DEDICATED TO

AMMA PAPA AMD SACHIN

for..

loving ..

listening ..

caring ..

understanding

supporting ..

reassuring ....

FREQUENCY BE IN NORMALS - EFFECT OF FREQUENCY, SENSATION LEVEL, EAR DIFFERENCE, SEX AND INTERACTION EFFECTS

Register No.8708

THE DISSERTATION SUBMITTED AS PART FULFILMENT FOR M.SC.
(SPEECH AND HEARING) TO THE UNIVERSITY OF
MYSORE.

ALL INDIA INSTITUTE OF SPEECH AND HEARING: MYSORe-570 006.

CERTIFICATE

This is to certify that the Dissertation Entitled "Frequency DL in normals - effect of frequency, sensation level, ear difference, sex and interaction effects, is the bonafide work in part fulfilment for the degree of Master of Science (Speech and Hearing), of the student with Register No.8708.

15/84

Dr.N.Rathna
Director,
All India Institute of
Speech and Hearing,
Mysore - 570 006+

CERTIFICATE

This is to certify that the Dissertation entitled "Frequency DL in normals - effect of frequency, sensation level, ear difference, sex and interaction effects" has been done under my guidance and supervision.

Dr.M.N.Vyasamurthy
GUIDE

DECLARATION

This Dissertation is the result of my own work done under the guidance of Dr.M.N. Vyasamurthy, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

Mysore.
May, 1989. Register No.8708

ACKNOWLEDGEMENTS

I sincerely thank my guide Dr.M.N.Vyasamurthy, Dept. of Audiology, All India Institute of Speech and Hearing.

I thank Dr.Ratna, for having provided me with an opportanity for the completion of this task.

I extend my gratitude to Dr.s.Nikam, Prof, and HOD, Audiology Department, AIISH, Mysore.

In acknowledging helping hands, its difficult to be comprehensive ...

Thanks to all my subjects.

Thanks to Mr.Basavaiah, Statistician, RCE, Mysore.

Thanks to SATYA for her concern at all stages of this word

Viddu..., how do I thank you?

To Ma'm - with a shade of envy for her unmatched efficier

To 'KEMBHUTHA' and 'KAPIL' - with a thousand thanks for the joy their company has always brought me and for shared moments of laughter and mirth.

To RAJ - with admiration for his "unassuming" nature. Thanks for those cherished memories. . . .

Thanks to Raji for typing this manuscript.

TABLE OF CONTENTS

Chapter		Page.No.
INTRODUCTION	:	1- 7
REVIEW OF LITERATURE	:	8 - 39
METHODOLOGY	:	40 - 41
RESULTS AND DISCUSSION	:	42-52
SUMMARY AND CONCLUSION	:	53- 55
BIBLIOGRAPHY	:	56 - 59

INTRODUCTION

A large past of the research into auditory phenomena includes the threshold of audibility as the index of auditory function. However, it has been proved clear that, threshold effects do not provide a complete description of the functional status of the auditory system. This fact has made researchers to attach importance to the suprathreshold procedures also, such as suprathreshold discrimination of intensity and frequency (Brandt, 1967).

Our auditory capacities and experiences would have been very limited indeed, if by hearing, we could only tell whether a signal is present or not. It becomes essential that, we also note that a change haa bean made against an otherwise constant background. Thia ability is basic to the auditory part of our ability to "discriminate", to tell that two "different" stimuli are "different". The ability to detect a difference in telling apart the voices of friends, telling a car born from a train, whistle, telling one word from another, gives us a prediction of a patient's ability to hear in everyday listening situations (Hirsh, 1952).

Normal listeners can surely tell that one sound is different from another, if the two sounds are sufficiently different in their physical properties. Certainly we can distinguish the highest note on the piano from the lowest.

But is there a limit to thia ability to discriminate between two auditory stimuli that are same in all respects except frequency? How small a difference in frequency can we establish and still have the liatener report that the tones are different? when we set out to detect this, we are actually trying to quantify thia sufficient physical difference. Such is the nature of the measurement of DL in audition. DL here refers to "Difference Limen" (Hirsh, 1952).

"Limen" is an anglicized version of the Greek word for "threshold". There may be a difference either in intensity and frequency between two physical stimuli, and yet an observer may be unable to detect thia difference. Also, this detection may not be a constant, varying from moment to mamnnt. The determination of Difference Limen or DL involves not the detection of the presence of a single stimulus, but the detection of the difference between two stlmuli. To an observer, two stimuli may seem to be equal even though there exists infect a, slight difference between the two. If an observer detects very small differences consistently, then we can say that be has a "high differential sensitivity" i.e. high differential sensitivity is associated with small DLS (Small, 1978).

Thus, the smallest perceivable difference between two physical stimuli or sounds is either called 'DL' or the 'just noticeable difference' (jnd). The DL can be the smallest perceivable difference in dB between two intensities (ΔI) or the smallest perceivable change in Hz between two frequencies (Δf). This difference can be expressed in two ways:

a. As an absolute difference between two sounds. As an example, suppose its necessary to change a 1000Hz tone (f) by a 2.6Hz(Δf) in order to just detect the frequency difference, then, the absolute frequency DL is 2.6Hz.
b. As a relative difference, which is got by dividing the absolute DL by the value of the frequency at which it is being measured. In the above example then, absolute DL would be, $\Delta f/f = 2.6/100 = .0026$HZ (Gelfand, 1981).

Although these basic discrimination studies were first conducted nearly 50-60 years ago, there is still little agreement on the answers to the questions on frequency discrimination. It has been noted that this ability to detect small changes in frequency depends somewhat upon particular paychophysical procedure and treatments of the data. Also, it depends upon the frequency region of the tones, their intensity and individual capacities of the observer (Wever, 1976).

There are not sufficient data to speak of both a normal DL for certain stimuli and an abnormal BL (Hirah, 1952). Studies concerning BL for frequency indicate that a difference does exist between normal listeners and those with cochlear hearing loss. It appears that a value of 1% DLF may serve to divide the results of the two types of listeners (Campbell, 1970). However, one encounters a number of problems in trying to compare data on frequency discrimination, for, several procedures have been used to study this parameter. It is of importance to have a set of normal values of DLF.

It is well known that, frequency discrimination may be influenced by pathological conditions in the auditory system (Meurman, 1954; Konig, 1957; Campbell, 1970). In particular, it is most affected whenever a pathological condition in the auditory system disrupts the resolving power of the ear. This would mean that differential threshold measurement would help us differentially diagnose those ears with cochlear hearing loss or wherein there exists a disturbance in the resolving capacity.(Campbell, 1970). If we have with us a set of normal values for DL, it would provide a reasonably sensitive means of detecting ears with affected frequency discriminative ability

The following study was aimed at determining the frequency increment size or DL values in NORMALS across five frequencies (250Hz, 500Hz, 1KHz, 2KHz and 4KHz), at 4 different intensities (20 dBSL, 40 dBSL, 60 dBSL and 60 dBSL). In addition, interaction effects of frequency and intensity were analyzed. Apart from frequency and sensation level, two other variables were also taken into consideration. They were, effect of ear difference (left vs right ear DL values) and sex difference (DL values in males vs in females).

The knowledge gained from such investigation might provide useful information concerning the meahanism of frequency discrimination processes in normals. A standardised set of DL values would be available for further clinical use. A comparison with other studies reported in literature on frequency discrimination might prove interesting.

The test in short, consisted of finding out the minimum change in frequency which the subjects could detect. This Change in frequency was denoted in terms of percentages. The test was conducted at five frequencies in octave levels (250Hz to l000Hz) and at four intensities (20 to 80 dBSL). Twenty males and twenty females were taken as subjects and both the groups were tested for DL in both ears. The following hypotheses were made:

<u>Null Hypothesis</u>:

1. Hale subjects and female subjects perform the test alike i.e. these is no difference in DL values between the two groups.
2. There is no ear difference seen for DL values, i.e. right ear EL values are similar to left ear DL values in both the groups (Males and Females).
3. DL values show no significant difference across five frequencies and across four sensation levels i.e. there is no significant change in DL values with increase in frequency and increase in intensity.

4. There is no interaction effect seen between frequency and intsnaity i.e. frequency does not bear any effect on intensity.

Sub-Hypotheses:

1a) The average DL value at each of the frequencies and intensities tested is similar in both males and females. Males as a group perform aimilar to females as a group.

2a) Right ear average DL values are aimilar to left ear average DL values in the male subjects.

2b) Right ear average DL values are aimilar to left ear average DL valuea in the female subjects.

2c) Right ear average DL valuea in males are similar to right ear average DL values in the females.

2d) Left ear average DL values in males are similar to left ear average DL values in the females.

