } ?)$$

You can derive this formula from the figure.1.

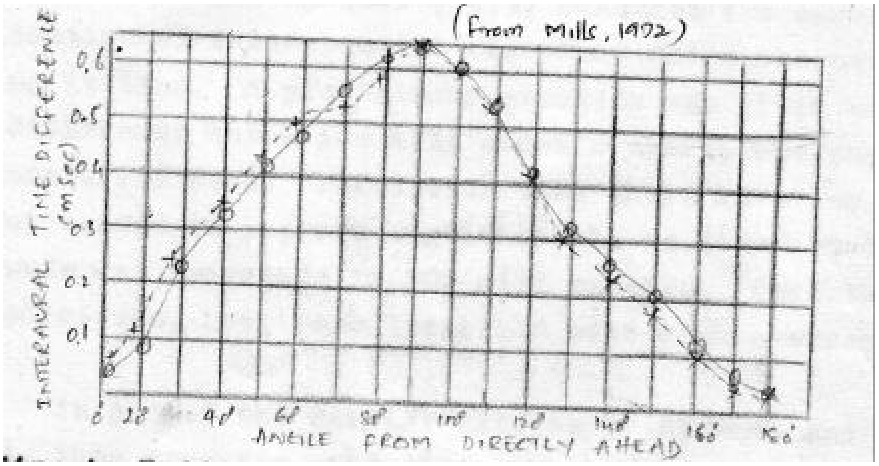


(from Mills, 1972)

The angle 0 is measured in radians with respect to the median plane of the head. If we assign a radius of 8.75 C_m to the spherical head and take the velocity of the sound C to be 343 meters per sec. the interaural time difference `t' is given by

$$t \quad \text{Sec.} = d/c = 225\ (? + \text{Sin}\ ?)$$

This time difference `t' is in good agreement with the actual measurements of interaral time differences for adult males. (Ref. to fig. 2).


(From Mills, 1972)

According to Fedderson, et al (1957), the interaural time difference varies regularly between 0^0 and 180^0. It varies between 0 and 0.65 m.sec. It is maximum at 90^0 and 270^0 (Fedderson, et. al. p. 305) (From Mills, 1972).

Zwislocki and Feldma (1956) ITD is important for frequencies between 1500 to 2000 H_z. According to Christian and Roser (1957) the ITDs are important for the localization of complex sounds. Bekesy (1930) and Matzkar (1967) have demonstrated also that ITD's are important for the lateralization of clicks.

Kuhn (1977) performed an objective study of the steady state ITD,on a manikin, comprised of a head and Torso. Data were taken for both bare and clothed torso. The measured ITD's correspond reasonably accurately to the low and the high frequencies to the computed theoretical values for a rigid sphere of an effective radius `a'. The results support that in man there was no localization improvement below approximately 500 H_z, poor localization between 1000 Hz and 2000 H_z and a change in the localization cue around 1400 H_z from ITD to IID.

Thurlow and Jacques (1975) measured the accuracy of localization of 2 independent wide-band noise sources, overlapping in time. A preliminary practice was given when the time difference was a few mill seconds apart, the perception of 2 tones was poor. Perception that there were two sources present tended to improve significantly as time between onset of sounds was increased to 100 mill seconds. Once the sounds were perceived, they were localized with high accuracy.

In one of the earlier studies by Stevens and Newman (1936), they reported, the time cue available to the subjects was the difference in time between the sinusoidal wave forms at the two ears. They assess that, to utilise such differences, auditory tracts should carry the cycle – cycle wave form temporal relationships of the stimuli. The study assumed such cues available upto 1000 H_z and failed to occur after 2000 H_z, also that this cue provided basis for localization at low frequencies. Mills (1958) also reached similar conclusions. Details of these earlier studies can be found in topic (3.4).

Recently Henning (1974 a, 1974 b) remade a point that, the auditory system `can' utilise ITD to `lateralise' high frequencies when wave forms are complex (See Chapter 4 for details).

It is now quite clear that, the ITDs are one of the important cues for localization of sounds. Of course, when, dealing with pure tones a difference between the time of arrival at the left and right ears also means that there is a phase difference between the two signals. In real situations, however, sounds do not consist of a signle pure tone. They have complex wave forms with irregularly spaced transients and consisting of low as well as high frequency components. The various component frequencies of a complex sound its envelope, and its transients will be diffracted by different amounts; they will be phase shifted by different amounts; and also they will be delayed differentially at the two ears. Thus localization of a complex sound may depend upon a simultaneous effect of the intensity and time of arrival differences. Consequently it can be stated that sound localization is based on a complex running cross-correlation of intensity and time of arrival differences. Consequently it can be stated that sound localization is based on a complex running cross-correlation of intensity and time of arrival interaural differences each of which can be "traded" with the other, a feature known as the "precedence effect" (Markides, 1977).

3.3.2 Interaural Phase Differences (IPD)

Rayleigh (1907) suggested phase differences to account for low frequency directional hearing; the rationale being that when two continuous tones varying only in phase are fed t the ears the listener tends to lateralize the sound as caming from the side of leading phase. Various upper limits, 1000 H_z (Jongkees and Groen, 1946), 1500 H_z (Sandel et.al., 1955), 800 H_z (Christian and Roser (1957). It seems that phase differences alone do not explain directional hearing for low frequencies, as intensity factor should also be considered (Hartley and Fry, 1922). Now we know that time of arrival has replaced phase as a factor that affect directional

Hearing (From Markides, 1977, pp.9-10). Phase differences are mainly considered in laterlization experiments. Christian and Roser (1952) and Keitz (1957) gave two reasons for phase factor. 1. The wave length for 800 H_z tone in air is about 42 Cms ie., double the distance, between two ears. 2. For tones with a shorter wave length, a particular phase difference may correspond to several positions of the sound source. Rayleigh (1909) also agreed with this statement.

Mastudana and Fukani (1973) reported that inphase produces a sharp and centrally located image. As phase differences became larger, the sound image moves in the direction of leading phase loud speaker. Above an azimuth angle of 90^0 phase difference almost became certain. At 180^0, localization is almost completely uncertain. Hence regardless of the type of sound source the overall tendencies of localization versus phase differences are similar except for a sound source of impulsive nature.

3.3.3 Interaural Intensity Differences (IID)

The difference in intensities at the two ears on the arrival of sound is referred to as interaural intensity difference (IID). This has been long considered as cue for localization at higher frequencies.

It is very obvious that is a sound originates on the side of a listener, for example, the left ear will be stimulated at a higher intensity than the right ear because the left ear is nearer the sound source and because it is not in the `Shadow’ of the head (Markides, 1977).

Lord Rayleigh (1904) suggested that a listener by making use of these intensity differences localizes the sound source towards the side receiving the louder stimulus. Intensity differences, however, occur if the wave length is small compared with the dimension of the head.

The higher the frequency the shorter the wave length and thus greater the sound shadow caused by head in establishing the IIDs. Thus large interaural intensive differences exist at high frequencies.

Al already mentioned the head casts a shadow for the high frequency signals on their wave length is smaller than the distance between the ears. It is therefore nil or very little at low frequencies, while it could be as much as 20 dB at the high frequencies. The head therefore acts as a low pass filter (Sivian and White, 1933; Wiener, 1947) [In Mills, 1972].

Stevens and Newman (1936), report that IID is present at all frequencies but is pronounced at frequencies above 4000 H_z. Steinberg and Shaw (1933) have shown that the head casts much densor sound shadows at the high frequencies than at low, thus providing much longer differences of level at high frequency. Also at high frequencies, the pinna casts stranger shadows, thus making sounds coming from the back weaker than those from the front, and so, improving front back discrimination for high frequency tones and for clicks and hisses (quoted by, Jeffress, 1975). Mill's also conducted similar results. Blauret (1972) reports, the interaural intensity or level differences, as more important with common daily sounds.

Mills (1972) reports that, the interaural difference in intensity is not so well behaved. ie., to say that, the

IID does not vary regularly either with respect to frequency or with reference t azimuth angle. The far ear lies in a sound shadow whose depth depends upon the direction of the source and upon the wave length of the sound. The head is a low pass filter for the far ear, but, its properties are not a simple function of either the direction or the frequency of the sound (Mills, 1972).

Hartley and Fry (1921) examined IID at different azimuths and cocluded that it is important for frequencies above 300 H_z. Sivian and White 1933; Rosenberg and Slavinsky (1940), Nordlund and Liden (!963) have expressed similar view. Even Weiner (1947) came out with similar results, using artificial head.

Mills (1958) reports that for frequencies above 1400 Cps. Intensity differences seem to provide the basis for azimuth discrimination. Two kinds of intensive cues are possible monaural differences between the sound pressure levels successively present at either ear, and interaural differences between the sound pressure levels simultaneously present at each ear. But he was not clear, in his experiment which one was effective.

We can deduce from all above studies that the phase/time differences help in localizing low frequency sounds and at higher frequencies, the intensity cues contribute for localization.

3.3.4 Time Intensity Combinations

3.3.4.1 Ambiguous cues: Many times, the researchers have noticed that explaining a localization behavior, with the help of only one cue ie. either ITD or IID is rather difficult. This is especially true, in the middle frequencies. In these mid frequency ranges an aubiguity in localization exists. This is shown by decreased localization performance around 1500 H_z (Klumpp and Eady 1950, Mills, 1958, Stevens and Newman, 1936 etc.).

Supporting this notion, Sandel et al (1955) performed a similar experiment with a different technique. He found an average error of absolute localization was also greatest at 3000 Cps. The variability of localization (the error after allowance was made for constant biases in each subject's judgement) increased with frequency upto about 1500 Cps and decreased again in much the same way as the functions relating the minimum audible angle to frequency (From Mills, 1958).

This confusion in localization of sounds of mid frequencies is explained by the presence of an "Ambiguous Temporal Cue". At 1,666 H_z one cycle has a period of 0.6 M.Sec. Thus the ear to the side of the source receives the sound .6 M.Sec. Earlier. It takes .6 M.Sec. for the sound to travel from one side of the head to the other. Thus the lagging can misses one cycle or gets it .6 M.Sec. later. Thus, the subject should turn towards the side which is leading in phase. But this does not happen. When a difference in intensity is apposed by a difference in intensity is apposed by a difference in time between the two ears, the two tendencies to lateral localization may cancel one another and leave the apparent source in a median plane (Yost and Neilson, 1977).

3.3.4.2 Transient Disparity: Interaural differences in the time of onset or time of arrival of the first wave of a tone pulse at the ears are not limited by the period of the tone and are not subject to the phase aubiguities of steady tones. Such time of onset disparities are usually carefully eliminated from experiments by turning the tones on and off very slowly. They are avoided because they constitute a temporal cue of a basically different character from ongoing ITDs. The range of frequencies over which interaural disparities in time of onset may be effective is not limited either by the size of the head or by refractory periods of the auditory neurons. The duration of an onset disparity is no longer than the interaural time difference itself – the onset information ends when the sound has reached both ears. ITDs for a low frequency sound, on the other hand, are ongoing disparities – they continue to provide temporal cuew as long as the sound lasts (Mills, 1972). This has leads to the studies on discrimination of ongoing differences in time. At 1000 H$_z$, an interaural disparity of 10 to 15 M.Sec. is detectable (Klumpp and Eady, 1956; Zhislocki and Fieldman, 1956) [Mills, 1972]. A lot of studies in this area can be found in section 3.4. Where in early studies are described. To summarise, in this area, with sounds of such relatively long durations, the influence of ongoing disparity is favoured; even in the shortest burst (10 M.Sec.) the ongoing duration is much greater than the transient duration. For short impulsive sounds, the effects of transient disparity should be much greater, although and may not be meaningful to extrapolate the trading relationships directly to brief clicks.

3.3.4.3 Time Intensity Combinations: The effect of ongoing, transient and IIDs on localization of actual sources of sound change with the spectrum of the sound. Time intensity trading relationships are attempts to determine how these two kinds of disparity interact by presenting them dichotically varying one kind of disparity independently of the other (Mills 1972). Many experiments on these lines are attempts to develop models of physiology of auditory lateralization [Ashort discussion can be found on these lines in Chapter 4]

Thus, a combination of time and intensity cues, act simultaneously and also differentially. Sometimes they are inseparable, especially during daily normal listening.

3.3.5 Spectral and Distance Cues

The ability to localize a complex sound also depends upon their short term interaural “Spectral differences” brought about mainly by the diffraction effects of the head and pinnae, the reflective properties of the environment and the impedence mismatching of the sounds at the two ears depends upon the angle of incidence (Mach, 1865, Markides, 1977).

Reviewing the literature, we find many contradictions between studies, usually because of methodological differences and individual differences of subjects.

Jongkees and Groan (1946): noise and complex sounds are better localized than pure tones. Nordlund (1962 and 1964), found low pass filtered noise better localized than pure tones. Christian and Roser (1957) reported that no such difference exists between the notes and pure tones. Banks and Green (1973) found that subject’s ability to localize transient signals in a free field depends upon the low frequency energy mainly. The minimal audible angle is about 3 or 4^0 for all transients containing energy below 2000 H_z.

Butler, Roeffler and Naunton (1967) asked listeners to judge location of tone bursts and differently filtered noise bursts on the horizontal plane. Stimulus frequencies within the range of 2,000 to 4,000 H_z appeared further towards the medial plane, than the stimuli of higher and lower frequencies. They also found that, more the peripheral the sound is, the more the azimuth angle displacement.

Doeffler and Butler (1968) observed higher pitch sounds are perceived as originating above the lower pitch sounds in a localization task on a vertical lane. Similar phenomenon was observed in congenitally blind persons, and young children. They implied that, tonal stimuli have intrinsic spatial characteristics which result in the perception of frequencies with shorter periods as being higher in space than those with larger periods.

Butler and Belendiuk (1976) found no improvement in localization until the band width became more than 4,000 H_z. They implied that spectral differences do not improve or lower performance. The same authors (1977) compared loud speaker data with ear phone data. Analysis of these spectra showed that a notch in frequency response curves which migrated toward the lower frequencies as the sound source moved from above to below the aural axis. They indicate this is an important feature, for localization in median suggital plane (MSP). Additional testing, indicated, spectral cues provided by some subjects were more efficacious than others in functioning information on the elevation of sound sources.

Makabayashi (1974) found that the ability of directional hearing to a real sound source of 1 octave noise is very poor. For correct directional hearing, a sufficient amount of 8 to 16 k comparent and widening of signal band are effective. He stresses the signal frequency and sound pressure level factors for misjudgement.

Kuhn (1963) reported that for frequencies below 2,5 k H_z, the directivity can be predicted mathematically and for higher frequency inter pinna differences are proposed, alng with cut off frequencies of stimuli and pinna size. Kuhn (1977) reported that in man there was no localization improvement below approximately 500 H_z, poor localization between 1000 and 2000 H_z and a change in the localization cue around 1400 H_z from ITD to ILD. This is in accordance with older studies (Nordlund 1962 and 1964; Newman and Stevens, 1936, Christian and Roser, 1957).

All these multiple differences and their systematic changes due to head movement govern the quality or timbre or the sounds at the two ears, and according to pierce (1901) this binaural information enhances auditory localization. Added to this, according to Sayers and Cherry (1957), we have also our acquired knowledge of acoustic properties of typical situations like open door ways, windows, corners of rooms, etc., and we have our whole sensory integration faculty (From Markides, 1977, p. 11).

Distance cues, are majorly supplied by the spectrum of complex sounds with distance. The high frequencies are attenuated more rapidly than the low, of course the loudness of sounds of familiar level also provides a cue to distance (Jeffress, 1975). Coleman (1962) found even when loudness factor was ruled out, the accuracy of localization was maintained. Bekesy (1930) argued that in judging distance the ear can utilize the varying differences in attenuation with distance between partical velocity and pressure in a spherical wave, differences which vary as a function of frequency. This cue would be operative over distance of a few feet (From Jeffress, 1975).

3.3.6 Head movements/Off head position and Visual cues

3.3.6.1 Head movements and Off Head position: Wallach (1960), Thurlow and Runge (1967) and Thurlow, Mengels and Runge (1967), have studied on influence of head movements on localization of sound sources.

Thurlow and Runge (1967) induced head movements involving rotation, during auditory localization tasks. A significant reduction in the sizeable horizontal errors of directional localization for both high and low frequency noise and click stimuli was observed.) This obviously involved reduction in front-back confusions "Subjects were photographed with a moving camera, during localization task. Changes in angular position of head was studied. Rotation movement of the head about a vertical axis (turning, left/right) were most commonly found alone, in combination with tipping and pivot movements (nose up or down and increase in the vertical height of one ear and a decrease in vertical height of the other ear). A number of subjects also showed reversals in movement. The reversals were most prominent in the case of rotation movements [(Thurlow, Mangels and Runge, 1967)].

Gilman, Dirks and Hund (1977) have designed a system to trade human head movement response to sound originating at different azimuth locations with respect to head. A vedio recording is made of the movement of a light `beamie' placed on the subjects head. The X-ray coordinates are marked to measure movement and a computer programme to calculate amount of head movement.

Gatehouse and Russel (1979) studied the horizontal and vertical localizing accuracy and bias of 72 normal hearing subjects under monaural vs binaural, restricted vs unrestricted head movements and training with or without feedback listening conditions. Although same well documented effects were confirmed (eg: binaurals localize better in both planes; sources are shifted to unplugged ear side), the results demonstrated that no simple relationship exists between training and head movement conditions.

Role of head movements have been explained variously. The kinesthetic cues from neck muscles and changes in binaural cues of level and time with movement combine to improve the accuracy of localization, especially in regions where binaural cues are ambiguous. Front back reversals are virtually eliminated, if the subject is permitted to move his head or is instructed to do so. Accuracy of localization in the vertical plane is greatly enhanced if a tilting movement of the head occurs (Jeffress, 1975).

Head movements, however, do not seem to give a complete explanation of front rear discrimination, for it is well known that localization both in the horizontal and in front rear discrimination can be very accurate even with the head rigidly fixed. In view of this, several workers asserted that pinna plays a role in auditory localization.

The effect of off head position on localization: Karner and Davidson (1967) reported that when the head was rotated with respect to the body, a significant displacement of the auditory image straight ahead in the same direction as the head turn was found for both the body and head in apparent mid plane.

A study by Comalli and Altahuler (1973) demonstrated the apparent straight ahead of a tone was found to shift in the direction of the head turn for the body reference, but not for the head turn for the head reference.

3.3.6.2 Visual facilitation: Warren (1975) has clarined that there are visual facilitation effects on auditory localization in adults but not in children. He suggested that a `visual map' organizes spatial information and that considerable experience of correlated auditory and visual events is necessary before normal spatial perception is developed.

