AUDITORY FATIGUE AND ADAPTATION-A REVIEW

H.R. Shreemathi

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CERTIFICATE

This is to certify that the project entitled "AUDITORY FATIGUE AND ADAPTATION - a review" is the bona fide work in part fulfilment for the degree of M.Sc, III Semester M.Sc, (SPEECH AND HEARING) of the student with Register No. 9

Director
All India Institute of Speech and Hearing
Mysore

CERTIFICATE

This is to certify that this independent project work has been prepared under my supervision and guidance.

(M.N.Vyasamurthy)
Guide

DECLARATION

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

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: PREFACE :

A striking characteristic of our century is the rapid expansion of science. In the family of sciences, Audiology is a young feat lusty infent. It is no longer possible for a person to have an up-to-date familiarity with all the information in this science. New knowledge is being brought to light and new fields explored, at a rate that makes it difficult for students to keep abreast of developments in this field.

The purpose of this project work was to collect within a single volume the more important findings emerging out from diverse sources in recent years about auditory adoptation and auditory fatigue.

The loudness decrement during acoustic stimulation is termed auditory adoptation or perstimulatory fatigue. The temporary threshold shift has been referred to as auditory fatigue following acoustic stimulation.

Writing a project about auditory fatigue and auditory adoptation was a rich, varied, protracted experience. In such a work decision after decision had to made-decisions concerning level, style, length inclusion, exclusion, sequence, organization, approach keen and even punctuation.

Totally 7 chapters are there. It contains information of the major findings of those who have studied and presented.

This work will he helpful for the ex-students who have lost touch with this particular area and also for those who have not had a regular course in the topic. It also lays a good foundation and a better feedback to a beginner. It also helps the students to understand the problems, issues and concerns in this area.

An attempt is made to keep the information up-to-date, but perhaps the desire to do so wastly exceeds the accomplishment.

The assistance of many people in this endeavour deserves acknowledgement. To the extent that the work is clear, concise, and accurate, I am deeply indebted to Mr. M. N. Vyas Murthy, for his able guidance.

I take this opportunity of thanking all those who have been good enough to draw my attention to different aspects of the topic and those who offered valuable and useful suggestions and comments with a view to make the work a success.

I will be highly pleased to receive suggestions from the readers.

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CHAPTER I

1.1 INTRODUCTION

One of the common functional characteristics of all sensory systems is a redaction in sensitivity following exposure to any stimulus of significant duration and exposure intensity. For some systems the sensation may disappear completely. Gustatory and olfactory senses are examples. For others there is merely a reduction in apparent magnitude or an increased threshold. Auditory sense is an example. In all cases such changes are temporary changes as long as the stimulation does not exceed critical limits, which is the case of everyday life for most receptory systems.

All our senses tend to become less responsive to stimuli after a certain duration of stimulation. Adrian (1928) and his colleagues have studied the phenomenon in sensory nerves and in end organs. They used the term 'adaptation' to describe the gradual settling down of neural activity as the stimulus is continued. It seems that the stabilized level of activity to moderate stimuli as we experience It in peaceful rural life is a natural phenomenon and represents a steady state at which the dissipation of energy in the muscular or neural processes just balances the supply of chemical energy in the system. If an endorgan that has reached this adapted state is kept free from excitation for a little while and then subjected to the stimulus, it responds rather vigorously at the onset and then quickly reaches the adapted state. The first burst of enhanced activity is known as the 'oneffect' and it manifests itself very quickly after an exceedingly short rest.

It is as though a cell of chemical activity becomes supercharged in the quiescent state and when put into operation sets into a balanced state where the energy supplied to it just makes up for the energy supplied to outside sources. The combination of adaptation and oneffect show themselves also in ordinary life in the way we become accustomed to a steady continuous background, but are immediately alerted by its cessation or the arrival of a new sound. From this viewpoint the cessation of a sound to which the ear has become adapted is just the same as the sudden onset of an equal but phase preserved sound.

Mathews (1931) showed the response of the nerves leading from single muscle spindles of the frog in response to a constant stretching force and it seems likely that the results he obtained can be considered as representative of the activity arising in auditory neurons when the cochlea is stimulated by steady sounds. There was an initial high rate of discharge, the oneffect, followed by a rapid decline during the first fifth of a second followed by a slow decline. The decline in frequency of response, or adaptation rate was found to be more rapid as the stretching load was increased. Thus the end organ power of setting upnerve impulses was found to depend on the duration of the stimulus as well as on its intensity. Mathews found that after adaptation and removal of the stimulus for a few seconds rest, reapplication of the stirmulus produced nearly the same oneffect followed by a rapid decline again, in which there was evidence of a quicker approach to an adapted state than when the end organ was excited from the completely refreshed state.

If a sense organ is stimulated excessively it is found that the period of rest required before the maximum sensitivity can be achieved becomes prolonged. We can then say that the sense organ is 'fatigued'. It is difficult to give a precise definition of the difference between adaptation and fatigue, for presumably there is always a short period after the cessation of a stimulus during which the sensitivity of a receptor is below the unadapted level.

1.2 DEFINITION.

Auditory adaptation is the progressive reduction of the excitation level of the cochlear receptor when a continuous stimulus is applied (Moraler-Gariea, Chile 1923). The loudness decrement is termed auditory adaptation (Tobias 1970). Auditory adaptation is the process by which the sensitivity of the sensory system is modified due to the continuous presentation of a stimulus at a constant level of sensitivity (Corso 1967). Auditory adaptation is the change in the functional state of the auditory system brought by an acoustic stimulus or merely a reduction in apparent magnitude or an increase in true threshold (Eliott and Frasor 1970). Small (1963) operationally defines as shift in some aspect of the intensive dimension of subjective experience, often in the threshold brought about by previous stimulation of a sense organ by the same type of stimulus used to determine the threshold. Auditory adaptation can be taken to refer to any change in the functional state of the auditory system brought about by any acoustic stimulus.

Auditory fatigue is one of a number of terms used to describe a temporary change in threshold sensitivity following exposure to another auditory stimulus (Ward 1963). Temporary threshold shift has been referred to as auditory fatigue, that is, post-stimulatory auditory fatigue (Tobias 1970)

The amount of loudness adaptation is the difference between the intensity of the post adapted stimulus and the intensity of the pre-adapted stimulus which produces the same magnitude of reflex as that of the post-adapted stimulus (Vyasamurthy 1977).

1.3 DIFFERENCES BETWEEN AUDITORY ADAPTATION AND FATIGUE

These are the two terms which have in the past been used loosely and synonymously and yet they represent two entirely different physiological phenomena (Hood 1972). Even though auditory adaptation and fatigue may occur parallely, it is important to differentiate still clearly from each other (Zwislockl and piroda, l952; Kietz, 1960; Zwislocki, l960; Hood 1950; Dishocek 1954).

It is true that both represent a falling off of the neural fibre to a sustained stimulus but they do so for entirely different reasons.

Thus in the physiological sense it can be shown that fatigue is increased in the presence of nitrogen and retarded by oxygen but uninfluenced by changes of ionic concentration in the media surrounding the receptor. Adaptation by contract is little influenced by the presence of either oxygen or nitrogen but markedly affected by the presence or absence of certain ions.

In addition there are marked differences in the characteristics of the time courses of the two phenomena both in respect of their development, their recovery, their dependence upon intensity and duration and their frequency distribution and all these can be shown to have their identical subjective counterparts in auditory fatigue and auditory adaptation (Hood 1972)

The important feature of fatigue is that it results from the application of a stimulus which is usually considerably in excess of that required to sustain the normal physiological response of the receptor and it is measured after the stimulus has been removed.

Harris and Rawnsley (1953) have said auditory adaptation to be a special phenomenon of auditory fatigue. They differentiate auditory adaptation and auditory fatigue as follows:

1) In auditary adaptation, the duration of a stimulation does not have a cumulative effect on the threshold upto 10 seconds, while In auditory fatigue the effect of duration are cumulative from 30 seconds to 10 minutes.

2) The recovery curve for auditory adaptation is

a straight line, whereas the temporal course of recovery of threshold from auditory fatigue is negative accelerated.

3) In auditory adaptation, the maximal threshold shift occurs at the stimulus frequency, but in auditory fatigue, the maximal effect may be a half octave higher.

Auditory adaptation occurs at all intensity, whereas auditory fatigue was only appreciable for intensity above a critical intensity (Hood 1950)

Degree of auditory fatigue increases continuously with the duration and the intensity of stimulation, or a balance is not reached until at abnormal sound intensities. Recovery is slow, it is related to the degree of auditory fatigue and if the stimulus is strong enough, on irreversible change may result. Pure auditory adaptation quickly attains a definitive level in relation to the stimulus and there is no further increase, the greatest changes takes place at the stimulus frequency. Recovery is rapid and does not depend appreciably upon the amount of auditory adaptation.

Corso (1967) described auditory adaptation as short duration auditory fatigue in which the threshold shift is produced by relatively weak and brief stimuli and is of short duration and auditory fatigue which arises from more intense stimulation and is of larger duration.

Adaptation is less near threshold but Increase at higher intensity (Hood 1950 and Egan 1959) while auditory fatigue enhances loudness growth which is the result of hair cell dysfunction (Davis et al. 1960 and Bekesy 1960).

Thus, it can be said that, evidences available from the psychophysical data show that auditory fatigue and auditory adaptation reflect different physiological changes.

1.4 Ward (1973) distinguishes the phenomena commonly included under adaptation in two different ways.... whether they are observed during or after exposure to the acoustic stimulus (concomitant or residual) and whether they require one ear (monaural) or two (binaural) for their measurement.

1.41 Concomitant binaural: perstimulatory adaptation

The first investigation of auditory adaptation of any sort was that of Dove (1859) who noted, during the course of a study of binaural beats, that if one ear were exposed for sometime to a tuning fork, then binaural presentation of this same frequency would result in perception of a tone only at the unexposed ear. This is a demonstration of what has now become known as 'perstimulatory adaptation' - a shift in the lateralization of a diotic tone following a period of monotic adaptation to a steady sound.

1.4.2 Residual binaural: Loudness redaction and timber change

J.J. Muller (1871) led the sound of a tuning fork to both of his ears by means of a stethoscope. Firsta fork of frequency 'n' was presented to one ear at the highest Intensity he could master, while the tube to the other ear was squeezed shut. He then quickly substituted a fork of frequency n/2 and then squeezed the 2 tubes one after the other, so that he was able to listen with the exposed and non-exposed ears alternately. Under these conditions, he had produced a slight fatigue. By observing change in timber, Muller demonstrated that in fatigue, the loudness of a weak but suprathreshold tone at the frequency of the adapting stimulus was diminished.

1.4.3 Residual Monaural: Temporary threshold shift TTS

Victor Urbantschitsch (1881) proved that not only was loudness diminished, but that absolute sensitivity was also decreased. He used apparatus similar to Mullers but with 2 completely separate tubes to the two ears. He first matched the ears of his observer by having him listen alternately with the two ears as the tone from the tuning fork gradually decayed. In case perception disappeared in one ear before the other, he reduced the sound reaching the more sensitive ear, either by constricting the tube or by moving the pick-up end of the tube further from the fork, until the tone disappeared simultaneously at both ears. Next he exposed one ear to a large fork for 10-15 seconds. At the end of this exposure period, he damped the fork with finger, as rapidly as possible, until the tone was just audible. As soon as it disappeared, he switched to the other ear, noting how much longer it was audible in the unfatigued ear.

1.4.3.1 Ultra short term TTS: Residual Masking: In 1910 Schulze observed that if one simultaneously sounds a tuning fork and a monochord, with the latter so loud that it marks the former, then if the monochord is suddenly damped, the tuning fork is not heard immediately, but becomes audible only after a fraction of a second. The tuning fork is masked by the monochord, the monochord Is turned off. Yet the tuning fork is still not audible hence this is called residual masking (Munson and Gardner 1950). Later it has also been called forward masking. It is that portion of TTS that disappears within a second after exposure even though there is probably very little masking involved.

Zwislocki and Pirodda (1952) study indicates that the residual masking at some fixed time 't' is proportional to **the** SPL of the fatiguer. The shift is relatively independent of the duration of exposure frequency, from 100 msec. upto a few secs., as long as so the intensity of exposure frequency is low enough that full recovery occurs within half a second (upto 70 dbSPL) and the cause of recovery is exponential in nature, which means that if one plots the TTS against the logarithm of the recovery time 't' a straight line results.

1.4.3.2 Short term TTS: low level adaptations This is also associated with exposure to moderate levels of pure tones. If the duration of a fatiguer below about 85 dbSPI is a minute or so, then in addition to transitory residual masking, a more persistent TTS can be measured. The first actual measurement of such TTS was done by Wells in 1913.

Experimentation on short duration TTS established certain facts:

1) The TTS is maximal at the exposure frequency, with a reasonably symmetrical spread to closely adjucent frequencies (Causse and Chavasse 1947).

2) This particular type of TTS is relatively independent of the level of the fatiguer, upto 90 dbSPL or so, being nearly the same following on exposure at 20 dbSPL as to 80 dbSL (Flugel 1920, Hirsh and Bilger 1955; Liele Reger 1954).

3) The TTS increase with exposure time, but by one min has essentially reached its maximum value.

4) Approximately the same magnitude of TTS is produced by frequencies of about 800Hz. or above (seldom exceeds 150 db), but at or below 500Hz. little TTS of this variety can be demonstrated (Causse and Chauasse 1947).

5) The TTS is much diminished if an interrupted test tone is used instead of a continuous tone and completely recovery occurs more quickly. Interposition of a quiet period between exposure and test reduce the TTS.

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CHAPTER 2.

AUDITORY FATIGUE

2.1 Auditory fatigue and masking:

Both auditory fatigue and masking refer to a reduction in sensitivity to one acoustic stimulus as a consequence of another. Inspite of this it cannot be said of them that they are alike. Their methods of demonstration differ, their underlying physiological procedures differ.

Masking is a kind of exception to our ability to analyze out of a complex sounds the one to which we wish to attend. It is one way In which a sound affects the audibility of another sound.

Auditory fatigue is another differing from masking in that a sound has an effect on the audibility of another sound that follows it in time.

Fatigue is a temporary loss in sensitivity to one stimuli following exposure to another stimuli. Masking is a loss in sensitivity to one stimulus during exposure to another stimulus. Herein lies the methodological difference; fatigue is sequential and masking is concurrent.

As far as the underlying physiological processes are concerned, it seems clear that, auditory fatigue literally comes about from a fatiguing of sensory or neural processes. The acoustic system is either temporarily incapable of responding or it requires more energy in order to respond. Masking apparently occurs wherever that portion of the acoustic system which normally responds to one stimulus is simultaneously activated by another stimuli.

Under usual condition the masking remains fairly constant so long as the masking sound is constant. Fatigue changes in time after the fatiguing sound is turned off. Immediately after exposure to the fatiguing sound the amount of fatigue will be maximum and it will decrease in time until recovery is indicated by a return to the prefatigue threshold.

Fatigue measurement must, therefore, either be specified for a particular interval of time or else be measured as a function of time, whereas the data on masking do not need to be specified.

The pehnomenon of masking is an exception to the auditory system's ability to analyze out of a combination of sounds one sound or signal. But the fact is that we can usually hear several sounds at once and identify them separately. This is only slightly more remarkable that the fact that the auditory system resists fatigue by previous stimulation. There are exceptions, however, to this ability also.

Thus a broad band noise may mask a 2000Hz. while it is on and also produce fatigue at 2000HZ. afterwards. In the case of masking, the sensory elements that normally respond to the masked tone are already being aroused by the masking noise, to be perceived, the intensity of the 2000Hz. must be raised until its energy is significantly greater than the energy of the masking in the immediate vicinity of 4000Hz. This is called 'line busy' phenomenon and auditory fatigue a 'line dead' situation (Ward 1963). The appropriate neural elements either are temporarily incapable of being fired, or at least refractory in masking. In masking, then, there is a great deal of neural activity; in fatigue, there is much less.

2.1.2 Influence of auditory fatigue or masked pure tone thresholds:

Parker et al. (1976) detected thresholds of 3000*Hz*, tone embedded in a 2121-4242Hz. octavqftand of masking noise or a 6000Hz. tone in 4243-8486 Hz. masking noise before and after fatiguing noise exposure. Masking noise levels were varied from 0 to 90dbHl. The fatiguing noise was a 1414-2828 Hz. or a 2829-5658 octave band of noise set at intensities between 90 and 115 db. Their observations included the following parts:

1) prefatigue threshold determination
2) 3 min. exposure to Intense noise
3) 90 sec. delay and
4) post exposure threshold determination.

The results which they got are interesting,

Masked tone detection thresholds remained essentially unchanged following fatigue if the masking noise intensity was sufficiently great. At zero and low levels of masking noise, tone detection thresholds were shifted upward, depending upon the intensity of the fatiguing noise.

Parker et al. (1976) discusses these results in terms of the spread of excitation on the cochlea, A recruitment model for the influence of intense noise on masked pure tone thresholds can also be used to explain the results.

2.2 Parameters in auditory fatigue:

The experimental literature on auditory fatigue is discouragingly large. The unsolved problems greatly outnumber the established facts. The most common index of auditory fatigae is 'temporary threshold shift'.

The general procedure used is, a stimulating sound is turned on for a specified length of time, may be 2 sec. or 30 min. After it is turned off, the absolute threshold for the test sound is higher than it was before stimulation is the amount of auditory fatigue. The ear recovers from auditory fatigue and if the absolute threshold is measured at a particular time, the time must be specified.

In the stimulating tone we can vary the frequency, intensity and duration. Then we can vary the interval between the cessation of stimulation and the presentation of the test sound. We can also vary the frequency and duration of the test sound but not its intensity since this intensity remains the dependent variable.

The measurement of threshold shift 2 minute (TTS2) post exposure is widely accepted as a uniform reference for the temporally changing threshold and it is commonly used to describe the TTS produced by particular exposure to noise.