3a) DL values at 250Hz tested at different sensation levels show no significant difference.

3b) DL values at 500Hz tested at different sensation levels show no significant difference.

3c) DL valuea at 1KHz at different sensation levels show no significant difference.

3d) DL values at 2KHz at different sensation levels show no significant difference.

3e) DL values at 4KHz tested at different sensation levels show no significant difference.

3f) DL values at 250HZ tested at each of the different sensation levels show no significant difference from DL values at the other four frequencies tested i.e. Across all five frequencies tested at all sensation levels, the average DL values show no significant difference.

4a) Frequency does not have any bearing on sensation level during DL measurements.

REVIEW OF LITERATURE

The ability to discriminate between different stimuli is characteristic of all our senses. Discrimination becomes very important in the case of audition, because, often we are more interested in knowing whether the character of a sound has "changed" rather than in knowing its absolute value (Littler, 1965).

An obvious question about any sensory system is about how much a stimulus must be changed before the system can detect the alteration. In the case of an auditory system, the sinusoid is the basic and elementary stimulus. It then becomes natural to ask how much a sinusoid might be altered in either intensity or frequency before a person notices the change. This smallest perceivable difference between two sounds is either called the 'Difference Linen' (DL) or the "just noticeable difference" (jnd). The DL can be associated with either frequency (DLf) or with intensity (DM). It can be represented as an absolute value (Δf) or as a relative value ($\Delta f/f$) (Green, 1976).

There are great difficulties in determining the differences between sounds. In a natural situation, we are not accustomed to concentrating on minimal differences between the tones, and, it needs an unusual degree of attention which is not easy to maintain. Also, the slightest background noise in the environment or in the examination room, or even tinnitus diverts attention due to which concentration ia lost: we naturally attach more biological importance to disturbing acoustic impressions. Even when the EL ia determined in surroundings free from noise in the background, there exists variation in the responses of even a normal subject bacause of difference in the ability to concentrate (Langanbeck, 1965).

It is important during the determination of DL values, that, we not only detect the presence of one tone, but detect the difference between two tones. That point at which the two stimuli appears to be equal is called the point of "subjective equality" i.e., to an observer, two stimuli may seem to be equal, even though in fact one is slightly different from the other (Small, 1978). when an observer is able to detect very small differences between two stlmuli, we say that he has a "high differential sensitivity". That is to say, a high differential sensitivity is associated with small DLs. Physical equality and subjective equality need not necessarily coincide (Small, 1978).

A threshold can be defined aa a statistical value. This is because of the variability of a given threshold value from moment to moment. This sholds true even when dealing with the measurement of differential thresholds. Therefore, an operational defintion of the differential threshold is.."that stimulus value which ia just perceived as being different from another stimulus 50% of the time" Quote: Richards, 1976. In other words, the differential sensitivity of a living organism is in a continuous state of fluctuation. The ideal value then, for a DL would be that difference which is detectable by the organism atleast 50% of the time (Stevens and Davis, 1938).

Various studies have been reported in literature concerning the differential sensitivity for both frequency and intensity. However, one encounters a variety of problems in trying to compare data on frequency discrimination. This is due to the fact that, several procedures have been used to study this parameter. The data are so widely discrepent that, the absolute values sometimes differs by as much as a factor of 10 from one study to another (Green, 1976). Also, sensitivity to a change in frequency varies greatly from one subject to another. This variability has been reported to be certainly more than those encountered in intensity discrimination. The amount of variability is impressive. When one might hear a 2Hz change at 1KHz, some may require 20Hz or more (Green,1976).

Basic discrimination studies were first conducted nearly 50 years ago. A variety of paychophysical methods have been used to determine this discrimination ability. Two methods have been used in abundance -the "method of limits" and the "method of constant stimuli". Determination of the DL using the "method of limits" requires that 'two' stimuli be presented.

The first stimulus, which is the standard stimulus remains at a constant value throughout the investigation. The second stimulus, the comparison stimulus, assumes one of the many values which are distributed ia small increments above the standard. The comparison stimuli are presented in alternating ascending and descending series. The "method of constant stimuli" may be used too to determine a DL. The method used is similar to the method of limits in that, the observer is presented with a standard and a comparison stimulus, but differs in that the comparison stimuli are presented randomly (Richards, 1976).

The absolute value of Δf depends to a great extent on the method of measurement and therefore, in comperitive studies one must take care that it should be constant. These are the factors which have been found to affect DL measurements.

a) Mode of presentation - air conduction or bone conduction.
b) Monaural or binaural measurement.
c) Duration of the stimulus presented.
d) The frequency region of the tone.
e) The way in which frequency is altered and the number of alterations of frequency per second.
f) Ascending or descending method of presentation i.e. by progressing from near threshold or above threshold region.
g) The intensity of the tone.
h) Practise effects.
i) Kind of alteration from one frequency to another.
j) Musically trained vs musically untrained ear.

k) The critical band of the stimulus.

1) The kind of stimuli Eg. pulsed vs modulated tones.

m) Culture bound effects (Langenbeck, 1965).

Various studies on DL measurement reveal the dependence of DL value on these factors. The review that follows helps us understand the process of discrimination the factors that affect it and the kind of studies that have been conducted in this aspect.

The pioneer work on discrimination of frequency is associated with Preyer, 1876; Luft, 1888 and Meyer, 1898 (cited by Stevens and Davis. 1938). They reported exceptionally small values for DL. The earlier work have been criticized en the ground that extraneous cues for the identification of the lower or higher tone were eliminated. This is so because, they used tuning forks and vibrating strings as a source of sound in which it is particularly difficult to eliminate extraneous cues (Stevens and Davis, 1938). Luft, 1888 esteblished with a very crude equipment,a Δf of 0.2 cps for a tone of lKHz. Vance, 1914 published the results of a more comprehensive study of frequency discrimination. He found the average Δf of 50 listeners for a 1KHz tone to be 3.0 cps. We would expect that early work would show smaller Δf's than does current work, because, there were so many uncontrolled cues that listeners would have made use of during the process of discrimination (Gullick, 1971).

The first systematic determination of differential sensitivity threshold to frequency by means of electrically generated tones was introduced by Knudsew, 1923. He used a wall designed equipment to find DL for frequency. A telephone receiver actuated by an ac source of a tuned inductance triode oscillator was used. A motor controlled key caused known amounts of fluctuations of the amplitude of the current operating the telephone. Frequency was varied by the periodic addition subtraction of a capacitor in the tuned oscillatory circuit. The shortcoming of this early work was the fact that no experiment was able to measure DL's at all audible frequencies and at all levels of intensity (Littler, 1965; Stevens and Davis, 1938).

A more thorough investigation of differential sensitivity, which has been referred to in literature as a 'classic' study was conducted by Shower and Biddulph, 1931. This study has remained the most widely cited study of differential sensitivity (Gelfand, 1981). They devised the novel technique of a sliding tone, in order to minimize the effects of harmonics and of the transient frequencies which arise whenever a tone is turned on or off abruptly. In the tuning circuit of an oscillator, a rotary condenser was so arranged that, the observe could listen to a tone of unvarying pitch for a short interval of time. Then the frequency was changed sinusoidally to a new value to which the observer listened for another short interval of time, whereupon the frequency returned sinusoidally to its original value. This means that, there was a smooth transition from one frequency to the other. The separation or the distance between the plates of the rotary condenser controlled the difference between the two frequencies. The subjects' task was to detect the presence of a modulated tone as opposed to a steady tone. The difference in frequency between the two constant phases was increased until the listener detected a difference. The observer had to report when the difference was "just" large enough for the variation in pitch to be detected. They included frequencies over the range of 62Hz to 11,700Hz and sensation levels (SL) from 5 to 80 dB. Under this method, the differential sensitivity becomes a function of the rate at which the frequency was varied. The best rate of frequency variation waa taken to be 2/second. The following observations were made:

It was evident that over a conaiderable range of frequency, i.e. from 125Hz to 2KHz, the value of Δf or the jnd remained remarkably constant. It was found to be 3 cps for the stronger stimulus (i.e. high SLs) and 4 cps for the fainter (i.e. low SLs). At higher frequencies, the value of jnd mounts rapidly; at 40 dBSL, the Δf had risen by about 4 fold and about 11 fold an octave higher, than 500 Hz. Some Additional measures have been made upto 15,000Hz (Wever, 1936). These have yielded enormous value - a Δf of 187Hz, which is about 62 times that for the low tones of the same loudness level. This clearly indicates the fact that, in terms of an absolute change of frequency, our discrimination of high tones is very poor (Waver, 1936). Below 125Hz, the curves show a moderate fall. This has been attributed to the introduction of harmoaic frequeacies. More particularly, it would seem that the presence of a noise pattern that changes rather rapidly in frequency lends assistance to discrimination in this region, i.e. below 125Hz. It is said to be likely that, without this adventitious aid, the discrimination function would continue to be uniform (Wever, 1936). Shower and Biddulph's data showed that at all frequencies, Δf decreases moderately as SL rises, and the effect ia more pronounced for the higher frequencies. However, the influence of Δf en frequency is much more pronounced.i.e. where as for any given SL, Δf remains very nearly constant from 62 to 2000HZ. it grows progressively larger with further increases in frequency.