In an experiment by Jones (1975) children in grades 1, 4 and 7 had to identify the position right or left of a single tone either blind folded or with their eyes open. Analysis of data showed that Ss were more sensitive to auditory position when vision was available. Reaction time was also generally faster in the light. Jones (1975) argues that the increase in sensitivity in the light represents updating of auditory position memory of voluntary eye movement. In the dark eye movements are subjected to involuntary and unperceived drift, which would introduce noise into the eye control mechanism and hence into auditory spatial memory.

Jones and Kabanoff (1975) tested the hypothesis that auditory position are in part determined by target directed eye movements. The results showed that sensitivity to the position right orleft of a lone decreased when the subject kept his eyes fixed. Also, sensitivity declined considerably if the subject's eye movement was cued away from the tone either by a light source or by an instruction to the subject. Since providing the subject with a tactile spatial cue did not bias reports of auditory position, the author argues that eye movement serves to update and stabilize auditory position memory. Finally, the author concludes that, voluntary movement rather than a `visual map' (Warren, 1970) is likely to provide the frame work for spatial judgements.

3.3.7 Pinna

Recent studies together with others dating back as far as 1851, leave little doubt that the cavities and convulsions of the pinnae play an important role in the localization of signals that originate in the medial plane (Gardner, 1973). Pinna performs a direction dependent transformation on the high frequency (more than 4 k H_z) specral energy content of incoming sound (Bloom, 1977).

Mach (1875) claimed that the Pinna seened to be a resonator for the high frequency Sounds. In doing so, the pinna affects the timbre of the stimulus.

Even the modest pinnae with which man is equipped play a substantial role in the localization of noise with high frequency component (Jeffress, 1975).

Roffler and Butler (1968 a) found that flattening the pinnae down by means of a plastic band reduced the ability of human subjects to localize high frequency bands of noise in vertical plane. With pinnae in normal position localization in vertical plane was considerably accurate. This is also supported by other studies (Navarro, 1972).

With tones Roffler and Butler (1968 b) found that subjects localized tones according to frequency, the highest frequency at the top and lowest at the bottom, with the middle frequencies assigned to localizations between in an orderly

Progression and irrespective of the actual localization.

No adaptation to functional loss of pinnae is reported (Navarro, 1972). Bauer et.al. (1966) reported that localization of sounds with one pinna is possible with some amount of practice in localization. Also supported by Gardner (1973), Russel, (1976). Binaural reception also adds upto the information for localization (Gardner, 1973). Animal studies also support these notions (Fisher and Freedman (1968). Two theories **are** put forward to explain the role of pinna in localization.

A. Pinna shadows
B. Pinna reflections.

A.Pinna Shadow: Mills (1972) imply that the significant transformation of the incoming signal is in the intensity – frequency domain. The power spectrum is not an invariant transform of location, but also depends upon other characteristics of the source.

However, for a complex sound, the second ear or movements of head could specify a `difference' spectrum that would be useful since the ear can detect very small changes in energy distribution (Karlin, 1945). The role of pinna in monaural localization, according Mills (1972) is still a controversy (Mills, 1972, p. 334).

For higher frequencies the azimuthal directivity is shaped by the coupline of higher order acoustic modes in the pinna to the ear canal. Inter pinna differences can be resolved on the basis of transverse acoustic modes, cut off frequency and pinna size (Kuhn, 1979).

B. Pinna reflection: Batteau (1962) proposed an additional action of the pinna - a transformation of the incoming signal in the amplitude time domain by means of echoes would have to vary in relative delay as the angle of incidence of the wave front varies. This theory places a severe requirement for temporal resolution on a single ear. This hypothesis requires that each ear resolves events following one another within less than 300 M.Sec. and transmit to the central nervous system, in one form or another, an indication of more than one temporal dimension. A neural mechanism for recoding echoes from amplitude – time domain into the familiar amplitude – place domain of the basilar membrane might provide the required temporal resolution in advance of the synaptic delays of the auditory tracts.

Bloom (1977) hypothesized from his study that the auditory system in cooperation with the brain, has `learned’ that specific spectral modifications are carriers of directional information. And modifications for a given angle of elevation will be in some respects unique for each pinna.

Probably, the most important role of the human pinnae is the alteration of the high frequency from sound coming from the back. The consequent change in the spectrum of familiar sounds is an excellent cue to determine whether the source is in front or in back. The large moveable pinnae of many animlas are no doubt of even greater value in localizing a source of sound (Jeffress, 1975).

3.3.8 Precedence Effect/Hass Effects

Echoes reflected from surfaces in the environment could provide additional information about the location of a source of sound if the auditory system were equipped to use them and if the listener were familiar with the arrangement of the reflectors. But such echoes would be confusing in unfamiliar environments, and the auditory system seems designed to suppress awareness of them. The suppressed reflections are not literally inaudible. The echoes are commonly heard, but their influence on localization is largely suppressed by the precedence effect' (Mills, 1972, p.340).

This phenomenon is given by Haas (1949) and by Wallaeh, Newman and Rosenzweig (1949), called `Hass Effect' by sound engineers and as the `precedence effect' by psychologists (Jeffress, 1975). Wallaech et.al. studied the phenomenon first by using phonograph records with two pick ups, one directly behind the other in the same grove. When the earlier sound is reproduced in one direction and later from another, the listener heard the sounds as fused and as coming from the direction of earlier sound, even when it was weaker than the echo (quoted by Jeffress, 1975).

Later Wallaeh et.al. (1949) determined the interaural time difference of the first click pair (ITD_1) needed to offset a fixed and opposite ITD of a second click pair (ITD_2), when the pairs were separated by a time interval short enough to yield a single fused image. For several valves of ITD_2, they found that the indifference point, ie. where the left and right judgements were equally likely, occurred when $/ITD_2/ /ITD_1/ = 6$. (Quoted by Brandauer and Ward, 1979). Brandauer and Ward (1979) repeated this experiment at various sensation levels and found that the ratio decreases from valves greater than theirs at SL=20 dB to nearly one at SL=65 dB.

Blauret (1971) reported at times some test persons reported a disintegration of their auditory sensation into a front and a rear component. Explanation for this is given by Harkness (1973). The author quotes, Seashore (1899) and Pierce (1901) who each showed that their subjects tended to localize relatively weak sounds behind and relativelystrong sounds in front.

Closely allied to the precedence effect is a finding by Blodgett, Wilbanks and Jeffress (1956), that a wide band noise delayed at 1 ear by more than 20 M.Sec., confuse into a single sound, ie., heard as coming from the undelayed side. Even when the ndelayed noise is 9 dB below the delayed, the subjects hears the sound as coming from the undelayed side, if the time difference is not in excess of 4 M.Sec. This phenomena like precedence effect indicates the length of time a pattern of excitation can be held in storage by the auditory nervous system (quoted by Jeffress, 1975).

The precedence effect plays an important part in "Stereophonic Sound" (Milla).

Recent neuro physiological experiments show that some neurons in the auditory systems of Cat and Monkey are responsive to – interaural time differences that are larger than the maximum value possible for animals with their head widths. Such neurons could be activated in several ways in real world situation and it is also suggested that, these neurons might be involved in the suppression of erraneus localization information, the suppression of reverberation and/or in the analysis for periodicities in the acoustic stimulus (McFadden 1973).

3.3.9 Effects of ear muffs. Ear plugs and helmets:

Bauer et.al. (1966) study, had the subjects wear the ear plugs from 6 hrs. to 3 days. Predictable shifts in localization errors were observed when the stimulus was a broad band noise made up of frequencies above 3000 Cps.

Reorientation required atleast 3 days, without training.

Noble (1975) investigated results concerning the break down of localization. Localization was tested in normal and while ear protectors were worn. Results suggest, ear plugs cause errors of localization which require an improvement of the classical theory. Also wearing ear muffs disrupt localization, and increase risk of accidents. The selective hearing is disrupted.

Russel and Noble (1976) attempted to determine effects of ear muffs and ear plugs on localization. Results support an spectral information transformation and was suggested that spectral invariants are central to the localization of complex sounds in the horizontal plane. To support this a modification of pinna shadow hypothesis were proposed.

Russel (1976) examined spectral transmission characteristics of ear muffs and ear plugs, to determine whether the behavioural findings could be related to changes in azimuthal spectral patterns. This notion was supported. Ear plugs produced a systematic change in the energy region of 600 to 10,000 H_z at azimuths in the region 15 to 19^0 – the same region for which consistent rear ward shifts occurred. This suggests that ear plugs disrupt resonance at cocha.

Ear muffs severly impair localization. The author concluded that spectral changes generated by the head and pinnae are critical in complex sound localization and that monaural differences in this drain are more crucial than interaural differences. Russel (1977), found that Ear muffs produce a permanent loss of information, which are difficult to adapt to and as such wearing ear muffs could be dangerous in some industrial settings.

Bharthraj et.al (1976) studied localization functions under helmet wearing and non-helmet wearing conditions. The results pointed to definite overall impairment under the helmet wearing condition, with worst hit directions being bottam, back and top.

3.3.10 Loudness balancing on complex sound localization

Russel (!974) examined the role of loudness information to investigate the possibility that monaural information is processed and used in binaural localization decision. 10 subjects were tested with white noise for localization, with 5 cncealed loud speakers in the left front quadrant of the medial horizontal plane. The loud speakers were balanced for 1. sound pressure level 2. loudness. No differences were found between equal intensity versus equal loudness either for percentage correct responses or for a number of front – rear confusions. It was concluded that monaural loudness information is not a criteria for binaural localization but that more information is needed to investigate other monaural variants of localization especially the pinna generated difference in the frequency domain, amplitude domaine.

3.3.11 Effect of age on localization

Matzkaer and Springborn (1958) considered that directional hearing deteriorated with increase in age. Clicks were utilized as stimuli. Nordlund (1964) did not find any definite effect of age in his investigation of directional hearing in free field situation for tones and low pass white noise.

Viehweg and Campbell (1960) found that poorer directional hearing can be expected with advancing age. Toning (1973) also found poorer directional hearing with increasing age.

3.3.12 Vestibular apparatus

Nordlund (1962 and 1964) found that an intact vestibular apparatus was not essential for auditory localization of sounds.

3.3.13 Effects of Alcohol (in persons with normal hearing on localize of sound).

The intake of alcohol causes deterioration of the central hearing capacity. This effect can be well demonstrated by regression in the directional hearing ability. The decrease in ability of localization of sounds is similar in characteristics as in presbycersis. The decline can be detected at blood alcohol level of 1000 ml. Males and females manifest identical deterioration. The directional hearing test is said to be as reliable as vestibulogram of 20 subjects tested. The blood alcohol level obtained was between 0.71 and 1.77 parts per mililitre (Rrued, 1974).

3.3.14 Adrenal insufficiency

Pruszenicz and Kosowiscz (1972) performed tone audiometry, loudness recruitment test, auditory adaptation (according to Feldman) and auditory localization test in a group of 29 subjects with primary and secondary adreno cortical insufficiency. They found 14 patients had disturbed sound localization, mainly with concentric and symmetrical hearing impairment was observed. Afterwards disturbed functions improved. Authors relate effect of sterioid harmone on the various parts of the hearing organ and on the CNS, to these functions.

3.3.15 Auditory localization and Body tilt

Lackner (1974 a, b) reported that the induction of an error between a subject's true orientation and his registered orientation in relation to gravity results in auditory mis-localizations of a similar size and time course. The presence of visual cues prevents development of errors in localization. The author interpreted these observations as evidence for a spatial reference systems responsible for maintainance of auditory and visual direction constancy. They demonstrated that where a subject hears a sound is dependent not only on the auditory cues at the ears but also on his registered orientation in relation to the gravitational force vector.

Atshuler and Comalli (1970) demonstrated body tilts of 30^0 and 60^0 the location of a single over head source is displaced opposite the body tilt, when the task is to localize the sound as directly over head, ie., in the mid line, these results are reported to be consistent with other studies. It is said that a compensation is involved for body position when a tone is localized in the environment.

3.3.16 Localization and pitch sensation

Butler (1973): stimuli with sameness of pitch (75 Sec. pulses, repetition rate 200 times/Sec. and narrow bands centered at .63, 1.6, 2.5 or 6.3 kH_z) were presented to listeners for localization in median saggital plane. Butler, reported that despite the sameness of pitch, the .63, 1.6 and 2.5 kH_z centered sounds were perceived as originating low, middle and high positions respectively, regardless of their actual positions. 6.3 kH_z stimuli was more accurate with all subjects. It is considered that when auditory cues lack, timbre nor pitch influences perceived elevation. This puts timbre as also a cue to locate elevation of high frequency sounds. When Korburger and Elfner (1970), made 1 ear of 18 normal subjects, functionally useless, and presented noise bursts (0.01 or 1 M.Sec. duration, 3 M.Sec rise – fall time) from mid line, the subjects were asked to localize. They found that additional spectral cues led to the better performance and a general deterioration with shorter bursts noticed. Conclusion was that subjects judged and localized on the basis of pitch cues, which are reduced at the shorter durations used in the study.

3.3.17 Monaural Vs Binaural localization

Binaural hearing has been emphasized as a must for localization, usually described in terms of interaural difference cues. Monaural localization is considered to be less effective means of localizing sound. It is thought that monaural localization occurs if subject can turn his head to generate difference cues or if he has had previous experience with the particular sound (Perrott and Elfner, 1968; [quoted by Bothe and Elfner, 1972])

Hebrank and Wright (1974) write several investigators have shown that monaural localization of sound sources on the median plane (M.P.) is inferior to binaural M.P. localization. This causes speculation that two ears are necessary for M.P. localization and further that two ears may allow binaural processing of a symmetrical pinna filtering making localization of unfamiliar sounds possible. In their study, binaural and monaural subjects had similar difficulty in localizing unfamiliar sounds. They also indicate M.P. localization is fundamentally a monaural process. This is also supported by Bothe and Elfner (1972).

Monaural localization in median plane studies (Bothe and Elfner 1972; Gardner 1973; Bloom, 1977; Hebrank and Wright, 1974; Gatehouse, 1976) suggest that,

1. Spectral changes, are considered to be possible cues for localization in median plane.

2. Pinna and its cavities have a definite monaural components – Pinna optimizes cues for location, and produces spectral changes enabling localization.

3. Monaural subjects are similar to binaural subjects in localizing and monaural listeners can be trained easily.

4. Conductive and sensory neural subjects localized these stimuli equally well and at greater than chance performance. This is contrary to previous findings.

5. A correspondence between human detection of a delay tuning process and an equivilant spectral filter.

6. There by stressing that monaural localizations are equally possible.

Presumably same views are held for horizontal plane localization, but this has not been shown unequivocally, there are data which white not discounting the importance of the higher audio frequencies in monaural localizations of sound in the horizontal plane, clearly indicate the cues provided by these frequencies are not utilized as effectively as they seem to be in median saggital plane localization (Butler and Planert, 1975).

Belendiuk and Butler (1975) Experimented monaural localizations with low pass noise bands in horizontal plane. Listeners showed no localization ability until the upper cut off frequency reached 5 $kH_{z,}$ later performance increased, with addition of still higher audio frequencies. When spectrum measurements were done with a head – pinna model, it was seen that spectral compositions were distinguishable only at higher frequencies.

The same authors in another experiment (Belendink and Butler (1977) reported, increase in band width did not necessarily lead to improved localization performance until, the band became broad, including for eg: all frequencies above 4 kHz. They explain this by saying that listeners perceive narrow bands of noise originating from restricted places in the horizontal plans, which may differ one from another, depending upon the frequency composition of the stimulus. This case then, does not bring about improved performance, by augmenting spectral information. This suggests that the expression of judgemental biases, may prove useful to explain why some specified width and center frequencies are localizable and others are not.

Gatehouse and Cox (1973), tested accurate monaural localization, using a strict definition of monaural deafness. They found monaural localization is better than chance.

Monaural localization is dependent on timber differences, as experienced by external ear and are compared with cortical impressions (Fritz and Gloning, 1973). In functional monaural listeners, pitch cues helped in localization and these pitch cues reduce with stimuli duration reducation (Kornburger and Elfner, 1972).

3.4 EARLY STUDIES IN AUDITORY LOCALIZATION

3.4.1 Introduction

To localize a source of sound, it is necessary and sufficient to determine the curvature of the oncoming wave front and to establish a perpendicular to it (Mills, 1972). Early investigators started recognizing the importance of having two ears on the side of head. This led to the concept of azimuth of a source of sound. The early studies looked for two important cues, the interaural differences in time and level. In this section 3.4 on `Early Studies', an attempt is made to present studies that were available, a picture of studies done before 1970. Some studies may be found overlapping with other sections, although attempt is made to avoid this. These studies found to present information which could not be easily assigned to other sections.

3.4,2 Classical Studies

The first study to be conducted in a reasonably anechoic environment (free field) was that of Stevens and Newman (1936). [Jeffress, 1975]

In this study subjects sat in a chair on top of the building. The sound source was a speaker, attached to the chair 6 feet away from subjects. Tones of various frequencies, Clicks, hiss sounds were stimuli. The sensation levels of tones were 50 to 60 dB, except for highest tones, which were about 30 dB. Sounds were generated at every 15^0 position, always to the right of subjects. Subjects indicated verbally the 15^0 psotion of the sound source.

Results were expressed as average deviations in degrees from position of the source. An average error as a function of frequency was determined. The results show that errors grow with frequency from 1000 H_z upto about 3000 H_z and then diminish. At 10,000 H_z the average error is about that for 500 H_z . The average error as a function of the location of the source is given below:

Localization	0^0	15^0	30^0	45^0	60^0	75^0	90^0
Average Error (Degrees)	4.6	13.0	13.6	16.3	16.2	15.6	16.0

The proportion of front – back reversals were proved to be a fnction of frequency. Ranging from 40% upto 2000 H_z to about 15% for 4000 H_z and above frequencies.

The clicks and hiss – complex sounds were localized more accurately than tones. The average error for clicks 8.0^0 and for hiss 5 to 6^0, front back reversals were less frequent.

Stevens and Newman, accounted their data to two binaural cues ITD and IID. ITD: since tones were switched on gradually, the only time cue was the difference in time between the sinusoidal wave forms at the two ears. Study assumed that such cues available upto 1000 H_z and lack after 2000 H_z. IID: is said to be present at all frequencies, but is pronounced at frequencies above 4000 H_z. Steinberg and Snow (1933) had shown that, the head shadows is more at high frequencies, thus larger level differences are present at high frequencies. Also at high frequencies pinna casts strong shadows, making sounds from back weaker, thereby helping in localization at high frequencies (Jeffress, 1975).