Five primary factors influence the size of the temporary threshold shift:

a) The intensity of the fatiguing exposure ... I

b) The frequency of the fatiguing exposure .... F_e

c) The duration of the fatiguing exposure .... D

d) The frequency of the threshold test signal.. F_t

e) The time between cessation of the fatiguing exposure and the post exposure threshold determination.. we can call this period the recovery interval. . . . . .RI

The basic schemes for measuring TTS is illustrated in Fig. I A TTS arousing stimulus is presented for a period of time 'T'. Then the test stimulus of duration 'T' is presented at a time 't' after cessation of the TTS arousing stimulus. If the testing is repetitive, then the duration of the total cycle is from onset of the TTS arousing stimulus to the onset of the next is designated as ' t ' .

In some cases, not all these parameters are important. In studies of the more long lasting effects, 't' is made long enough to guarantee complete recovery. The size of these in these studies is significant only in so far as the measured threshold is dependent on duration of test signal(Zwislocki 196). When t is several min. t+v is so nearly equal to 't^1 so the recovery time t+v is t or t+v.

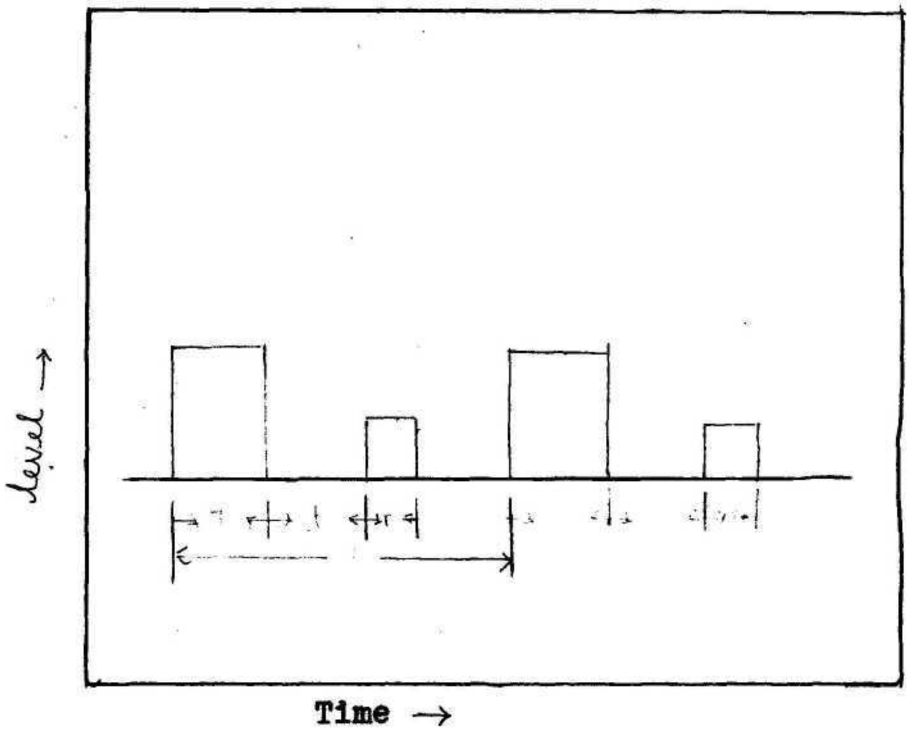

Fig. 1. Schematic temporal programme for studying TTS. A fatiguing stimulus of duration T is followed, after a pause t, by a test stimulus of duration . In case the test is repetitive, the total cycle duration is 'T' (Ward 1963)

2.2.1 Intensity of the fatiguing stimulus.

In general, more intense the stimulating sound, other things being equal, the greater is the auditory fatigue at any instant and the longer it will last.

Three ranges of intensities are of particular interest. The first is the low intensity range in which $F_t = F_e$, auditory fatigue increase little if at all as a function of intensity and decrease in a symmetrical fashion above and below F_e. At such levels auditory adaptation rather than auditory fatigue may be the source of the TTS. Under such conditions, the TTS may be only a special cause of loudness decrement, which has been found to be relatively invariant with adapting stimulus (Hood 1950).

The second intensity range is that in which one finds the maximum TTS slightly above F_e, eventually as intensity continues to increase, the maximum TTS is found one half octave and more above F_e. At these levels, and with $F_t > F_e$, TTS is quiet clearly a positive function of intensity. The positive function makes it probable that auditory fatigue as well as adapting changes are taking place.

The upward frequency shift, on the other hand, may have more than a single explanation. It probably results from the constantly changing mechanical characteristics of the basilar membrane. Because stiffness toward the basal end, the elastic limits become more and more restricted and tissue alteration from approaching or exceeding limits become more likely. Consequently the decrease in the response of the basilar membrane on the high frequency side of the point of maximum response may be more than by the decrease in its elastic limits. Whether the upward shift of the maximum TTS results exclusively from the mechanical characteristics of the basilar membrane Is unknown, however, since the stiffer portions are more subject to permanent damage from intense stimulation, it is possible that they are also more susceptible to reverse tissue alteration.

The third Intensity range is that in which the accelerating increase in TTS becomes more marked. Although the overall function tends to accelerate positively for $F_t > F_e$ one generally finds some intensity range through which the acceleration is particularly large. This maximum indicate the onset of damaging auditory fatigue. If so, then the recovery time should also accelerate as the rate at vhich auditory fatigue accumulate with increased duration of exposure even minor and reversible tissue damage will probably not recover as rapidly as the metabolic change that underlie auditory fatigue. In addition, if this critical intensity does result in pathological process, recruting phenomena should emerge, together with other types of hearing changes that reflect tissue damage in the cochlea. If this intensity range, the effeetin of increasing the fatiguing duration should differ from that of non-damaging Intensity, indeed, if these stimuli, if continued long enough, might result in permanent threshold shift.

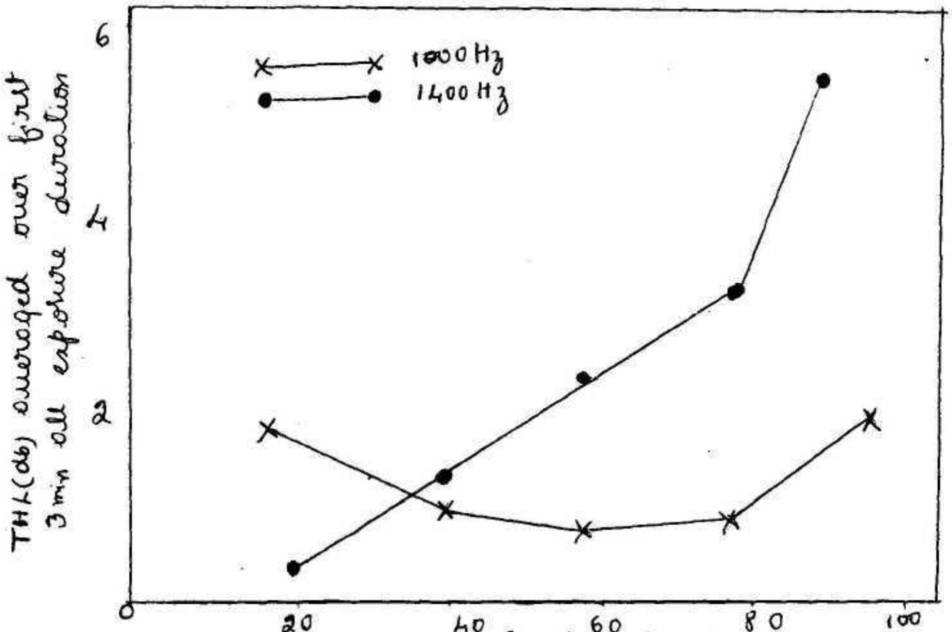

Fig. 2. Increase in TTS (THL) as a function of intensity increase Lock of any increase in TTS below 80db when F_t = Fe When F_t is one half octave above F_e growth is continuous and becomes greater than that found at the exposure frequency. (Hirsh and Bilger, 1955)

As duration is increased, additional features begin to appear. At low intensities, the TTS is reasonably well restricted to the frequency of the fatiguing stimulus, is relatively small and is not much affected by the intensity or duration of the fatiguing stimuli. It may well be that the TTS observed over this intensity range reflect neural change, changes in the metabolic conditions of the cochlea, all of which recover quite rapidly. However, as the intensity of the fatiguing tone increased, the TTS effect broadens toward frequencies above fatiguing frequency becomes more closely related to intensity, duration and recovery time becomes proportional to TTS_2. In all probably the various changes do not show up at the same intensity levels and the search for the critical level of intensity that clearly separates damaging from non-damaging stimulation is a futile one.

There are 2 interesting exceptions in the expected positive relation between intensity and TTS. The first is when $F_t = F_e$, an intensity of 20dbSL results in larger TTS_2 than do intensity of 80 dbSL and greater. The reversal is short lived, and recovery curve often cross. Although small, this reveral does illustrate the danger of using TTS_2 observed very shortly after cessation of the exposure tone as indices of long term auditory fatigue effects. In general, such a reversal means that the TTS resulting from the higher intensity recover faster than the TTS following the 20 dbSL (Lierle and Reger 1954; Hirsh and Bilger 1955).

The second reversal of the expected positive function occur at intensity about 110dbSPLC Davis et al. 1950, and Miller 1958) for a duration greater than one minute. Such reversals are not great but have been observed for frequencies above 2000 Hz, when duration has been brief. Since the reversal is found at intensity well above those that trigger the aural reflex and since it is found at high frequencies, there is some question as to whether this reversal is due to the reflex.

When the duration is one minute, and auditory fatigue is measured 10 sec. after stimulation, Hood reports only slight increase in auditory fatigue as the SL of stimulating tone increase from 60 to 90 db but then the auditory fatigue increase more rapidly as the SL is further increased to 110 db. When the duration are from 1-8 min, Davis et al. report that the temporary hearing loss continues to increase as the intensity of stimulation increase from 110 and 130 db. Exceptions are reported in which auditory fatigue appears to be maximum at 12 db and a further increase in intensity does increase the subsequent hearing loss.

For recovery time less than a sec. and longer than 2 min,, then, the TTS is proportional to the amount by which the SPL exceed some base value; this base value is about 750 75db for octave band noise. The main exception to this rule is that TTS increases with intensity occurs at very high levels. In the classic Harward study of the effects of high intensity noise, it was noticed that a given exposure to 130dbSPL sometimes produced less TTS than the same exposure at 125dbSPL. This observation has been confirmed by Trlttipol(1958), Miller (1958) and Ward (1962). This most likely explanation for this reversal is that the mode of vibration of the stapes may change at very high levels, a change that in turn produced by the maximum contraction of the middle ear muscle (Bekesy 1949).

The middle ear muscle can also affect the growth of TTS with intensity in a less dramatic manner. Even at intensity too low to produce the shift in mode of vibration of the stapes (80 to 120 dbSPL) the incoming signal produced some reflex arousal of the stapedius muscle (Moller 1961), and this action tends to reduce the amount of signal energy reaching the inner ear, and hence reduces the TTS produced. Since the degree of arousal increases with intensity, so does this self-limiting action and therefore the observed growth of TTS with intensity will have a lower slope than it would if the middle ear muscle were inoperative. Low frequencies are attenuated by the action of the muscles than the high frequencies; above 2000HZ., the transmission of sound is apparently unaffected by the contraction of the reflex. One would therefore expect that the growth of TTS with intensity should be more rapid for high frequencies than for low frequency stimulation, and indeed this seems to be the case. Although other factors may be involved (ex. it is possible that the high frequency sensory elements are inherently more fragile than the low frequency elements) it is clear that the auditory reflex play an important role in limiting TTS at /and from low frequencies.

At recovery times from a few secs, to a minute unusual effects are often seen, presumably because of the interaction of the R-1 and R-2 recovery processes (Hirsh & Bilger 1955).

These authors confirmed earlier reports by Reger and Lierle (1954) that a short (1 min.) exposure to a lOOOHz. tone at about 250dbSPL produced more TTS at the exposure frequency during the first 2 min. of recovery than exposure at 65 to 105 dbSPL. This effect can be seen even when the test tone is interrupted. This suggests that the test tone itself maintains the TTS. Hirsh and Bilger suggest that the 20dbSL tone simply is too weak to energise the R-1 process, so that in this ease all that one observes is the longer lasting, gradually decaying R-2 process.

The effects of stimulation just at threshold are currently of great interest. Bronstein (1936) reported that if observers were tested for threshold, stimulated continusously at this threshold level and retested at 5 min. interval, the threshold dropped, that is, became more sensitive. This increase in sensitivity was as high as 17db with an aierage of about lOdb.

More solidly supported by empirical data is the observation that continued stimulation at threshold may result in disappearance of the tone. Kobrak et al. (1941) credit Albrecht with the first report of this effect and Ward (1963) called this effect as "Albrecht effect".

The most thorough study of the Albrecht effect was reported in 1944 by K.Schubert. His principle results may be summarized as follows.

1. For normal ears of young people (under 30 years) and frequencies below lOOOHz. there was no effect, the threshold intensity was heard for the entire 20 minute of the test period.

At higher frequencies these young people gave slight effects (upto a final shift of about 5 db at 1200Hz.)

2. As age of the observer increased, both the final shift and the rate of change increased.

3. For individuals with inner deafness, the effect was grossly exaggerated, especially at high frequencies.

4. Persons with middle ear deafness should no more effect than normal persons.

5. General bodily condition seems to have a large effect.

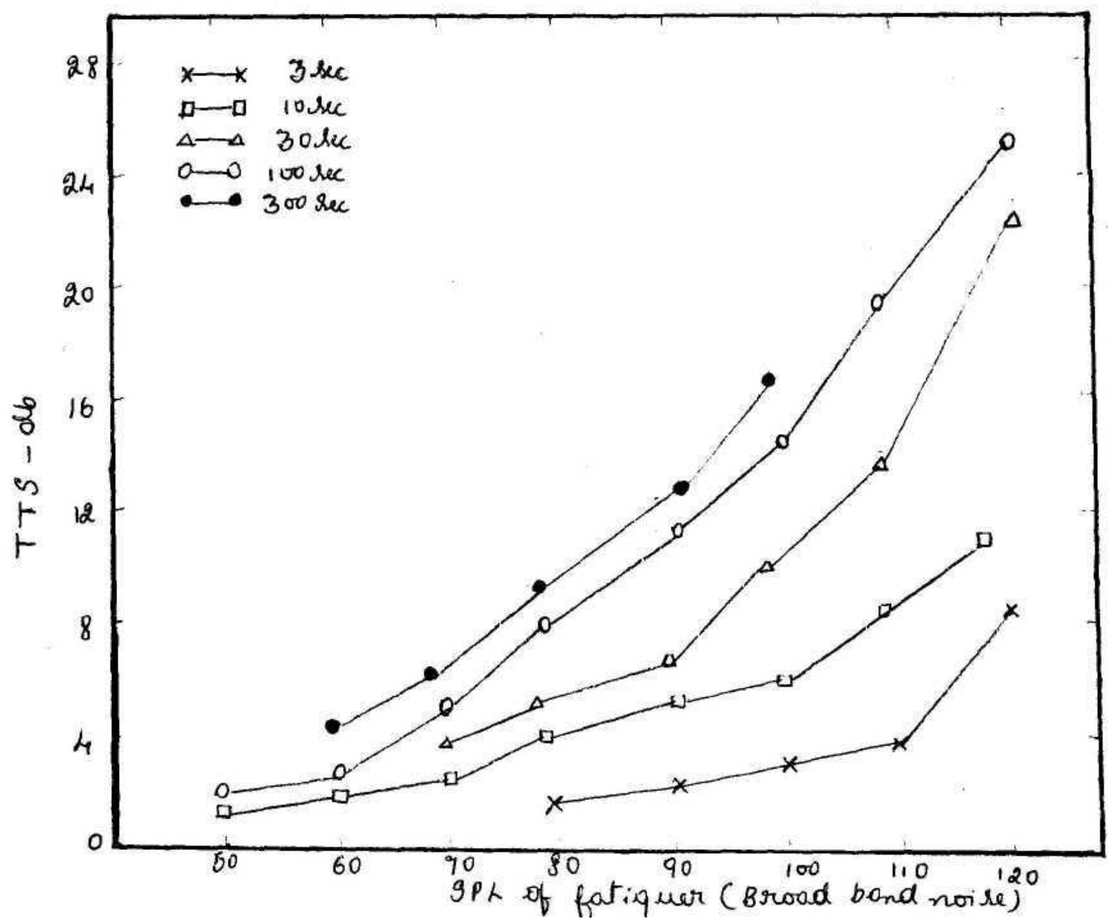

Fig.3 . Growth of short term TTS at 1000Hz as a function of level of broad band noise for several durations of fatiguer (Schaefer, 1959, quoted by Ward 1963).

The relation between TTS and SL of the noise to which one is exposed is not simple. For exposure to noise of moderate SPL(80-106db) for durations of less than 8 hours, the TTS_2 above a linear increase with increasing SPL of the noise. The orderly growth of TTS with the level of sound exposure has a lower as well as upper limit. The lower limit depends slightly on frequency content of the noise. For low frequency octave bands centered at 250 and 500Hz. it is 75 dbSPL., for 1 Khz., 2KHz., 4KHz. it is 70 dbSPL. For exposure to bands of noise having an octave band level between 80 and 95 db for periods exceeding 8-12 hour the threshold shift for the maximally affected sound frequencies appear linearly related to the octave bend level of the noise increasing at 4KHz. and neighbouring frequencies at the approximate rate of 1.6db for each db increase in octave band level.

2.2.2. Duration of the fatiguing stimulus.

The growth of long term TTS at 4KHz. with time follows a simple rule: the TTS grows linearly with the logarithm of time.

The range of duration of the stimulating sound in the literature on auditory fatigue extends about 0.1 sec. to 64 min. The relation between auditory fatigue and the duration of stimulation is not the same throughout this range.

The short duration range has been most extensively explored by Harris 1950. When he used a primary or stimulating tone of 1000 Hz. a secondary or test tone of 1500Hz., an interval of 20 msec. between the two, and a duration of 30 msec. of the test tone, auditory fatigue reamined constant as duration of the stimulating tone increased from 0.l to about 5 sec. for SL ranging from 40-80db.