Frequency discrimination study using pulsed tones from 200Hz to 8000Hz at SLs from 5 to 80dB has been reported (Wier at al, 1977). It was found that the frequency DL becomes larger as frequency increases and smaller as SL increases. The smallest value - one the order of 1HZ - occur for low frequencies presented at about 40 dBSL or more. It was seen that DL increases substantially above about 1KHZ, so that, absolute DL at 40 dBSL is roughly 16Hz at 4KHz and 68Hz at 8KHz. It waa also reported that Δf does not always get larger as frequency increases. A departure from a monotonically rising function between 200 and 400Hz it seen, and there are rather dramatic peaks in the vicinity of 800HZ. The origin of these peaks are not yet clear. It has also been reported that the SL is relatively more important at low frequencies, where the carves tend to converge. Results of this study when compared to the results reported by shower and Biddulph, 1931 reveals that the Δf is larger for frequency modulated (FM) tones at low frequencies, smaller at high frequencies and about the same for the two kinds of stimuli at around 2KHz. Other studies using pulsed tones at sensation levels between 30 and 50dB (Harris. J.D. 1952; Rosenblith. W.A., 1953y Henning, G.B. 1967; Nordmark, J.D. 1968; Moore, B.C.J., 1973; - cited by Gelfand, 1981) agree with the findings of Wier et al. 1977.

Harris, 1952 determined frequency DLs for a wide range of frequencies (60Hz to 4000Hz) at various constant loudness levels (5-30 phons). A variant of the method of constant stimulus was used to collect the data, subjects listened to pairs of tones and were required to judge the second tone either 'higher' or 'lower' in pitch than the first tone. Each tone was on for 1.4 sees and separated by 1.4 secs. A period of 4.2 secs between the tone pairs permitted the subjects to record their answers. DL was found to vary as both a function of frequency and loudness level. As loudnese level decreased.

there was an increase in DL values. This increase is more rapid at the higher test frequencies, particularly at 4KHz. Also, for all frequencies, as the loudness level is increased, the DL values tend to stabilize (cited by Richards, 1976). Harris, 1932 reports that the time interval between the two tones (separated in time) does not play a role in determining the DL for frequency. Although the interval of the time between two successive tones is crucial when they are compared with respect to loudness, the comparison with respect to pitch (by varying frequency) is independent of the time interval.

Nordmark, 1968 obtained DLs for puretones from 62.5Hz to 12KHz and for short pulses from 1 to 4 KHz. He reported that the discrimination of duration and the discrimination of pitch are both based on time measuring processes.

Fasti, 1978 has reported the estimates of pulsed vs modulated frequency discrimination as obtained by eleven observers at 300, 500, 1000, 2000, 4000 and 8000Hz. At low frequencies, frequency difference limen's were larger for modulated than for pulsed tonesy at 8KHz, the contrary was found. Frequency DLs as determined by different methods and procedures, differed by a factor upto 4; extreme individual frequency DL's varied however, by a factor of 27.

Data reported by several authors for jnd's in frequency of tones differ by more than a factor of 30. These large discrepancies are assigned to individual differences of observers and effects of experimental procedures. Particularly, there is evidence that modulation experiments lead to larger frequency difference limen's than those experiments using poised tones. Wier, Jesteadth and Green, 1977 (cited by Fasti, 1978) compared several data from several pulsed tone experiments with Shower and Biddalph's (1931) data on modulated tones. They found smaller jnd's for pulsed tones at low frequencies and for modulated tones at high frequencies. Given however the larger individual differences, the comparison of results of different experiments seems questionable. Comparison of frequency discrimination by the same observers for modulated aad pulsed tones either are available only for a few observers (Verschure and Meeteren, 1975) and/or for only one frequency (Moore, 1976) or just two frequencies (Sims, 1975) (cited by Fasti, 1978).

In his experiment. Fastl, 1978, presented the test tones monaurally through a dynamic earphone to observers who were tested one after another in a sound insulated chamber. The method of adjustment was used i.e. the observer turned the frequency control of a tone generator until the perceived pitch of successive tone bursts was equal. For the FM tones, a modulation frequency of 4Hz was used. The frequency deviation was controlled by the observer by means of a step attenuator, influencing the driving voltage of a voltage controlled oscillate

A method of bracketing was that used, during which the observer varied the frequency deviation until the pitch fluctuations were just audible. At large attenuation, virtually no FM took place, which helped the observer hear an unmodulated tone for comparison. The results thus obtained revealed that, generally FM tones lead to larger FDL's than pulsed tones. However, at higher frequencies, the frequency discrimination may become poorer for pulsed tones than for modulated tones (Fastl, 1978).

A comparison of frequency DLs for pulsed and modulated tones has been reported by Moore, 1976. Frequency DLs were determined for 20 subjects (unpractised) in two separate tasks using a two interval forced choice method. In the first task, subjects were required to decide which one of the two tones was modulated in frequency, when one of them was modulated at the rate of 4Hz. In the second task, subjects had to decide which of the two steady tones was at a higher pitch. Each subject was tested twice for each task, sessions separated by a week. It was seen that FDL's for modulated tones did - not correlate significantly with those for steady tones, indicating that probably the two kinds of DL's are meassure of separate auditory abilities. Results also confirmed the fact that OLs for steady tones differed widely among subjects and ahowad larger practise effects. By contrast, the DLs for modulated tones differed little among subjects and showed smaller practise effects. He suggested that the DL for frequency modulation might be thus a useful clinical tool as a measure of the frequency resolution of the auditory system (Moore, 1976]

Another method of tracking frequency DL uasing frequency modulated tone has been described (Feth, Wolf and Bilger, 1969). The system uses a Beat frequency oscillator. Feth et al 1969 describe frequency modulation as that type of modulation in which instantaneous frequency is the sum of a constant and a time varying component that is proportional to the amplitude of the modulation signal. Modulation voltages are generated by a function generator, which is passed through a recording attenuator before being applied to the reactance - tube modulator of a beat frequency oacillator (BFO). Since maximum carrier deviation is proportional to the peak amplitude of the modulating voltage, the recording attenuator allows the listener to adjust the Δfs). Modulation rate ia controlled by the experimenter via the function generator. It was found that Δf does not increase with modulation rates from 1 to 16Hz, as has been reported previously by Shower and Biddulph (1931) and Filling (1958) (cited by Feth et al, 1969).

One serious error committed during discrimination testing has been mentioned by Henning, 1966. At very high frequencies, the wavelength of sound approximates the acoustic resonances of the ear canal, especially whan measured under earphones. As the sound stimulus is varied or changed, standing waves and other interference phenomena develop, which drastically alter the SPL developed at the eardrum (Henning, 1966y Shaw, 1966; cited by Green, 1976). Consequently, a small change in frequency can produce a relatively large change in intensity, which, at high frequency can be a sufficient cue for detecting a change in frequency. This means, at these frequencies, say above 4KHz, the subject may have discriminated between two sinusoids differing in frequency on the basis of apparent Changes in loudness.

Modulated frequency discrimination in relationship to age and musical training has also been cited in literature. (Madsen and Edmonson, 1969). Auditory discriminations of a modulated frequency was tested in 200 subjects. The stimulus frequency was 369.99Hz, which was presented to subject individually in 30 sec trials in 3 ways (a) without frequency alteration (b) ascendingly and (c) descendingly. Modulation for the ascending and descending tones was 2 cycles/sec during the last 25 sees of the stimulus tone. Results showed that auditory discrimination was partially a function of age as wall as a function of musical training. Comparitively, younger subjects responded to tonal stimuli incorrectly and sharply whereas older subjects evidenced better discrimination while demonstrating a proclivity toward flatness. Also, perception of the modulated frequency is beat during the first 5 sec. (10 cents) of the frequency change (Madsen and Edmonson, 1969).

There are only a few studies on infanta or young children available on frequency discrimination. The general conclusion appears to be that infants can discriminate very gross differences in frequency, such as 300 to 600 c/s differences, but are limited in their ability in spite of their mature neurophysiological and auditory system, some interesting trends have been reported. First, Difference Limen for children are as would be expected, greater than adult values at the same point on the frequency spectrum. Secondly, it has been found that the DL values are inveraely proportional to age upto 8 years approximately. Also, frequency discrimination, even in young children can be improved with training (Soderquist and Moore, 1970).