A second and thorough free field study was conducted by MILLS (1958) (Jeffress, 1975).

Early investigators demonstrated that sounds are localized toward the ear that is stimulated first, or toward the ear receiving the greater intensity (Trimble, 1978) [Mills, 1972]. Mills (1972) quotes, Sandel et. al. (1955) and Zinslocki and Feldman (1956) who drew same conclusions as Stevens and Newman (1936).

The accuracy with which an observer can localize an actual source of sound has been investigated in two ways, one, the observer may be asked to indicate direction from which sound appears to come. This is used in many studies (Stevens and Newman, 1936; Sandel et.al. 1955; Held, 1955) or the observer, may be asked to indicate only whether two successive sounds come from the same or different directions. This measures relative precision, or resolution, of auditory localization (Mills, 1958).

The difference limen for the azimuth of a source of pure tones was measured as a function of the frequency of the tone and the direction of the source. Tone pulses between 250 and 10,000 Cps were sounded in the horizontal plane around the head of a subject seated in an anechoic chamber. The smallest angular separation that can be detected between the sources of two successive tone pulses (theminimal audible angle) for each of the 3 subjects. These threshold angles are analyzed in terms of the corresponding threshold changes in the phase, time, and intensity of the tone at the ears of the subject (Mills, 1958).

In this study, the smallest change in azimuth from which the listener could identify the direction of change correctly on 75% of the trials is called “Minimum Audible Angle (MAA)”. The results are similar to Stevens and Newman (1936). The conclusions drawn from this study were as follows:

Differential azimuth discrimination varies with azimuth discrimination varies with azimuth and frequency of stimulus tone. MAA is smallest between 250 and 1000 Cps and for sources straight ahead. The MAA increases rapidly between 1000 to 1500 Cps and as azimuth approaches 90^0. At all azimuths MAA drops between 3000 and 6000 Cps, and raises to a second maximum at about 8000 Cps.

In this experiment Mills reports, a comparison of thresholds for dichotic stimulations and indicates that the resolution of the direction of a source is determined at frequencies below about 1400 Cps, by interaural differences in phase or time and at higher frequencies by differences in intensity. At optimum conditions for temporal discriminations the threshold of ITD is about 10 micro seconds, and when the conditions are optimal for intensity discrimination, thethreshold for IID is about 0.5 dB. These results are similar to other studies.

The poorer accuracy of localization at large azimuth angles is suspected whether due to smaller changes in time or level or is the auditory system less sensitive to these angles. Mills did not present comparable data with IIDs. It is found that ITD increases as angle increases. The poorer performances at frequencies around 1300 Cps has been related to ambiguous temporal cues. Here neither time nor level cues are effective. This would also suggest a limit to the auditory systems ability to follow cycle by cycle movement of the stimulus (Mills, 1958).

3.4.3 Other Studies

Freedman and Praff (1962) studied 12 subjects to find whether during exposure to dichotic noise, postural conditions would affect post exposure discriminations of dichotic time differences. They concluded that auditory disorientation is not important as reported in most studies of sensory deprivation. These findngs are relevant for astronauts whose movements are restricted in a unusual sensory environment. Bocca and others (1964) hypothesized that the auditory pattern of 2 ears are analyzed separately and again at higher mechanisms analysis takes place. Central fusion is dependent upon binaural separation within the limits imposed by the anatomical placement of two ears.

Freedman and Stampfer (1964) displaced ears by means of a high fidelity pseudophone, that effectively rotated the interaural axis through a 20^0 horizontal angle. After exposure to sound source subjects demonstrated significant shifts averaging 6^0. These shifts partially compensated for by error of localization produced by pseudophones.

Butler and Naunton (1964) tried to study the role of stimulus frequency and duration in the phenomenon of localization shifts. They reported, displacement towards the side of maximum interference, when interference stimuli frequencies were 1 octave or more below that of the signal. As the level increased the magnitude of the pulling effect became greater. Another experiment showed that the puling effect increased as the signal duration was lengthened from 0.5 to 100 mili seconds. The interaction is thought to be central.

Igarashi and Beek (1964) considered theoritically,.

the localization of sound from two plane wave sources. Phase and angle of arrival of waves are diminished in relation to the amplitude.

Bauer and Blackmer (1965) summarize three studies of unaided auditory localization of fixed noise sources. It was indicated that pointing was as accurate as aiming at auditory targets in darkness. Elevation errors were not significantly larger than azimuth errors. Subjects with hearing deviations (defects) performed as well as normals, in auditory localization.

Hochberg (1966) presented a sentence to 65 hearing blindfolded subjects in median plane. It was found that localization was more accurate in front than in rear positions of azimuths. Front back reversals were equal in both quadrants of azimuths. Subjects who demonstrated less errors for back rear confusions were regarded as more accurate localization.

Gardner (1968) reports the `proximity image' effect, that of selecting the nearest rational location as the apparent position of the source, although particularly striking at 65 dB level, tends to occur even at very low levels. The effect is also found to be independent of the relative distances of various units over a considerable range.

Listeners locate higher level signals at the nearest loud speaker. Lower level signals than are attributed to longer distances, regardless of which speaker was in use.

This effect emphasizes difficulty in estimating distance, as well as directional sign, of a sound source on the basis of subjective impression of its location. This is particularly true, in the absence of such cues as reverberant content, familiarity with the position of level to be expected, vocal effort or relative audibility of breath sounds in the case of live speech etc.

Gardner (1968) was interested in loud speaker reception. The ability to locate transient signals directly in front of the listener, was studied for high quality speech signals in noise free anechoic space. The average error ranged from 1.50 to 5^0 on a wide range of levels.

Perrott and Barry (1969): The presentation of complex signal to a listener in free field generates interaural differences which are not readily relegated to the classical cues frequently discussed. The listeners head acting as a progressive low pass filter, may spread the area of action to several thousand cycles.

3.5 RECENT STUDIES

Here the studies published after 1970 are considered.

3.5.1 Studies in median plane

Gardner and Gardner (1973): Localization of sound sources `outside’ the median plane is influenced by differences caused by head shadow and time of arrival of sounds at the two ears. For the sources in median plane, primarily pinna plays an important role. They progressively concluded the pinnae cavities, and showed that localization ability decreases with increasing occlusion. This effect is better for anterior than posterior sector. It was also reported that high frequencies signal content is more important. Banks and Green (1973) found low frequency energy is more important to localize transients in free field.

The problems in localizing in mediam plane, involve a change in distance perception, including reversals, - front back confusion (proximity image effect; Gardner, 1968). Here included a tendency for reverberant signals to appear farther away from their non-reverberant counterparts. With increasing loss of high frequency components, sound source appears to move farther away (Snow, 1953) [Gardner and Gardner 1973]. The absence of head shadow and time of arrival of signal in median plane are some factors that are accounted for (For details please ref. to Gardner and Gardner, 1973).

Morimoto and Nomachi (1978) compared SP (spectral) cues and ID (Interaural difference) cues, in two median plane localization taks. They found that all subjects can localize stimuli with only SP cues, but with both cues localization accuracy is decreased. With only ID cues localization was not possible. These results indicated that `SP' cues are more important than ID cues in median plance localization. However, authors warn not to neglect ID cues.

Blauret (1971) presented two identical broad band (noise and music) signals from front and rear positions. The subjects head was in fixed position. A time delay of maximum ± 880 micro seconds could be set. It was found that direction of sound sensation coincided with the angle of incidence of first wave front for delay times, greater than about ± 500 micro seconds (law of first wave front). For smaller delays this law does not apply. At these delays, the reflected sound contributes for localization, generally one sound sensation occurs in the direction of reflected sound source. For this effect, the factors are, type of signal; the directions of incidence of primary sound and reflection; the difference of time and level between them. This effect is termed as `Summen lo Kalisation', which can be translated as `Summing Localization' (Blaret, 1971).

Explanation for this effect is by the assumption that the sound fields of primary sound and reflection superpose in such a way that the resulting sound field, depends on characteristics of both. And a definite sound source is formed usually referred to as, `Bhantam Sound Source'. This summing localization is one of the principles of stereophonics. Similar attempts are made also by Theile and Plunge (1977) with discrete quadriphasic system.

Davis and Stephens (1974) found that noise is localized more accurately than speech stimuli in vertical plane. Increasing the sensation levels, decreased localization errors till 80 dB than reached a plateau. They also reports there is little or no apparent learning process in the localization task. Sagolovitch and Petrovskaya (1973) reported that `a wide band' noise only with frequencies more than 4 $kH_z$ was localized accurately. They emphasized that below 4 $kH_z$ localization was almost impossible. They also found persons with hearing asymmetry resulting from `Meniere's disease' had a more significant localization impairment.

Lambert (1974) attempted to explain a dynamic theory of sound source localization. He explained that, a listener can calculate the azimuth and range of a sound source `wholly' on the basis of interaction with the sound stimulus. Prior knowledge about sound source, is not a prerequisite for localization.

Terhune (1974) also found noise band localization was more accurate than that for sine waves. The difference has been attributed to prior experience with acoustic cues. Author says that, as sine waves are not common in nature, subjects had less opportunity to develop localization ability using these cues.

Thurlow and Jack (1973) presented evidence which shows that, localization ability can be produced by adapting to both intensity and time differences. In general the displacement of the test stimulus is away from the perceived location of the adopting stimulus. However, exceptions have been found. Authors relate these mechanisms to some final control mechanisms.

Gerber and others (1971) found that the interaction among interaural phase angle differences and the diotic binaural thresholds were limited to frequencies of 1.5 kc/s and lower. The significant interactions were limited to 45^0 and 90^0, there was no significant interaction at any frequency for 180^0.

3.5.2 Studies in horizontal plane

As it has been already pointed out, the cues for localization in horizontal plane, are head shadow and differences in arrival of signals at two ears. Cobat (1978) described accuracy and bias of 12 subjects in localizing sounds in horizontal plane. The perceived directions were biased away from the median plane, has being greater for sounds from back than in front.

Tolkmitt (1974) investigated individual localization times, keeping 8 speakers equidistant in horizontal plane.

Accuracy of localization increased with increasing delay. The same effects were observed even when the subjects were rotated by 90^0. The fact of differential processing of time was supported.

3.5.3 Studies with populations other than normal adults

Moore and others (1976) found that the visual reinforcement conditions produced most localization responses in 48 normal infants followed in order by social and no reinforcement conditions. Results indicate that auditory localization behaviour of infants is influenced by reinforcement and effect dpends on type of reinforcement employed. Cohen (1974) asked blind folded subjects to point to auditory targets both before and after prism wearing sessions in order to determine if intermanual transfer of prism aftereffects was due to a change in sensed position of the head relative to the trunk.

Tonning (1975) found no difference in localization ability between normal hearing, blind and normal sight groups. For blind orientation may be facilitated by fixed appropriate sound sources and type of stimuli. Devens and McCroskey (1978) compared dynamic auditory localization of normal and learning disabled children. The learning disabled children as a group were inferior in their ability to follow a moving speech signal and a moving white noise.

3.5.4 Ear phone listening for out of head localization

Sakamoto and others (1970) report that, `out of head localization' in binaural head phone listening is possible. But here the acoustic energy density ratio of reflected sound and direct sound in a room has to be controlled properly.

This ratio was reported as one of the factors in localization by Gotch and others (!975).

Sakamoto and others (1978) constructed a binaural head phone for out-of-head localization. The mixed sounds (direct sounds + indirect sounds) are transmitted through the acoustic transmission paths to the left and right ears, so that a sound image is localized externally.

Molino (1974) achieved simulation of distant sound sources, with ear phones by inserting in the ear phone channels various combinations of ITD and IID, for various azimuth positions. Results of these studies were comparable to studies reported in literature.

3.6 ANIMAL STUDIES

Sokolovski (1974) compared monaural thresholds of hearing for Cat Vs binaural (freefield) thresholds for man. Cat is found to be superior to man in the ability to hear not only a wider range of frequencies and also a lower absolute frequency intensity. The hearing thresholds of Cat lie below those ofman, for frequencies tested (0.125 to 16 kH_z9 frequencies) particularly in the region of high frequencies.

Casseday and Neff (1973) provide the following review of studies on Cat's localization ability:

Many studies would indicate a ITD threshold of 10 to 20 micro seconds. As experiments (Nauman, 1958; Casseday, 1970) used complex stimuli or stimuli with high frequency components, both time and intensity probably contributed. Masterton et.al. (1967) found 20 to 50 micro seconds ITD for Cat. The authors assumed that Cat like man uses both time and intensity ones. As the cat’s head diameter is 1/3rd of man, the Cat is expected to be less accurate in localizing low tones (less than 1000 H_z). If Cat’s nervous system can process, ITD’s in middle range, Cat would do better than man. At high frequencies both Cat and man are expected to improve. In summary the shape of localizing function is same in both Cat and man. Man should be better at low frequencies than Cat. A decrease in threshold shows at low frequencies for man. As high frequencies are approached, thresholds for both would approach each other, other functions are provided based on other possible explanations (Please refer to Casseday and Neff, 1973, for details).

The study of Casseday and Neff (1973) used frequencies 250 H_z to 8 kH_z and minimal detectable angle (MAA) was determined for each frequency. The thresholds changed little between 250 and 2 kH_z, then increased greatly at 4 kH_z and decreased greatly at 8 kH_z. It is possible that Cat like man uses binaural system for sound localization.

Kelly (1974) studied localization of paired sources in Rat. It was found that transition from single clicks to paired clicks was good for values between 0.5 and 4.0 mili seconds. Between 0.25 and 16.0 mili seconds, discriminations of paired clicks was easier. Upper limit was between 20 and 32 mili seconds and lower limit was between 31 and 62 micro seconds. These results compare well with human data under similar conditions.

Brown et al.(1977) and Brown (1979) studied localizations in Monkeys (Macaca). Monkeys were tested with calls-natural and filtered vocalizations.a Results indicated that

Frequency modulations and band width were relatively more salient than the harmonic content of the call for directional hearing. When MAAs were measured for various sounds, they were found dependent upon torse reflections rather than pinna transformations.

Rosowski and Saunders (1979) measured cochlear microphonic thresholds and phase, in pigeons, exposed to freefield sound stimulation of varying horizontal azimuths. Comparison of the control (normal) and ear blocked measures showed differences in angular sensitivity of CM. Results suggest that, the combination of interaural sound conduction and the defraction of sound about the head enable the pigeon to localize sounds.

Knudsen (1978) reports that birds face a difficult task in localization of sounds because, (1) They must localize with both azimuth and elevation, (2) As heads provide little sound shadow and no pinnas, only a limited frequency range (less than 12 kH_z) is available for localization. But, birds are found to show extremely fine time resolution, and also a patent air way connecting two middle ears, improving localization function in birds. Finally, some birds have asymmetrical ears, causing interaural cues. These adaptations help in more accurate localization in birds.

3.7 UNDER WATER LOCALIZATION

3.7.1 Under water localization in humans

If man is to work effectively under water, he will have to be able to navigate reliably, than he has to possess directional hearing that approximates audition in air. This is important because of the dramatic reduction in visual cues, during diving situations (Lurian and Kviney, 1970 [Feinstein, 1973]).

It has been assumed, until very recently that the transformations imposed on binaural localization cues by the increased speed of sound in water and changes in acoustical impedence at the head – medium interface would preclude any sound localization b the human listener (Feinstein, 1973).

There are now a considerable numbr of studies, showing human under water localization ability (Anderson and Christensen, 1969; Feinstein, 1966; Hollien et al. 1969; 1970; 1971; Ide 1944; Leggiere, et al, 1969; Norman and Wightman, 1971) [Feinstein, 1973]. Same is supported by Hollien (1973).

Feinstein (1973) compared human under water localization to marine mammals. It would be useful to compare human responses to mammals that are adapted to the marine environments. It was concluded that, the man would be an effective sound navigater in water.

Stouffer and others (1975), tried to find the effect of training on under water localization of 1000 H_z and 25 pps signals. Improvement was found only for 1000 H_z signal and an insignificant improvement for 25 pps signal. Evidence for tympanic hearing under water was given and greater individual differences were revealed (Anderson and Christensen (1969). (For a detailed review for these studies refer to Anderson and Christensen (1969)).

3.7.2 Comparison with marine animals.

In harbour propose (phocaena phocaena), Vantleel (1962) found a MAA of about 8^0 and 11^0 at 6 and 3.5 kc/s. In same species, Anderson found 3^0 at 2 kc/s.

In sea lion `zalophus californianus', Gentry (1966) found a MAA of 10^0 and 15^0 at 6 and 3.5 kc/s. respectively.

In harbour sealphoca vitulina, Mohl (1968) found a MAA of 3^0 at 2 kc/s.

Among whales and dolphins, the ear capsule is acoustically isolated from the other skll bones time giving excellent conditions for sound localization (eg: Reysenbach d'eltan, 1956) but in sea lion and houbour seal, the bone is fused to the skull. Horbour seal possesses a good angular discrimination [Anderson and Christensen, 1969].

Several fish with swim bladders have been shown to detect the angular localization of a source of low frequency pure tones. Eg: 75 H_z in `horizontal plane' of the fish. Time differences appear irrelevant, the otolith organs might act as detectors of acceleration and acoustic pressure of particle at the position of the fish ear (Schuijf, 1978).

Moore and Au (1975) found sea lion utilized time differences for low frequencies (.5 to 1 kH_z) and intensity differences cues for higher frequencies (4 to 16 kH_z). The transitional frequencies were difficult for localization.

3.8 PHYSIOLOGICAL ASPECTS

(Also refer Chapter 2.2.3.2)

Since it was recognized that the auditory system is sensitive to interaural phase differences for tones below 1400 H_z, and only level differences at high frequencies, it has been apparent that two neural mechanisms for localizing sounds exist. One is phase locked, that fires at a particular time in the sound cycle. The other has fibres whose firing rate is determined by the level of stimulus is independent of stimuls frequency (Jeffress, 1975).

The existence of such fibres has been demonstrated by Moushegian (1971) who found in the superior olivary complex, phase locked, and stimulus frequency determines firing rate, and other fibres, fire at rates determined by differences in levels and does not depend upon frequency. These two fibres effects are combined in a complex form. And differences in accuracy may be based on number of neural units activated (Jeffress, 1975).

Interaction of binaural nerve impulses takes place at superior olivary nucleus level and discrimination is controlled by cortical level (Neff, 1964). The stimuli presented, is assumed to be converged by afferent nerve impulses (Alekseyenko, and Komenkovich, 1974). The delyed and contralateral direct impulse depends upon temporal difference between two impulses for which some central process is involved (Roser, 1960).