According to auditory fatigue measurements of Causse and

Chausse (1947) made about 25 sec. after cessation of the stimulating tone, as the duration are further increased from 10 sec. to 40 sec., auditory fatigue increase linearly in db. Their results involve SL of the stimulating tone from 10-40db and a frequency of 1000Hz. At a SL of 100 db, Hood also reports a linear increase of auditory fatigue with increase of duration of the stimulating tone from 10-20 sec. Davis et al. (1950) report that at intensity levels of 110-, 120-, 130-, db the relation between auditory fatigue and duration from 1-64 min. goes from linearity to positive acceleration.

At lower frequencies the situation is complicated by the action of the reflex. The longer the noise is on, the more the reflex relaxes, and so the greater is the effective level reaching the inner ear. Therefore one would expect that if one plots TTS at low frequencies against the logarithm of exposure time one get a curve that is positively accelerated(Selters 1962).

For exposure to octave band SPL between 80-l05db, TTS2 post exposure is approximately proportional to the log of the duration of the exposure, upto 8 hours. Experiments involving exposure of human subjects to octave bands of noise at levels sbetween 80 and 95 db for time periods exceeding 8 hours have shown that TTS increase as duration of exposure increase upto a certain time limited and then reaches a plateau. The increase is called asymptotic threshold shift. This condition is reached after 8-12 hours of exposure.

The TTS_2 is approximately proportional to the log of the exposure duration upto 12 hours. This implies an exponential growth that reaches a maximum after about 12 hours (Muth et al. 1970). Thus if a 15 min. exposure produce a TTS_2 of 10 db and a 30 min, exposure one of 15 db, thane a 1 hour exposure will result in a 20 db TTS_2 etc. The actual rate of growth with time, will depend on the particular frequency and the level of the fatiguer.

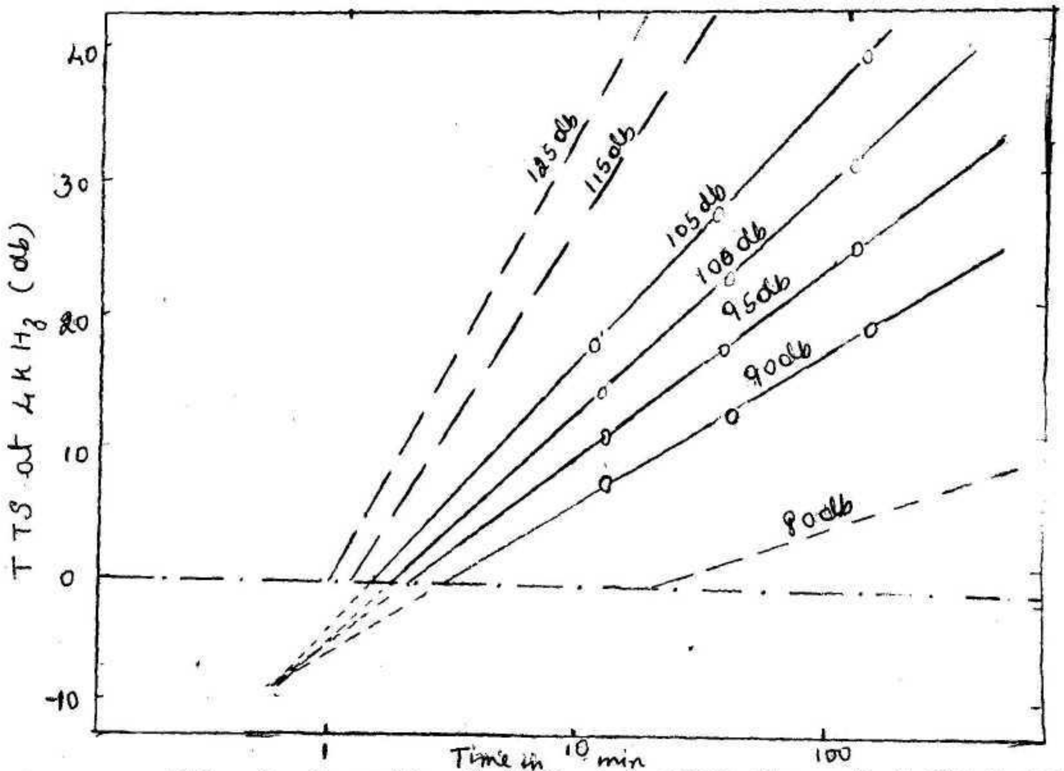

Fig.4. Growth of TTS_2 at 4000 Hz. at 4 KC full exposure to octave band noise at several different intensities as a function of exposure time; time is plotted logarthmically. [Ward et al 1959]

If we ignore the great differences among these experiments in respect of frequency, intensity and time interval between stimulation and test, we can summarize the results by saying that auditory fatigue remains small and constant as the duration of the stimulating tone goes up from 0.1 to 5 sec. As the duration is increased further between 10 and 60 sec., the auditory fatigue increase linearly in db. Above one min. as duration are increased to 64 min. auditory fatigue increase more

and more rapidly with duration.

2.2.3 Frequency:

TTS involves areas, not points, on the basilar membrane. At low levels of stimulation, the maximum effect is produced at the stimulation frequency, less at adjacent frequency. Causse and Chauasse (1947) report that with levels upto 40dbSL, the shape of the curve is symmetrical, ie., if one plets TTS against frequency level, or better against the pitch in mels (which corresponds to distance along the basilar membrane), a tone, a given distance below the stimulus frequency is affected as much as one the same distance above the stimulus frequency.

As one raises the level, however, this no longer is universally true, instead higher frequencies are sometimes more affected than lower. The results of Munson and Gardner (1950) indicates a significant asymmetry of the short term TTS (100msec) at 50 dbSL and above. At around 80 dbSL the locus of maximum TTS shifted from the stimulus frequency to half an octave above. However, de Mare' (1951) using slightly longer recovery times got the same symmetrical pattern observed after low intensities.

Results with long term TTS (t = 2 min. or more) also indicate that the maximum gradually shifts upward, sometimes becoming as high as two octaves above the stimulating frequency (Van Dishoeck 1948), although it is more generally one half to one octave above. Even at the highest intensities, studied, there has been no evidence of TTS peaks at multiples of the stimulus frequency, the only exception is the study of Luscher & Zwislocki (1949) said here the physical stimulus was admittedly so impure that the TTS peaks at harmonic frequencies can be attributed to objective harmonics.

The same holds good to TTS produced by noise (Ward 1962): the maximum effect after high level exposure is ge-generally found one half to one octave above the upper cut off frequency of the noise. However, the region from 4 to 6 KHz. seems to be anamolous in this regard. If the stimulus is a broad bend noise that includes frequencies upto 3000Hz., then the maximum effect will be produced at 4, 5 or 6 KHz. regardless of whether there is energy at higher frequencies or not (Rtiedi and Furrer 1946).

The higher the frequency, at least upto 4 or 6 KHz. the more TTS will be produced. Therefore, DRC generally permit exposure to higher levels in the 150-300 and 300-600Hz octave bands than in the 600-1200 and 1200-2400HZ bands (Roa[1] 1956; Kylin 1960).

Pure tones are assumed to be more dangerous than octave bands of noise (Anonymous 1956). The notion (Kryter 1950) was that if a given amount of energy were concentrated within a single critical bond it would be more dangerous than if it were spread over several critical bands. Recent research has shown critical band hypothesis is no more pertinent. The effect is completely explained by the difference in the ability of the two stimuli to produce sustained reflex arousal of the middle ear muscles. When a pure tone is presented, the muscles, after an initial contraction, rapidly relax. However, a noise produces a more sustained reaction, presumably because of its random nature, which continuously rearouses the reflex. Therefore more energy reaches the basilar membrane under puretone exposure conditions. That the reflex, not the critical band hypothesis, is the determining factor was supported by 2 lines of evidence (Ward 1962).

First, the TTS produced by a very narrow band of low frequency noise (one eighth octave in width) was consistently less than that produced by a pure tone at the same frequency, desp the fact that both stimuli were less than a critical band in width. The second demonstration was more involved. The TTS produced by the tone was measured, next the TTS produced by the noise. Finally the TTS produced by the tone was again measured, but this time the noise was simultaneously presented to the other ear. Because a reflex arousing stimulus activates both reflexes nearly equally, the middle ear muscle of the ear receving the tone were now as strongly contracted as when it was receving the noise. The resultant TTS in this case dropped to the same value as that produced by the noise.

At low frequencies, then, pure tones are Indeed more dangerous than noise, not because 'one is concentrating energy in a small area' but because of the aural reflex. Since the difference in degree of activation of the muscles during exposure to tone and noise respectively is a function of level (and of frequency). A single 'correction factor' such as the lOdb in current use (Anonymous 1956) is at best a poor approximation. Ideally, DEC for pure tones should simply be developed independently of criteria for octave band noise.

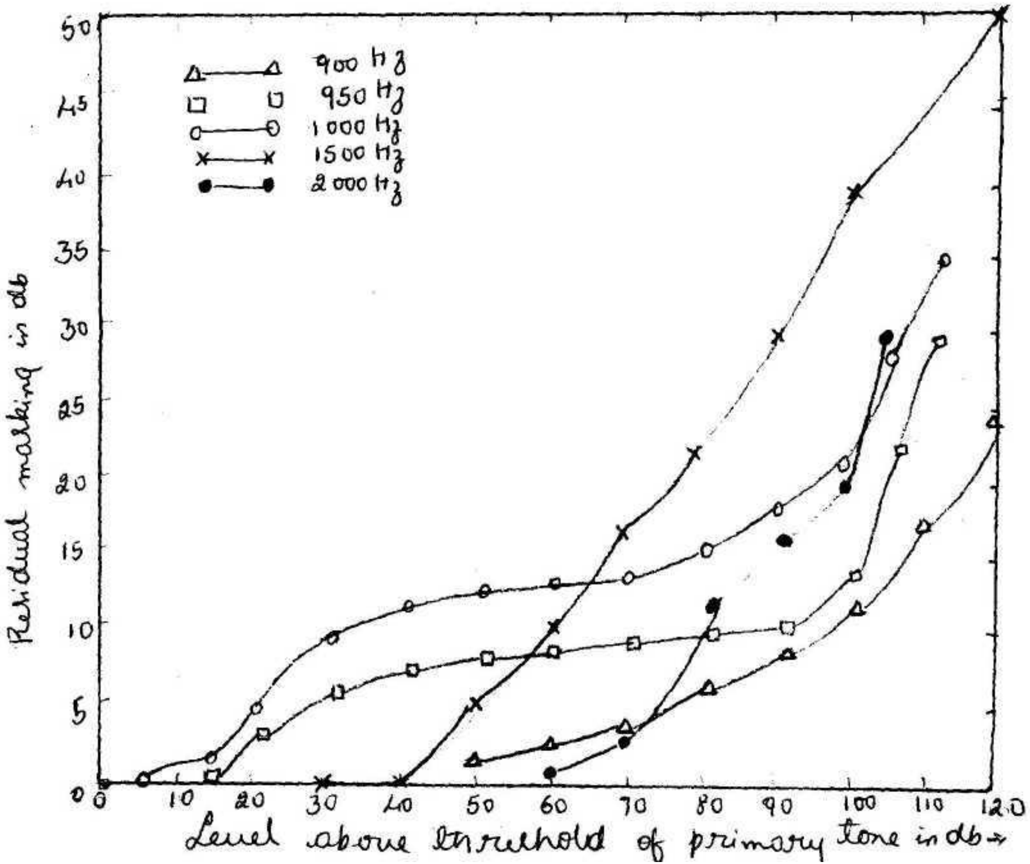

Fig.5. Relation between level of a 400msec. lOOOHz. adopting tone and the resultant TTS for test tones at various frequencies (quoted by Ward 1963).

The ear is most subject to auditory fatigue at the higher frequencies at least upto around 4000-6000Hz. TTS Is found to increase as exposure frequency increase (Davis et al. 1960, Ward 11939). It probably results from the greater stiffness of the high frequency portion of the basilar membrane and possibly, the more limited response areas of these portions.

2.2.4 Growth:

The production of TTS is dependent *on* many factors. As far as the fatiguing stimulus Is concerned, practically everything one can measure is relevant. If a steady pure tone is used, the frequency, the Intensity, and duration are important. For continuous noise, the level, band width, duration, and peak factor are the salient aspects. In the cases of pulses, reports and explosions the peak intensity and the pulse rise time and duration all determine the TTS produced. If the fatiguer is a combination of tones and noises and/or pulses, still other rules apply. Finally, if the fatiguer is intermittent or has time varying frequency characteristics, the TTS produced will be less than that produced by the same amount of energy in a steady exposure.

Parameters are interactive. Many characteristics of the listener are apparently also important. There are large differences between individuals in the TTS produced by a given exposure.

Except when it results from a high intensity impulse stimulus, auditory fatigue develops gradually consequently, its development has been explored in a number of studies, with intensity, exposure frequency, test frequency as-parameters.

Hood (1950) using a lOOdbSPL tones and the same frequency for fatiguing tone, investigated TTS growth at frequency from 500-4000Hz. for duration ranging from 100-320 sec. He found that TTS increase as a linear function of logD, ie., it is negatively accelerated. Harris (1953) investigated TTS_2 growth over exposure duration of 30 sec. to 15 min. and found that TTS growth is generally a linear function of duration. These and other studies show that TTS growth is linearly proportional to logD except for frequencies below 2000 Hz, particularly when the fatiguing stimuli is noise or a rapidly interrupted tone.

A number of studies have been concerned with the cumulative aspects of auditory fatigue. Auditory fatigue rate increase with fatiguing intensity, although the nature of the intensity duration relation is not a simple multiplicative one, which should not be too suprising in view' of the fact that auditory fatigue is an accelerating function of intensity. Greater increase in exposure intensity are needed to produce given TTS at shorter duration than at longer duration.

Several authors have been concerned with the growth of TTS in a partially recovered ear. If we assume, that during exposure, recovery processes are set up to oppose the fatiguing processes the question of re-exposing a partially recovered ear is seen to be merely a special case of the situation in which the fatiguing exposure is. continuous.Ward et al.(1959) investigated TTS growth as a function of the TTS still existing after the ear was allowed to recover partially. When the recovery time and re-exposure times are relative short, growth is proportional to the duty cycle, which suggests that the recovery growth characteristics of auditory fatigue interact in an additive manner, although their rates may be inversely proportional. Recovery rate is proportional to the TTS whether the ear is being stimulated or not. Further, rate of auditory fatigue is related to exposure intensity, so if TTS growth curves were allowed to continue to their asymptotic to levels, these levels should be proportional to the intensity of the fatiguing stimulus.

2.2.5 Recovery:

Recovery from TTS depends on fewer of the stimulus parameters than the growth process. That is, once a given TTS has been generated, it tends beyond large, to recover at a certain rate that depends very little on how the TTS was produced (Ward et al. 1959 Kylin 1960).

The recovery is usually exponential in form-faster at first, slower later - so that when plotted TTS against the logarithm of the recovery time, a straight line will be obtained. This is true of the recovery process at very short times (during first second) and also after about 2 min.

Luscher and Zwislocki (1949) and Rawnsley and Harris (1952) report that in their studies of 3hort term TTS, the recovery seemed to be linear in time than in the logarithm of time.

Rate recovery is said to be same for different intensed sound and of different durations. That is to say, the recovery curve for t = 2 min. will not cross: if there is more TTS at t = 2 min. after one exposure than after another, the same original relation holds for all subsequent values of 't'.

The recovery process seems to be relatively independent of test frequency. That is, if TTS_2 is 25 db then TTS_{100} will be about 10 db, whether the test frequency is 500 or 5000Hz.

The most well known exception to the rule that recovery is linear in log time is the so called 'bounce phenomenon[1] that sometimes occurs in the first 2 min. of recovery. Although the recovery during this time may be smooth and monotonic, certain

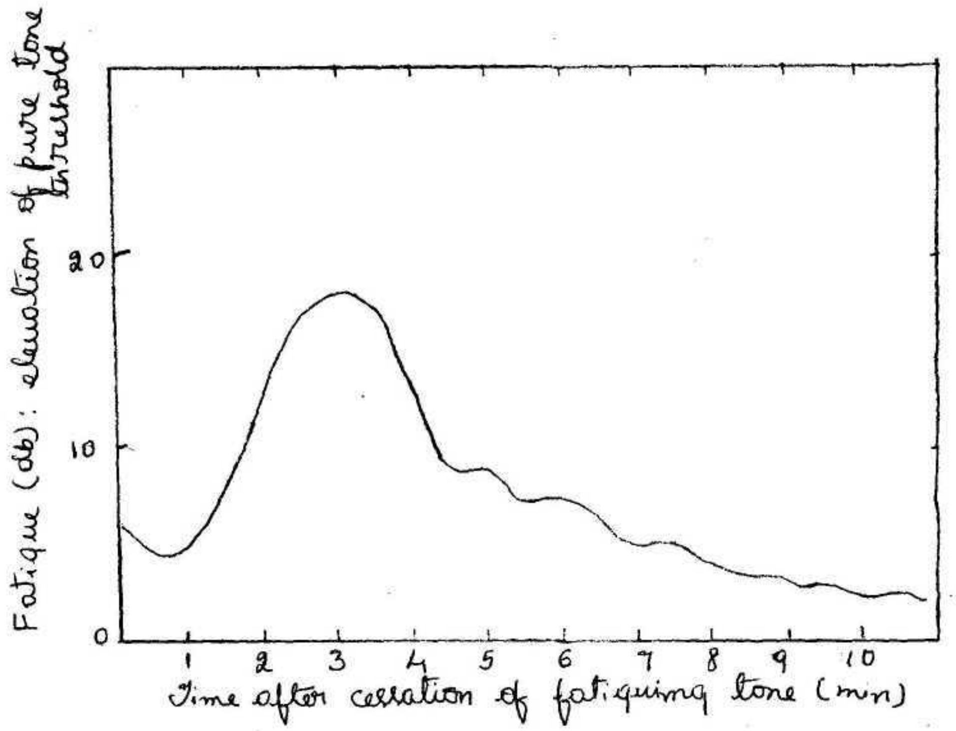

Fig.6. Recovery curve illustrating the two min. 'bounce'.
Exposure 500: Hz. at 120dbSPL for 3 min.
(Hirsh and Ward 1952).

exposures produce quiet different results. Bronstein In 1936 first reported that multiphalic recovery curves are sometimes found. After a first rapid Initial recovery of threshold, the direction may reverse, so that at t = 1 min. the TTS may be greater at t = 30sec. Hirsh and Ward (1952) found pronounced of this sort in studies of the effect of 3 minute exposures to to various tones at levels of 100 to 120 dbSPL and labelled it the 'bounce'.