Frequency DLs have bean tested even for narrow bands of noise (Moore, 1973). He has discussed the fluctuations in amplitude and phase characteristic of narrow band noise in relation to the difference limen for the centre frequency of auch bands of noise. He has triad to elaborate these in terms of models of frequency discrimination - the "temporal" model on which pitch is derived from the time pattern of neural impulses and a "place" model in which pitch is derived from patterns of excitation on the basilar membrane. These models predict how the DL for centre frequency varies aa a function of the bandwidth of noise which is used as the stimuli. The temporal model was found to predict certain effects for vary NBN which could not be expected on the place modal. The predictions from the two models were tested using bands of noise synthesized by the addition of a large number of sinusoids. The spectrum of these bands was essentially rectangular in shape. It was seen that the results confirmed with the predictions of the temporal model for center frequencies 2KHz and 4KHz and with the predictions of the place model for a centre frequency of 6KHz. He concluded that the pitch of pure tones and very narrow bands of noise is determined primarily by a temporal mechanism for frequencies upto 4KHz, and that at some frequency above this, the place mechanism becomes predominant. Moore's evidence consisted of showing that observers were more accurate at discriminating the pitch of short duration tones than could be expected on a place model.

A number of workers have considered the relationship of frequency BL to the critical bandwidth of noise. It is generally assumed that the frequency DL ia a constant fraction of the critical bandwidth (Zwlslochi, 1965y cited by Moore. 1943). Many workers considered this relationship to support the idea that pitch of a pure tone is closely related to the situation and the pattern of excitation produced by that tone along the cochlear partition (Maiwald, 1967; Zwicker, 1970; cited by Moore, 1943). However, the DLs upon which this relationship was based were all obtained using modulation technique and Heaning, 1966 has shown that especially at high frequencies, subjects may use intensity fluctuations as cues to discriminate frequency increments. Moore, 1943 used a two interval forced choice method to obtain values of FDL, wherein the loudness cues are not completely eliminated, but are minimized by using headphones with a wide and smooth frequency range. It was found that there occured smaller DL's at low frequencies and larger at high frequencies when compared to the results of Shower and Biddulph,1931. This meant that the relationship of CBW to FM was no longer constant.

Various studies have suggested that differential sensitivity for both frequency and intensity is better binaurally than monaurally. (Churcher, 1934; Harris, 1963; Rowland, 1967; Pickler, 1955; cited by Gelfand, 1981).

Frequency discrimination thresholds have also been reported for short duration tones (Moore, 1973). frequency EEL* were measured over a wide range of frequencies and duration. Results showed that the product of Δf and d (duration) was about one order of magnitude smaller than the minimum value predicted for the pulse toae from the 'place' model,, except for frequencies above 5KHz for short durations. It was concluded that this result was consistent with the operation of a time measuring mechanism for frequencies below 5KHz and with a place model for frequencies above this.

Zwicker, 1970 suggested a model in which frequencies changes are detected on the basis of changes in the pattern of excitation on the basilar membrane (cited by Moore, 1973). He suggested that variations in stimulus will be detected whenever the excitation pattern on the basilar membrane Changes by 1 dB or more (anywhere on the basilar membrane), and that, for a frequency change, detection will take place at the point of ateapeat slope on the low frequency edge of the excitation pattern. It was seen that this model gives a good fit to the data for frequency Δfs measured by a modulation method, but Δfs obtained by other methods indicate discrepancies at higher frequencies. Moore, 1973 reports of a number of other variables other than duration, which may be expected to shift the value of difference limen such as intensity or the sensation level, successive presentation to same ear, presentation of one tone to one ear and the second tone to the other ear, rise and fall time of the tone pulses and envelope shape, and phase of onset and offset of pulses. These have not been very must elaborated on in literature.

FREQUENCY PL IN VERTEBRATES; A COMPARISON

From experimental literature, pare tone frequency discrimination threshold values for 13 vertebrate species were taken and graphically represented by Fay, 1974 as a summary of the extent of existing data in this area. The FDL was plotted as a function of the frequency at which the threshold was measured. DL values were averaged over individuals when group means were not available. DLs in Hz were computed from Δf/f values in many cases. One drawback was the fact that the SLs of the stimuli across all the experiments were not equal, but ranged between about 30 to 50 dB. The effects of sensation level differences could not be evaluated for nonhuman vertebrates except by a data presented by stebbins et al, 1969; who found no essential differences in the differential threshold on the monkeys at SLs of 40 and 60dB. This is not true for man. Another drawback was the kind of stimuli used across this sample of experiments. Some used abrupt frequency transitions separated by brief silent intervals while some others used FM signals. Fay, 1974 has reported however, certain gross features of the compared data. The thresholds for man were clearly lower than for any other vertebrates tested at frequencies below 4KHz. Above 1 and 2 KHz, all curves tend to be linear. Below lKHx, generally lower slopes appear to be the rule. The similarity in the slopes of these functions tends to support the notion that all mammals make use of a similar mechanism for frequency analysis, regardless of the overall hearing bandwidth or cochlear length (scharf, 1970y Fay, 1974). It appears then that, inspite of wide differences in experimental technique, the paychophysical data from these two quite different measures of frequency analysis correlate quite well for the several species of animals which have been tested i.e. ability to make tonal discriminations depend upon similar, if not identical mechanisms for all mammals. "It is moat likely that this mechanism involves the spatial filtering properties of mammalian cochlea at frequencies above 1 or 2KHz. Also, there must be a low frequency mechanism for frequency analysis based upon temporally coded information. However, even in a goldfish, good FDL was seen. Since a cochlea like filtering process is considered unlikely for the fish on anat mical and physiological grounds, these psychophysical data suggest that both signal detectability and frequency resolution are based upon temporarily coded information". Quote.Fay,1974. Frequency DLs have been obtained from trained chinchillas also (Nelson and Kiester, 1978). The DLs were reported to be considerably larger than human data, especially for the frequency tones. Human differential sensitivity was found to be about 10 times better than that of the chinchillas.

A number of models have been suggested to account for frequency discrimination. All the available models of auditory discrimination based on current knowledge of the peripheral system have difficulty in accounting for the interactions found between the frequency DL, sensation level and signal frequency. Most of the models have been introduced in connection with as attempt to describe and account for the results depicted by shower and Biddulph's data (Waver, 1936; Moore, 1962; Stevens and Davis, 1938; Gullick, 1971).

Wever, 1936 explained the variation of pitch discrimination as revealed by Shower and Biddulph's data, on the basis of volley theory. Over the low frequency range and partway into the intermediate range where the nerve impulses afford a precise representation of the stimulus frequency, it is reasonable to find a differentiation that is constant or nearly so in terms of cyclic changes. Then, it would seam that the central auditory system is able to appreciate a frequency difference of 3 or 4 cps, under the conditions indicated. As we saw in the review of Shower and Biddulph's data, over a considerable range of frequencies from 125 to 2KHz, the jnd was remarkably constant, being 3 cps at 40 dBSL and 4 cps at 15 dBSL. Immediately above 2KHz, discrimination begins to gro poorer. This is the point where, based on the volley theory, frequency is still maintained, yet the neural pattern is becoming more complicated, owing to the increasing number of fibres required to carry the information. Still farther along, as 4KHz is reached, discrimination falls off more rapidly and it is here that firing inaccuracies of the fibres cause impulses to became dispersed and partially asynchronous. At further higher frequencies, where discharges are wholly asynchronous, the only one available for frequency discrimination is the place of activation along the basilar membrane. It is evident that this clue measured in terms of the change in tonal frequency that is just perceptible, is rather a one.

It is of interest to note that at mid-frequencies, discrimination is no better than low range value. At low frequencies, only frequency serves. At mid-frequencies, according to the volley theory there is both spatial and frequency representation of pitch. It then is clear that frequency cue alone is much more accurate and the presence of spatial cue is of no appreciable help to discrimination function.

The relative difference limen has alao been explained based on the volley theory (never, 1936). According to the literature cited so far, there are two main approaches to explaining frequency diacrimination. Some follow the excitation pattern theories and argue that frequency discrimination is based on the detection of a shift in excitation pattern. This is the traditional 'place' analysis. Another approach says that frequency discrimination is based on a detection of a Change in the interarrival time between neural impulses. Which refers to the traditional 'tamporal analysis'. Very few theories have bean developed to an extent as to predict how Af will vary with frequency or any other obvious parameters such as intensity or duration of the signals. The place theory assumes that a change in the frequency of a tone produces a change in the distribution of excitation in the peripheral auditory system and that the change in frequency will be detected if the change in excitation at any place is sufficiently larger. The temporal theory assumes that a change in the frequency of a tone produces a corresponding change in the temporal patterning of neural discharges (i.e. in the pattern of phase locking) and frequency discrimination ia based upon the detection of these changes in the temporal pattern" Quote Moore, 1986.