So called cyclic or periodic response functions have been reported for single neurons responding to interaural differences in time of arrival. These data apparently been misinterpreted by some, for in real world situations these cells wold not be the source of ambiguous localization information for higher auditory centers (McFadden, 1973).

3.9 SUMMARY

A detailed review of factors involved in localization the studies done in past and recent on auditory localization have been presented. Briefly animal studies on auditory localization and the factor of under water localization are also touched upon. The reader is reminded that models of binaural hearing are not dealt here.

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CHAPTER 4

LATERALIZATION

4.4.6 Masking Effects on Lateralization

4.4.7 A Very Brief Introduction to Models of MLD’s

4.5 DETECTION AND LATERALIZATION

4.6 ROTATING TONES

4.7 BEATS

4.8 TIME SEPARATION PITCH

4.9 EAR ADVANTAGE FOR LATERALIZATION

4.10 ANIMAL STUDIES

4.11 OTHER STUDIES ON LATERALIZATION

4.12 SUMMARY

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CHAPTER 4

LATERALIZATION

4.1 INTRODUCTION

Listening through stereophonic head phones has been referred to as lateralization. More specifically, when a tone is presented through ear phones, under appropriate conditions, the listener perceives an auditory image within the head.

It is agreed that some authors consider localization and lateralization processes as similar (Jeffress and Toylor, 1961). However, the experiments that use head phone listening conditions (lateralization) have been distinguished from, free field listening condition (localization) (Plenge, 1974).

The image within the head moves as a function of interaural temporal and interaural level differences. Most of the laws and rules governing auditory localization phenomenon, hold good for lateralization also. It has also been asserted that the temporal and intensity cues can be manipulated independently and precisely in lateralization experiments.

Many experiments have suggested that when listening through ear phones, extra cranial localization of the auditory image is also possible (Plenge, 1974). Similarly, when listening to an external sound source, intra cranial localization (image within the head) is also possible (Schirmer, 1965; Tool, 1970; Sone and others, 1968; Sandel et.al., 1955; Fedderson, 1955; [Plenge, 1974]).

It is generally agreed that, the location of image – whether inside or outside the head depends on what we ask the subject to do, rather than how we present it (Jeffress and Toylor; 1961 [Plenge, 1974]).

Foregoes a presentation of the information concerned with this intra cranial localization or lateralization.

4.2 MEASUREMENT OF LATERALIZATION

Many experimenters report, a difficulty in qualifying the results of lateralization experiments. Some of the methods that are still in use are as follows:

1. Subjective Judgement: Here the subject judges the position of the image inside the head. Usually, a two alternative forced choice procedure is employed: (a) image at center; or (b) image lateralized (Bocca, Teatini and Antonelli, 1971).

2. Centering: Centering methods are used in evaluating, the effects of ITDs (transient, ongoing, or both) on lateralization, and also in trading experiments. Trading experiments find the equal effects of intensity nd time against each other. For eg: If one sound is leading in one ear, because it is louder, can be brought back to center by delaying the sound in that ear.

Harris (1960), for eg: used this centering technique to investigate differences between time and intensity combinations at low and high frequencies [Mills, 1972].

These centering experiments are also called nulling measurements. This method is faintly objective, because they do not require a scale of subjective laterality (Mills, (1972). Mills opines that, in order to explore the interaction of interaural differences in time and intensity more generally, it is necessary to define such a scale for values of `lateralization' other than zero.

3. Equilaterality: This is by means of a comparison within the auditory modality. Dichotic signals produce images inside the head. The subject receives another set of dichotic signals as reference images or indicator signal. The subject judges the position of auditory images relative to the indicator image. Even the indicator images are allowed to more, to get a correct judgement (Mills, 1972).

The same equilateral pointers can be used to investigate the constant errors of localization. These errors are usually due to under lateralizing the actual source of the sound. This pointing method is believed to atleast partially overcome this difficulty of underlateralization (Mills, 1972).

Yost, Turner and Bergert (1974), obtained psychometric functions from two listeners in 4 psychophysical tasks. The task was to make discriminations of interaural temporal differences of a 250 H_z tone. The tasks employed were:

1. A single interval yes-no task.
2. A single interval left-right task.
3. A two alternative forced choice task.
4. A two interval same different task.

The results were consistent with the assumption that, observers use lateral `motion' as a cue for detection in two interval tasks and lateral `position' as a cue in single interval tasks.

4.3 FACTORS IN AUDITORY LATERALIZATION

4.3.1 Introduction

When head phones are used, the task of locating the auditory image, is referred to as lateralization (Hafter and Jeffress, 1968). Essentially, the two important factors ITD/IPD and /or IID, are responsible for the lateralization of an auditory image. Generally it has been accepted that, the lateralization of a signal, is to the side that receives louder signal and/or receives the signal little earlier. Interaural differences of phase of the signals at two ears, is emphasized much in lateralization experiments. As, said, use of the head phones permits the experimenter to manipulate and control the two parameters, independently and precisely at the two ears (Yost and Nielson, 1977; Bocca and others, 1971, etc.).

The factors such as, interaural frequency differences; the onset and offset disparities of the signals; the subjective proneness to time or intensity cues; the signal durations; the spectral components of signals; different types of signals; the effects of body tilts; masking effects on lateralization; etc., are also being studied extensively. The foregoing description, deals with these factors separately, in detail.

It is to be recognized that, the two ears analyze these disparities separately and combine their results at some point in the auditory system, to produce the effective lateralizations. These neural interactions are not fully understood yet. The reader is reminded to kee the links between each topic in mind, to get a more clearer understanding.

4.3.2 Interaural Phase/Time Differences

Lateralization of an auditory image depends upon time properties of the signal or expressed more precisely, upon the differences in time of arrival of the signals at the two ears (interaural ? t) (Bocca and others, 1971).

Usually, when two signals of same intensity arriving at the same time are given to the two ears, the image is lateralized at the centre. Now, if one of the signals is delayed by a few micro seconds, than, the image shifts to the other ear. Antonelli and Teatini (1967) report 800 micro seconds time differences for complete lateralization. They also report that the image at the center is approximately circular in shape. When the signal arrives at the leading ear, it assumes an ellipsoidal or pyriform shape; the vertex pointing towards the center of the head [Bocca and others, 1971].

Mills (1972) quotes, Bekesy (1960), who found that the relation of angular to rectilinear displacements varies with the shape of the path followed by the image inside of the head. But generally the laterality of the image increases linearly with the interaural time differences upto a limit beyond which the image remains near one ear (until it breaks up into two sounds perceived successively). Mickunas (1963) also supported these findings.

`Yost' in a simple study showed that as the phase difference increased towards 180^0, the fused image moved towards the ear that received the tone first (leading in time). As the interaural phase difference (IPD) exceeded 180^0, the image moved from the ear that received the tone last (lagging in time), towards the middle of the head.

This centered image could be placed in different perceptual positions within the head by introducing an IPD [Yost amd Nielson, 1977].

Klumpp and Eady (1950) used an electrical delay line to introduce time delays into the stimulus in one of the ear phones. Using various delays, 75% correct lateralization judgements were obtained. Their results show that the best performance involved bands of noise – the smallest threshold (9 micro seconds) – best with 150-1700 H_z. Lower frequencies gave poorer performance. For tones, thresholds were larger, but diminish with increasing frequency upto 1000 H_z (11 micro seconds). At 1300 H_z, thresholds were considerably larger. [Jeffress, 1975]. These results agree with those of Mills (1958). Yost, also indicated similar results, emphasizing that interaural phase (time) is a poor cue for detection, for frequencies above 2000 H_z. We can relay back to Stevens and Newman's study, to find this result was same. It is also emphasized that, observer's are less sensitive to changes in location when the image is at one ear, than when it is in front. This also confirmed finding supporting the view that ITD's are useful only for low frequencies, approximately below, 1500 H_z.

Similar results are obtained by many researchers (Moss and others 1978; Matsudaira and Fukami, 1973; Nordmark, 1976; Zurek and Leshowitz, 1976). These researchers used many types of stimuli and discrimination tasks. After reviewing research on pure tones, filtered clicks, steady state signals, Bocca, Antonelli and Teatini (1971) reach the following conclusions.

1. With sine wave signals (pure tones) interaural time (or phase) differences can only be assessed for frequencies lower than about 1000H_z.

2. Dichotic trains of high pass filtered clicks may be lateralized on the basis of ?t, between the low frequency contours of signal envelope.

3. When ?t reaches around 1 mili second, maximum lateralization is achieved and when this value is exceeded, lateralization does not alter any more. However, beyond 15 mili seconds the images split into two, ie., one image at each ear. This point at which one image is replaced by two is called threshold of `duality' or of `succession'. This threshold of duality occurs at a value slightly over 2 mili seconds for clicks.

For steady state signals, this threshold of duality can never be observed. With a rise of ?t, the image simply looses its coherence, and eventually lateralization can no longer be perceived.

For broad spectrum noises, the largest ?t still producing lateralization is around 20 mili seconds. For narrow bands of noise, ?t is slightly higher for low centered frequencies than for high centered frequencies.

4. It is reported that the image shifts within the head in a slightly different manner for high frequency signals as compared to low frequency signals.

5. The intensity and duration also affect discrimination of interaural ?t's. Phase discrimination has an optimal value at comfortable listening levels; it deteriorates with decreasing sensation levels as well as with increasing ones.

Jud ?t value decreases as signal duration is increased, indicating better localization performances.

In recent years interest is prevailing, in utilizing interaural time difference cues for lateralization at middle and high frequencies. It has been shown that the auditory system is much more sensitive to interaural time differences at high frequencies than had been believed. This fact was widely appreciated only once experimenters began using wave forms more complex than the simple sinusoids so common in older binaural research [McFadden and Moffitt, 1977].

It has been argued by many researchers (McFadden and Moffitt, 1977; McFadden and Pasanen, 1976, 1977) that, although the auditory system is unable to lateralize using cycle-by-cycle time differences in a high frequency wave form, it is able to `follow' the relatively slow fluctuations in the envelope of complex high frequency wave form, and to lateralize using time differences present in the envelope. In a number of listening conditions, only tens of micro seconds are needed to accurately lateralize certain complex, high frequency wave forms – essentially the same sensitivity as for low frequency sinusoids. Individual differences are also observed to be great. Usually authors remind that the number o opportunities to observe the interaural time difference is not the only factor determining lateralization performance. There presumably is some true integration as well. Also, at very slow or very fast envelope fluctuations, additional factors intrude to make lateralization more difficult than intermediate fluctuating rates.

Nuetzel and Hafter (1976) have reported the inability to obtain lateralization of amplitude modulated complexes at one ear, against pure tones (at the modulation frequency) at the other. They contend that this strengthens the argument

That all stimulus information used is carried in high frequency channels, supports above views.

4.3.3 Onset – Ongoing – Offset disparities

Originally, sound localization was thought to be mainly affected by interaural ?t in terms of signal `onset' at the two ears. The fact that prolonging the signals lets the value of the just noticeable ?t decrease demonstrates clearly that sound localization depends also upon the `ongoing' periods. It turned out that in actuality there are three kinds of interaural ?t's that must be considered:

1. Time difference between signal onsets: "Onset disparity".
2. Time difference between the ongoing signal periods "Ongoing disparity".
3. Time difference between signal and points "Offset disparity" [Bocca, Antonelli and Teatini, 1971]

Many investigators have studied the lateralization of sinusoidal stimuli vased on interaural time. In such studies the ITD can be onset, or ongoing or offset temporal differences or some combinations of these. The effects of the interaural onset and offset are usually reduced by shaping the tones, or eliminated by using an interaural phase difference. A few investigators (Elfner and Tomsic, 1968; Perrott, 1969; Perrott and Barrs, 1974; Tobias and Shubert, 1959; and Tobias and Zerlin, 1959) have studied the effects of onset and offset temporal differences on lateralization. In only few studies (ef: Flfner and Tomsic, 1968) has the stimulus been a sinusoid [Yost, 1977]

Yost (1977) tried to compare lateralization of pulsed sinusoids having all three interaural temporal differences present with the lateralization of pulsed sinusoids having primarily an ongoing temporal differences. His results suggested that low frequency information is the crucial variable for lateralizing sinusoidal stimuli present with onset, ongoing and offset disparities. This view has been widely supported.

4.3.4 Interaural Intensity Differences

Differences in intensity at the two sides of the head aids in recognizing the direction of a sound source. First suggested by Venturi (1796 to 1801), he also reported that intensity differences are particularly significant over 300 H_z [Meenadevi, 1977].

When two identical signals are simultaneously delivered to the two ears of an observer, the image, as expected lies at the center of the head. If intensity of one signal is increased on one side, the image shifts towards that side. This phenomenon is well known as stinger effect, used in testing malingering cases (Bocca and others, 1971).

When interaural intensity difference equals zero and overall signal intensity is low, ie., near threshold, the resultant auditory image is virtually `point – shaped'. However, if ? I becomes 1 dB, the image spreads and begins shifting toward the side receiving greater intensity. When ? I is further increased, the image becomes elongated ie., spindle shaped, pointing towards the side of higher intensity. Trained observers report that the shift of the auditory image caused by ? I's is marked than that caused by ? t's.

Finally when ? I becomes longer than 6 dB, the image splits suddenly into two, each part being lateralized in one ear (Bocca and others, 1971).

As it is already known, the Jnd's for time are fairly constant over low frequency range. Hafter et.al. (1977) measured sensitivity to interaural intensity, for band pass clicks of either low or high frequencies. They found that ? I was reasonably constant over a large frequency range. This has been generally accepted.

Reviewing the research, Bocca, Antoneli and Teatini (1971), report that `interaural intensity differences affect localization of sound sources (or the lateralization of their images) in a manner that is different from that of ITDs. Their effects are completely independent of the spectral composition of the signal.'

It is generally shown that the interaural intensity differences are very small at low frequencies and are detectable clearly only at higher frequencies (Mills 1960; De L'Aune and Elfner, 1974; etc.). Elfner and De L'Aune (1977) used a rating method to determine sensitivity to intensity produced lateral shift in a binaurally fused and centered auditory image. Stimuli were pure tones at 0.5, 1,2, 4, or 8 kc/sec at 30 dB SL. A significant trend was found for higher frequencies to yield diminished sensitivity. No effect of interaural intensity though imbalance was observed on the detectability of right vs left direction of the shift. However, subjects with audiometric imbalance of moe than or equal to 5 dB performed at a significantly higher level than those with symmetric audiograms at the test frequency. Mills (1960) found, the ? I values of about .7 dB for 250 H_z and 500 H_z tones; a maximum of about 1 dB at 1000 H_z, and a minimum of about 0.5 dB at frequencies in the range from 3000 to 10,000 Hz.

Elfner and Tomsic (1968) reported, that the threshold for just noticing a difference from a centered image is relatively independent of the onset time disparities and mainly dependent upon IID's. As already noticed, even few micro seconds of onset disparity can produce Jnd's from centered image. On the other hand, the range of IID's when the signals cross the threshold of hearing is not very large, from 3 to 3.5 dB. IID at threshold for 10 and 50 mili seconds rise times is negligible.

Elfner and Perrott (1967) reported that, as SL (sensation levels) decreased, the IIDs had to be increased to reach the threshold (2, 3 and 5.5 dB respectively at 60, 40 and 20 dB SLs). The Elfner and Tomsic (1968) study reported the differences occurred before signal reached 20 dB SL. Hence, one would expect that the IID's to be higher than 5.5 dB obtained by Elfner and Perrott (1967) study. The differences are attributed to methodological differences. Elfner and Perrott used methods of limits – whether subjects heard a change or not. In Elfner and Tomsic's study, either ear would have been leading and the subject was forced to guess which one was leading. This method with forced choices, is known to produce lower threshold (Guilford, 1936).

Elfner and Tomsic (1968) also report in their experiment that, the difference in thresholds for lateralization between the high and low frequency did not appear as expected for all rise times. It only occurred at 10 mili seconds rise time condition. The reason for expecting the difference was that the low tones are partly dependent on phase information for lateralization. In this experiment; phase angle was kept zero, ie., a central image. Since the lower frequency tone produces interaural phase information that could conflict with interaural intensity cues, we might expect that larger IIDs would be required to produce shifts from the center.

Herschkowitz and Durlach's (1969) study suggests that interaural lateralization system is more sensitive to intensity than to temporal changes. Further that temporal factors become important only when intensity is not a major variable; the phase of sinusoidal tone bursts analogous to the `time of arrival' for transients is a cue which the nervous system uses only under certain conditions (Berlin, 1970) [Meenadevi, 1977].

Pinheiro and Tobin (1969) observed that the nature of neural interaction involved in the IID for lateralization is unclear. They recall, Von Bekesy's hypothesis that "this interaction between 2 ears is similar to the interaction he noted between the two adjacent areas of skin surface. They followed these findings that a normal as well as peripherally and centrally involved subject needed to be observed to test the relevance of model of hearing." They positively reported that Von Bekesy's model could be applied to the auditory phenomenon.

Elfner and Perrott (1967) indicate a functional relationship between image movement and sensitivity to intensity change. This has been mentioned above.

4.3.5 Interaural Frequency Difference

Dichotic presentations of identical signals matched for frequency, arrival time, phase and intensity are usually reported by the listener as centered in the head. Introduction of temporal or intensive differences in one of the signals may result in a shift in the apparent locus of the sound image. The minimal change of these factors that produces a detectable change in locus of the image is frequently referred to as “lateralization threshold” (Elfner and Perrott, 1967).

The dichotic listening procedure does not depend upon the matching of frequency of signals. On the other hand, a gross mismatch in frequency may not result in fusion of dichotic input into a single resultant image. Without fusion, there is no spatial resolution of interaural differences. At higher frequencies, however fusion can occur between dichotically presented signal with gross interaural frequency difference. For eg: above 3000 H_z, binaural fusion threshold is larger than ± 7% of the base frequency (Perrott and Barry, 1969) [Perrott and Williams, 1970].

Perrott and Williams (1970) found that very large IFDs (± 300 H_z of 5000 H_z base frequency) have no effect on lateralization as measured by the just noticeable threshold. These authors, also quote Perrott, Briggs and Perrott (1970), who reported that, the input in a common channel of limited band appears to be treated alike for fusion.

Deutsch (1978) presented 400 H_z and 800 H_z to the ears alternatively (250 mili seconds tones) in a dichotic sequence. A strong tendency to lateralize each tonal percept toward the ear receiving the 800 H_z signal was weaker in loudness. However, this lateralization by frequency effect becomes weaker with sequences of tone pairs.