Hirsh and Bilger (1955) suggested that 2 separate processes are Involved. The 'R-2' process is thought to be a monophasic process, ie., one that decays regularly in time, and that is dependent on the severity of the exposure. Superimposed on this is an 'R-1' process that lasts only about a minute, if the R-1 process is thought of as a faeilitatory in nature, that is, acting in opposition to R-2 which always produces a decrease in sensitivity, then a diphasic recover curve can be accounted for. In fact, if the R-2 fatigue is not too severe, a strong facilitory R-l showed sometimes produce a net negative TTS- a transient sensitization of threshold. Such sensitization is indeed found (Bronstein 1936, Hirsh and Ward 1962, Hughes 1954).

Even when the recovery curve during the first 2 min. is not diphasic the rate of recovery during this time may be significantly different from that after 2 min. which supports the notion that more than one type of underlying process is -iA involved.

A second exception to the uniformity of recovery of TTS is found when TTS_2 is too great. If the exposure has been so severe that TTS_2 at some frequency exceeds about 50 db, then recovery is much slower. Instead of being linear in log time, recovery proceeds linearly in time (Ward 1960); the rate is so slow that several weeks may be required for complete recovery (Davis et al. 1950).

An auditory stimulus that would not itself produce a measurable TTS would also not influence the rate of recovery from a given TTS (Ward 1960).

2.2.6. Sensitization or facilitation:

Not all shifts in threshold are in the direction of decreased sensitivity. Under certain conditions, example moderate expose intensity (60-100dbSPL) low exposure frequency (500Hz.) the initial portion of the recovery function exhibits the auditory sensitization.

Hughes (1954) called this increased responsiveness asimulate sensitization. He used this term to describe pure tone threshold sensitivity that was better than it had been before another pure tone stimulated the ear and that appeared as the first notable deviation from the pre-exposure threshold.

Hughes demonstrated this phenomenon by employing low frequency stimulating tones at moderately intense levels (80-100dbSPL) for one minute. He found that immediate sensitization appeared only when the frequency of the test tone was lower than that of the exposure tone. The time course for these events featured on immediate threshold sensitization that grew to maximum size at about 30 sec. post exposure and then gradually disappeared by one minute.

In sensitization, greater sensitivity, as measured by means of absolute threshold, from 1-2 min. after exposure to the fatiguing stimulus than it did prior to any stimulation(Hirsh and Ward 1952, Hughes 1954). This phenomenon has also been confirmed neurophysiologically.

There have also been some studies that indicated an enhanced sensitivity of the auditory system following exposure to low intensity stimuli (5-20dbSL) short duration(5 msec.-10sec.), short recovery time (5 msec.-1.0sec.) (Zwisloekl, Pirroda and Rubin 1959, Rubin 1960). This phenomenon was termed 'facilitation' by Rubin to distinguish it from sensitization as described by

Huges (1954) which is elicited by relatively long exposure duration and more intense stimulation.

Thomas J. Moore (1970) reported two different types of sensitization.

1. A sustained type that was elicited following exposure to low intensity stimulation and which may be related to the density of functional receptor elements in the region stimulated.

2. A transitory type that required exposure to moderately intense stimulation and which apparently occurred only when two regions of differing sensitivity were stimulated simultaneously. In the auditory system, sustained sensitization appeared in both the ipsilateral and contralateral ears, transitory sensitization occured only in the ipsilateral ear.

In experiments involving an increase of the intensity of the exposure tone on successive runs, an effect can be seen earlier for test frequencies below the exposure frequencies than for those above it. NaffAinger and Tillman (1970) stimulated human ears by three minute 65-90dbSPL continuous tones and post-exposure thresholds for tones of lesser frequency were examined. In most cases such procedures allowed demonstration of auditory sensitization that was not preceded or succeeded by desensitization and then ran its course in the first post-exposure minute. Such sensitization was noted at 200Hz. following certain 500Hz. exposure tones and at 2000Hz. following certain 3000Hz exposure tones.

There appears to be greater sensitization to a continuous test tone (Hughes 1954) than to an interrupted one(Noffsinger and Tillman 1970).

Sensitization Is not restricted to the ear exposed. Hughes (1954) using a special apparatus to produce an interaural attenuation of 85 db. found nearly as much sensitization at 500Hz. after stimulation by a 500Hz. 85dbSPL tone in the contralateral ear as after ipsilateral stimulation. Noffsinger and Tillman (1970) have also demonstrated this.

Threshold for a tone can be affected in three major ways by exposing the ear to another tone.

1. isolated sensitization
2. multiphaslc behaviour (sensitization and deaensitlzation - the bounce effect)
3. isolated desensitization.

These changes seem dependent on at least the following variables.

1. the frequency of and the frequency relationship between the test and exposing stimuli
2. the intensity of the exposure stimulus
3. the duration of the exposure stimulus and
4. the condition applying during the exposure period ex. whetter the subject was required to track threshold during the exposure tone(T_r) or not (DN T_r).

To study these Noffsinger and Olsen (1970) examined the threshold sensitivity for train of 250 msec, test pulses (250, 1000, 4000 Hz.) following exposure tones of various types. Associated with each test tone were 2 min. exposure tones of the same frequency, half the frequency and twice the frequency as well as 2 additional tone, one of whose frequency was considerably higher and one considerably lower than that of the test tone.

Each exposure tone was presented at four intensities levels namely 20, 60, 85 and 105 db. Both DNT_r and T_r procedures were employed.

The results of the experiment showed following facts:

1) isolated auditory sensitization is a real phenomenon, it can be demonstrated for both high and low frequency tones. Duration of such sensitization ranged from 20 to 100 see, Sensitization that occurs later in the post-exposure time course, usually following R-l was also demonstrated in some experimental conditions. It usually attains maximum magnitude at about 1 min. post-exposure has a duration of 16-30 sec. and generally is of smaller magnitude than more immediate sensitization.

2) If an ear is stimulated by a pure tone whose strength is gradually increased, the first noticeable post-stimulation change in threshold for another pure tone in some instances is sensitization. Such sensitization will increase in magnitude and/or duration to a critical point and then decline with further increase in exposure tone strength. Following even stronger stimulation, desensitization will become apparent in the post-exposure thresholds, first as an initial threshold shift that rapidly declines (R-l) and may yield to sensitized threshold then as a multiphasic process containing R-l, a bounce and a second period of desensitization (R-2) and finally as a long lasting period of desensitization that is most aptly described as R-2 alone.

3) The sequence of post-exposure events described above is initiated at lower exposure levels following tones whose frequency is lower or equal to that of the tilt tone than following those

with higher frequencies. Given this distinction, decreasing the frequency differential between the test and exposure tones has an effect similar to that produced by increasing the exposure tone intensity.

4) Continued threshold tracking of the test tone during the exposure tone period usually produces more post-exposure desensitization than is produced when the exposure tone is presented alone.

Sensitization and desensitization reflect the state of at least partially separate physiological mechanism that are affected in different ways and for different periods of time by prolonged stimulation. One reasonable hypothesis is that sensitization mirrors a presynaptic electrical or electro-chemical hyper-excitability, ie., hyper-polarizatlon and desensitization reflects a reduced post synaptlc receptive capability.

2.3 General equation:

Ideally it is necessary to have a single equation that would predict the TTS existing at any frequency at any time following an exposure to a fatiguing stimulus having any given duration, level, spectral distribution and temporal characteristics. But we are far from that goal. However, equations describing the TTS produced by a limited range of exposure parameters can be derived fairly easily, particularly in the areas where a simple monotonic relation can be seen and where the complicated action of the auditory reflex is not relevant.

Corso (1967) has derived the following equation to express relationship between TTS and the SPL for intermittent noises

$$TTS2 = 1.06R(S-85)(\log T/1.7)$$

where S is the SPL of noise, R is the fraction of time that noise is 'on' and T is the duration of exposure. This equation holds for

1. T greater than 75 min.
2. $85 < S < 100$ db. and
3. all values of R provided the noise bursts are 250msec. to 1 min. in duration.

Ward et al. (1959) gives one such equation.

$$TTS = K_1(S-S_0)(\log_o T - K_2)+K_3$$

where $(S-S_o)$ is the average value of the amount by which the sound pressure level S exceeds the base value, T is the exposure time, K_1, $K_2 = K_3$ are constants that depend on the specific values of some of the other parameters. Equations of this form can be fitted to TTS data gathered under conditions within the following ranges: exposure durations of 10 min. or more, recovery times of 2 min. or longer, exposure frequency 2000 Hz. or greater SPL below 125 db, if the exposure is intermittent burst durations of from 1/4 sec. to 2 min.

2.4 Miscellaneous factors affecting auditory fatigue:

2.4.1 Interactive effects - Recovery from TTS will proceed no more swiftly in silence than it will in a noise low enough in intensity and no TTS would be produced by this noise (Ward 1960). Even when noise is intense enough to produce TTS at one frequency region, it will not affect the course of recovery at frequencies outside this region (Ward 1961). Apparently the course of the fatigue process at one area of the basilar membrane is relatively independent of conditions existing at other areas.

2.4.2 Resting threshold - persons with inoperative middle ear muscle but normal sensitivity (as in Bell's palsy, where the muscles are paralyzed or after a successful stapes mobilization, on operation in which the Jendons are cut) will show more TTS following low frequency exposure than normal. Those with normal middle ear muscle but impaired sensitivity will show less TTS. In the case of pure conductive loss, the effective level of sound reaching the cochlea is reduced. Individuals with pure end organ perceptive losses will also show less TTS than normal individuals, but only because they less to lose, as it were. The energy entering the cochlea of such a person is no different from the normal case. But if there is already a considerable loss of sensitivity, then the threshold shifts produced by a given noise will be less than in normals, even though the shifted threshold of the impaired ear is always higher. After exposure to a given noise, ears with end organ deafness will still require greater signal energy for hearing than will normal ears. So the fact that he shows less TTS does not mean that he is better off- the acquirement of a permanent loss from noise does not constitute protection against further loss.

2.4.3 <u>Latent and residual effects:</u> A study by Harris (1955) indicates that residual effects may sometimes be found. He repeatedly restimulated his listeners with a TTS producing stimulus Just as the TTS from the previous exposure 'reached zero' and found that the TTS gradually increased. So the ear may still be under the influence of fatigue processes for sometime after it is no longer possible to measure them by means of TTS.

2.4.4 <u>Vitamin A</u> Some reduction in the TTS can be produced by administering 100,000 units of Vitamin A daily(Willemee 1952 Rliedi 1954). Later investigations have failed effect of vitamin A on either the resting threshold or the TTS produced by means of a given noise (Ward and Glorig 1960). It appears that large doses of Vitamin will not affect TTS in persons vhose diet is reasonably normal, although it is still possible that a deficiency of the vitamin might change the course of auditory fatigue.

2.4.5. Oxygen: A reduced oxygen intake might increase TTS Tondorf et al. (1955) found the reduction in cochlear microphonic from guinea pigs produced by one minute exposure to a 1000 Hz. pure tone at 130dbSPL. When the guinea, pigs were in a reduced oxygen (10% oxygen instead of the normal 20%) throughout the entire experiment (a min. pre-exposure period, the one minute exposure, and 32. min. recovery period) the reduction in cochlear microphonic produced by the tone was greater than if only pre-exposure period were in reduced oxygen. Recently Von Schulthness (1971) has found hypoxia corresponding to an altitude of 500m influence of auditory fatigue at 4000Hz. Normal adaptation was not always regained after return to oxygen supply or normal atmospheric supply.

2.4.6 Salt Cook (1952) has sprculated that excessive use of ordinary salt may cause the ear to become waterlogged, produce endolymphatic hydrops and increase TTS.

2.4.7 Vibrations Morita (1958) has reported that when 10 subjects were exposed to 100 db. white noise for 30 min. while simultaneously being vibrated, the TTS was greater than if the 100 db. noise acted alone. Perhaps the protective effect of the middle ear muscle is reduced by the vibration. Akira Okada and Hirotsugu (1972) came with the same result. TTS caused by the noise is enhanced by vibration. Yokoyama, Osako and Yamomotee (1974) found no significant change in the threshold sensitivity after exposure to vibration alone. Exposure to vibration and noise simultaneously caused greater TTS and longer recovery time than exposure to noise alone. They suggest that the effects of the combined noise and vibration might be the re-suits of some disturbances of physiological homeostasis or possible mechanical interaction with its blood supply.

2.4.8 Drugs and level of consciousness: The data in general support the lack of central involvement in TTS. Lehnhardt (1959) has recently shown if the subjects are given ayorelaxln then the TTS produced by a 2 min. exposure to white noise at llOdb is change; there is more TTS at 3000HZ. and below,less at 4000Hz and above. The locus of maximum TTS was shifted from 4000Hz. to about 2400Hz. with administration of the drug. Some Russian investigators found less TTS to be produced by a given noise if the listener were hypnotized and told he was in silence.

Logoux (1977) recorded CM, AP, SP on guinea pigs after the introduction of KCI solution in the perilymph. This introduction provoked a moderate decrease of CM and AP. During the period of depressed but stable amplitude, the presentation of intense sound provoked an exaggerated susceptibility to fatigue and a delayed recovery. Similar changes were observed in the evolution of 15P. However, the recovery was slower for EP than for CM. The results, as a whole, suggest that the fatigue which is manifested in the depression of CP is related to a leakage of potassium ions from endolymph to fluid spaces within the organ of corti.

In 1975 Woodford and Henderson studied the effect of salicylate and noise in combination on auditory threshold. No consistent interactive effect was found either in magnitude or time course of post treatment threshold shift.

In one Russian study, changes in the cortical recovery patterns from auditory fatigue under several different experimental conditions in 22 eats,,. Results indicated that at the level of the auditory cortex it was difficult to secure data from anesthetized animals which compared with psychological data gathered by the classical psychological techniques. Evoked potentials were recorded over the auditory cortex before and after exposure of the ear of anesthetized cats to intense, low frequency tone. In light chloralose anesthesia, post-exposure enhancement was related to intensity and duration of exposure but there was a decrease in post exposure enhancement with increase in chloralose. In deep chloralose anesthesia, post-exposure depression preceeded enhancement and became more severe as depth of anesthesia increased.

2.4.9 <u>Sex, age and experience</u>: Kylin (1960) Dieroff (1961) found women have better hearing than men after studying industrial workers hearing. Ward et al. (1959) report some amount of TTS when normal hearing college students of both sexes were exposed to the same noise.

Nerbonne and Hardick (1971) exposed 10 men and 10 women to 110dbSPL of broad band noise on four separate occasions for 15 min. Bach subject's threshold at 4000Hz. was determined after 1, 9, 10 and 20 min. of recovery. Even though the 2 groups experienced similar amounts of TTS immediately following ex-when the initial amount of TTS was held constant for each sex. With continued exposure to noise, the ear somehow becomes more resistent to TTS that 'tender' ears become 'tought'.

Novotimy (1975) analysed the results of 160 exams of the auditory thresholds after 3 min. stimulation with white noise in different age groups of workers suffering from occupational deafness due to noise. He concludes that:

a) auditory fatigue expressed as the temporary decline of the auditory threshold in db is not significantly higher at a more advanced age.

b) the temporary decline of the auditory threshold does not attain in any of the examined age groups pathological values.

c) in the fourth and seventh decade, the values are relatively the highest but do not obtain a level of significance.

d) the temporary decline of the auditory threshold after short term stimulation with noise cannot serve as a basis for decision whether more advanced age groups of employees with occupational deafness should be left in or transferred from a noisy environment.

2.4.10 Temperature: Dennis G Drescher (1976) studied the effects of temperature on cochlear responses during and after exposure to noise. Anesthetized chinchillas were maintained in the qiet for 24-48 hr. with virtually no loss of maximum voltage or sensitivity of Cm. Changes in body temperature and cochlea temperature from 29° to 39° C had little effect on normal Cm. With presentation of steady octave band noise with centre frequency of 1000Hz. at 90dbSL overall, Cm decreased and approached an asymptote at a rate dependent on the temperature of the preparation. The rate of redaction was less at low temperature than at higher temperatures. With termination of the noise, an initial rapid recovery of Cm preceded a slow recovery toward normal Cm value. The slow recovery was inhibited at low temperatures and could be enhanced by raising the temperature. This finding indicate that noise induced reduction of Cm may be linked to processes of energy metabolism and/or involves temperature dependent structural changes that do not affect normal cochlear response.

2.4.11 Physical exercises: Saito (1959) studied the effect on hearing acuity produced by various physiological conditions. He had 76 young persons aged 17-21 years play nine kinds of games; tennis, judo, japanese fencing, volley ball, basket ball, rugby, wrestling, 1500 and 5000 meter race. Immediately before, after 30 min. after, one hour after, 2 hour after the exercise he obtained pure tone audiogram and examined the variations in auditory acuity. The exercise appeared to produce a TTS shift in some of the subjects. The TTS after exercise was most evident in the frequency of 4096Hz. The restoration of TTS took 30 min. with tennis, judo and japanese fencing, one hour volley ball, basket ball, 1500 meter race and rugby and 2 hours with wrestling and a 5000 meter race. The appearance of the dip at 4096 Hz. became more frequent and Its depth greater in proportion to the severeness of the exercise and the degree of fatigue. The author compares this TTS at 4096 Hz. after physical exercises with auditory fatigue and hypothesize that it is a result of circulatory disturbance.