Zwicker, 1970(cited by Moore, 1986) assumed that the change in frequency can be detected if the amount of excitation changes on any part of the pattern by 1 dB or more. Rephrasing his predictions in terms of auditory filters, it it assumed that the subject listens to the auditory filter for which the change in the pattern of excitation is the largest and that the change will be detected if the output of the filter changes by 1 dB or more. Largest change usually will occur for a filter on the low frequency aide of the excitation pattern i.e, for a filter with a centre frequency below the signal frequency. In other words, the size of the DLF is predicted according to Zwicker's model to equal the smallest detectable change in the output of any auditory filter divided by the slope of the auditory filter Whose output changes the most.

Neither of the theories - place or temporal can account for our perception of pitch over the whole audible range. Van Bekesy, 1960 showed that the patterns of vibration on the basilar membrane do not shift as a function of frequency for frequencies below 50Hz. Also, it was found that the synchrony of nerve fibres to stimulus cycles have not been observed for frequencies above 5KHz. Therefore, there must exist a large range of frequencies over which "either or both" of these mechanisms could be operating (cited by Moore, 1982). Quote Moore, 1982, ... "A basic problem for any theory of hearing is to account for the remarkably small size of the frequency DL; for e frequency of 1KHz and at a moderate intensity, a change of about 3Hz can be detested and with practise even smaller DL's are achieved by some. This is a particular problem for the place theory, since the patterns of vibration which have been observed on the basilar membrane seem much too broad to account for this acuity. To determine whether place information is sufficient to account for frequency discrimination, it is perhaps more appropriate to use neural measures of frequency selectivity such as a tuning curves".

Other types of place models have been introduced (Curtiss, 1967; Henning, 1967 cited by Moore, 1982), but tone have satisfactorily explained the DL size at short durations or Changes that occur at about 5KHz. An alternative mechanism chosen to seek satisfactory answers was the temporal model, The loss of neural synchrony at about 5KHz explains the changes of DL at this frequency. It also explains certain Changes in the way puretones are perceived, one such change being a loss of musical pitch for puretones above 5KHz. A sequence of such tones is found to produce no sense of melody. It seems clear than that, some sort of Change occurs at around 5KHz and the fact that this change occurs at the same frequency at which phase locking of impulses ceases to exist is highly suggestive of an alternate mechanism controlling the behaviour. An important drawback of the temporal model however, is the fact that there has as yet, been no evidence of a physiological mechanism which would carry out the time measurements involved with sufficient accuracy.

Recently, Goldstein et al. (1977) (cited by Moore, 1982) have shown that it is possible to predict the dependence of DLF on frequency and duration by assuming that the auditory system processes the time intervals between sueccsive nerve impulses ignoring higher order temporal dependencies. Absence of physiological or anatomical evidence for an appropriate time measuring mechanism was suggested not to be discouraging since we clearly do have this ability.

Intensity pitch relationship has figured prominently in some of the discussions of auditory theorise (wever, 1936). It was considered a feature of vibrating strings which are made to put more strongly than usual against the end supports when they are vigorously excited and so they are made more tense. The incoming tone than must excite a string that his lower in the series than it would at a fainter frequency. Therefore, a lower pitch is heard. Middle tones show little or no change in pitch with intensity. These tones lie at the centre of the basilar membrane and do not shift their positions with intensity whereas other tones located at the ends of membrane move outwards when intensity is raised why this shift should occur waa not made clear. Another hypothesis begins with the fact that cochlear response is linear at low levels and nonlinear at high levels, which reflects the combined action of many segments of the basilar membrane. A given segment when overloaded, yields a smaller and smaller response in relation to the applied energy. The point of reduced responses will be reached earliest in the middle frequency region Where sensitivity is greatest. Therefore, as intensity is raised, there is a shift in the weight of the response away from the midregion. For high tones, this accounts for a shift toward the basal end and a raising of pitch and for low tones, a lowering of pitch. This has been stated as an ingenious hypothesis (Wever, 1936).

Quote Stevens and Davis, 1938 "present evidence does not permit us to state definitely by what aspect of basilar excitation one tone is distinguished from another in pitch ... we have seen that there are open to us certain reasonable possibilities for explaining the high resolving power of the tar. Among this possibilities further experiments may decide".

FREQUENCY DL AND HEARING LOSS

An understanding of the problems and difficulties faced by hearing impaired listeners in perceiving speech will require eventually a description of the losses in discrimination ability that accompany threshold sensitivity losses. A study of the consequences of a hearing loss for making simple discrimination becomes essential.

A number of studies have been reported previously on the frequency discrimination ability of hypacusis (Gengel, 1973, Jerger, 1967; LinStrom and Durek, 1976; Hupp, 1964; cited by Zurek, 1981). These studies have shown that some degree of impairment in frequency discrimination accompanies a nonconductive hearing loss.

Langenbeck, 1965 has given a clear comparison of the results obtained for frequency discrimination tasks among normals and hearing impaired listeners. In normals, absolute values of Δf increase with rising frequencies. The absolute value in the medium loudness intensities of 40-60 dB show a flat optimum and rise again with a smaller and greater intensity. From the age of 50 onwards, Δf increases especially for the high frequencies and usually earlier than the hearing loss for tones.

In patients with conductive hearing loss, Δf values are same as normals. If Δf values are higher, one can presume an inner ear component to be the cause. With an intensity of 10 dB above threshold, patients with inner ear deafness show 1.2 to 4 times greater Δf values than maximal Af values of normal subjects at the same frequency. The Δ f rise becomes steeper with increasing frequency and Δ f minimum becomes narrower. Greater Δf values are seen with increasing hearing loss.

According to Langenbeck, 1965, if the ratio 'r' of Δ f at 10 dBSL to Δf minimum at approximately 45-70 dBSL ia greater than 1.5 - 1.8, "recruitment" can be said to be present. Patients with mixed hearing loss dhow Δf values which depends on the magnitude and type of the inner ear component. Thus, Δf measurement can be a useful monaural method for the diagnosis of recruitment and hence cochlear type of hearing loss. It may be suitable for differential diagnosis between conductive and inner ear disorders and also in otoneurological cases, for greater precision in the indication for operation for the improvement of hearing and for detection of malingerers.

Clinical use of differential sensitivity measure in the phenomenon of diplacusis binauralis can be mentioned too. If we prseent a tone of constant frequency to one ear and ask him to adjust the frequency of the tone preaented to his opposite ear until the two tones sound equal in pitch, he will, if he ia a normal listener, set the second tone to the frequency of the firat plus or minus the associated DL for frequency. A listener with 'DIPLACUSIS' will set the frequency of the second tone off by more than DL i.e. he tends to hear two widely separated pitches as equal. Deviations such as these are associated with pathological audiograms. In short, diplacusis phenomenon is demonstrated in a listener with a hearing loss and seems to confirm a recruiting type of deafness (Hirsh, 1952).

We yet do not have basic information on discriminatory behaviour. If we had, it would than be possible to suggest what pathologic conditions might influence the behavior for better or for worse.

Nielsen and Elliot, 1970 have demonstrated the effect on FDL in adapted ears. There are changea reported in the quality of auditory experience produced by an adapting stimulus which increases with duration. These changes possibly have an effect on frequency DL causing a shift in pitch. They obtained data under normal and adapted conditions at two frequencies (250 and l000Hz), two intensities (40, 60 dBSL) and with two modes of presentation. The DLF analysis showed significant results for the main effects of frequency, adaptation and mode of presentation.

Brandt, 1967 gave a description of the effect on FDL after exposure to noise. Measures of threshold and FDL were obtained at I, 2, 4KHz before and after exposure to WBN. Stimuli were presented at 10 and 40 dBSL (re TTSL). No differences between pre and post exposure jnd's were noted at 40 dBSL or greater at any frequency. However, at low SLs, a differential effect on jnd owing to noise exposure was seen. At 2KHz, a 10% impairment in the jnd satiated in the later stages of recovery. A 1KHz, post exposure jnd's were about 40% greater than preexposure values. It could be interesting to examine the effect of auditory fatigue upon such measures as discrimination. It might provide useful information concerning the fatigue processes and their manifestation and quite possibly may also increase our understanding of the mechanisms of intensity and frequency discrimination processes as well.