4.3.6 Time Intensity Trading

A method of studying the interaction between interaural time differences and interaural level differences involves introducing a time difference in one direction and a level difference in the other; and asking the subject to produce a centered image. The ratio of time differences in micro seconds to the level differences in decibels has come to be known as the "trading ratio" (Jeffress, 1975). It is better to use a 4 quadrant plot, ? t along ordinate and ? I along abscissa, positive values indicating leading.

One of the earliest studies to yield a trading ratio was that of Shaxby and Gage (1932) who found a value of 1.7 micro seconds /dB for tones (Jeffress, 1975). Shaxby and Gage found a linear relation between the time differences and level differences required to yield a centered image, whereas Deathrerage and Hirsh (1959) found that the ratio dependent upon the amount of time difference being used. Yost and others (1975) using pure tones indicated that a progressively smaller amount of IID was required for the 2 stimuli to occupy a similar lateral location as ITD was increased. The slopes of functions suggested that the images associated with larger values of ITDs are less distinct and blend together more than the image associated with small value of the temporal differences.

Gilliom and Sorkin (1972) reported that a larger fraction of the total sensation arising from one interaural cue will add or subtract as a scalar quantity with the sensation produced by other interaural cue, but a residual sensation will always remain for all combination of time and intensity cues.

Young (1976) reported the following (1) The largest T-I trades were accomplished for lower frequencies (2) The maximum trade for each requency occurred at IPDs of 90^0 and 270^0, and (3) When low frequency tones were 180^0 out of phase, essentially the same interaural intensity relationship was required to achieve mid line as was needed for the 0^0 interaural phase condition.

Christman and Victor (1955) using click trains found trading ratios in excess of 120 micro seconds /dB. Using clicks, Freedman and Praff (1962) found to center a click an average value of 43 micro seconds /dB for 4 subjects, when intensity was varied. When time was varied, only 23 micro seconds /dB, as a function pre-set dichotic intensity differences was obtained. Yong and Levine (1977) reported similar results and they hypothesize that the time intensity trading ratio does not accurately reflect the central auditory processes that are involved with interaural time and intensity on a lateralization task.

Hafter and others (1979) in a previous study (1978) showed that lateralization of trains (of length n) of 4000 H_z band pass clicks on the basis of an ITD is related to the inter click interval (ICI) in a way which suggests a dynamic rather than a stationary process description of neural refractory periods. In 1979 study, varying IID's they found similar results.

Gaskel and Henning (1979) found that the addition of various levels of broad band white noise did not influence the relative effectiveness of a two lateralization cues with pure tone signals; however, the addition of noise to clicks and to AM wave forms lead to lateralization judgements, in which the cue based on interaural delay was less effective than it had been in quiet. This effect can be explained by changes in the frequency region used by observes listening to clicks but not to AM wave forms.

Warden and others (1966) recorded evoked potentials with ITD’s and IID’s of clicks delivered to two ears of Cats from superior olivary nucleus. An analogue of the time and intensity trade was seen in cancellation of evoked potentials when T-I differences were opposed.

Using transient signals Babkoff and others (1973) indicated that the ratio of ?t/?I (micro seconds /dB is found to be inversely related to summed binaural sensation level.

In general, with respect to the lateralization of auditory images, time and intensity (expressed in terms of their interaural differences) are interchangeable with certain limits, ie. a lateral shift of image produced by one factor may be compensated by the other factor (Bocca, Antonelli and Teatini, 1971).

The relationship between ?t and ?I is nonlinear. This makes the use of a single coefficients impossible. Such relationship can only indicate a general magnitude of relationship. Also, the T-I trade is found to be inversely propotional to signal level. Another observation is that, for low frequencie substantial intensity differences are required to compensate for small ?t’s. For high frequencies, the same intensity difference serve to counteract much larger ?t’s. So, all the dimensions of sound intensity, frequency and time are important in lateralization. T-I trades would be feasible to all kinds of acoustic signals (Bocca, Antonelli and Teatini, 1971).

4.3.7 Time Images and Intensity Images

Jeffress (1975) quotes the following study by Whitworth and Jeffress (1961), using a tone pointer (Ref: pointing methods, 4.2). of the same frequency – that of, the tone unders study studied T-I trading relationships. They `rediscovered' a fact mentioned much earlier by Banister (1926) that when a tone is presented with a conflicting time and intensity differences, the subjects may hear two images in different locations in his head.

They found that one image, which they called the `time image' showed very litte movement as a result of a difference of level, the other image, the `Intensity' image was much more affected by IID. The time images gave trading ratios ranging from 29 to 20 micro seconds /dB. In all cases, the ratios were constant for a particular subject across the time differences.

Hafter and Jeffress (1968), with tonal stimuli found that intensity image trading ratio feel in the range of 20 to 50 micro seconds /dB and the other was less than 10 micro seconds /dB time image. A slight increase in ratio with duration was found for both images.

With high pass clicks, trading ratios fell in the range from 85 to 150 micro seconds /dB (Intensity Image) and 2 to 35 micro seconds /dB for time image.

This disparity in literature has been attributed to stimuli employed and to uncertainity about what image was being centered.

Bileson and others (1978) represented similar results and reports, the existence of at least 1 class of stimuli that evoke the time image only, and that are in sensitive to intensity differences. These signals are dichotically presented white noise with a conventional ITD, in addition, an interaural 2 IT phase shift in one (or more) small frequency band(s) below 1500 H_z.

4.3.8 Signal Duration

The sensitivity of the auditory system to very small ongoing differences in time is remarkable (Ref to 4.3.3). Of these five discriminations were the results of presenting the same ongoing time difference over and over again throughout the duration of sound, the accuracy of localizing sounds containing low frequency components would improve with increased duration of sound upto some limit beyond which the system's information storage is saturated. Tobias and Zerlin (1959) found threshold for ITD for a burst of noise (low pass at 5000 H_z) decreases by about 2 micro seconds for every doubling of burst duration. For bursts more than about 700 mili seconds long, the threshold levels off at about 6 micro seconds [Mills, 1972, p. 313].

Mills (1972) summarises studies and states that `small ongoing disparities overcome much larger transient disparities. With duration larger than 300 mili seconds, the effects of the transient disparity at the onset of the burst are wiped out. For shorter durations, the trading between ongoing and transient disparity increases with negative logarithm of stimules duration (Tobias and Schubert, 1959). This improvement of lateralization performance is supported by many researchers, eg: Nuetzel and Hafter, 1976; McFadden and Moffit, 1977; Bocca and Antonelli and Teatini, 1971, and many others).

Bocca and others (1971) report that for longer signal durations, the lateralization process depends exclusively upon the ongoing time disparities. For shorter durations, transient disparities are important.

McFadden and Moffitt (1977) hypothesize that, this improvement could have stemmed either from a greater ability of the binaural system to process the higher envelope periodicities or from the binaural system simply being supplied with an increased number of `looks' at the interaural time difference. It is simplified to state that, one reason for improvement is that, as signal duration is increased, more opportunities are available (and taken) to sample the relevant stimuluscues. Another reason is that a true integration is occurring.

4.3.9 Spectral Dominance/Signal Frequency

It is the general contention, from the preceding discussion, that the frequency of the signal is an important factor in lateralization process. Interaural differences of time are argued to cue lateralization at low frequencies. As wel some recent examinations show, that ITD's can also be helpful in lateralizing high frequencies also (Ref. to 4.3.2). At higher frequencies, the IID's are more helpful for lateralization (See section 4.3.4).

Raatgener (1974) studied on spectral dominance for lateralization using filtered clicks based on Flanagan's model of lateralization. The model proposes that Cochlear filtering takes place first, and the output of each ear are compared. The time difference between major positive peaks in the responses of corresponding fibres is expected to determine the position of lateralized image. The results agreed with this model for filtered clicks. They observed 600 Hz region dominates over all the other possible frequency regions. Author concluded that, there exists a common dominant spectral region, where optimal binaural interaction takes place.

Similarly Yost, Wightman and Green (1971) suggest that discrimination of lateral position depends largerly on the low frequency content of the click and thus, presumably on the spical end of Cochlear partition. McFadden and Pasanen (1976) suggest with only tens of micro seconds of ITD, sensitivity to ITD at high frequencies, compared favourably with sensitivity at low frequencies. And most probably the ongoing interaural level differences would contribute for lateralization at high frequencies (1978).

Working within similar frameworks, Elfner and De L'Aune (1977) found that diminished sensitivity was observed at higher frequencies for intensity produced lateral shifts. Using noise bands, intensity produced lateralization shifts were more detectable at higher frequencies. These contrasting differences are attributed to methodological differences (De L'Aune and Elfner, 1974).

4.3.10 Signal Types

When we take a birds eye view of the studies of lateralization, we can detect some types of signals used. They are usually pure tones, speech and other complex signals; noise both narrow band and white noise; filtered clicks and pulsed sinusoids. As we are aware of the experiments using these signals, it is felt that, segmenting some factors about these experiments provides better understanding.

In a realistic acoustic environment, steady state sounds do not provide reliable information about the location of a sound source. Relectors of the sound wave have as much influence on the wave forms present at any two points in the space as the locus of the source. Thus transient wave fronts, especially if echoes can be suppressed, provide the most reliable cue to the location of the source. Lateralization procedures, provide an analytic procedure for studying the cues responsible for the localization of transients (Yost, Wightman and Green, 1971).

Sayers and Tools (1964) report experiments with clicks and click pairs and show that with pairs, each member can be readily identified in the forced images, they says such studies help to clarify certain aspects of perception of acoustic transients.

Repetition rates and number of repetitions did not affect lateralization of high or low pass transients (Yost, 1976).

Combinations of tones are identified as functionally identical to spectral components in the stimulus (Zure and Leshowitz, 1976). Multiple component signals may produce multiple sound images which may be independently lateralized and are manipulable in many ways. And impulsive images produced by repetitive binaural transients, do not arise as a synthesis of harmonic tonal images. For them different regions of cochlea are held responsible (Tools and Sayers, 1965). Complex tones – jittered and unjittered show small just noticeable differences for low and medium frequencies.

It is possible to lateralize noise bands containing no energy at frequencies below 1400 $H_{z.}$ The auditory system is capable of extracting unseable temporal information from the envelope of wave form, even though there are only high frequency envelopes (Jeffress, 1975).

Complex signals, regarless of frequency composition may be lateralized on the basis of interaural differences of either level or time (Bocca, Antonelli and Teatini, 1971).

4.3.11 Body tilt and lateralization

When subjects were asked to localize sounds directly overhead (mid line), the location of sound source are displaced opposite the body titl (Altshuler and Comalli, 1970). Similar experiment was tried for lateralization (Altshuler and Comalli, 1970). They found that results were opposite to localization experiment results, ie., no compensation was made by subjects for body tilt during head phone listening (lateralization) experiment.

4.4 LATERALIZATION AND MASKING

4.4.1 Introduction

In recent years, it has become clear that the auditory system will use one of the two different processing modes – monaural and binaural systems – under the conditions of masking depending upon the interaural configuration of signal and masker (McFadden, details not available).

Detecting or recognizing signals in a background noise is often called `the Masking Level Difference' (MLD) (Green, 1976).

The two ears permit selective attention to certain parts of auditory space and thus ameliorate masking effects of distracting noises. The selective process include the redundancy of the conversation. The ability to recognize certain qualitative features of the speaker's voice and long and short term memory. With one ear these operate very poorly (Green, 1976).

The fact that auditory system is much more sensitive in some listening conditions than in the other was first demonstrated by Licklider (1948) and Hirsh (1948) [McFadden, details not available).

Licklider (1948) found improvement in the reception of signals when noise and signal are in different phase relations at the two ears (Green, 1976).

Hirsh's data showed that when a wide band noise and a tonal signal are identical in both ears (dictic), detectability is same as when they are both present in only one (the same) ear. For certain other binaural conditions of listening, however, Hirish's data showed detectability to be substantially better than in monotic or diotic cases – to maintain the same level of detection performance, the signal must be attenuated by several decibels. The magnitude of this change measured in dB is called `MLD'.

Experimentally a MLD is an improvement in detection performance for some dichotic listening condition as compared with monotic or diotic listening. Typically MLDs are expressed as the differences in signal to noise ratio (S/N) necessary to obtain similar detection performance in the MLD and non MLD conditions being studied (McFadden and Pasanen, 1974).

In binaural masking experiments, one may reverse in either ear, the phase of the masking signal or that of the signal masked; this makes room for number of experimental combinations as follows:

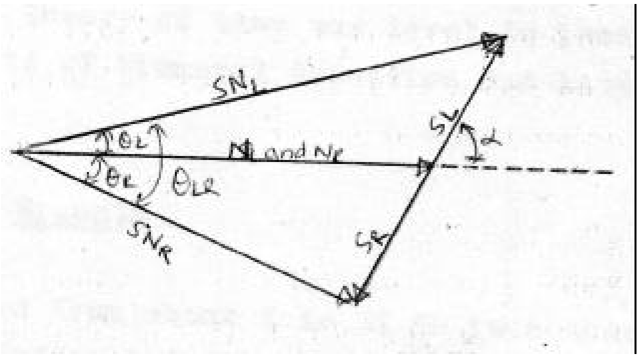
1. N_o - S_o : Noise and Signal both in phase
2. N_{TT} - S_{TT} : Noise and Signal both shifted in phase by a given number of radiance (TT) in one of the two ears.
3. N_{TT} – S_o : Noise out of phase and signal in phase between the two ears.
4. N_o - S_{TT} : Noise in phase and signal out of phase between the two ears [Bocca, Antonelli and Teatini, 1971]

In addition `m' indicates a wave from to only one ear. Thus monotic condition becomes, N_m – S_m, the diotic N_oS_o and N_oS_m and N_oS_{TT} designate two (of many) dichotic conditions that produce MLD's (McFadden, details not available).

In general, the MLD's range from 3 dB to 15 dB in trained observers. MLD has been found to decrease as the frequency of signal increases. They never go to zero (Yost and Nielson, 1977).

If graded, the largest MLD improvement is seen to result from both antiphasic conditions (3) and (4), usually both of them being equal in magnitude; then follow the conditions (2) and (1) both in phase (Boca and others, 1971; Yost and Watson, 1977; and many others).

To make clear the nature of our control over the two interaural cues, we can use the following figure proposed by Jeffress and Webster. In this figure, the masker, in



phase interaurally (N_o), is represented by phasors N_L and N_E. The signal to left ear is represented by SL and that to right ear, reversed in phase relative to the left, by SR, The two resultants are SN_L for left and SN_R for the right. The difference in length of the two resultants represents the difference in voltage at the two earphones, and the difference in phase Q_{LR} represents differences in interaural phase when signal is added.

At the moment in figure, the phase angle α between Narrow band of noise N_L and N_R and the signal to the left ear, is approximately 45^0. Consequently, the signal to the right ear, SR, lags the noise by approximately 135^0. The two resultants differ in phase by about 35^0 with SN_L leading SN_R. This phase difference, corresponds at 500 H_z, to a time difference of approximately, 190 micro seconds (Jeffress and McFadden, 1971).

This time difference was the principle cue for detection of the signal in masking condition (Webster and Jeffress et.al.). The differences in levels are neglected here, but they are also found to be important from Time Intensity Trading Studies – represented by larger resultant to the left ear than one to the right ear. From figure it is clear that IID's will occur for all values of except

90^0 and 270^0 (Jeffress and McFadden, 1971). Jeffress (1971) feels that this simple theory of time and level is inadequate for accounting for facts of binaural detection and lateralization.

4.4.2 MLD's for Tonal Signals

The MLD's ranged from about 1 to 11 dB in a tonal masking experiment (McFadden and others, 1972). In the presence of a white noise background, tones (500 Hz, 250 mili seconds) were lateralized differently for S_o and S_{TT} conditions. Both time and level cues were held responsible (McFadden, 1969). For all tonal cases, the release from masking or MLD, is found to relate primarily to the fundamental component. Elimination of the fundamental substantially reduces the MLD (Flanagan and Watson, 1966). Using tones and clicks, it was reported that MLDs were invariably small with high frequency signals and with clicks. With the low frequency signals, the magnitude of MLD depended on observers ability to lateralize the signal (Henning, 1979). The temporal system over which the binaural system is able to effect a correlation between events occurring at the two ears is estimated to be at least 9 mili seconds (Longford and Jeffress, 1964). MLD's with bone conducted noise were found to be correlated with airconducted noise maskers (Sorenson and Schubert, 1976).

When the masker is a noise and the signal a tone, the phase angle α (See fig.) will be constantly changing. Obviously $?_{LR}$ will also be changing. So, changes in level and phase is accordingly will be in conflict. So, if one is interested in studying time and intensity contributions, one should select a masker and signal, so that can be controlled (Jeffress and McFadden, 1971).

4.4.3 Clicks and Transient Signals

Henning (1974) reported that the magnitude of binaural MLD depends on signal parameters and the noise against which the signal is to be detected. This effect is maximum at low frequencies (10-15 dB) and minimum at 1500 H_z (3 dB). Binaural MLD is closely related to our ability to detect IPD is., localization on the basis of IPD. Using clicks, no MLDs were observed with high frequency signal.

In spite of the fact that, IPD effects were readily observed as changes in the apparent location of the source of signal. Raab and Osman (1962) report that rate of recruitment after release from masking was not as fast as in pure tones.

Since they were unable to obtain fusion in the center of the head until the masked clicks were 2 dB above the masking lines. Berg and Yost (1976) obtained MLD's for all temporal masking conditions studied (Forward, backward, combined masking condition). They found differential effects for conditions studied. Zerlin (1966) studied MLD's for low pass transients as a function of ? t, ? I and their combinations. They found (1) MLD increases with signal ? t, in a manner similar to that for IPD of the tonal frequency. For larger ? to values – ie., transients no longer overlap in time – the MLD decreases, suggesting temporal integration of two brief signals. (2) As ? I increases, MLD approaches a limiting value of 7 dB; for monaural condition. An IID of 24 dB yields an MLD of 6 dB – still 1 dB short of the nonaural value. (3) When combination of ? t and ? I is greater than .4 mili seconds, the MLD decreases as ? I increases, no matter whether the louder signal is leading or lagging in time.

4.4.4 Noise Signals and MLD

It is to be recalled that by using the same wave forms for both masker and signal and by maintaining a constant phase difference between them, it is possible to achieve trial-by-trial control over the binaural cues. By this one can present entire blocks of trials having only a level difference of a particular value, blocks having only a particular time difference, or both (McFadden and Pasanen, 1974).