2.4.12 Stress and Nonstress stimuli :Beh and Matealfe (1972) conducted study using the adaptation technique to investigate sensitivity to 'stress' and 'nonstress' auditory stimuli . The stress stimuli was defined as a stimulus previously paird with electrick shock and rate of recovery from auditory adaptation taken as the index of sensitivity. The results indicate that recovery is significantly faster for stress stimuli than for non-stress stimuli and provide evidence favouring the perceptual sensitization hypothesis.

2.4.13 Ear:(a) During the past few years, much attention has been devoted to the study of ear differences in the processing of auditory stimuli. In 1970, Spellacy and Blumsteim reported data which suggested than when normal hearing subjects are asked to recall or identify dichotically presented complex stimuli, they show a greater degree of accuracy for sounds presented to one ear over the other. Other studies have suggested that when the stimuli is long, the right ear, is typically the dominant ear (Shankweiler and Studdent - Kennedy 1967, Kimura and Folb 1964). Studies by Kimura (1964) and Curry (1967) have suggested that the left ear appears to be the dominant ear when the stimuli are not complex language sounds.

Ear: differences in susceptibility to auditory fatigue has been reported. Jerger's (1970) study showed differential effects in the TTS in the 2 ears of the performance. Ward(1967) pointed out that the same ear may also exhibit different susceptibility to different frequency bands. In a recent study by Weiler et al. (1974) show the average TTS was greater at 250 Hz. and 500Hz. in the right ear. The left ear had more TTS than the right ear at 1000 Hz. and 2000Hz and the right ear had more TTS at at 4000 Hz. and 8000 Hz. than the left ear. One might hypothesize that the microscopic physical variations between the 2 ears in the position or angle of the cochlear duct relative to the oval window could be responsible. Such a difference might cause the fluid pressure waves in the inner ear to stress the sensory structure at slightly different points.

2.5 Functional changes in the ear due to Auditory fatigue:

Elliott and Fraser (1970) have quoted many of the studies of how the auditory system handles contiues signals, During the process of continuous stimulation of the auditory system, functional changes will take place at the hair cells, endolymphatic, the neural discharge. These changes are:

2.5.1 Neural Changes - Reduction in neural responsiveness occur when a continuous auditory stimuli is presented and the neural response rate decrease rapidly until after about 3 min. a stable level is reached. Cessation of the stimuli, neural discharge rates rapidly increase and reach their original level within one minute (Derbyshire and Davis 1935).

When a receptor or nerve fiber has been adequately stimulated it will discharge at a constant strength and thereafter no matter how intense the stimuli is it will cease to respond for a finite period of time known as the absolute refractory period until it has had time to recover. The feature of this response is known as the all or none low. Beyond the absolute refractory period there is a slightly longer period known as the relative refractory period during which a stimulus exceeding the adequate stimulus may evoke a response. As a result of this the rate of this the rate of the response of the receptor, ie., the number of responses per sec. to a continuous stimulus will continue to decline until it reaches a steady level at vhich the energy expended by the receptor is just balanced by the metabolic energy which becomes available to sustain it. This process which has been labelled equilibration by Stevens and Davis is the essential feature of adaptation. Adaptation results primarily from the activity of the receptor, in other words providing the stimulus is adequate, adaptation is independent of stimulus intensity and once adaptation is complete, that is to say the state is reached at which energy expenditure is just balanced by the release of available energy then no further increase in adaptation can take place so that to this extent adaptation is independent of stimulus duration.

2.5.2 Hair Cell change; When moderate or high intensity is presented continuously, decrease in cm. in the form of shift in linear portion of input-output and also reduction in the level of maximum cm. with some sharpening of the peak of the input-output curve (Wever and Smith 1944)

2.5.3 Endolymphatic changes - continuous stimulation produces decrease in oxygen and reduction in endolymphatie DC potential (Bekesy 1951, Tonndorf and Brogen 1952), There will be reduction in CM and AP also due to reduction in oxygen in endolymph. If this continues there will be accumulation of metabolic waste product and interfere with nerve cells.

2.5.4. Other changes: Bekesy (1951) and Torndorf and Brogan (1952) found that stimulation causes a reduction in the potential difference typically found between the scala vestibuli and scala tympani. This reduction may reflect a decrease in the impedance of Reissner's membrane and the basilar membrane; if so the ionic transfer between the endolymph and the perilymph could increase and interfere with normal functioning (Shimizee et al.1957, Buttler 1962)

2.6 Auditory fatigue and iris pigmentation:

It has been reported that individuals with highly pigmented irises (brown) experience significantly less TTS than individuals with less-pigmented irises (blue) and those with green grey pigmentation display intermediate amount of TTS.

Tota and Bocci noted the high correlation between the melanin content in the stia vascularis and that found in the pigmentation of the iris. Specifically their data revealed that subjects with light brown or dark brown irises exhibited much less TTS (13 and 12 db. respectively) than subjects with blue irises (27 db) and that those with green grey irises displayed intermediate TTS (17 db). Concomitantly Tota and Bocci (1967) found that recovery time from auditory fatigue was shorter for those with brown irises, somewhat longer for those with green-grey irises and longest for those with blue irises.

Tota and Bocci (1967) attributed the TTS differences to the protective effects of melanin. They noted Bonaccorsis (1965) demonstration that the melanin content in the striavascularis was directly proportional to the melanin content of the iris.

Specifically, Bonaccorri (1965) observed that the stria vascularis was without pigment when the iris was blue and the concentration of melanin in the stria vascular is increased pigmentation of the iris. Turaine (1955) reported that albino subjects often display a loss of hearing sensitivity.

Bonaecorri and Galiotlc (1965) demonstrated that auditory defects in the guinea pig from industrial noise was inversely proportional to the pigment in the stria vascularis and finally, homolateral hearing loss may occur on the side depigmented iris in persons with two different colour eyes (Prizbsm 1948). Tota and Bocci (1967) concluded that their auditory fatigue data represented clinical confirmation that the function of melanin content in the cochlea is to protect the neuro-epithelium from acoustic trauma and also that, other conditions equal, the person with lighter coloured iris is more likely to suffer hearing loss from intense and prolonged sounds.

J.D. Hood and J.P. Poole also support the above view. They say the correlation is not particularly strong at stimulus intensities of 80 db but becomes more persuasive at higher intensities. At 120 db the evidence seems conclusive, with blue subjects exhibiting significantly more TTS than brown eyed subjects. They conclude that, since this relationship is evident only when the threshold determination are carried out using continuous tones and is absent with pulsed tones, the underlying mechanism is predominantly auditory adaptation and not auditory fatigue.

In 1975 Karlovic replicated the methodology adopted by Tota and Bocci (100 Hz. at 110 dbSPL for 3 min.). The results do not support the hypothesis that individuals with fcighly pigmented are more resistent to auditory fatigue than those with less pigmentation of the iris.

2.7 Auditory Fatigue during vocalization:

Karlvich and Fluterman (1970) exposed four subjects to a high level puretone fatigue stimulus for 3 min. During exposure, the subjects read a passage aloud during one session and they read the same passage silently during another session. The reading aloud condition produced consistently greater TTS than the reading silently conditon for the entire 3 min. of recovery measured.

Articulation is an important factor affecting the course of auditory fatigue. Vocal articulation has been shown to alter the impedance of the auditory system (Shearer and Simmons 1965, Solomon and Starr 1963). Sound transmission for higher frequency stimuli is enhanced by contraction of the middle ear muscle (Ward 1966). So the increased stiffness of the system during the reading aloud condition has enhanced transmission of the 4000 Hz., fatigue tone, thus resulting in a greater post-exposure TTS a 8 compared to the reading silent condition (Karlovieh and Flutenaan 1970).

In man the stapedius muscle is active largely throughout the whole range of vocal intensities. The acoustic reflex activation plays a role at high voice levels but at low and medium voice levels the situation is more ambiguous. Air-counducted sound does not activate thestapedium muscle during at least low and medium intensity levels of persons own voice(Zakrisson 1975).

2.8 Auditory fatigue during humming:

Benguerel and Mc Bay (1972) studied the effect of humming on TTS from a 5 min. 500 Hz. 118 dbSPL exposure. The experimental technique consisted of measuring hearing thresholds at 700 Hz.

before and after exposure, this exposure being accompanied by the humming. Subjects vere asked to hum at 125 Hz. (males) or 250 Hz. (females) humming loudly at the same frequency, humming at high frequency. Analysis of the results indicate that TTS from the exposure accompanied by humming was significantly less than TTS from exposure without humming. TTS during later 2 conditions was consistently less than TTS in former condition. Listening to recorded humming during exposure did not significantly alter TTS from the exposure, nor did the activity of exhaling after preparing to hum.

One possibility for the reduction of the TTS during humming condition is middle ear muscle contraction. In addition to the middle ear muscle contraction, another change in the peripheral auditory transmission system which is known to occur during vocalization is en alteration in the vibration pattern of the stapes.

Bekesy (1960) found that for moderate sound stimulation, the stapes rotates about a vertical axis near the posterior edge *of* the foot plate. When the ear is stimulated by intense sounds (above approximately 130 dbSPL) at low frequencies, the rotation about a vertical axis shifts to a rotation about a longitudinal, ie., horizontal axis running through the foot plate. As a result, the motion of the cochlear fluid is markedly decrease as compared to when the stapes rotates around a vertical axis in a piston like movement. A similar rotation around a horizontal axis takes place during phonation, due to vibration of the head, which is maximal in a vertical direction (Bekesy 1960). In the case of airborne sound, there is a transition range of intensity over which both mode of vibrations are superimposed (Bekesy 1960).

It seems likely that during phonation, the rotation about a horizontal axis (due to the vertical vibration of the head caused by phonation) is superimposed to the rotation about a vertical axis produced by the airborne sound.

There are reasons for doubting that middle ear muscle is wholly responsible for the TTS reduction observed for the phonation conditions. Fiarst the exposure frequency used in Ben uersal and Mc Bay (1972) study, ie., 500 Hz. is known to be attenuated to a quarter degree by the middle ear muscle than is the frequency used by Karlowich and Luterman (1000 Hz). Yet the reduction in TTS for the phonation condition of both studies was very similar. If TTS reduction during phonation were entirely the results of middle ear muscle action, one would expect phonation to reduce TTS from a 500 Hz. exposure more than TTS from a 1000 Hz. Second, phonation, thus presumably middle ear muscle activity in Ben querel and Mc Bay's study had a longer duty cycle than a in Karlowich and Luterman»s experiment (70% V/S 50%) but in both studies the TTS reduction brought about by phonation was similar.

Several studies have proposed that middle ear muscle contraction during phonation may be neurologically associated with laryngeal activity. As Shearer and Simmons (1965) suggest, the occurrence of middle ear muscle activity before voice onset seems to indicate that the middle ear muscle are activated concurrently with the laryngeal musculature. Perhaps a non-acoustic reflex exists between the larynx and the middle ear muscle during phonation. Mc Call and Rabuzzi (1970) found evidence for the type of reflex arc in the cat, when they recorded reflex activity in the middle ear muscle of both ears in association with contraction of the criclothyroid muscle of the larynx.

State of the larynx as the subject exhaled, exhaled without phonation after preparing to hum (H_o) and hummed at approximately 125 Hz. (H_2) were studied by Benquerel and Nc Bay (1972). During the H_o activity there was partial adduction of the vocalfold and constriction of the glottic sphincter brought about by contraction of muscles of the larynx. If the laryngeal muscle action of the H_o activity reflexively elicits middle ear muscle contraction, TTS from the H_o activity or condition should be similar in magnitude to TTS from a condition such as non-vocal activity during exposure which is believed to elicit middle ear muscle contraction. However, there was no TTS reduction from the H_o activity, although non-vocal activity decreased.

The second mechanism that is postulated to explain contraction of the middle ear muscle during phonation is that the middle ear muscle are stimulated to contract concurrently with the laryngeal musculature by neural impulses directly from the motor cortex. If TTS reduction should occur when a laryngectomee thinks about humming, during the exposure tone, ie., when he tries to hum without a larynx and without being able to produce sound the hypothesis of middle ear muscle activation by neural impulses from the cortex would seem more promising.

2.9 Auditory fatigue associated with non-vocal activities.

Benquerel and Mc Bay (1972) studied the effect of certain non-vocal activities on TTS from a 5 min. 500 Hz. 118 dbSPL range Non-vocal activities included turning of the head, swallowing, chewing, and smiling with forceful eye colour. These activities believed to elicit middle ear muscle contraction, resulted in less TTS than no activity during exposure.

2.10 Changes in hearing due to auditory fatigue.

With continued presentation of a sustained suprathreshold stimulus, its judged loudness declines and becomes inaudible, thus qualifying as a threshold shift phenomenon.

A shift in the pitch of tones Is also generally associated with threshold shifts, especially when the threshold shifts occur over only a limited frequency range. This is musical paracusis. It is usually studied by producing a threshold shift in one ear and then matching the pitch of a tone in the shifted ear to another tone in the non-exposed ear. The difference in frequency for equal pitch, as thus measured, Is assumed to be approximately equal to the difference In pitch for equal frequency, this particular procedure defines the degree of diplacusis. It is also possible to measure use of subjective musical pitch relations such as the octave (Ward 1954).

Pitch shifts associated with narrow bond of masking noise have most recently been studied by Webster and Schubert (1954). They found that the pitch tends to shift away from the region of shifted threshold. Thus frequencies above region of maximum masking appear higher in pitch, those below slightly lower than normal. The general conclusions as to direction of shift are the slight downward shifts of pitch where fatigue is increasing with frequency, larger upward shifts where it is decreasing(Ruedi and Furrer 1946; Davis et al. 1950).

Ward et al. (1961) made diplacusis measurement on ears that had been given a broad fatigue - 20 db or more of shift, measured several minutes after exposure, from 1000 to 1300 Hz. This diplacusis, in this case was downward shift of pitch in the affected ear, amount to about *5%* at 500 Hz. dropping to 4% at 200 Hz. and *2%* at 150 Hz. No diplacusis could be demonstrated at 100 Hz.

Davis et al. (1960) reported other qualitative changes. Their subjects said that tones within one half octave above F_e sounding noisy, rough or buzzing.

Other experimentation have reported the development of tinnitus after cessation of the fatiguing stimulus(Hischchilff 1957). More often, however, if a tonal tinnitus is present, it will have a relatively high pitch, ie., one corresponding to that of an objective tone in the 2000-6000Hz. region. If the tinnitus has nearly the same pitch as the test tone, some masking may occur, especially when the test tone is continuous rather than interrupted.

The most common subjective noise heard immediately after exposure consists of a rushing noise not unlike that of a waterfall. Strangely enough, this noise does not seem to interfere with the perception of a test tone, indeed, some studies have indicated that the gradual disappearance of this noise is paralleled by an increase in threshold shift (Hirsh and Ward 1952; Hirsh and Bilger 1955).

Hirsh and Ward (1952) reported that clicks sound 'thud like' an indication that the lower frequency components of the click reappear before the higher frequency components.

Other changes include the development of recruitment (Davis et al. 1957, Bekesy 1960) and changes in the temporal integration of short tone bursts. Both of these changes suggest hair cell dysfunction.

The combined effect of loudness changes and pitch shifts in auditory fatigue may become quiet apparent even to casual listening. When severe shifts are present, music may sound completely unmusical (Ward et al. 1961).

In 1947 Rosenblith et al. reported that for a few seconds after exposure to high intensity pulses at about 100 per sec., a peculiar metallic quality was added to the timbre of familiar sounds such as speech.

As Muller observed a century ago, suprathreshold stimuli may be altered in loudness, pitch or timbre following stimulation usually the changes are so minor that a comparison with the unexposed ear is necessary to reveal them. Ear with a high frequency TTS will judge most sounds containing high frequencies as muffled or dull. Musicians particularly, also often comment on distortion of pitch correlated with TTS. Music may sound utterly unmusical. Familiar melodies were recognisable only on the basis of rhythm. In addition to sounding muffled, the orchestra or piano appeared completely out of tone. Measurements indicated that the downward shift in pitch in the affected ear was about 3 semitones at 100 Hz. but only 1 semitone at 500 Hz. Thus since the higher frequencies were shifted downward in pitch more than the lower ones, harmonies become excruciatingly inharmonic and consonances turned to dissonances. All these changes were noticed by Ward when his ear was accidentally exposed to

70 db TTS at and above 2000 Hz.

2.11 Auditory fatigue and induced tinnitus.

There have been a considerable number of experiments with the nature and extent of permanent or long lasting tinnitus aurium. Generally, investigators have asked patients with hearing disabilities to describe their tinnitus and to match it to an external stimulus in frequency and intensity, they have then attempted with varying degrees of success, to relate their findings to types of hearing loss and to the frequency of maximum loss.

Graham and Newby (1962) have reported that patients with conductive losses reported tinnitus in a more restricted, low frequency range than did patients with Sn or mixed losses or normal individuals. Ward (1963) reported that most commonly tinnitus is a broad band noise resembling that produced by a waterfall, that when it is a tonal it tends to be of relatively high frequency 2000-6000 Hz. and that it does, to some extent mask a test tone of similar frequencies, especially when the test tone is continuous.

Loeb and Smith (1967) exposed subjects to intense pure tone and broad bond acoustic stimuli and their TTS were measured. They were asked to match the pitch of any resulting tinnitus by manipulating the frequency of an adjustable low level pure tone in the opposite ear. It was found that both the frequency of tinnitus and the frequency of the tone used for the pitch match increased as the frequency of the traumatic stimulus increased, but maximum loss frequency and tinnitus frequency did not coincide.

Atherley et al. (1968) used the term noise induced short duration tinnitus(NTST) to describe the after sensation that can be induced by and persists for about 15 min. after a few min, exposure to an acoustic stimulus that is sufficiently great to produce auditory fatigue. They exposed subjects one ear for 5 min. to one third octave band noise centred at either 2, 3, 4 or 6 KHZ. at 110 dbSPL. NIST was matched for pitch and loudness in the non-stimulated ear.