Zurek, 1981 measured the thresholds for frequency modulated signals using a 2IFC method in 10 listeners - 8 who showed varying degrees of SN loss and 2 with normal hearing sensitivity. Results showed that relative to normals, the ability of the hearing impaired listeners to detect a sinusoid: modulation is diminished above a certain level of loss and is more disrupted for low frequency tones given the same degree of hearing loss at the test frequency. The second finding has been explained in two ways (1) by differential impairment of the temporal mechanism presumed to encode pitch at lower tones and (2) for certain configurations of hearing loas, by the asymmetrical pattern of cochlear excitation that may lead to the underestimation, from measurements of threshold sensitivity, of hearing impairment for low frequency tones and consequently to relatively large changes in frequency discrimination for small shifts in hearing thresholds.

A study of monaural frequency discrimination in cases with Menieres disease showed that the group mean values for DLF in subjects with Menieres disease were substantially greater than values for normals, especially at the higher frequencies (Meurman, 1954; cited by Parker et al. 1968).

The studies concerning DLF thus indicate that a difference in DLF does exiat between normal listeners and those with cochlear hearing loasea. It than becomes essential for us to have a set of normal values of DLF (in normals) across all frequencies and intensities.

With this view in mind, the 'FIST' was developed by Campbell in 1970. "The frequency increment sensitivity test" was used on 11 normal hearing subjects and 11 with cochlear hearing loss. It is an audiometric test using incremental frequency variationa in a presentation and scoring method analogous to the SISI test. A range of frequency increment sizes and a range of sensation levels were employed.

The mean score differences between the 2 groups were found to be highly significant at 20 dBSL with an increment size of 1.5% at 500Hz, 1.0% for 1, 2 and 4KHz. Campbell referred to FIST aa a useful differential diagnostic tool to differentiate between normal hearing subjects and those with cochlear hearing loss.

Campbell, 1970 for the administration of FIST had used a Standard Beltone Audiometer, a Beltone SISI adapter and a warble tone adapter. A continuous tone was used in which the frequency changed incrementally every 5 second. This frequency variation was 200 msec long in a smooth sinusoidal variation. The difference between the maximum frequency during the increment and the bate frequency was the measure of the increment size which waa represented as the % of the baae frequency. A difference in the results of both groups did exist indicating the importance of the FIST in clinical use for frequency discrimination.

The following atudy was conducted to establiah a set of normal values of frequency 'Difference Limen' in 40 normal hearing subjects.

METHODOLOGY

This experiment was aimed at establishing norms for the frequency DL, Also, effect of frequency, sensation level, sex and ear difference on frequency DL was to be evaluated.

Subjects: The atudy population composed of a group of forty normal subjects, age ranging from nineteen years to twenty four years. Out of the forty subjects, twenty were males and twenty were females. All subjects had their hearing threshold within 20 dBHL across all frequencies tested at Octave interva from 250Hz to 8KHz. None reported of having any ENT problem.

Instrumentation: For the administration of this test, MADSEN 08-822 Audiometer was used. This instrument consists of separate settings for incrementally altering the frequency of a puretone. Rate of change of frequency is 4 times/second. Increment change was represented in terms of percentages of the base frequency - .1%, .2%, .4%, 2%, 5% and so on. For example, 5% increment size for l000Hz means that the frequency wobbulated between l000Hz ± 50Hz. This change occured 4 times/ second. Two earphones were used as accessories to aid in direct presentation of the signals from the audiometer.

Instructions: The subjects were tested Individually. They were instructed to raise their index finger whenever they felt that they heard a continuous tone, however faint. When they detected a change in signal, i.e. whenever they detected the presence of wobbulation in frequency, however minimal, they were asked to indicate the same by wobbulating the index finger. They were specially instructed to detect as small a Change in frequency or as minimal a wobbulation as possible.

Test procedure: The subjects were seated comfortably in the test room and the headphones were placed over the ears.

All subjects were made familiar to the presence of wobbulation superimposed on the continuous tone, by presenting a large increment size i.e.5% at 1000Hz. This was easily detectable (for all normals) and gave an insight as to what to expect. All subjects were questioned as to whether they could detect change in frequency at 5% increment size. If they could, they were then asked to be prepared for minimal changes in frequency.

All subjects were tested first for 250Hz at four different sensation levels (SLs) - 20 dBSL, 40 dBSL, 60 dBSL and 60 dBSL,in this order. The next four teat frequencies - 500Hz to 4000Hz at octave intervals were then tested in the same order. Increment size was decreased step by step from 5% to 3% to 1% upto 0.2%. If subject could detect large increment size, a smaller value was presented. This was decreased until he could no longer detect change in frequency. The increment size which the subject could detect 50% of the time was taken as his/her frequency DL in terms of percentages. For eg. if the subject could detect 1% increment at 1000Hz and could not detect change in frequency below 1%, then 1% was taken as the subject's FDL. This applied to all sensation levels and all frequencies tested.

RESULTS AND DISCUSSIONS

ThE data was subjected to statistical analysis. ThE following steps were under-taken.

1.(1) The maan DL values at all sensation levels across all the frequencies tested were determined for right tar of males.

(2) The mean DL values at all sensation levels across all the frequencies tested were calculated for right ear of females.

(9) The mean DL values at all sensation levels across all the frequencies tested were determined for left ear of males.

(4) The mean DL values at all Sensation Levels across all the frequencies tested ware determines for left ear of females.

II. Significance of the difference between the mean DL values was calculated for significance at .05 and .01 levels of confidence using the 't' test of significance.

1. Significance of the difference between the mean DL values of right ear and left ear in males was calculated (at each frequency tested and each sensation level).
2. Significance of the difference between the mean DL values of right ear and left ear in females was calculated (at each frequency and sensation level tested).
3. Significance of the difference between the mean DL values of males as a group and females as a group was calculated (at each frequency and sensation level tested).

III. 2 way classification of Analysis of Variance was applied to analyze interaction between frequency and sensation level. This was done to note Whether different sensation levels yield different DL values (mean) and Whether different frequencies yield different DL values (mean), following are the tabulated values:

1) Mean DL values in MALES (RIGHT EAR)

	Frequency in Hz				
	250	500	1000	2000	4000
20 dBSL	1.18	1.24	.99	1.27	1.20
SD	.73	.89	.45	.95	.99
40 dBSL	1.25	1.14	1.02	1.04	1.22
SD	.77	.61	.46	.40	.73
60 dBSL	1.03	1.10	1.09	1.10	1.08
SD	.84	.73	.53	.64	.55
80 dBSL	1.16	1.24	1.22	1.24	1.16
SB	.90	1.01	.53	.52	1.10

2) Mean DL values in MALES (LEFT EAR)

	Frequency in Hz				
	250	500	1000	2000	4000
20 dBSL	1.20	1.20	1.01	1.14	1.16
SD	.75	.78	.97	1.01	.99
40 dBSL	1.20	1.10	1.0	1.02	1.19
SB	.98	.61	.60	.52	.80
60 dBSL	1.12	1.20	1.99	1.20	1.05
SD	.89	.84	.70	.34	.55
80 dBSL	1.16	1.22	1.24	1.27	1.20
SD	.89	1.10	.64	.53	1.10

SD - Standard Deviation.

Values in Table 1) and Table 2) were subjected to the 't' test for determining the significance of the difference in mean DL values (at each frequency and each sensation level)individually. There was no significant difference noticed at both levels of confidence (0.05 and .01). As there was no difference, the right ear and left ear DL data (of MALES) was merged to give one set of DL scores. The following table shows those mean values.

Mean DL values in MALES (Right and Left ear data grouped together).

Table-3

	Frequency in Hz				
	250	500	1000	2000	4000
20 dBSL	1.19	1.22	1.0	1.25	1.19
40 dBSL	1.20	1.12	.99	1.03	1.20
60 dBSL	1.10	1.1	1.04	1.15	1.06
80 dBSt	1.16	1.23	1.23	1 25	1.18

The same procedure applies to FEMALE group data also.

4) Mean DL values in FEMALES (Right ear)

	Frequency in Hz				
	250	500	1000	2000	4000
20 dBSL	1.18	1.20	.99	1.24	1.15
SD	.82	.89	.48	1.01	.97
40 dBSL	1.24	1.22	.99	1.22	1.10
SD	.78	.54	.39	.44	.67
60 dBSL	1.23	1.21	1.03	1.20	1.20
SD	.84	.83	.94	.96	.74
80 dBSL	1.20	1.22	.98	1.15	1.18
SD	.89	1.01	.69	.73	1.02

5) Mean DL values in FEMALES (Left ear).