A sories of experiments used narrow bands of noise as both maskers and signals:

McFadden et al. (1971) used a narrow band of noise (50 H_z wide centered at 250 H_z) as both masker and signal. For all subjects, for all values of , the MLDs were positive and substantial. As expected at $=90^0$ and 180^0, the time and intensity cues were in opposition and some subjects were sensitive to one of these cues, this was true for both detection and lateralization. For each subject there was a value of between 120^0 and 170^0 at which detection performance was good while lateralization was nearly impossible.

Jeffress and McFadden (1971), used 50 H_z wide 500 H_z band of noise, and found similar results. McFadden, Jeffress and Lakey (1972) used similar bands of noise, centeredat either 1000 or 2000 H_z, in different experiments. 1000 H_z experiment is in accordance with other studies. At 2000 H_z IID was the primary cue. McFadden and Pasanen (1974) used various frequencies at 2000 and 4000 H_z, large MLDs of 6-12 dB were obtained and IID was the major cue. When ITD was sole cue detection performance was essentially identical to that in comparable non MLD condition.

Similar results are also reported by Wilbranks (1971) McFadden (1966) observed that MLDs were 4-6 dB smaller with burst than with continuous noise masker. Bell (1972) reported that at the end of observation interval switching from uncorrelated noise to correlated noise of same level, as masker, restored MLDs. Measuring MLD's in a reverberant environment, they were found to be approximately 3 dB (Koenig et al., 1977).

4.4.5 MLD's with Speech Signals

Westen, Miller and Hirsh (1965) confirmed MLD for speech (monosyllabic words) but did not find any ear difference. But Findlay and Schuchman (1976) found right ear advantages for different age groups. With modulated noise, MLD's for monosyllabic words were ranging from 3 to 9 dB (Carhart, Tillman and Johnson, 1966). MLD's for complex amplitude varying stimuli can be best accounted, if energy in 250 to 500 H_z band relative to the spectral maxima in the signal. The energy around this band, decides the differential effects of interaural phase.

4.4.6 Masking Effects on Lateralization

Pulsed tones in masked ear had little or no effect on lateralization until it exceeds masked threshold (Dunn, 1971). To interfere with lateralization, a forward masking tone had to be presented with 80 mili seconds of the presentation of test tone. Also observers tended to lateralize test sound in the direction of masking sound, if both occurred with a 100 mili seconds period (Massaro, Cohen and Idson, 1976). Lateralization performance goes down as the interaural relation of noise is changed from perfectly correlated to 180^0 out of phase. The presence of uncorrelated noise does not cause a similar increase in Jnds (Cohen, 1979). If the signal is strong enough to be detected with correlated noise, lateralization was found to be still poor (Benson and Egan, 1966). Obviously high levels of noise were more effective (Raab and Osman, 1962).

4.4.7 Brief introduction to modles of lateralization

Jeffress (1965), Durrlach (1963), Colburn (1977), Metzetal (1968), Hafter (1977), Webster (1951 and many others have proposed the models for lateralization process. Usually the ability of binaural system, to analyse, synthesize and process the interaural cues is the basis for all models.

4.5 DETECTION AND LATERALIZATION

Ypst (1975) argued that lateralization and binaural detection of complex wave forms are not essentially different. But McFadden and Pulliam (1971) argue that nature of the signal processing or the aspect of signal being processed, is different for lateralization and detection. The two facts that imply above view are, (1) that the wave forms of the psychometric functions are different. Eagen and Benson (1966) first established the lateralization functions are less steep than the detection function, and they are displaced towards greater signal levels. (2) that, McFadden (1969) reported as maximum interaural time difference was made greater detection performance improved and lateralization function steadily increased. The two tasks are affected by different manipulations. The same author (1971) reported definite difference between lateralization and localization for all signal durations they studied. As more interaural time information available, the more different the lateralization and detection functions (McFadden, 1969; McFadden and Sharpley, 1972).

The basis for detection performance with time delayed conditions appears to be ongoing IIDs (level) (McFadden and Pasanen, 1978). For detection performance, both offset and onset transient thresholds were inversely related to signal duration and directly related to signal correlation (Perrott and Baars, 1974). Ahumada, et al. (1971) suggested that, for detection, not only the absolute level of the output of an energy detector is important, but also the sensitivity to temporal and spectral changes in the signal. The interaural phase differences were held responsible for improved detection performance by Phipps and Henning (1976).

With pure tones no binaural summation occurs for detection at low signal levels (De L'Aune and others, 1974) Signal detection is more difficult in a dynamic than in a static environment (Grantham and Robinson, 1977). Cats are found to be less sensitive in homophasic conditions than man and at 1.5 kH_z, the Cats showed larger MLDs, under binaural masking conditions (Gessa and Longford, 1976; Wakeford and Robinson, (1974).

In a `monaural detection with contralateral cue' (MDCC) experiment, subject detects a monaural masked signal, with the help of a relevant cue containing relevant information presented to the other ear. Adding noise to this cue restores the performance in this MDCC condition. On the basis that MDCC is also judging the apparent lateralization of cue, it has been argued that the lateralization mechanism is not by itself the detecting mechanism (Taylor and Smith, 1975; Taylor and Clarks, 1971).

In general, the lateralization and detection performances are considered different.

4.6 ROTATING TONES

A good presentation of this topic has been given by Bocca, Antonelli and Teatini (1977). This has been summarized below:

Identical primary signals of equal strength given to both ears, are obviously lateralized at the center of the head in normal listeners. In such a condition if the frequency of one signal in one ear is increased or decreased by a small difference like 1 H_z, then the image position stays at the same place or remains in the center, Frequencies above 1000 H_z do not yield any such shifts. For the frequencies below 1000 H_z the image is found to undergo a rotating movement shifting between the ears. This is referred to as `rotating tone' or `turning tone' or `Spatial auditory sensation'.

It is observed that number of revolutions per unit time is determined by the interaural frequency difference. By practice even small frequency difference of .008 H_z can also be perceived for rotations. If the frequency difference gradually increased between two dichotic signals, then angular velocity and number of revolutions per unit time also increases, ie., the rotations become faster, at a level, the sensation of rotation turns into perception of `binaural beats'. The image, on leaving the ear receiving low frequency signals, crosses the median sagital plane, in the anterior region and moves into opposite ear. Here image is usually `deffused'. Then on return, the image moves in the posterior region, at a lesser speed than before and is relateralized in the low frequency side. As this is very subjective, description is rather fictious. A periodic in tensity modulation is also suggested.

The neural basis for this phenomenon, is reported to be the centers where binaural analysis is carried out. These centers use the constantly changing (angular velocity) phase/time relations between dichotic stimuli, in analyzing the relative position of image inside head.

4.7 BEATS

As noted in the case of rotating tones, as the frequency difference increases between the signals (2 H_z to 10 H_z) still a single image, fluctuates periodically. If frequency difference becomes 10 to 20 H_z, the auditory image hasan appearance of roughness, if frequency difference becomes higher than 15-20 H_z, primary signals splint into two images – one in each ear. This sensation of rate of fluctuation of loudness is referred to as `binaural beats' (Bocca, Antonelli and Teatini, 1971; Yost and Nielson, 1977).

The frequency of the binaural beats is the average of two primaries and rate depends on frequency difference between the signals at the two years. Usually, the two tones must be equal in amplitude and should not exceed an frequency difference of 50 H_z, for beat effect to occur. Beats are also reportedat harmonics [Yost and Nielson, 1977]. Listeners responded to beats whenever, the primary tones were above the threshold (Tobias, 1963). Detectin of beats is found to be independent of whether or not fusion has occured (Perrott and Nelson, 1970).

Upper frequency limits for binaural beats vary considerably: 1255 H_z (Perrott and Musicant, 1977). Others have reported from lowest 640 H_z (Rayleigh, 1907) to highest 3000 H_z (Wever). Usually 1000 H_z, [Bocca, Antonelli and Teatini, 1971] But McFadden and Pasanen (1975) report that it is possible to hear a binaural best at high frequencies by using complex wave forms, whose envelope periodicities are slightly different.

This is explained by that, there is an interaction in the nervous system between the envelopes extracted from two ears. These beats at higher frequencies are similar to beats at low frequencies, except that they are more faint, less spontaneously detectable and fast fatiguing. Males were reported to perceive beats at higher frequencies than females (Tobias, 1965).

`Monaural beats' are called `best beats' when both primaries have equal intensity (Bocca, Antonelli and Teatini, 1971). Binaural beats lack the intensity of a monaural beat for some tones and binaural beat sensation was less sensitive to changes in intensity than the monaural condition (Garcia and others, 1963). But when an inphase noise is added to the sinusoids, binaural beats became quite noticeable (Egan, 1965).

For `binaural beats', the limit of audibility in terms of ? I is very much wider. With one signal set at 50 dB SL in one ear, it is still possible to perceive binaural beats when the signal in the other ear is at subliminal levels. Also in such conditions, image fluctuates between center of the head and ear receiving louder sound. It is also noed that, a single pitch is being perceived with a pitch, averaging the two primaries – a true inter tone is formed (Bocca and Antonelli and Teatini, 1971).

A neural basis for beats has been hypothesized, although not exactly by many researchers (Giaccai, 1962; Plazza, 1972; Oster, 1973 and others).

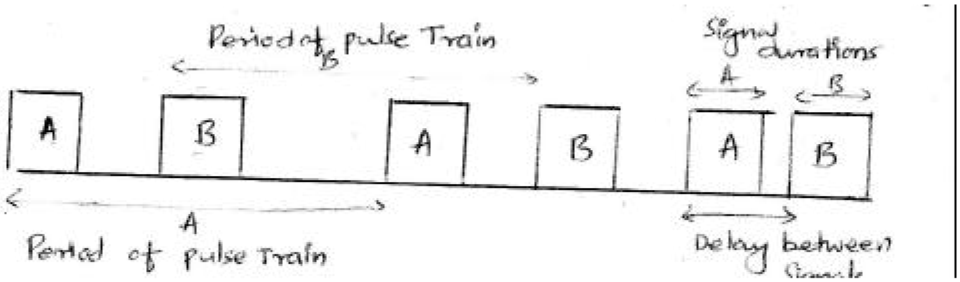
4.8 TIME SEPARATION PITCH

Nordmark (1963) employed two trains of clicks (A and B) one to each ear with equal intensity and at a repetition rate of

25 H_z. He employed a time difference of 5300 micro seconds between these two click trains, A going to the left and B going to right. A was leading obviously lateralization to leading ear is observed.

Now, a 3rd train `C' of click is sent into left ear (leading ear), with an equal intensity and with a time difference of 23000 micro seconds with train `B' in right ear. Now the image shifted fom left to right side. So, if, with repetitive dichotic signals, timing is arranged in such a way so as to produce two different time differences, one longer than the other, the lateralization process takes only one of them into account, ie., the briefer of the two (Bocca and others, 1971, p. 19).

An analogous phenomenon, in monaural hearing, called as `Time – separation pitch', was described first by small and McClellan (in 1955). Then it was called `Sweep tone'.



Schematic diagram showing temporal distribution of pulses in the production of a time separation pitch (From: Bocca, antonelli and Teatini, 1971, p. 19).

Now, let there be two trains of pulses A and B, with same repetition period (inverse is repetition rat) representing the repetition or periodicity pitch. With these two trains subject is reported to hear an additional pitch to periodicity pitch, ie. `time separation pitch.' It's period equals to the A-B interval.

The closer these two trains in time, higher th time separation pitch and vice versa. It is explained that, this is a monaural phenomenon, therefore shift in the image cannot take place, so, a sensation of a new pitch is present – still taking shortest time interval available.

[Bocca, Antonelli and Teatini, 1971, pp. 18-20]

A `dichotic repetition pitch' phenomenon due to the presentation of continuous wide band noise in one ear and the same noise, delayed by a time `t' in the other ear is reported. Although this is less pronounced, it is observed to be closely resembling monotonic repetition pitch (Bilsen, 1974).

4.9 EAR ADVANTAGE/DOMINANCE FOR LATERALIZATION

Weston, Muller and Hirsh (1965) did not find any sizable differences between right and left ears for amount of MLD. But Schoeny (1968) observed a right ear advantage in magnitude of intensity required for lateralization. Later Vargo and Carhart (1972) confirmed this ear bias, but found that left ear was advantageous – although the differences were statistically not significant (Meenadevi, 1977). Similarly, ear dominance is supported by many researchers (Findlay and Schuchman, 1976; Efran and Yund, 1976; Craig, 1971 and Meenadevi, 1977)

4.10 ANIMAL STUDIES

Cat has been studied extensively for lateralization (Masterton and Diamond, 1964; Axelord and Diamond, 1968). They have demonstrated that Cat is able to employ bot temporal and intensive cues in lateralizing transient stimuli [Meenadevi, 1977]. This has been supported by Wakeford and Robinson (1974).

Diamond et.al. (1964 and 1967) study with Cats, reported that, binaural interaction (generally at superior olivary complex) is necessary for accurate lateralization; interfering with ipsilateral neural transmission say by ablation of inferior colliculi, lateral leminiscus resulted in problems in lateralizing; with large bilateral ablations of cerebral cortex may result in loss of lateralization ability (Strininger and Neff, Unpublished observation, 1961) [Meenadevi, 1977]. Hall (1965) found that the average firing of the cells in the superior olivary nucleus in Cats increased as the stimulus t the contralateral ear increased. And average intensity level was not found to affect relative amount of response activity. Rose et.al., found that Cat could detect interaural intensity differences as small as 1 or 2 db. From these studies, it can be said that the first level of binaural interaction takes place at the level of superior olivary complex and then this information reaches cortex (Meenadevi, 1977).

4.11 OTHER STUDIES

Melnick and Bilger (1965) indicated that hard of hearing listeners are able to make approximately the same use of these binaural cues as listeners with normal hearing.

Gescheider (1965) compared cutaneous sound localization (delivered through skin with a pair of vibrators) to auditory localization (ear phones). It was found that auditory localization was more precise for random noise bursts than for low frequency tones. Cutaneous localization, however was s accurate for tone as for the noise stimuli. Auditory localization was influenced by both time and intensity cues, whereas cutaneus localization mainly depended on intensity differences.

Previous research (McFadden et.al., 1972; McFadden and Sharpley, 1972; Jeffress and McFadden, 1971 etc.) has indicated that there exist two classes of people, one group more sensitive to ITD than to IID, other group more sensitive to lvel than to time differences. To estimate relative proportion of people in these groups, McFadden and others (1973) surveyed under-graduate population. Out of those classified, about 25% were more sensitive to time differences than to level differences.

Elliot and Genla (1979) found that the time intensity ratios required for median plane localization were found to increase with increasing adaptation effects.

Randolph and Gardner (1973) found that interaural phase relations of an intense exposure stimulus influenced subsequent binaurally determined TTS, ie., homophasic conditions produced larger TTS.

Babkoff and Sutton (1966) studied the end point of lateralization which the referred to as the lag click threshold (? t_2), Clicks were stimuli. The results indicate that the lag click threshold is decreased by an increase in the SL of both clicks, by an interaural intensity asymmetry favouring the lag click; or by decrease in the low frequency components of both clicks. Characterisitics with noise are also similarly reported.

Lag of sound localization due to IID was significantly smaller than that due to ITD. These results seem to contradict the hypothesis that the ear converts intensity differences into time differences before perceiving the direction of sound sensation (Blauert, 1972).

Barret (1972) tried to explain time intensity trading occurring with lateralization of sounds. CNS appeared to respond primarily to uncertainity relation and not to signal parameters per se. Mathematical explanation is attempted.

The concept of sound images having perceived position in an auditory space usefully describes a relevant auditory experience, can clarify occurance of multiple images, poor localization of images, T-I trades (Sayers, 1964).

4.12 SUMMARY

Auditory lateralization, like auditory localization is mainly based on time/phase, and intensity cues. A detailed review was available in this chapter. Masking effects on lateralization, the other factors affecting lateralization judgements, some concepts emergents of these experiments were discussed. Animal studies on the same lines were also given.

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CHAPTER 5

CLINICAL UTILITY OF THE PHENOMENA OF AUDITORY LOCALIZATION AND LATERALIZATION

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5.1 INTRODUCTION

In the diagnosis of auditory disorders particularly, in terms of differential diagnosis `battery' of the tests has always been emphasized. Recently, to the available tests are added the tests based on the phenomena of auditory localization and lateralization. These tests generally are: (1) Tests using directional hearing (Eg: Tonning, 1970); (2) Tests using lateralization phenomenon (Eg: Stenger tests and other head phone tests); (3) Tests using masking level differences (MLD's) (Eg: Goldstein and Stephens, 1975); (4) Tests that utilize the binaural integration and summation properties (Eg: Brasier, 1973); and (5) Some of the tests using directional hearing, have also been used, with hearing aid users, to test their abilities in terms of localization and lateralization (Eg: Markides, 1977).

All these areas will be briefly dealt in this chapter. As far as possible, the available literature will be compiled here.

5.2 DIRECTIONAL AUDIOMETRY

5.2.1 With Normals

As far back as 1876, Politzer observed that the directional hearing of people was impaired, with the unilateral being more affected followed by those suffering from conductive deafness and finally, by those with inner ear pathology (qoted by Jongkees and Veer, 1967) [Markides, 1977].

The ability of directional hearing to a real sound source of ioctave band noise is very poor. The misjudgements are observed when the direction of sound source and perceived direction are in line made by 2 ears. This misjudgement is influenced by signal frequency and sound pressure level. 8 to 16 kH_z band and `band widening' are found to be effective. The phase differences at the ear canal is very important in determining the direction of sound source (Makabayashi, 1974).

Roser (1960), postulated that impulses in central apperception of acoustic direction, two discrete impulses are needed. The specific time difference between the impulses activate specific cortical cells. These cortical cells encounter the delayed and the centralateral direct impulses. Experimentation on this hypothesis is awaited.

Nordlund (1962) developed a method of directional audiometry, with two properties (a) physiological directional hearing ie., the angular localization in free field can be estimated, and (b) defective ability to discriminate interaural time, phase and Intensity differences can be detected individually.

Baschek (1978) has developed a modified artificial head recording system to test directional hearing. Baschek and Battmen (1977) demonstrated, directional hearing by a test, in which a model `hears' loud speaker impulses at known changes of angle. These sounds are recorded and presented through head phones. Responses are by a visual signal. They demonstrated this directional hearing in 40 normals, and claim that, this method is simple as it uses only tape recorder and head phones.

Tonning, has published a series of papers (1970 to 1973) concerving directional hearing and its applications to testing. His studies would be summarized in different sections of this chapter.