They found a close and consistent relationship between NIST and a maximum threshold shift in that the pitch of one and the frequency of the other are both related to the centre frequency of a 1/3 octave stimulus. Bach stimulus also found with each stimulus centre frequency that the pitch of NIST is always lower than the frequency of maximum threshold shift. The difference between the pitch of noise induced short duration tinnitus and the frequency of maximum threshold shift when expressed as a distance along the baailar membrane is independent of stimulus frequency and is constant at about 1.3 mm,,which corresponds to one critical bandwidth.

2.12 Critical band and temporary threshold shift.

The problem of the CB for TTS seems to have attracted a considerable interest of a few investigators engaged in the study of auditory fatigue. But there are few studies in the literature which deal within this problem systematically.

Pure tone is assumed to be more dangerous than octave band of noise (Anonymous 1956). This was explained on the basis of critical band hypothesis that stated that if a given amount of energy were concentrated within a single critical band, it-would be more dangerous than if it would be more dangerous than if it were spread several critical band, eg. over an octave(Kryter 1950).

Thompson and Galen (1961) examined the TTS at 500 and 4000 Hz. produced by 5 min. exposure to pure tone of 500 and 3200 Hz. and to the noise of different band width centered at the same frequencies, having an SPL of 110 db. They reported that TTS at these frequencies were eventually the same regardless of the exposure stimulus type. Comparing the TTS at some test frequencies affected by the exposure, Ward (1962) concluded that there were no significant differences in TTS produced by a pure tone and a band of noise.

Kryter (1963) showed that the amount of differences between the TTS produced by one third and one octave noise was about 4 db in average. He deduced from this study's finding that the critical band width for auditory fatigue was slightly more than one third octave but less than half ectave.

Wreesing (1968) seems to have paid particular attention to the problem of the critical band for TTS. He proves the existence of the critical band for TTS at 1000 Hz. in his own way by using the pure tone of various frequencies. Nevertheless he dealt with this problem only in a qualitative way.

Yamamoto and Takagi (1970) results on the study of critical band and TTS revealed that the critical band for TTS differs from the critical masking band in the following points.

1. The centre frequency of the critical band for TTS does not coincide with the test frequency and it exists about half an octave below the test frequency.
2. The critical band width in dbs for TTS is about 6 db wider than the critical band width for masking.
3. Difference is concerned with the quantitative relation

of both phenomena to a noise. In the masking phenomenon, it is assumed that the acoustic power of a noise in critical band is equivalent to that of a test tone just masked while in TTS, the relationship between TTX and the :CB level can be given by $TTS_F{}^{s}$ aX+b where a and b are constant that depend on the exposure time, test frequency, the time between the end of exposure and the measurement of TTS. X is a critical band level on SPL within the critical band).

One of the interesting problem which is little examined is the relation of the critical band for TTS to the mechanism of the inner ear. As is well known, the critical band concept by Fletchei (1953) is closely related to the behaviour of the vibration of the basilar membrane. The place on the basilar membrane at which the vibration of maximum amplitude occurs is supplied to correspond to the frequency which is most affected.

But the study by Yamamoto and Takagi (1970) show that the centre frequency of the critical band doesnot coincide with the test frequency. They investigated systematically the critical band with respect to TTS. On the basis of the results showing the existence of the critical band for TTS, the centre frequency and the width of the critical band at 500, 800, 1000, 2000, 3000, 4000, 6000, 8000 Hz were calculated together with the 95$ confidence limit of each value. It was found that the centre frequency of the critical band is about half an octave below the test frequency and that the width in dbs is about 6 db width than that or the critical masking band.

This critical band hypothesis is found not to be pertinent in explaining the different amount os the TTS produced by pure tone and noise of some intensity level (Ward 1963). Acoustic reflex is responsible for the difference in the amounts of TTS produced by octave bands of noise and pure tone, below 2000 Hz. of same intensity. The action of middle ear muscle differs for noise and pure tone stimuli. In the case of pure tone, the muscles after an initial contraction rapidly relax and hence more energy reaches the cochlea and consequently TTS will be more, whereas noise produces a more sustained reaction(there will be a continuous rearousal of the reflex of the middle ear muscle probably because of the random nature of the noise) thereby will be less as the energy reaching the cochlea will be less.

It is reported that the TTS produced by a narrow band of low frequency noise was consistently less than that by a pure tone at the same frequency despite the fact that both stimuli are less than a critical band in width (Ward 1962). This evidence supports the acoustic reflex hypothesis and also acts as a counter evidence to critical band hypothesis.

In another study, TTS was measured for tone and noise at equal intensity levels. Later TTS produced by tone, at the same intensity level, was again measured but this time the contralateral ear was stimulated by the noise of the same intensity. As manaural stimulation results in binaural reflex, there was a sustained reflex even in the ear which was receving pure tone. The results was that the TTS produced by the tone in this case, dropped to the same value as that produced by the noise(Ward 1962) This study again supports the acoustic reflex hypothesis.

The difference in the amount of TTS produced by noise and

and tones when presented at equal Intensity and for equal duration can be attributed to the action of middle ear muscle especially when tones and noise are below 2000 Hz.(Vyaaamurthy et al. 1973).

2.13 Developmental changes of susceptibility to auditory fatigue.

Not enough literature is available regarding this as enough attention has not been given towards this topic.

Gregory R.Bock (1978) conducted a study to assess the developmental changes of susceptibility to auditory fatigue in young hamsters.

Susceptibility to auditory fatigue was studied in young hamsters by using an evoked potential criterion of sound induced threshold shift. The characteristics of auditory fatigue as measured using evoked response criterion appear to be similar to the characteristics of auditory fatigue induced by brief exposure to loud sound in humans. (Ward et al. 1959)

Animals aged 15, 28, 40, 54 and 84 days were anesthetized and stimulated with a continuous tone (3000 Hz, 110 dbSPL) for 10 min. Threshold shifts 1 min. post exposure were highest in animals aged 40 days and lowest in animals aged 15 or 85 days. Threshold shifts recovered within 100 min. in 15 and 85 day old animals, but required considerably longer to recover in the other age groups. The data suggest that young hamsters pass through a critical period of susceptibility to auditory fatigue. Comparison of this critical period with various indices of the development of hearing in the hamster suggests that the developmental events underlying the critical period do not occur in the middle ear.

The increase in fatigue susceptibility between 15 and 40 days of age is said to be because of hearing is maturing during this time. The rate at which threshold shift achieves its asymptotic level varies as a function of age, but the magnitude of the acoustic threshold shift is constant. Both the rate at which threshold shift increase and the value of threshold shift vary with the age.

Young mice (Saunders and Hirsch 1976), hamsters (Block and Saunders 1977), guinea pigs (Falk et al. 1974), and cats (price 1976) are susceptible to noise induced permanent hearing loss than for adults.

Novotiny (1975) analysed the results of 160 examinations of the auditory threshold after 3 min. stimulation with white noise in different age groups of workers suffering from occupational deafness due to the noise. He concludes that auditory fatigue expressed as the temporary decline of the auditory threshold in db is not significantly higher at a more advanced age. In the fourth and seventh decade, the values are relatively the highest but do not obtain a level of significance.

2.14. Interaural phase effect on binaural Temporary threshold shift.

The psychoacoustic literature on TTS affords little information bearing directly on this question. Several studies, do, however, consider the comparability of monaural and binaural exposures upon monotonically measured TTS.

Hirsh (1958) reported little difference between binaural and monaural exposures in the average ear. Ward (1965) found that binaural exposure produced less TTS than did monaural and concluded that these differences resulted from more vigorous contraction of the middle ear muscle during binaural stimulation. He did ack-knowledge through efferent connection.

Guiot (1969) also showed greater TTS for menaural than for binaural. Study by Nagaraja Rao Shivashankar (1976) revealed that there is no significant difference in TTS between monaural binaural exposures to high frequency tones at equal Intensity levels for equal duration of time.

Ward (1965) in addition to the acoustic reflex hypothesis also considers the action of ollvocochlear bundle and cochluro-chlear pathways to account for the reduction in TTS after binaural exposure to low frequencies.

Shivashankar's (1976) finding of no difference in TTS between the monaural and binaural exposure to high frequency is explained in the light of the action of homolateral olivocochlear bundle. As crossed olivocochlear bundle is not responsible for the inhibitory effects at high frequencies, this no significant difference in TTS between the monaural and binaural exposure to high frequency tones ~at equal Intensity levels for eaual duration of time, could be due to the action of homolsteral ollvocbchlear bundle, which might suppress the responses reaching the higher centres.

Melnick (1970) presented a fatiguing signal of 500 Hz. for 2 min. at 120 dbSPL either monotically to the test ear binaurally in phase or he subsequently recorded monotonic TTS at 750 Hz. and found less TTS with binaural exposure. The interaural phase of binaural signal did not seem to have a significant effect on the magnitude of TTS.

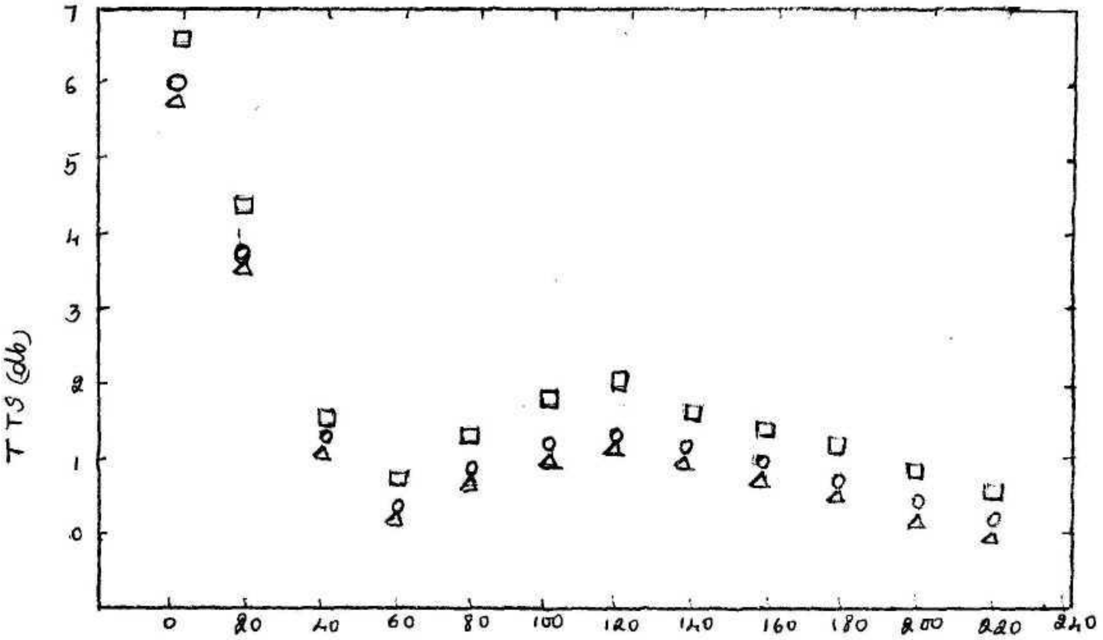

Fig. 7. Mean TTS for a test signal of 750 Hz. following monaural, binaural phase, blnaural out of phase by 180° exposure of 2 min. to a 100-600 Hz. filtered bandof noise at an overall SPL of 120 db (William Melnick 1967).

Pairing of simultaneously occurring tone and noise stimuli of like interaural phase demonstrate negligible masking level differences while sequentially occuring tone stimuli having like interaural phase relationship exhibited most TTS(Randolhp and Gardner 1973).

Randolph and Gardner(l973) varied the interaural phase relation of pure tone exposure and recovery stimuli sequentially to explore TTS for four conditions of binaural listening. 17 normal hearing subjects were exposed binaurally for 3 min. to a 500 Hz. tone at 100 dbSPL. TTS for the same tone was subsequently tracked binaurally for 5 min. significantly greater TTS resulted from homphonic conditions where theexposure and teat tones were of the like phase relationship at the 2 ears than for anti-phase condition where the exposure and test tones respectively-differed in interaural phase by 180°. Interaural phase relations of an intense exposure stimulus thus influenced subsequent binaurally determined TTS.

2.15 Acoustic reflex and auditory fatigue.

The reflex contraction of middle ear muscle in response to acoustic stimuli known as the acoustic reflex alternates sounds below 2000 Hz. by upto 20 db. This is believed to protect against noise induced hearing loss. The effectiveness of the protection is limited with steady state noise, however, by the adaptation of the reflex that occurs within a few mins. Likewise, with short duration (eg. 1-4 msec.) impulse noises the auditory fatigue is rendered ineffectively by its 5 to 10msec. latency. On the other hand, if the impulses occur within intervals of 2 secs, each suceeding impulse arrives before the previous reflex contraction has fully subsided and some degree of protection results. There is also evidence that when extremely loud impulses are expected, the middle ear muscle can contract in anticipation of them and provide some protection thereby.

Reflex may be more effective with:

1) if a steady state noise is added to stimulate the reflex immediately prior to impulses or if impulses occur in rapid succession or

2) by decreased adaptation as when impulses intermittencies or level fluctuations are superimposed on steady state noise or where noise of wide band type is over about 120 dbSPL(Coles 1974)

More recent work suggest that with rapidly repeated impulses also there is still no clear relationship between acoustic reflex threshold and TTS.

Bernath (1973) discusses the auditory adaptation of normal persons over the hearing threshold. He draw adaptation of acoustic reflex over the hearing threshold parallel to an automatic feedback system.

Nilsson and Liden (1980) exposed normal hearing subjects to 30 min. of tape recorded shipyard noise of 97 db. which is characterized by a variable temporal structures. The stapedius muscle activity was continuously recorded in the opposite ear as a change of the ear's acoustic impedance. The reflex function was assessed as stimulus response curves obtained before and at various after exposures. A. slight reflex fatigue was observed together with a parallel shift of the stimulus response curve (average 4 db). The recovery was slow and not complete even 10 min. after the end of the exposure. The stapedius reflex showed slight decay after a 30 min. exposure to industrial noise, recovery was slow. The resistence of the reflex to fatigue contradicts the rapid decay during puretone stimulation. This has been supported by Luscher (1950) and Kobrak et al. (1941). This fatigue resistence supports the assumption of the middle ear muscle being active throughout a noisy work day.

Dunavitses (1971) studied auditory adaptation to sound @000 Hz) IN 80 PARIENTS WIIH OTOSCLEROSIS BEFORE and after stapedoplasty. persons with normal hearing constituted the control group. The main values of increased auditory threshold both before and after the operation showed no significant difference from the indices of control group. By the time of reverse adaptation the patients were divided into 2 groups. In patients of the first group the time of reverse adaptation failed to differ from the indices of the control group and constituted ,6. In persons of the second group the time of reverse adaptation was considerably prolonged. Comparison of adaptation curves in patients after stapedoplasty carried out without disturbing the Intactness of the tendon of the muscle stapedius and in the same number of patient with derangement of this anatomical formation showed no significant difference.

Perception of the frequencies of 3000-8000 Hz. by BC in persons who have worked after stapedoplasty in condition of noise of 70-80db showed no significant change. This concludes that patients who sustained stapedoplasty can work under condition of moderately intense noise.

Zakrisson et al. (1975) conducted experiment in 18 patients with peripheral facial palsy including unilateral stapedius muscle paralysis. After exposure to narrow band noise at 0.5KHz. TTS at 0.75 FHz. was significantly higher in the ear with paralysis than In the normal ear. After exposure to 2000 Hz. narrow band noise there was no difference in TTS at 3000 Hz, between affected and non-affected ear. It was concluded that the stapedius reflex has a protective function against low frequency sound exposure and suggested that this protection might be extended to higher frequencies only when high frequency noise also contains low frequency components.

A reduction in the sound transmission of 2odb has been found by acoustic middle ear reflex mainly in the low frequency range (Pichler and Bornschein 1957, Nurgaart et al. 1963, Borg 1968, Concura 1970).

Fletcher (1962) showed that a tone which elicited a stapedius reflex could diminish the TTS after exposure to rifle noise by about 10 db.

Lehnardt (1959) found that TTS maximum after exposure to broad band noise was at 4000 Hz. when the stapedius reflex normally but shifted to 3000 Hz. when the stapedius muscle was paralysed by a muscle relaxant.

Patients with unilateral facial palsy have been shown to be more sensitive to auditory fatigue (Perlman 1938) to have an increased sensation of loudness, (Japsen 1957) and phonophobia (Hansen 1965) on the paralyzed side.

Johanson et al. (1967) found a close correlation between TTS at 500 and 1000 Hz. and the latency time, the rise time and full activation time of the contralateral reflex in 5 subjects.

Brasher et al. (1969) however, could not establish any significant correlation between TTS at 1000 and 4000 Hz. and the reflex, reflex threshold, the contraction strength initially and after 2 min. of the contralateral reflex in normally hearing subject.

Low frequency noise can be especially harmful under the following conditions:

1. When the low frequency sound is repetitive and has most of its energy within the latency of the stapedius reflex.

2. When the stapedius reflex response is abnormally weak such as when influenced by alcohol or barbiturates (Borg and Melleter 1967)

Low frequency pure tone produce more TTS than low frequency bands of noise because of the differential effects of the acoustic reflex in responding to these 2 types of sounds. In a series of experiments concerned with TTS, Ward (1962) found that, a high frequency pure tone and a high frequency band of noise of equal 3PL produce more TTS than a low fre$_n$uency band of noise. Ward hypothesized that acoustic reflex was responsible for the difference between the TTS produced by the low frequency pure tone and the low frequency noise. Important to this hypothesis are the suppositions that the acoustic reflex affects low frequency signals more than high frequency signals and that the intraural muscles especially the stapedius muscle, relax *or* adopt in the presence of pure tone, but sustain contraction in the presence of random noise. Ward supported his hypothesis by showing that the TTS produced by a 700 Hz. tone can be reduced if a low frequency noise is presented simultaneously to the opposite ear. Presumably the noise presented to non-test ear kept into the intraural muscles contracted in both ears.