	Frequency in Hz				
	350	500	1000	2000	4000
20 dBSL	1.23	1.15	1.04	1.28	1.09
SD	.96	.98	53	1.02	.99
40 dBSL	1.20	1.24	.99	1.26	1.10
SD	.78	.60	.69	.70	.70
60 dBSL	1.20	1.22	.95	1.22	1.27
SD	.89	.92	1.01	.96	.92
80 dBSL	1.20	1.19	1.04	1.15	1 18
SD	.72	1.03	1.03	.72	1.01

Values of table 4) and table 5) were subjected to 't' test for determining the significance of the difference between Mean DL values (at each frequency and sensation level). It was found that, there was no significant difference between the means at both the levels of confidence. As there was no difference, the right ear mean scores were marged with the left ear mean scores even in this case as before. This yielded the overall performance of females as a group. This table indicates thevvalues.

DL value in FEMALES (Right and Left ear means grouped together)

Table-6

	Frequency in Hz				
-	250	500	1000	2000	4000
20 dBSL	1.21	1.18	1.01	1.26	1.12
40 dBSL	1.22	1.23	.98	1.24	1.10
60 dBSL	1.21	1.22	.98	1.21	1.24
80 dBSL	1.20	1.20	1.01	1.15	1.18

New, the 't' test of significance was applied to denote the difference between the grouped means of Males and those of Females (at all frequencies and sensation levels). There was no significant difference seen even among these scores. Hence, the values were again merged to yield DL values for a single group as a whole i.e. all 40 subjects tested. Following table 7) shows the group mean DL values at different frequencies and intensities.

	Frequency in Hz				
	250	500	1000	2000	4000
20 dBSL	1.2	1.2	1.01	1.26	1.16
40 dBSL	1.21	1.23	.99	1.14	1.15
60 dBSL	1.15	1.16	1.01	1.18	1.15
80 dBSL	1.18	1.22	1.12	1.20	1.18

This data was finally subjected to 2-way classification of Analysis of variance (ANOVA) to yield (1) presence or absence of interaction of frequency and sensation levels (2) also to determine whether across different frequencies and/or different sensation levels, the DL values showed any difference.

Analysis of variance was also conducted on absolute values of DL scores, similar to the above. The respective percentage DL score was converted into an absolute value for all frequencies and at all sensation Avals. This was done to determine whether across different frequencies and/or sensation levels, the absolute DL values showed any significant statistical difference.

These results of ANOVA 2-way is indicated below.

Analysis of variance was done to find presence of interaction between frequencies and intensities (for DL values in percentage

Table-8

Source of variation	Sum of squares	Mean squares	Variance ratio
Between frequency	0.003	0.0007S	0.127
Between intensities	0.00	0.0	0
Reminder or error	0.0712	0.0059	

Variance ratio 0.127 was found insignificant at both levels of confidence (.05 and .01).

ANOVA - Interaction effect between frequency and sensation levels (DL values in absolute scores).

Source of variation	Sum of squares	Mean squares	Variance ratio
Between frequencies	5090.1412	1272.5353	.147
Between intensities	2.3817	0.7939	
Interaction	103502.83	8625.24	

Variance ratio 0.147 was found insignificant at both levels of confidence (.05 and .01).

DISCUSSION:

It was assumed initially that -

1. There will not be any significant difference between mean DL values of Males (Right ear vs Left ear). This was hypothesis 2a).Statiatical analysis proved this hypothesis. Males performed in a similar fashion during both Right ear and Left ear DL measurements.
2. Similarly, hypothesis 2b) can also be accepted. There was no significant difference between the mean DL values of Right and Left ear tested, in Females.

Aa already seen, literature does not quote any significant experiment conducted which could support this test finding. It has been a general view that right ear performance is usually better than left ear performance, even when it comes to frequency discrimination. Dominance factor has been attributed as a reason for thia. Thia experiment however does not yield such commendable difference between right ear and left ear per-

3. Males as a group and Females as a group performed similarly. Results of 't' test of significance are indicative of this conclusion. No supportive data to this was noticed during review of literature. Therefore, Null-hypothesis (1) and (2) were accepted.

Results which supported the Null-Hypothesis 3) sad 4) were surprisingly found to be in contradiction with the results of DL measurements cited in literature. It was seen that, with increase in frequency the mean DL values showed no significant difference in the group data. Neither was there a significant difference in DL value with increase in intensity. This was conclusive of the Null-hypothesis that frequency did not bear any effect on sensation level during DL measurements. Literature cites contradictory values. It has been suggested by shower and Biddulph, 1931 that, from frequencies 125Hz to 2KHz, value of DL remained constant. However, discrimination of very high tones was very poor. Δf decreases moderately as SL increases, and the effect is more pronounced for the higher frequencies.

One minor factor which could have played a role for this difference is the experimental conditions and the way tones were presented to the subjects. Also, if very high frequencies i.e. above 4KHz to 12KHz are tested, the same conclusion as cited by Shower and Biddulph, 1931 could have possibly been obtained. The rate of change of frequency variation was 2/sec in their experiment/whereas in this experiment the rate was maintained at 4/sec. Whether this could mean a significant factor can be evaluated further. However, the general tread that normals have poor discrimination at higher frequencies i.e. 2KHz and 4 KHz has been contradicted by this experiment. It could be that a larger sample would yiejd better indications to support literature. Another fact underlying this could be the great individual variability in frequency discrimination measures.

There is another possibility which could be considered. This experiment did not give any scope for practise effects. Perhaps if the same experiment was conducted twice or thrice on the same subjects, results might have varied. Practise effect yields better DL values, especially at high intensities and low frequencies.

Whether this data is a centra-indication to the place vs temporal theory reviewed in literature, is also a query. A deeper analysis across a larger group of data is needed to base our conclusions. However, how these results could be so very contra-indicative of the DL data cited in literature, is an enigma. It has generally been stated however that, comparisons of experimental results during DL measurements can be questioner because of lack of controlled variables across all the experiments. More needs to be done to reach a final conclusion.

Another factor needs to be observed. In this experiment, DL values were found out in an'Ascending method', i.e. DL value was first found at 20 dBSL and then subsequently at higher SLs. Similarly, it was first recorded at 250Hz and then at subsequent higher frequencies. Whether this could play any role in supporting this data is also questionable.

The value of mean DSL at all sensation levels across all frequencies tested lies within 1% end 1.25%* This means to say that normals can detect a change in frequency which corresponding to 1% to 1.25% of the frequency under consideration at all sensation levels. For example, if the frequency under consideration is 250Hz, than minimal frequency variation of 1% can be detected by normals. 1% at 250Hz indicates 2.5Hz. This means to say, normals hearing group can detect the charge when frequency 250Hz is varied by±2.5m (250 to 252.5Hz as an example). Further investigation with cochlear impaired subjects could give valuable test interpretations.

SUMMARY AND CONCLUSION

This experiment was conducted to find out the minimum Change in frequency which normal subjects can detect. This minimum Change in frequency (Difference limen for frequency) was denoted in terms of percentages. The test was conducted at five frequenciea in octave levela (250Hz to 4000Hz) and at four sensation levels (20 dBSL to 80 DBSL). Twenty males and twenty females were taken as subjects and both the groups were tested for DL measures in both the ears.

The following hypothesis were made prior to the experiment.

1. Male subjects and female subjects perform the test alike i.e. there is no significant difference in DL scores between the two groups.
2. There is no ear difference seen for DL values i.e. right war DL values are simllar to left ear DL values in both the groups (Males and females).
3. DL values show no significant difference across five frequencies and across four SLs i.e. there is no significant change ia DL values with increase in frequency and increase in sensation level.
4. There is no interaction effect seen between frequency and sensation level i.e. frequency does not bear any effect on intensity.

From this experiment, it was concluded that mean frequency DL values showed no significant difference across frequencies tested (350Hz to 4KHz at octave intervals) among all subjects. Frequency did not bear any effect on sensation level during DL measurement. Moreover, neither were better DL values observed with increase in sensation level. These are in direct contradiction to Shower and Biddulph's (1931), data cited in literature. This could be due to great subject variability and experimental methodology. All the four null-hypothesis were thus accepted.

The normal DL value was computed to be anywhere between 1% to 1.25% of the frequency under consideration. This value can be used as a standard value to compare with test results obtainable from the clinical population.