Tonning (1970), argued that, if pure tones are used while testing directional hearing, for adequate information, a whole series of frequencies have to be used. And, we recognize that this is impractical especially with patients. Then, the daily occurring complex signals, at a level around 65 dB (SPL) is a better signal, to test the ability to localize sounds. Accordingly a white noise of 65 dB was presented to persons from 12 different positions in an unechoic room. The person would be seated in center of the room. Normal hearing subjects were selected. White noise signal was presented for 10 mili seconds, the subject was permitted to turn the head by 5^0 to left or right. When noise was switched off, the subject was asked to indicate, from which direction the sound came from. Symbols were used to designate speaker positions. He has provided a graph representing the objective position and corresponding subjective position of the sound source for 30 normal subjects. This graph would serve as a basis for comparison and evaluation of directional hearing ability of hearing impaired persons with and without hearing aids.

Frost and Richardson (1976) presented 3 experiments to demonstrate that tactile sound localization is possible with an accuracy that approaches normal audition. They can track moving sound sources and even analogue ofselective auditory attention was found using tactile sound localization. Thus these experiments indicate a possibility of incorporating a localization unit in future design of artificial ears for the completely deaf.

Nilsson, et al (1973) compared, sound localization ability in normal hearing subjects with three different methods: (1) Free field test in an echoic chamber, utilizing pure tones of 500 H_z (Nordlund, 1963); (2) Tests with head phone, with variable delay units; and (3) The stethoscope test (Groen, 1969). ((2) and (3) are explained later in this chapter). Authors, report that, the free field test has proved useful in diagnosing retrocochlear disorders, but the need for anechoic room is a disadvantage. Head phone tests substitute for detecting interaural phases or time differences. The simpler stethoscope test serves the same purpose. Testing on 100 normals proved the superiority offree field test, in safety and diagnostic value. The head hone tests provided lot of confusion, in locating sound images, and the difficulties in handling the stethoscope test are reported.

Hochberg (1963) reported that normal auditors demonstrate some degree of auditory localization difficulty as a function of their average interaural delay levels of 21 dB or greater. Hirsh (1950) using loud speakers investigated threshold of speech intelligibility, in a background noisesource. This threshold was found dependent on interaural phase angles of speech and noise stimuli. With normals highest thresholds were seen, when the position of speech and noise loud speakers coincided [Tonning, 1971].

Nordlung and Fritzell (1963) attempted spectragraphic analysis of qualitative variations in speech as a function of the azimuth of the source. They found that the information reaching the ear towards the sound source was greater than that reaching the ear turned away from the sound source, especially for frequencies above 2000 H_z (Tonning, 1971).

Tonning (1971) used speech and white noise signals at 65 dB at the point corresponding to the centre of the subject's head. The Directional Threshold of Intelligibility (DTI) was calculated with and without background white noise, giving 16 different combinations of speech and noise loud speakers. The DTI was defined as the highest intensity level (in dB.re. 0.0002 dynes/square Cm.) at which the person tested can not perceive and repeat correctly four consecutive words. The intelligibility was tested with falling intensities in 1 dB/word steps, and head movements were not allowed during the test. Results: indicated, no significant difference in DTI values with front and back positions of loud speakers, likewise right and left positions. But, there was significant differences between DTI values with loud speakers in right and left positions and these with front and back positions. The thresholds were lower when the loud speaker is on right or left of the subject. Subjects were 30 normals, age ranging 19 to 52 years. The lowest DTI values were found when signal loud speaker is on right or left of ear and noise loud speaker behind. These are in agreement with Hirsh, (1950). In this experiment no ear differences were noted. For older age group (above 24 years age) the mean DTI was 16.1 dB whereas for younger age group it was 14.7 dB. The results are graphed, with DTI values without noise along X-axis, and DTI values with noise plotted along Y-axis. This is suppose to be a standard for comparisons.

5.2.2 Directional Audiometry with Hearing Impaired

Jongkees and Van Der Veer (1958) moved a sound source along a graduated circle, to examine localizing ability of a group of patients with various types of hearing losses. They found that otoscleratic patients showed strongly disturbed directional hearing. `3’ out of `10’ unilateral deaf patients had normal directional hearing. They attributed this to head movements and pinna shadow effects. They found no relationship between the types of audiogram, degree of hearing loss, difference in hearing acuity between two ears and directional hearing [Markides, 1977]. The assertion that no relationship exists between difference in hearing activity between two ears and directional hearing has been supported by Bergman (1957) [Markides, 1977]. He reported if sound is above audibility threshold of poorer ear, then directional hearing is not impaired. Nordlund (1963, 1964) found no correlation between the pure tone thresholds and directional hearing in the normal group.

Wirth (1972) reported poor localization of sounds did not occur in all cases of unilateral deafness, by concentrating had many patients, differentiated sound qualities and intensities, often with the help of small head movements. They performed poorly, under difficult test situation, like interference by noise. Tonning(1971), performed directional audiometry, to study the influence of azimuth on the perception of speech in patients with monaural hearing loss. Free field speech audiometry, was used to obtain DTI (Directional Threshold of Intelligibility, with and without background noise. DTI without noise depended not only upon the amount of hearing loss in the defective ear, but also upon the slight variations in the hearing ability of the good ear. A relationship was found between DTI without noise and the normal ear’s pure tone average in the range of 500, 1000 and 2000 H_z. In persons with onsided PTA of 53 dB H_L or less, the poorer ear contributed to the perception of speech. When loud speaker was at the side of poorer ear, the listening condition was poorest and vice versa. It is reported that the anechoic room and effect of noise were more pronounced than normal daily surroundings. Viehweg and Campbell (1960) using 40 normal subjects and 51 monaural hearing loss subjects performed localization experiments for speech signals. It was found that normal hearing subject swere able to localize correctly 87% of all tst stimuli in quiet and 84% of test stimuli with noise, whereas monaurally hearing subjects localized only 44% of all stimuli without noise and 36% with noise. Other results are similar to Tonning (1971). It was also found that monaural deafness be it congenital or adventitious, had essentially the same disastrous effect on directional hearing and such effect is permanent and does not improve with time. Szmeja (1964) investigated localization function in 58 patients with Menieres disease. He reported that all patients localize very well, and there is a distinct influence of the appearance of the symptoms of auditory compensation in the course of sound localization.

Abel and McLean (1978) with a special apparatus tested sound localization ability in patients with different auditory pathologies. It was found that patients with otosclerosis were unable to localize low frequency sounds. Those with temporal lobe lesions were almost similar to normals. Patients with unilateral sensory neural deafness made errors while localizing high frequency sounds. Patients with acoustic neuromas made more errors than those without, but statistically difference was insignificant. Further research is recommended on these lines. In 1964 Sherliker and Appleton (quoted by Hart, 1970) [Markides, 1977] in line with other studies found, unilaterally impaired subjects experienced greater difficulty in locating sounds than the normally hearing.

Hausler, Marr and Colburn (1979) performed discrimination tests on persons with hearing impairments and on patients with multiple sclerosis. Results include estimates of horizontal minimum audible angle at 8 azimuths vertical MAA, straight ahead; interaural time delay (time Jnd), and interaural amplitude ratio (amplitude Jnd). The standard stimulus was broad band (0.25-10 kH_z) pulsed (1s) noise. Conductive cases (greater than 35 dB loss) gave abnormal value in all tests. Symmetric sensoninaural cases with speech discrimination scores of above 90% gave roughly normal values in all tests. While the corresponding group with scores below 80% gave elevated values for vertical MAA and horizontal MAA on the sides. Meniere's cases gave normal MAAs, and time Jnds and amplitude Jnd that was normal only at high levels. Neurinoma cases gave at abnormal values in at least one measurement each, with large inter subject variability. Persons with only one functional ear showed no ability to discriminate interaural parameters, but some gave MAAs, within normal range. For multiple sclerosis patients, time Jnds, amplitude Jnds, and vertical MAs were affected independently.

Nordlund (1962 and 1964) studied stereophonic hearing. He tried to find effect of sound localization on different audiological disorders. His methodological details would enhance our understanding of his results, ie. why a brief description of his method of testing directional hearing is given below.

Method: Auditory localization was tested two series of experiments (1) with subjects head free and (2) with head fixed. 1. Subject was explained briefly the test procedure and then he was seated in an anechoic chamber, with his head 1 meter away fro a graduated scale. From the control room experimenter could move the loud speaker at will, positioning loud speaker at graduated positions of the scale. The direction of sound source, was judged by the subject, who indicated corresponding scale mark. The difference between the estimated and the true position of the loud speaker relative to scale give the angle error and hence a measure of the subjects ability to localize a sound source.

The stimuli used were (1) pure tones of 100 H_z, 2 kH_z and 4 kH_z and (2) low pass filtered white noise. The level of signals was maintained sufficient for the worse ear – exceptions here are unilateral deaf cases. The case made 20 judgement of directions at each of the frequency and 10 judgements for the low pass filtered whitenoise presentations. In this condition head movement was allowed.

In another series, head was fixed, with same arrangement loud speaker was moved in steps chosen at random between limits of – 30^0 and + 30^0 on either side of median plane.

The average error, made by subject in judging the position of the speaker was called `target mark' and the SD of these errors was called `taget pattern'.

The sources of error in directional audiometry was investigated with the aid of artificial head. The influence of the chamber on the sound field was studied and with the guidance of these results, the physical limitation for locating different signals was estimated. At 500 H_z, the average accuracy was ± 2.5, at 2000 H_z the possible accuracy was approximately ± 15^0, at 4000 H_z, it was approximately ± 5^0. For low pass white noise, the physical limitations could not be determined.

1

51 normal hearing subjects of different ages and patients with various pathologies were also tested. Pure tone audiometry; speech audiometry and stapedius reflex test Bekesy audiogram and neurological evaluations were done.

Results: 2000 H_z tone was most difficult to localize and low pass white noise was easiest. In normals age and localizing ability was insignificantly correlated. Similarly no significant correlation was found between pure tone thresholds and directional hearing. A subject who makes errors, exceeding the above limits, for one or more different types of signals, is considered to have abnormal directional hearing.

Middle Ear lesions: Cases with chronic otitis, unilateral or bilateral, and also cases with otosclerosis had impaired directional hearing. Also, a few cases of successful stapodictomy also had impaired directional hearing.

Cochlear lesions: Especially cases with bilateral lesions, had emarkably good directional hearing. Only two cases had an abnormal target patterns and most of them had more abnormal target monks.

Other lesions: Brain lesions showed normal directional hearing. Cases with cochlear lesions and central lesions some times showed abnormal directional hearing. All unilateral lesions showed abnormal directional hearing. Finally, all cases with normal hearing and with vestibular dysfunction also had normal directional hearing.

Very often impaired directional hearing depends upon a reduced ability to discriminate time and intensity difference. This is fairly well established. This is true for chronic otitis media and otosclerosis. Cochlear lesions may have only slight influence on ability discriminate time and intensity differences. It is observed that a reduced speech discrimination with elevated pure tone threshold does not give any certain information regarding directional hearing, this point is quite important, as patients with retrocochlear lesions showed abnormal direction hearing. Tonning (1975) also emphasizes upon the use of directional audiometry as a differential diagnostic tool for cochlear nerve and pons lesions.

Temporal Lobe Lesions: Medial accessory nucleus of the olivary complex in the brain stern is the site at which afferent impulses from 2 ears first come together. As it is recognized that time and intensity cues are predominant in sound localization. Thus any disturbance of the condition time of neural impulses in one of the auditory nerves should register in this measurement. Thus lesions of 8th nerve or the brain-stern will render the centre unable to carry on its function properly. The fusion of the signal coming from the periphery will not take place in the normal way and will give rise to disturbances in sound localization (Nordlund, 1963). Alekseenko and others (1948, 1949) showed that lateralization of sound is undisturbed in patients with complete unilateral destruction of temporal lobe, including auditory cortex, as a result of injury. Localization function is disturbed in unilateral lesion of temporo – parieto – occipital and inferior parietal region of the brain. Greene (1929) supported this. But Schankweiler (1961) found patients with temporal and non temporal lesions performed similarly, this is supported by Nordlund (1962-64); Blagoveschenskaya (1962) found a disturbance of the localization of sound in an acoustic field on the opposite side of pathological focus in patients with lesions confined to the temporal lobe, but in the parieto temporal region of the cortex. This was supported by Sanchezlongo and Forster (1966).

Bosatra and Russolo (1976) tested directional hearing on 25 normals, and same individuals with temporary impairment of brain stern by barbiturate (3 mg/kg); 32 patients with nucleo reticular vestibular syndrome; 7 with unilateral menier's disease and 1 patient with acoustic neuroma. By changing 41 and _t of two pure tones (400 H_z and 600 H_z) presented via ear phones or two-fixed loud speakers placed at ± 30^0 from azimuth and with balanced intensity, temporal order and auditory patterns were tested with the same frequencies by changing the _t or the order of presentation of the stimuli at fixed intensity. Results indicate a distinction between brain stern lesion and menierls desease. In brain stern patients, directional hearing was impaired whereas temporal order and auditory pattern discrimination were normal. The author argues that, sensitivity to noxious agents, is to be taken into account along with other characteristics of the auditory system.

Dieroff (1973) undertook directional audiometry in 31 cases of noise induced hearing loss and he showed that upto the age of 65, the workers in noise had normal or only slightly reduced directional hearing. It was indicated that the directional audiometry is suitable for estimating non-noise induced central hearing losses in those working in noise upto the age of 65 years.

5.3 USE OF LATERALIZATION PHENOMENA (HEAD PHONE TESTS)

5.3.1 Stenger test

This procedure used in detecting unilateral simulated hearing loss component operates on the same set of principles in auditory lateralization by IID. A clinical audiometer providing simultaneous, independent control of pure tone levels in each receiver (Sullivan, 1974). A tone presented bilaterally at equal SLs produce an image in medial plane. A 10 or 20 dB shift shifts the image to ear receiving louder signal. Presence of sound in – 20 dB receiver with weaker signal can be only be verified by listening separately. A further reduction in level essentially has no effect on tone position. Any questioning, eliciting contrary answers, may lead to doubt the original threshold measured. This test is advantageous even with diplacusis patients. Substitute use of comples stimuli may fair as well. Audiometric configuration differing markedly between ears place interaural frequency difference cues in conflict with intensity differences, there by no affecting the total effect (Sullivan, 1974).

Chaiklin and Ventry (1965) reported a high incidence of negative or equivocal results on the stinger and speech stinger tests in the identification of functional hearing losses (Kinster and others, 1972). In a similar and extensive study Kinster and others (1972) contradicted the findings of Chaiklin and Ventry (1965). Raffin and others (1970) investigated time-intensity trade for selected spondiacally stressed words using a centering methods for various time delays and at 5 levels of presentation. Lateralization effects increased with level of presentation. With a maximum lateralization effect between 22 and 30 dB occurring at time delay of 2.25 mili seconds. At 2.75 mili seconds multiple images were observed, no ear effect was observed. A potential clinical application is discussed. Depaepe (1972) proposed a test based on the transcranial lateralization of sound in bone conduction and on the bilateral perception of sound in this way. This test can be used with a monocanal audiometer and author recommends this as a replacement of stinger test.

5.3.2 Weber Test

In cases of unilateral conductive loss, a tone presented at midline forehead via bone conduction vibrator will usually be referred to the affected side. With a unilateral Sn loss case, tone is lateralized to unaffected ear. In normal hearers tone is referred at the site of stimulation. If vibrator is at the center of forehead, physical time and intensity cues are essentially the same at each ear, giving rise to midline sensation (Sullivan, 1965).

McClung (1973) investigated the reliability of Weber test, in groups normal hearing adults and of conductive loss and Sn loss hypacusis. The variability in lateralization was so large, that they concluded that difficult to rely on Weber test alone and support of other audilary tests is necessary. In perceptive deafness cases (unilateral) the affected ear is equivilant to an actual physical intensity differences. As a consequence, tone is lateralized in better ear, on Weber test. Results in cases of long standing Sn loss should be rechecked and carefully considered (Sullivan, 1965). Novotny (1966) administered Weber test to 50patients and compared with other auditory measures. The results were in pure conductive losses lateralization does not change with increased intensity. The Weber test does not reliably lateralize in mixed losses. It was felt that the calibrated Weber test may be used to demonstrate recruitment when there are changes in lateralization. This method was thought to be more applicable and reliable than Fowler's recruitment test.

It has been shown that interference with middle ear may affect the cochlear conductive mechanisms creating both intensity and phase differences relative to the normal ear. Although there is no exact explanations, theoretical arguments lead to the hypothesis that, with impurity, the lower frequency lateralization may be attributable to mechanically induced phase shift, with high frequency effects ascribable to intensity variables and ambient noise reductions in conductive loss ear (Sullivan, 1974). Causes and others (1973), propose speech Weber test for measuring cochlear reserve in otosclerosis. This test audiometrically indicates, by the direction of lateralization, the ear to be operated on first: The test curve permits forecast of the post operative functional level for the ear towards which the test is lateralized or the levels of the 2 ears when it is unlateralized. Lymar and Moroz (1975), report, a complex of texts including Stenger's test to determine air conduction audiometric levels and a original bone air `overlap' test (details not available) to determine the level of bone conduction curve, make it possible to get reliable audiometric data without applying masking.

5.3.3 In diagnosis of central auditory disorders

Goodman (1963) reported that patients with unilateral Sn impairment of hearing – confirmed or suspected disturbance of the peripheral or central nervous system – reported sensation of hearing in markedly deafned ear, although tonal stimuli was delivered by earphone to apparently normal ear. This was effect was observed over a wide range of frequencies and was related to intensity.

Levine and Hausler (1979) estimated interaural time discrimination and brain stern potentials in patients with multiple sclerosis. A two alternative forced choice paradigm was used to determine interaural time and intensity Jnds for white noise bursts. Short latency (less than 10 mili seconds) click evoked potentials were recorded between vertex and ear lobes. The results indicate that the subjects with normal interaural time Jnds, usually had normal responses even if interaural intensity Jnds were abnormally large. Those with abnormal time Jnds usually had abnormal evoked responses, especially those with largest time Jnds exhibited no waves beyond the action potential component of the auditory nerve. Patients with abnormal time Jnds and different evoked potentials on stimulating each ear showed a lateralization bias: Whenever the interaural time of the stimulus was less than the subject’s time Jnd, the stimulus was localized towards the side for which potentials were more normal.