Mill and Lilly (1971) exposed 6 subjects with an acoustic reflex and 6 subjects without an acoustic reflex on separate occasions to a 710 Hz. pure tone and to a one eighth octave band noise with an upper cut off frequency of 710 Hz.. Both exposures were 10 min. at 110 dbSPL. TTS was measured at 1000 Hz. For the subjects with an acoustic reflex, the pure tone exposure threshold 10 db more TTS_2 than the noise exposure. However, for the subject with an acoustic reflex, the puretone exposure and the noise exposure produced the same amounts of TTS.

A TTS reduction paradigm has been used previously to evaluate the effects of acoustic reflex action on sound transmission to the cochlea (Karlovich, Abbs and Luterman 1972). This paradigm incorporated dichotic exposure (Exposure tone in one ear. broad band noise in the other) similar to paradigms used by others to deduce acoustic reflex involvement in TTS (Ward 1965, Mills and Lilly 1971). Results indicated that TTS generated by a 1000 Hz. exposure tone in one ear was reduced if a 100 dbSPL pulsed broad ba noise was presented simultaneously to the contralateral ear. Karlovich and Wiley (1974) observed that reduction in TTS and was related to the temporal pattern of the contralateral noise. The least reduction in TTS occurred when the contralateral noise was continuously on or when its period was 36 secs.(50% duty cycle). Additional reduction in TTS was observed when the noise period was decreased to 36 msec, and further TTS reduction occurred when the period of the contralateral noise was decreased to 27 360 msec, which was the shortest period used. Karlovich and Wiley hypothesized that their TTS data reflected in part, the dynamic properties of the acoustic reflex.

Reflex relaxation may be an important factor in determining the effectiveness of the acoustic reflex in response to pulsed stimuli is evidenced by data from a TTS study (Ahaus and Ward 1975). They exposed subjecs to a pulsed low frequency noise (50 msec. on time) but varied the off time between noise burets from 50 to 650 msec. The total energy during exposure was held constant by adjusting the exposure duration. They found that TTS_2 averaged across frequency most affected by their noise spectrum was least for the shorter off times (50 and 150 msec.) and greatest for the longest off times (550 and 650 msec.). They attributed the results to the dynamics of the acoustic reflex especially reflex relaxation. They stated for the 50 msec. off time each noise burst should reach the before the muscle contraction elicited by the burst had recovered and a minimum of TTS might be expected.

2.16 Theories of TTS:

Davis et al. (1950) suggested that TTS effects are related to temporary damage to the organ of corti. Hood (1950) related some of his findings to equilibration and some to place and frequency theories of the action of cochlea.

However, the first systematic attempt to formulate a theory regarding the mechanism of TTS came from Rosenblith (1950) who noted that TTS and masking of one sound by another, are similar in that both produce

1. shifts in thresholds
2. changes in yloudness
3. changes in pitch
4. effects upon localization and
5. a symmetrical spread of the effect with low intensity stimulation, whereas high intensity stimulation produced an asymmetrical spread of the effect. He suggested that TTS is explicable in terms of residual masking. This 'residual masking[1] theory of TTS was supplemented by work of Von Dishock (1953) and Miller, J.D. (1958). Hallpike and Hood (1951) concluded that TTS is associated with subnormal functioning of the organ of corti. pooler (1942), Jerger (1955) etc., also indicated the importance of inner ear in mediating TTS. Hughes and Rosenblith (1957) have shown that recovery of the cochlear microphonics exhibits many similarities and recovery from TTS.

Botsford (1968) recognised 4 different components responsible for the disagreement of TTS values at very early *or* very late recovery time as an exponential function of times. He suggested that the single electrical analog of the theory makes a simple TTS meter for appaaising noise hazard. Keeler (1968) also has suggessome mechanical and electrical models for TTS.

2.16.1 Hearing Damage Theories:

These are relied on to set limits for shorter daily exposures and they do not yield the same results either for continuous or for intemittant noises. However, one seems better for continuous and the other for intermittent noise (Glorig 1971).

2.16.1.1 Equal Energy Theory:

It reasons that hearing damage risk is determined by the total amount of noise energy to which the ear as exposed each day (8 hours). Thus for half-a-day exposure (4 hours) regardless of how the exposure is distributed throught the 8 hour period, 3 db greater noise levels are permissible for the same risk. Similarly each halving of energy permits adding 3 db. to the noise levels permissible. This theory has been verified for continuous noise, ie., a single long exposure each day. This rule has been recommended by IS0/TC-43/SC-1, 1969. The Walsh-Healy Act 1969, has however, adopted a 5 db rule viz. for every halving of the duration of a partial exposure, the intensity of the exposure can be increased by 5 dbz without increasing the risk. Burns and Robinson's (1970) equal energy hypothesis (EEH) - stating that exposure of equal total energy (the product of power and time) are equally dangerous has been questioned for its validity by Ward and Nelson (1971), and by Scheiblechner (1974).

2.16.1.2 Equal Temporary effect Theory:

It states that hearing damage risk is related to TTS in young ears that results from noise exposures. This theory is based on observation that those noise exposures that ultimately produce permanent hearing loss also produce temporary hearing loss. The converse is also true. TTS studies indicate that intermittent noise is much less harmful than steady noise.

In contrast to the 'energy principle[1], which depends on a physical explanation, the 'equinociuity principle[1] is based on the hearing organ itself as a biological measurement device of the noxiousness of noise environments.

2.17 Tests for Susceptibility to Noise induced hearing loss:

It has been hoped that there exists a unitary characteristic of ears called 'susceptibility' - a characteristic that determines relative resistance of that ear to both temporary and permanent damage (a) from long or short exposures (b) at high or low intensities (c) to high or low frequency stimulation from (d) tone noises or impulses of any shape or 3pectrum(e) that is relatively invariant for an individual throughout his life span (Ward 1963). This is based on the general recognition that there are individual differences in susceptibility of ears to damage from exposure to noise. Many references have been made in the literature to 'tough' ears and 'tender' ears, referring to differencies in degre of susceptibility. A considerable attention has been focussed on the problem of identifying those individuals, who, when placed in a noisy working environment, would be most susceptible to NTHL (Newby 1972). The assumption has been that if such individuals could be identified, they could be provided with the best possible ear protection when they are working in noise.

According to Newby (1972) these tests can be grouped mainly into two, i.e., tests based on TTS measurement and tests on aural harmonic distortion measures. Here we are concerned only with tests based on TTS measures.

The method involves presenting a subject with a fatiguing stimulus that may be either a pure tone or wide band noise. After a prescribed period of exposure to the fatiguing stimulus, the degree of shift of subjects threshold at some frequency (usually around 4 KHz.) is measured immediately and after soae time following the cessation of the fatiguing stimulus.

Predictions of susceptibility are then made on the basis either the absolute amount of the threshold shift observed, or the time required for subjects threshold at criterion (or test) frequency to return to normal, ie., its prestimulation level. The individual who incurs the greatest amount of threshold shift, or who requires the longest time for his threshold to return to normal level, is then presumed to be the most susceptible to permanent irreversible hearing impairment if placed in a noisy environment for his working life.

Ward's (1963) suggestion of a multifactor test that involves the determination of the growth of TTS after two or more values of: 1) exposure time 2) recovery time 3) exposure frequency 4) exposure SPL 5) test frequency 6) interruption rate (for intermittent noise) and 7) pulse repetition rate (for impulses) is also one of tests.

According to Kryter (1970), it seems that the pure tone and broad band noise tests of TTS_2 , proposed by Ward (1967) and Harris (1967), plus a TTS_2 test for impulsive sounds would be appropriate for evaluating possible, if not probable, susceptible to noise induced hearing loss. Further it seems logical to score these tests in terms of HL_2 plus TTS_2 as an index of susceptibility

The test and retest results should be combined to give better estimation of susceptibility (Kryter 1970).

The rationale for such test, in general, is based on assumption that the ear most susceptible to temporary fatigue or TTS, other things being equal, is the most likely to suffer some permanent damage. In general, while the relations between noise exposure and TTS and noise-exposure and PTS may be similar, it has been difficult, if not impossible to demonstrate that the persons or animals most susceptible to TTS are likewise the most susceptible to NIHL. Some possible explanation for this have been suggested by Kryter (1970).

1. Susceptibility to TTS within individuals from a given tone or band of noise is not too highly correlated with the TTS found from exposure to a different tone or band of noise(Greissen, 1951, Ward, 1967), mostly because that the hearing level at different frequencies could have as long as 35 db range in normals (i.e., the range is from -10 to 25 dbHL re ISO).

2. The noise in industry may be but one of the noises to which men are exposed in their daily lives, thereby introducing some uncertainty and variability in the data.

However, not being able to prove a strong correlation between the results from the susceptibility tests and eventual NIHL, does not mean that some persons do not have ears that are generally more resistent to NIHL than other persons, or that under some circumstance testing and screening programmes for this ability or lack thereof, would not be worthwhile (Kryter, 1970).

The grounds for a provisional acceptance of a relation between temporary and permanent threshold shifts depend on evidence

Table: Proposed susceptibility tests involving TTS

SI. No.	Report	Stimulus KHz.	Exposure t.evel (db)	Duration (min.)	Recovery time (min.)	Test frequency (KHz.
1.	Peyser (1940)	0.25	80(HL)	0.5	0.5	0.25
2.	Wilson (1943)	0.25	80(HL)	5	1	Octaves of 0.25
3.	Peyser (1943)	1	1OO(HL)	3	0.25	1
4.	Theilgaard(1949E	0.5, 1, 2, 4	1OO(HL)	5	5	Half octave above exposure
5.	Theilgaard(1951)	100	100(HL)	5	5	1.5
6.	Tonner (1955)	1	1OO(HL)	5	Immediately	1
7.	Theilgaard, according to Greisen	1.5	1OO(HL)	5	5	2
8.	Wilson (1944)	2	80(HL)	8	1	Octaves of 0.25
9.	Harris ($954)	g	97 SPL	5	Parameter	4
10.	Palwa (1958)	2	30 SL	3	2	2
11.	Van Dishock (1956	2.5	100(HL)	3	0.25	all (sweep)
12.	Greisen (1951)	3	80 and 90(HL)	5	5	4
13.	Jerger and Carhart (1955)	3	105SPL	1	Parameter	4
14.	Jerger and Carhart (1956)	3	100SPL	1	Parameter	4.5
15.	Wheeler (1950)	Noise	105SPL	1	Parameter	2,4, 6

such as that obtained by Jerger and Carhard (1956), Kylin (1960), Glorig et al.(1961), and others. The general postulate reached by Kryter et al. (1966) after study of the available data, is that the average PTS resulting from nearly daily exposure, 8 hour per day for about 10 years to a particular noise, is approximately equal in db to the average TTS_2 produced in young normal ears by an 8 hour exposure to the same noise.

Recently, Burns (1970), Burns and Robinson (1970) and Burns et al. (1970) have discussed the relation of susceptibility to temporary and permanent shifts, in more detail. Using the indices of susceptibility to TTS $(D_t$ - the deviation of individual points positive or negative, from the regression line for TTS against hearing level) and susceptibility to PTS $(D_t$ - the deviation of individuals age correlated hearing level from the predicted mean values for persons of the same age, sex and noise exposure), they observed low, but statistically significant values of the correlation coefficients.

However, Luz et al. (1973) point out the need for further studies to establish the relationship between TTS and PTS, and states that at best, TTS could only be used to pick out the most susceptible individuals within a given noise environment. Ward (1963), too, has cautioned earlier, that it would be unwise to restrict oneself to measure of TTS as the only indicators of susceptibility.

2.18 Psychoacoustic correlates of susceptibility to auditory fatigue.

Individual differences in susceptibility to TTS and PTS have been apparent since the 1830's (Fosbroke 1830). Agreat deal of interest and research has been directed toward using differences in susceptibility to TTS to predict susceptibility to PTS. Some investigators, however, have studied possible relationship between susceptibility to TTS and other psychoacoustic tasks. In 1954, Lawrence and Blanchard suggested that a psychoacoustic measure of cochlear nonlinearity, the aural overload test, might be a correlated of susceptibility to auditory fatigue. Later it was shown to be the case by Humes (1976) and Humes Schwartz (1977). Ward (1968) found a negative correlation between amount of TTS and two measures of contralateral masking. In this study, the measurement of perstimulatory fatigue was found to have no consistent relationship to TTS. In 1969 Hood suggested that a measure of loudness discomfort level might bear a relationship to TTS susceptibility. Humes and Bess (1978), however found no significant correlation between TTS and LDL. Mycheal and Bienuenue(1976) suggested that measure of critical band width phenomena might correlate with susceptibility to TTS.

Mustain and Schoeny (1980) designed a study to explore psychoacoustic correlates of susceptibility to auditory fatigue.56 normal hearing subjects were given auditory fatigue tests. The high frequency test contested of a 3 min. exposure to a 110 dbSPL, 2000 Hz. pure tone with TTS measured at 4000 Hz. The low frequency test consisted af a 3 min. exposure to a 115 dbSPL, 500 Hz. pure tone, with TTS measured at 1000 Hz. Amount of TTS and TTS recovery time were compared with performance on a test battery consisting of MLD, brief tone audiometry, speech discrimination in noise and threshold of octave masking test. The rationale for the selection of each psychoacoustic taks as a possible correlate of susceptibility to auditory fatigue as given by the Mustoir and Schoenv

2.18.1 M.L.D - are a measure of the ears increased ability to detect a binaural signal in noise when the signal or the noise at one ear differs in phase relative to the other ear. The magnitude of the MLD is the db difference between the masked threshold for a particular listening condition, such as the antiphase condition, S_0N_0 in which the signals are 180° out of phase, and a homophasic condition, usually, S_0N_0 , in which the signals are in phase. This homophonic condition usually serves as a reference condition. MLD measurement have aeen shown to be sensitive indicators of central auditory pathology, particularly in the areas of the brain stem (Noffeinger, 1972; Olsen, 1976). Cochlear pathology has also been shown to affect the size of the MLD(01sen, 1971; Ouaranta, 1974, Schosny, 1968). Moreover there are reports of abnormally small MLD's in patients with normal pure tone threshold sensitivity (Noffsinger, 1974; Schoeny, 1968). Auditory fatigue is generally recognised as a cochlear phenomeno. However, several recent studies have suggested that there are central components (Babinghass, 1975; Salvi, 1975). In as much as MLDs are sensitive to both central and cochle^r dysfunction, this psychoacoustic task was considered a potential correlate of susceptibility.

2.18.2. Brief tone audiometry is a procedure for assessment of/ temporal summation involving a comparison of threshold sensitivity for lond and short duration tones. Several studies have suggested that B.T.A may be sensitive to cochlear damage even when there is no significant pure tone hearing loss (Ganewell, 1966; Komoutic, 1973) Some have explained this finding by suggesting that normal hearing subjects may have subclinical cochlear pathology which is revealed by a flattened threshold duration fuction, especially in the high frequency region (Barry, 1974). In as much as BTA is sensitive to subtle cochlear lesion, particularly to outer hair cell, it was expected that this tasks might correlate with susceptibility to auditory fatigue, a process which also involves the cochlear cell.

2.18.3 <u>The TOM Test</u>; The tom test is a tonal masking technique used to estimate the threshold of cochlear distortion or non-linearity . It serves as a simpler alternative to the aural overload test of Lawrence and Blanchard. The close reltionship between Tom test results and the threshold of aural overload made the Tom test a potential correlate of susceptibility.

2.18.4 <u>Speech discrimination in noise</u>; It was hypothesized that speech discrimination ability tested in the presence of noise would also correlate with susceptibility to auditory fatigue. Cupp and Phillips (1969) observed large individual variation in discrimination ability in the presence of noise. They suggested that certain normal hearing listeners who perform poorly in difficult listening situation, may have normal fragile ears. Such variation in subject: with normal pure tone threshold sensitivity suggests that speech discrimination in noise is more sensitive to subtle differences in the auditory system than in pure tone threshold testing. The differences may be the result of minimal neural damage, either in the cochlear or in the central auditory system. Perhaps such neural damage is a contributing factor to individual susceptibility.

They found a small negative correlation between the amount of TTS and the results of the threshold of octave masking test and the results of brief tone audiometry subjects with larger amounts of TTS tended to have lower thresholds of octave masking and flattened threshold duration funcation.

The identification of psychoacoustic tasks which correlate with susceptibility to TTS would be for several reasons.

a) These psychoacoustic task could be used as new indices of susceptibility to noise induced hearing loss replacing traditional TTS based susceptibility test.

b) If several correlates were identified, they could be used test battery for susceptibility testing.

c) The identification of psychoacoustie correlates of TTS may also provide new information about the areas of the auditory system involved in the fatigue process. Certain psychoacoustie tasks evaluate the status of specific areas of the auditory system and could be useful in further refining the site of lesion of auditory fatigue.

d) A. test battery comprised of psychoacoustie correlates of susceptibility to TTS may be useful in detecting minimal auditory dysfunction. It is generally accepted that the pure tone audiogram is a poor indication of the histological status of the auditory system especially of the cochlea (Ward, 1971; Lipscomb, 1975). Several auditory pathology, including noise induced damage, are gradual processes which eventually culminate in a pure tone hearing loss (Hawkin, 1973). If auditory pathology is to be identified before irreparable damage results in a pure tone hearing loss then new tests which are sensitive to subtle dysfunction must be used. Indices of susceptibility to auditory fatigue can be considered more discriminating measure than are pure tone threshold because persons with identical threshold sensitivity show varying amounts of TTS following identical exposure.

2.19 TTS and Hock and Roll music:

Increasing concern about environmental noise pollution has prompted studies other than those in which acoustic trauma has been experimentally induced or attributed to industrial or military exposure to loud sounds. In the past decade the majority of young people have voluntarily exposed themselves to highly amplified rock and roll, discontheque or popmusic.