Recommendations:

1. Ascending vs descending method of testing can be used to find out PL values, whether there ia any significant difference can be noted.
2. Very high frequencies can be used as a part of the DL test i.e. frequencies above 4KHz. This data can than be used to compare with studies cited in literature.
3. Wider normal population can be subjected to this test to note significant variance in DL values.
4. This test Should be used over a wide range of clinical population, (specially so because frequency discrimination is very consistently cited to be affected in SH loss cases (more so in cochlear patients). The scores computed by measurement of DL values in cochlear patients can be used

as an indication of the true significant difference that exists between normal hearing subjects and hearing loss patients. This would play a very significant role in differential diagnosis. Another possibility is the presence of significant difference in DL values among different pathological conditions Eg. Menieres disease. Noise induced Hearing Loss, etc. Now that standard mean DL value has been calculated (1% to 1.25%) any change could be a significant aid to differential diagnosis. Perhaps, different pathologies show a significantly different performance in frequency discrimination measures. This is a very valid area of consideration for further investigations. It could further be analyzed as to whether cochlear patients show any significant frequency and sensation level interactions; and also whether DL values differ across sensation levels and frequencies. This might lead us to interpret the phenomenon of recruitment (Evidence by Langenbeck, 1965).

5. Specifically, the following population can be studied and their DL values can be compared with the adult DLf values obtained from this experiment.

a) Children (b) Cases exhibiting diplacusis(c) Patients exhibiting presbyeusis (d) Menieres disease and other cochlear hearing losses

More needs to be done in thia area to reach a final conclusion regarding differential diagnosis.

BIBLIOGRAPHY

Arlinger, S.D, Jerball, L.B, Ashren, T, and Holingren, B.C, (1977) "Discrimination of frequency ramps in subjects with cochlear hearing loss", Acta Otolaryngol, Vol.83, p.310—16.

Bilsen, F A , and Ritsna, R.J, (1970) "some parameters influencing the perceptibility of pitch", J.Acoust.soc. r, Vol.47, p.470-75.

Brandt, J.F, (1967) "frequency discrimination following exposure to noise", J.Acoust.SOC.Amer, Vol.41, P.448-57

Campbell, I,D, (1970) "The frequency increment sensitivity test", Acta Otolaryngol, vol.70, p.371-78.

Cuddy, L.L, (1968) "Practice effects in the absolute judgement of pitch", J.Acoust.Soc.Amer, Vol.43, P.1096.

Divenyi, P.L, Efron, R, Yund, W.E, (1977) "Ear dominance in dichotic chords and ear superiority in frequency discrimination", J.Acoust.Soe.Amer, Vol.62, No.2.

Evans, S+F, and Wilson, J.P,(1977) "Psychophysics and physiology of Hearing", AP, N.Y.

Fasti, H, (1978) "Frequency discrimination for pulsed vs modulated tones", J.Acoust.Soc.Amer, Vol.63(1), Jan. P.275-77.

Fay, R.R, (1974) "Auditory frequency discrimination in vertebrates", J.Acoust.Soe.Amer, Vol.56, No.l, July, p.206-9.

Feth, L.L, Wolf, R.V, and Bilger, R.C, (1969) "Frequency modulation and the DL for frequency", J.Acoust.Soc.Amer. Vol.45, No.6, p.1430-37.

Gelfand, S.A, (1981) "Hearing-An introduction to psychological and physiological acoustics" Marcel Dekker,INC,N.Y.

Gerhardt, C.J. and Goldstein, D.P, (1972) "Frequency discrimination and the MLD", J.Acouat.Soc.Amer, Vol.51, No.4, p.1228-32.

Green, D.M. (1976) "An introduction to Hearing", Hillsdale,N.J.

Gullick, W.L. (1971) "Hearing-Physiology and psyehophysics" (Chap.6) Oxfd.Uni.Press, N.Y.

Harrison, J.M (1984) "The functional analysis of auditory discrimination", J,Acoust.Soc.Amer. Vol.75(6) June, p.1848-54.

Haughton, P.M. (1980) "Physical principles of Audiology", Adam Hilger, Bristol.

Henning, G.B. (1967) "A model for auditory discrimination and detection", J.Acoust.Soc.Amer, Vol.42, P 1325-34.

Hirsh, I.J, (1952) "The measurement of hearing* (Chap.7), MH Book Cemp.lMT.

Jerger, J. and Jerger, S, (1967) "Psychoacoustic comparison of cochlear and VIII nerve disorders", J. Speech.Hear.Res. Vol.10, p.659-88.

Jesteadt, W, and Wier, C.C. (1977) "Comparison of monaural and binaural discrimination of intensity and frequency", J.Acoust.Soc.Amer, Vol.61, No.6, June, P.1599-1603.

Kiang, N.Y. (1968) "A survey of recent developments in the study of auditory physiology", Ann.Otol.Rhino. Laryngol, Vol.77, p.656-675.

Langenbeck, B,(1965) "Text book of practical audiometry", EA Pub.Ltd. London.

Leshowitz, B and Cudahy, B, (1973) "Frequency discrimination in the presence of another tone", J.Acoust. Soc.Amer, Vol.54, p.882-887.

Littler, J.S.(1965) 'The physics of the ear" (Chap.VII), Pergamon Press, N.Y.

Luce, D.R. and Green, D.M. (1974) "Neural coding and psyche— physical discrimination data", J.Acoust.Soc. Amer. Vol.54, p.1554-64.

Madsen, C.F., and Edmonson, F.A. (1969) "Modulated frequency discrimination in relationship to age and musical training", J.Acou*t.Soe.Amer. Vol.46, No.6, P.1468-72.

Moore, B.C.J, (1973) "Frequency difference limens for narrow bands of noise", J.Acoust.Soc.Amer, vol.54, p.888-96.

Moore, B.CJ. (1973) "Relation between critical bandwidth and frequency DL, J.Acoust.Soc.Amer, Vol.55, No.2, Feb. p.194.

Moore, B.C.J. (1973) "FDLs for short duration tones", J.Acoust. Soc.Amer, Vol.54, p.610-619.

Moore, B.C.J, (1976) "Comparison of frequency DLs for pulsed tones and modulated tones", Brit.J.Aud. Vol.10, P.17-20.

Moore, B.C.J, (1982) "An introduction to the psychology of Hearing", (Edn.2) AB. N.Y.

Moore, B.C.J. (1986) 'Frequency selectivity in Hearing", Academic Press, INC.

Naff, W.D, (1968) "Experimental studies on auditory discrimination", Int.Audiol.Vol.7, p.12-14.

Nelson, D.A, and Kiester, T.E. (1978) "Frequency discrimination in the chinchilla", J.Acoust.Soc.Amer.Vol.64(1) p.114-26.

Nelson, D.W., and Elliot, D.N.(t970) "Frequency discrimination in the adapted ear", J.Acoust.Soc.Amer, Vol.47, p.540-545.

Nordmarkm, J.O, (1968) "Mechanism of frequency discrimination", J.Acoust.Soc.Amer, 44, p.1533-40.

Parker, W, Decker, R.L, and Gardner, W.H., (1968) "Monaural frequency discrimination in subjects with Menieres disease", Acta.Otolaryngol, Vol.65, p.488-500.

Pollack, I, (1967) "Number of pulses required for minimal pitch", J.Acoust.Soc.Amer, vol.42, P.895.

Richards, A.M, (1976) "Basic experiments in psychoacoustics", Vpp, Baltimore.

Saslow, M.G. (1967) "Frequency discrimination as measured by AB and ABX procedures", J.Acoust.Soc.Amer, Vo1.41, p.220.

Soderquist, D.R, and Moore, M.J, (1970) "Effects of training on frequency discrimination in school children", J.Aud.Res.Vol.10, p.l8S-192.

Small, A.M, (1978) "Elements of Hearing Science - A programmed text", John Wiley and Sons, INC.

Spiegel, M.F, and Watson, C.S.(1984) "Performance on frequency discrimination tasks by musicians and nonmusicians" J.Acoust.Soc.Amer.Vol.76(6),Pec.0.l69C-P5.

Stevens, S.s. and Davis, H, (1938) "Hearing-its psychology and physiology", John Wiley and Sons, INC.

Tsnmura, T, Sone, T, and Nimura, T, (1973) "Auditory detection of frequency tranaitions",J.Acoust,soc.Amer, Fol.53, p.17-25.

Tyler, R.S.(1983) "Frequency resolution and doscrimination of constant and dynamic tones in hearing impaired listeners", J.Acoust.Soc.Amer, Vol.74(l), Oct.p.1190-99.

Wever, E.G. (1966) Theory of Hearing", Dover Publication, N.Y.

Wier, C.C, Jesteadt, W, and Green, D.M (1977) "Frequency discrimination as a function of frequency and sensation level", J.Acoust.Soc.Amer. Vol.61, No.l, Jan. p.178-64.

Zurek, P.M and Formby, C. (1981) "Frequency discrimination ability of hearing impaired listeners", J.Acoust.Soc.Amer, Vol.46, March, p.108-112.