Ryndina and Levina (1977) introduced the concept of `Sound lateralization threshold angle’ to assess qualitatively the changes in sound lateralization function in the disturbance of sound conduction system. Sound lateralization threshold angle increased in the presence of sound conduction disturbances, especially at low frequencies, also, it increased with increase in functional asymmetry between ears. It has been hypothesized that peripheral affections in sound conduction system resulted in functional reconstruction of cortex, leading to disturbed perception of sound image localization. Using this test, Ryndina (1978) compared patients with neuro-sensory hypoacusis (cochlear lesions) to patients with sound conduction disturbances and healthy persons. It was reported that cochlear form of hypoacusis suffered more than in patients with conduction disturbances. In eripheral injuries lateralization depends on sound frequency; degree of hearing impairment and functional asymmetry of the ears.

Shitara and others (1965) using directional hearing tst to aid in localization ofbrain lesions. Concluded that the test cannot clarify the site of lesion. Matzkar (1961) opines that the relation between cerebral facilitation and inhibition plays a role in localizing auditory stimulus. To investigate this more, he used a pulsed pure tone test with short impulses reading both ears with equal intensity and varied time delay in ears. Lateralization was optional at an interval of .633 mili seconds. A narrow zone was observed in which lateralization doesnot occur and this zone was found to increase with age, with its greatest width in aged persons. The deviation in midline were considered cerebral in origin. The cerebral lesion is localized according to the side of the deviation.

Groen (1969) reported that, brain tumors in the temporal lobe would impair the precision in locating a sound source. He also provides the following review on directional hearing tests used with temporal lobe tumors:

Greene (1929) observed that, the ability to locate the source in freefield or to lateralize it in a stethoscopic presentation was significantly imparired in patients with famous of temporal lobe. Similar findings were reported by Sancheg Longo and Forster (1957, 1958). Matzkar and Welker (1959), described an instrument (Mediophone). Where identical signals to ears can be presented, and ITD between them was variable from 36 micro seconds upto 648 micro seconds. Usually normal listeners, start lateralizing between 30 to 90 micro seconds. This instrument was connected to an audiometer to produce short tone bursts of selected frequency via an interrupter. A click free interrupter was used, to avoid that sharp click, during pressing, which can act as a lateralization cue. Time or phase cues provided lateralization for low frequencies, upto 800 H_z. When clicks is used lateralization was extended upto 4000 H_z, although with less precision, than low tone scale. This mediophone, assured constancy of equal intensity in two head phones, whatever time delay was introduced, this is very much necessary, not to allow any intensity cues to operate, which can interact with ITD effects. Neural disorders are most sensitive to time differences.

Nordlund (1963), used loud speakers in freefield to present tones (500 to 8000 H_z) and filtered noise bursts. In his patients, with acoustic neuroma, he found directional hearing was only impaired but not abolished in them, as they could use both time and intensity parameters for localization. Normals hae highly developed ITD detection ability. When two identical signals are presented to two ears almost simultaneously, the neural impulses pass from each cochlea, via, the acoustic nuclei to the accessary nucleus of superior olivary complex. Here, the signals from two cochleas meet. This conduction time is in the order of 3 mili seconds. Yet, a 1% precision is preserved during this relatively larger time. Such that a 30 micro second ITD is already noticed and interpreted by the listener. So, even a minor disturbance of conduction of nerve impulses would reduce the ability for ITD discrimination. This ability is not directly related to pure tone audiogram.

Author noted that a group of children with perinatal anoxia, having hearing losses ranging from 40 to 85 dB in both ears, showed normal ? t values 60 to 90 micro seconds (normal range). But, in contrast, a group of children with kernicterus at birth, having a sloping audiogram with a moderate loss of 45 dB, yielded ? t values ranging from 400 micro seconds to infinite (unmeasurable). A unilateral acoustic tumor with moderate pure tone loss, led to complete abolition of time discrimination. The two separate images never fused into one for lateralization. It appears, that there is a loss of coherence in time pattern along the affected nerve causing too great dispersion of conduction velocity in neurons. Even speech sounded confused, echoed, and speech discrimination was poor, 20% at best. Only 8^0 nerve disturbance produced ? t inability, this is in agreement with Nordlund (1963). Unilateral disorders in temporal lobe never abolish ? t perception, although minimum ? t values may increase slightly. This is in agreement with Nordlund, but, is in contrast to the opinion of Sanchez-Longo and Forster (1957); the author Groen (1969) modified the stethoscope to test interaural time discriminations. A rubber tube of 130 Cm length, order diameter 10 mm, inner diameter 7 mm, was connected to normal steth frame. 15 Cm below a brass tube and a frame for hold were added. Tapping on frame, right to left, the smallest distance from center is determined which gave rise to lateralization of the subject has hearing losses, the mid line lateralization occurs away from center, towards the poorer ear, this is according to time intensity trade. Tube produces a maxima of about 200, 400 and 60 H_z. A BC receiver is attached along with tube, this produces phase differences, depending on the distances between contract point and tube center (Van Boest and Groot, 1979), avariation of original work by Hornbostel and Wertheimen (1970). This phase difference serves good purpose for lateralization at low frequencies.

On tube, the error margin for normals was about 1 Cm, ie., 0.5 Cm from the center. As the velocity of time in air is about 30 micro seconds, which is the minimum delay, that normals can detect. This normal margin of error, would increase to 1.5 Cm with untrained listeners, and a 3 Cm margin around center is already pathological. Groen (1969) relates this to the abnoramalities of Ist and 2nd order neurons. The data is consistent that, purely cochlear loss do not disturb ? t detection, even middle ear disorders. The test takes around 1 minute to complete.

5.4 MLD's AND THEIR CLINICAL USE

MLD's are considered as characteristic of binaural auditory system. It is generally recognized that cochlear lesions do not necessarily impair MLD, and even cortical lesions can produce normal MLDs. Research is confusing for in between lesions. It should kept in mind that MLD is one of the measures in, the complex auditory processes (Goldstein and Stephens, 1975). Goldstein and Stephens (1975) also report that, MLD is fairly an independentmeasure of auditory processing ability.

Passali and D'Arco, (1974) studied a group of 35 patients with Bell's palsy to determine possible relation between middle ear structures and the binaural MLD, phenomenon. A reduction in MLD rates were seen with these patients. After the resolution of the paralysis, rates were normal again. By this a relation between middle ear structures and MLD phenomenon was indicated.

Olsen and others (1976) measured MLDs in 50 normals and 290 subjects and they found that, although MLD's were not affected by cortical lesions, they were very often abnormally small for patients with 8th nerve tumor, Meniere's disease or multiple sclerosis. This evidence of smaller MLD's with sub-cortical central lesions, like multiple sclerosis, suggests that MLD can be od diagnostic value in detecting retrocochlear lesions. However, in patients with hearing loss or significant interaural differences in threshold sensitivity, or both, the MLD tests did not prove reliable in differentiating cochlear from retrocochlear disease. Olsen and Noffsinger (1976) found that high frequency noise induced hearing loss do not affect MLD for 500 H_z tone, but do diminish the size of MLD for spondees. Meniere's disease patients showed reduction of MLDs for both tone and spondees. The central nervous system disorders, due to various causes, had normal pure tone hearing, but showed smaller than normal MLD for 500 H_z and spondees. This suggested, according to author that, MLD tests may have unique value in detection of subtle lesions of central auditory nervous system. Similar results are also reported by Quaranta and others (1978) and, they also opine that, the tonal MLD losses its diagnostic meaning, in sensory-neural hearing losses, because, the pathological conditions of the peripheral auditory system affects the binaural release from masking.

Thus, we can conclude that MLD phenomenon can prove useful in diagnosis of central lesions. And we can hope that MLD would become one of the routine tests in audiological test battery.

5.5 USE OF BINAURAL INTEGRATION AND SUMMATION PRINCIPLES IN CLINICAL TESTING

Berruecos (1970) observes that among the different t types of reduction of the extrinsic redundancy, those which involve in some way the temporal dimension of the message are associated with extremely poor performances. When the messages are binaurally delivered, a significant increase in the intelligibility of time compressed sentences is observed. Such an improvement is usually higher than the usual increment which is due to binaural loudness summation. A further increment is to be seen when the same messages are delivered with an interaural time difference of 600 micro seconds. Author points to our lack of knowledge to account for such a phenomenon. Brasier (1975) attempted to know normal variation of the binaural integration tasks. He presented speech to one ear, at a level below the threshold of intelligibility, this was assumed to be giving mainly low frequency information. Now, to the other ear, same material was given after high-pass filtering. Measurement of discrimination score for both monosyllabic and sentence materials were done under, filtered; unfiltered; and filtered and unfiltered presented binaurally. Results indicate, a clear improvement on binaural presentation, the improvement on monaural presentations of both materials was same, this is not explained. The author feels that, this test would be diagnostically useful in short future. The procedure of obtaining fusion thresholds can be outlined, as follows. Usually better ear is kept as reference ear, tone to this ear is presented at a 5 dB SL, while intensity of the tone at the test ear is increased from a sub-threshold level until the listener reports a change in the location of the tone or that he is hearing two tones independently. The binaural fusion threshold is obtained by deducting 5 dB from obtained level. The demerits of the test can be that, it is difficult to administer effectively below 10 years of age; it needs either a two channel audiometry or two perfectly synchronized signle channel audiometers; finally that, in patients having diplacusis, the fusion of sound image is lost. But, the test is simple and reliable results are obtained, it iswidely accepted that, it overcomes the problem of masking, and overcomes the effect of tinnitus (Dattatreya, 1974).

Dattatreya (1974) tested 33 normals and 100 pathalogical cases (4 groups, conductive loss, mixed loss, sensory-neural group and unilateral total loss), with binaural fusion test. It was observed that, there was no significant difference between fusion thresholds and masked a.c. thresholds for all groups. With normals centering of image was possible and it was concluded that, binaural fusion test can be used clinically as a useful tool for obtaining air conduction thresholds of poor ear, when masking is needed. This can be used as an alternative to conventional masking procedures. Of course, further research is required. Most of the cases of Meniere’s disease and acoustic neuroma showed a normal pattern on binaural fusion test and this preserves the diagnostic value of the test to central auditory disorders (Hayashi, 1965). This was confirmed by Hayashi et al., in 1966. In addition, a poor binaural fusion occurred when the high band (1200 to 2400 H_z) was presented in the ear opposite to the affected cerebral area. They also opine that, the site of binaural fusion may be the cortical or subcortical area, rather than the brain stem.

5.6 DIRECTIONAL AUDIOMETRY AND HEARING AIDS

It is quite well established that impaired hearing need not necessarily entail poor directional hearing (Tonning, 1973). These hard-of-hearing listeners are able to make approximately the same use of the binaural cues as listener's with normal hearing (Melnick and Bilger, 1965). Even with congenitally hard of hearing children, binaural amplification has been found to be superior to monaural amplification on speech discrimination and sound localization tasks (Lankford and Faires, 1973).

Binaural hearing aid fitting procedures are typically accomplished with an independent concern for each ear. The interaural intensity, phase characteristics, and time of arrival cues processed by hearing aids undoubtedly affect the quality of binaural fitting (Wilson and others, 1978). Kuhn and Munro (1979) determined, ITD, the primary localization cues for head worn and body worn hearing aids as a function of location and angle of incidence. The ITD's were predicted on the basis of scattering theories for a rigid sphere and cylinder for head worn and body worn hearing aids, respectively. The results indicate a reduced range of available time cues for aided than for unaided listeners. In monaurally aided listeners, the "apparent angle of incidence" was shown to be increasingly offset from true angle of incidence, as the hearing aid(s) is worn brward of the ear canal axis. This bivaluedness, leads to confusion of localization cones. It was also observed that, the body worn hearing aids can produce ITDs similar to those for unaided listeners, if the aids are spaced symmetrically about the median plane of the torso, at a distance of 22 Cm apart. Wilsn and others (1978), in their study had their listeners respond to tonal and click stimuli using four selected pairs of hearing aids. These pairs were selected for matched electro acoustic characteristics: interaural phase and interaural ambient distortions. Matched pairs produced smaller MAAs and central position shifts, than dissimilar pairs. This aspect has implications for improved binaural hearing aid fitting in hearing impaired. Similarly, Nabelek and others (1977) found that the assymetrical conditions produced images that shifted towards the ear getting more amplification. The average shift they found was + 4.6 and – 2.6 dB for left and right ears more amplified respectively. However, the amount of shift varied among subjects. These authors used ear level hearing aids in their study. The subjects, sitting in a chair with a head rest, varied the position of phantom source by controlling the relative level of the speech signal. The authors oine that such method would have potential for testing localization of hearing impaired.

Tonning (1972), using CROS' hearing aids, with monaural hearing loss patients, reported that this CROS hearing aids are advantageous. But, under certain conditions, the speech comprehension might become worse with an apparatus. So, a great care is warranted, while recommending CROS hearing aids. Tonning (1972) measured directional threshold of intelligibility (DTI) in 20 patients whose, hearing levels ranged from a pure tone average of 28 dB to 45 dB. DTI measurements were done, both, with and without hearing aids; with the without background noise. With binaural hearing aids DTI was better in both conditions than monaural aids. Author strongly, recommends binaural hearing aid fittings. But patients impression of their directional hearing did not always agree with experimental results (Tonning, 1973).

Nabelek and David (1978) studied the influence of binaural hearing aids on centering phantom images from stereophonic loud speakers. When a phantom image appears on the midline from loud speakers, when level difference is zero, the listener is a symmetrical receiver. The symmetry can be altered peripherally by means of ear plugs, monaural aids, by binaural unbalanced hearing aids or by asymmetrical hearing loss. This asymmetry was called "binaural asymmetry" and was studied on 10 normal hearing and 14 hearing impaired subjects. It was found that, the normal range of binaural asymmetry in the unaided condition is ± 2 dB, and it is slightly greater for the aided balanced condition. Unbalanced aids introduced average ± 3 dB additional asymmetry. The authors, hypothesize that, difficulties in adaptation to hearing aids and errors in localization may result from additional asymmetry introduced by hearing aids.

Bunce and others (1979) conducted a perview study to look at localization learning in monaural listeners. 8 normal subjects were asked to determine wich speaker a signal was coming through, with one aided and one plugged ear. Control group received no feed back, as to from which speaker the signal was coming, but the experimental group did. The results indicate that learning takes place with and without training. However, with training subjects had better scores.

Deaf-blind persons are also going to be better helped, if binaural hearing aids are used, because of enhanced localization ability (Tonning, 1975).

Markides (1977) conducted an elobrate study, on binaural hearing aids, their advantages in speech discrimination and localization abilities in normals and in various types of hearing impairments. Here, only the directional hearing aspects are presented briefly.

Directional hearing for speech material was tested, both with body worn and ear level hearing aids. Head or body movements were also variables. The localization test was always administered in quiet, both in the non-reverberant and the reverberant room.

It was shown that, binaural hearing aids, whether body worn or ear level type, were far superior to monaural hearing aids. This was true with both normally hearing subjects and with subjects with symmetrical or asymmetrical bilateral hearing impairment. Contrary to expectations, aidable unilateral hearing loss subjects did not show an improvement in localization, when fitted with ear level hearing aids. This was similar case even with CROS hearing aids. It is actually reported that, the CROS interfered with the localization tasks. But it is indicated that, practicing with CROS would improve localization ability. In all conditions, the differences between conductive groups and sensory-neural groups were not significant. No ear advantage was distinguished.

A comparison of different amplification modes revealed the following results: In normals, as expected, performance was less superior with aids, with hearing impaired subjects, it was concluded that, there is little to choose between the two pairs of ear level hearing aids, in terms of localization enhancement. Like normals, symmetrical hearing loss patients were better performing when without the prosthetic effects of hearing aids. In binaural listening mode, ear level aids prove slightly superior over body worn aids. The pseudo binaural system proved totally ineffective, in terms of localization enhancement than a true binaural hearing aid system. Finally, it was shown that binaural localization ability was not unduly affected by reducing the distance of separation between two body worn aids when worn at chest level.

Markides (1977) lists down the following factors, with a possible effect on the localization of speech thrugh hearing aids.

(a) Degree of hearing impairment.

(b) Minimum stimulation in terms of speech intensity required for an ear to contribute to binaural localization of speech.

(c) Patterns of hearing impairment.

(d) Cause of deafness

(e) Previous experience with binaural hearing aids.

(f) Diplacusis

(g) Reverberation

(h) Head movement

(i) Body movement

(For details please refer to Markides, 1977, Chap.9, p.163 to 189).

5.7 SUMMARY

A review on clinical applications of the phenomena of auditory localization and lateralization is presented. Whereever available, the data on normals was also briefly presented alongside, to enable better understanding these clinical applications on hearing impaired populations. The directional audiometry, the head phone tests, that can be used with available audiometers is supplemented with tests like binaural fusion test, to get a broader view of these applied principles. Finally, the most concerned problem, of hearing aid fitting is dealt in the direction of localizing speech and other signals, with both monaural and binaural hearing aid users. Whenever the material was deviating from central concern, the reader is referred to appropriate sources for detailed information.

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CHAPTER 6

SUMMARY

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SUMMARY

In the previous five chapters, an attempt was made to compile the available literature on the psychophysical phenomena – auditory localization and lateralization.

The first chapter was aimed at giving an orientation of this work and introduce into the subject matter dealt in here.

The second chapter presented the aspects of binaural hearing. Here the objective was to introduce the general aspects of our binaural auditory system. To present the main advantage it has over the monaural auditory system. The advantages, in particular, the enhancement of speech intelligibility and directional hearing were emphasized.

The chapter 3 `Auditory Localization', dealt with the factors and processes involved in the auditory localization phenomenon. The two basic cues for localization – the interaural time and intensity were emphasized along with the fctors related to signals themselves, factors related to the listener's auditory system and other factors of listener and listening condition.

The fourth chapter `Lateralization', was concerned with the another dimension of the auditory processing, the phenomena of lateralization. Auditory lateralization is mainly concerned with locating the sound images within the head, when the sounds are presented through head phones (Plenge, 1974). Like localization, the factors, time/phase and intensity differences at the two ears, different types of signals and signal durations, along with other factors, were highlightened, with respect to lateralization function. Another area of important discussion, was how the auditory system behaves under masking conditions. The phenomena of MLD, was discussed in various perspectives. The processing effects of binaural auditory system – the rotating tones, beats, time-separation pitch were also discussed separately. These results on human beings are also compared with studies on anmals.

The fifth chapter “On clinical applications of localization and lateralization”, mainly attempted at giving an idea of how these wel studied phenomena are applied clinically, to assess the hearing impaired. The directional audiometry; the head phone tests, binaural fusion tests and studies on clinical populations in these lines were presented. Studies were also presented, which were concerned with finding, how the hearing aid users fair with regard to the localization and lateralization processes. The studies were mainly on pathological populations, although data were presente for normals, for controlling and `norm’ purposes.

Finally, suggestions and comments are welcomed.

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