A well record for conflict between the parents and their children is popumusic. The young generation consider it a legitimate right to hear popmusic at very high sound levels both in discoteques when dancing and at concerts. Naturally their parents worry about the children's hearing with exposure to what they consider not music but noise, especially when the sound is presented at levels which, for the parents certainly are above the discomfort level.

Within the past 2 to 3 years, attention has been focussed on the potentially harmful effects of rock and roll music upon human hearing. Numerous articles in western lay press have warned young people that exposure to rock and roll music will undoubtedly result in serious permanent damage to their auditory mechanism. An expression of this concern by experts has also begun to apnear in various professional publications.

Newspapers and mazaines articles have reported that the intensity of rock and roll music ranges from 120 to 130dbSPL. A review of actual research findings, however, reveals that the average intensity of rock and roll music is considerably less intense than those estimate given in the lay press. Specifically, the average intensity of amplified rock and roll music measured with the linear scale (broad frequency response) of a sound level meter is approximately 104 to 111 dbSPL. at distances ranging from one to 20 feet from the centre of the stage. This finding is based upon sound level meter measurement mode in six independent studies in four states (California, Michigen, Minnesota and Tineuse). The results of the investigators are presented in table below;

Study	No. of groups	All groups	Loudest group	least loud group
Lebo et al. (1967)	2	113.5	118	199
Libscomb (1969)	1	122		
Rintelman (1969)	7	107.7	114.5	105.6
Rintelman and Borus(1968)	6	105	108	96
Plugrath(1969)	10	103.9	114.8	97.7
Speaks and Lelson(1968)	10	110.5	120	105

Average overall SPL in db of Rock and "Roll groups measured in 6 different investigations.

Measurement of SPL and frequency distributions led Lebo and Oliphant 1968 to conclude that prolonged exposure to such music was unsafe. Kryter (1970) described rock and roll as intermediate between impulsive and non-impulsive sound and pointed out that it exceeded limits set forth in DRC. Rintelman and Borus (1968) investigated musicians who were exposed to this type of music as an occupational hazard and reported that only 5% of 42 performers had permanent hearing losses after long term exposure. Most workers have argued that rock and roll produced at least temporary changes in the threshold of hearing. Rise et al (1968), Speaks et al. (1970), Jerger and Jerger (1970) measured shifts in the hearing threshold of performer at 2 min, 20 to 40 min. and

1 hour respectively after exposure. Temporary hearing losses were present In almost all subjects andpermanent losses were recorded in about 25% of the musicians. Lab. studies, because of recognised risk to hearing have necessarily limited the exposure of subjects to rock and roll music to one lession of an hour or less (Dey, 1970; Hickling, 1970). Recently Rinterman et al. (1978) had 20 subjects listen to an hour of rock and roll music under both continuous and intermittant condition. The hearing recovery pattern was followed up to 90 min. after exposure and it was concluded that daily exposure over an extended period be hazardous to hearing.

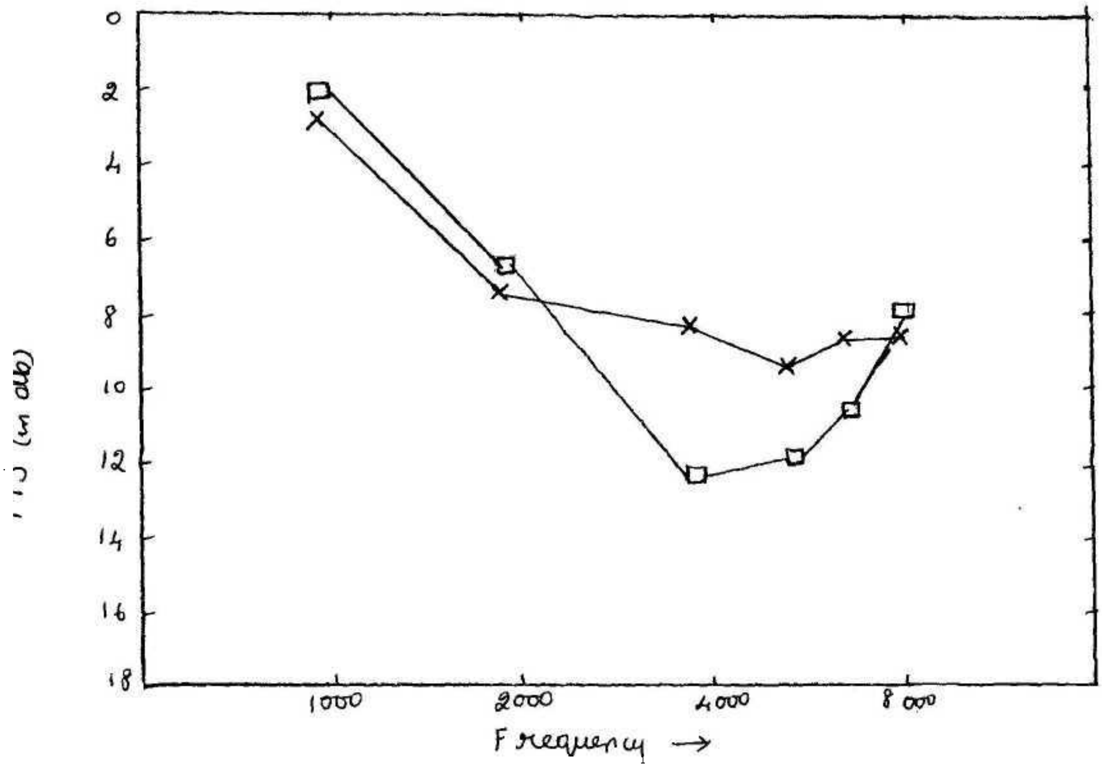

Fig.8. Mean TTS in listenersoand pop musicians X For listener a mean L_e Was 99 dbA, duration of exposure 99 min. and internal to test 11 min. for musicians, mean L

Subjects who initially had small threshold shifts tended to have less TTS for succeeding rock and roll sessions than subjects who initially had larger shifts in hearing level. Although individual hearing recovered between sessions, the average TTS generally becomes worse over the succession of weekly exposures.

The factors increasing the risk for hearing loss in pop musicians was studied by Axelson and Lindgrea (1977). The following factors were found to have statistically significant influence on heading: ageing, brief exposure as per session, long exposure time in years (2000 Hz.) participation in military service(250 Hz) listening to pop" music with head phones(2000 Hz).

Axelsson and Lindgren (1978) studied TTS in pop musicians and in listeners, This was explained by slightly inferior hearing threshold levels.than in the audience before exposure. After 2 hr. of exposure to live pop music a TTS_2 appears in pop musicians after an exposure to 98 db(A) as opposed to listeners where TTS_2 appearing at 92 db(A).

The amount of TTS_2 that could be allowed without risking a permanent hearing loss is the question actually put. CHABA sets the maximum limit to 10 db. on 1000 Hz. and below to 15 db. on 2000 Hz. and to 20 db. on 3000 Hz. and above. Tf we relate this figure to the Axelsson and Lindgren (1978) investigation it appears that a TTSg of 15db for listeners would result from an exposure to 2 hours of 100db(A). It suggests that this could be used as an approximate indication of the permissible exposure level on one session of pop music or a pop music concert etc., which is limited to 2-4 hr.

Chuden and Straus (1974) demonstrate that pop music presented in a head phone induced less TTS than BBN of the same equivalent level duration. This could indicate that the personnel experience of the noise eg. a meaningless less noise is one case versus beautiful loud sounds, would result in different TTS levels.

Although the relationship between noise induced temporary and permanent thresshold shift is still not clear, the fact that the hearing of most teen agers in different study returned to original levels of sensitivity does not rule out possible damage to the sensory elements of the inner ear. Histological examination of both human and animal ears have shown that large number of hair cell may be missing along the organ of corti when hearing thresholds are reported to be clinically normal. Recent data from studies of the cochlea of chinchillas and monkeys, exposed to loud noise to produce TTS revealed that the inner ear underwent observable permanent changes inspite of the recovery of normal hearing sensitivity (Mills et al.;1970; Miller et al. 1971; Pinheiro et al. 1972).

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Summary:

The experimental literature on AF is discouraglngly large. As a matter of fact, in auditory fatigue the unsolved problems greatly outnumber the established facts.

Auditory fatigue is a term used to describe a temporary change. Usually, but not always, a decrease is threshold sensitivity followi exposure to another auditory stimulus. Auditory adaptation refer to any change in the functional state of the auditory system brought about by an acoustic stimulus.

Auditory adaptation and fatigue occur parallely, evidences available from the psychophysical data show that auditory fatigue and adaptation reflect different physiological changes. There are marked differences in the characteristic of the time courses of the two phenomena of both in respect to their development, their recovery, their dependence upon intensity and duration and their frequency distribution and these have their identical subjective counter parts in auditory fatigue and adaptation.

Fatigue remains small and constant as the duration of the stimulating tone goes up from 0.1 to about 5 sec. As the duration is Increased further between 10 and 60 sec, the fatigue Increases linearly in db. Above 1 min., as durations are increased to 64 mins. fatigue increases more and more rapidly with duration.

The more intense the stimulating sound, other things being equal, the greater is the auditory fatigue at any instand and the longer it will last.

The maximum temporary hearing loss after prolonged exposure to to loud tones appear at a frequency that lies approximately one-half octave above the stimulating frequency.

The longer one waits before measuring the absolute threshold for a test tone after the cessation of the stimulating sound, the less will be fatigue. Recovery from maximum temporary hearing loss is rapid at first and then more gradually approaches normality. Recovery process seems to be relatively independent of test frequency . Multiphasic recovery, diphasicity has also been reported.

Increased responsiveness after stimulation Is termed sensitization. It is not restricted to the ear exposed. Its effects can be seen earlier for test frequencies below the exposure frequencies than for those above it.

A number of factors like resting threshold, drug effect, etc., have been correlated with auditory fatigue.

During the process of continuous stimulation of the auditory system, functional changes will take place at the hair cells, endolymph, the neural discharge.

Reports regarding auditory fatigue and iris pigmentation say individuals with highly pigmented irises experience less TTS than with less pigmented irise.

Vocalization, humming and nonvocal activities during the fatiguing exposure results in less TTS than no activity during exposure. These activities are believed to elicit middle ear muscle contraction.

Pure tones are reported to be more dangerous than octave band of noise. This was explained on the basis of critical band hypothesis earlier. Now this has been refuted. Acoustic reflex is responsi ble for the difference in the amounts of TTS. Middle ear muscle action differs for noise and pure tone stimuli. Pure tone stimulation produce an initial contraction and rapidly relax and hence more energy reaches cochlea. Noise produces more sustained rearousal of the reflex.

The average intensity of amplified rock and roll music is approximately 105db. Several studies report prolonged exposure to such muscle is unsafe and TTS is also been reported.

Individual differences in susceptibility to TTS and PTS are well recognised. A great deal of interest and research has been directed towards using differences in susceptibility to TTS to predict PTS. Some have studied_possible relationship between susceptibility to TTS and other psycho acoustic tasks. Some have found overload test, brief tone audiometry, and octave masking test to be a predictor of TTS.

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CHAPTER 3.

AUDITORY ADAPTATION

3.1. INTRODUCTION.

The first investigation of auditory adaptation of any sort was that of Dove (1859) who noted during the course of a study of binaural beats, that if one ear was exposed for some time to a tuning fork, then binaural presentation of this same frequency would result in perception of a tone only at the unexposed ear. He placed one tuning fork of an identical pair at each ear. Both of them were vibrating imperfect synchrony. One of the forks rotated continuously around its long axis (thus producing an intermittent sound) while the other one did not rotate(thus producing a continuous tone). It turned out that the sound of the stationar fork appeared weaker to the observer than that of the rotating fork.

Fluegel in 1920 reported a series of experiments in which he systematically determined the effect of various parameters on both perstimulatory and post-stimulatory adaptation carefully done studies whose generally is limited only by fact that tuning fork alone was used as the major source of adapter and test tone. He discovered different relations subsequently confirmed by modern experimentation.

Fluegel (1920) even tried to determine the effect of central factor. During the adaptation period he had his subjects read, look at a series of picture of an exiciting character to be attentively contemplated or perform addition. Such alternatives had no effect on auditory adaptation. In the context of the question of losses, Fluegel's most relevant findings was that the 2 ears of a given observer often displayed different degrees *of* asymptotic adaptation at a given frequency. He argued that if such a difference in susceptibility existed, then when one presented the tone binaurally to begin with the image should gradually shift to the less susceptible ear, or taking the alternative view the loudness in the more susceptible ear should decrease. When he subjected this hypothesis to empirical test no such shift occured the image stayted right in the middle. The result implies a complicated central mechanism, not a simple peripheral comparator.

Adaptation is a phenomenon which characterizes all sensory systems. Its operational definition has customarily been in terms of a shift in some aspects of the intensive dimension of subjective experience, often in the threshold, brought about by previous stimulation of a sense organ by the same type of stimulus to determine the threshold.

Auditory adaptation in its most generaly sense could be taken to refer to any change in the functional state of the auditory system brought about by an acoustic stimulus.

Such a change in the auditory system functional state manifest itself in a variety of ways. Indeed, it is possible to cite at least five psycho-physical measures which undergo modification as a consequence of acoustic stimulation of sufficient magnitude. Along intensive dimension, the absolute threshold of hearing, the masked threshold, and at supra-threshold levels, the loudness of a sound, have all been shown to change. In addition shifts in the pitch of an acoustic stimulus occur and, in the case of dichotically presented stimulus, a change in the apparent location results from prior presentation of an appropriate acoustic stimulus.

3.2 AUDITORY ADAPTATION VERSUS ADAPTATION IN OTHER SENSES.

Auditory system is not unique in showing adaptation effects. In other sensory modalities such effects have not been demonstrated as it is difficult to maintain a constant adequate stimulus for an appreciable time. Beyond stating that adaptation has been shown to occur in nearly all sensory modalities, it is difficult to make meaningful comparisons. The end organs of sensory systems vary tremendously in their response mechanisms. Adaptation in the visual system, for ex., seems to be governed primarily by the photochemical processes within the rods and cones. In the ear, however, stimulation of the hair cells is related to mechanical deformation and adaptation is almost certainly a completely neural process.

A survey of sensory modalities shows that the most common indexof adaptation is adaptation time. A stimulus of a given intensity is presented and the time for the complete disappearance of the elicited sensation is recorded. This is the procedure utilized in threshold decay test (Carhart 1957). Contrary to many modalities, the normal ear rarely shows complete adaptation even from very modest stimulus intensities. In those senses in which adaptation is complete, adaptation time increases as stimulus intensity is increased. The time taken to adapt completely for stimuli of moderate intensity varies from 0.5 to 3 min. The next most common index of adaptation is the measurement of absolute threshold.

3.3. PARAMETERS OF AUDITORY ADAPTATION

3.3.1 Growth:

In general, its course of development is one of negative acceleration, with the greatest rate of adaptation occuring during the first one or two minutes, and the asmptotic level being reached anywhere from three to seven minutes after the onset of the adapting stimulus. Mose of the recovery from adaptation occurs within one minute, and recovery is complete within two minutes. Adaptation has a: roughly linear relation to the intensity and little or no relation to the frequency of the adapting stimulus. Although the developmental course of adaptation is well established, the values found at any particular point on the curve vary widely between investigators.

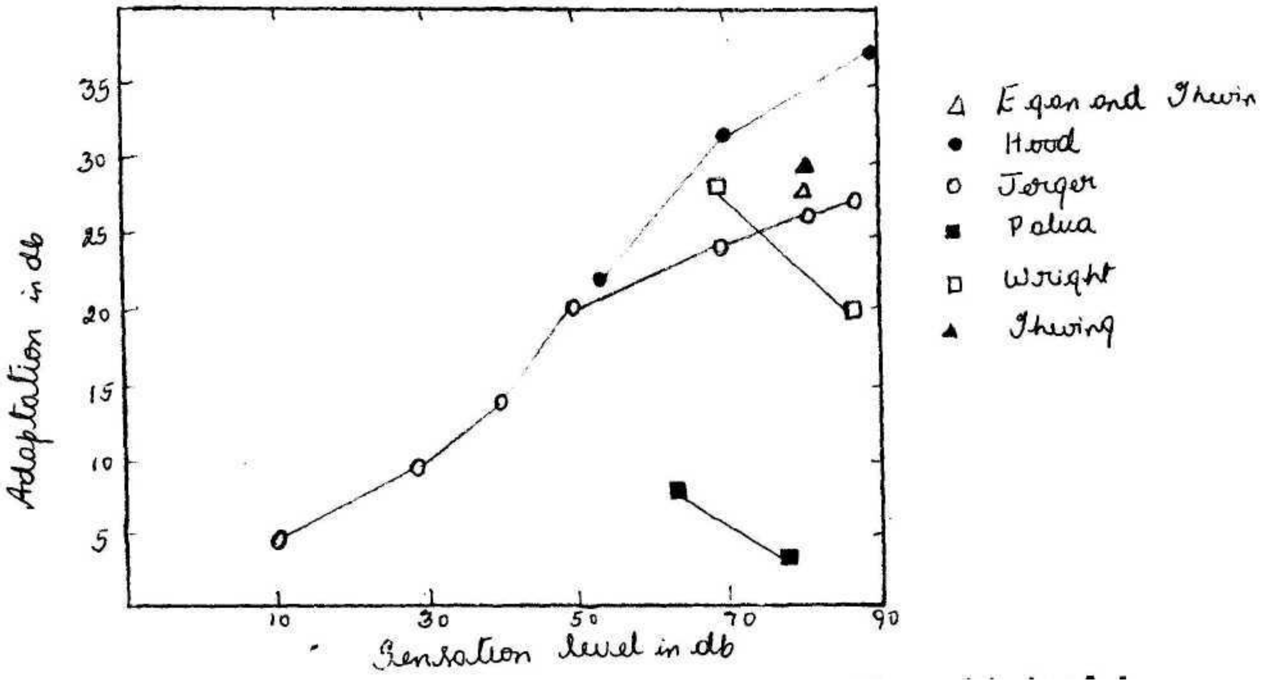
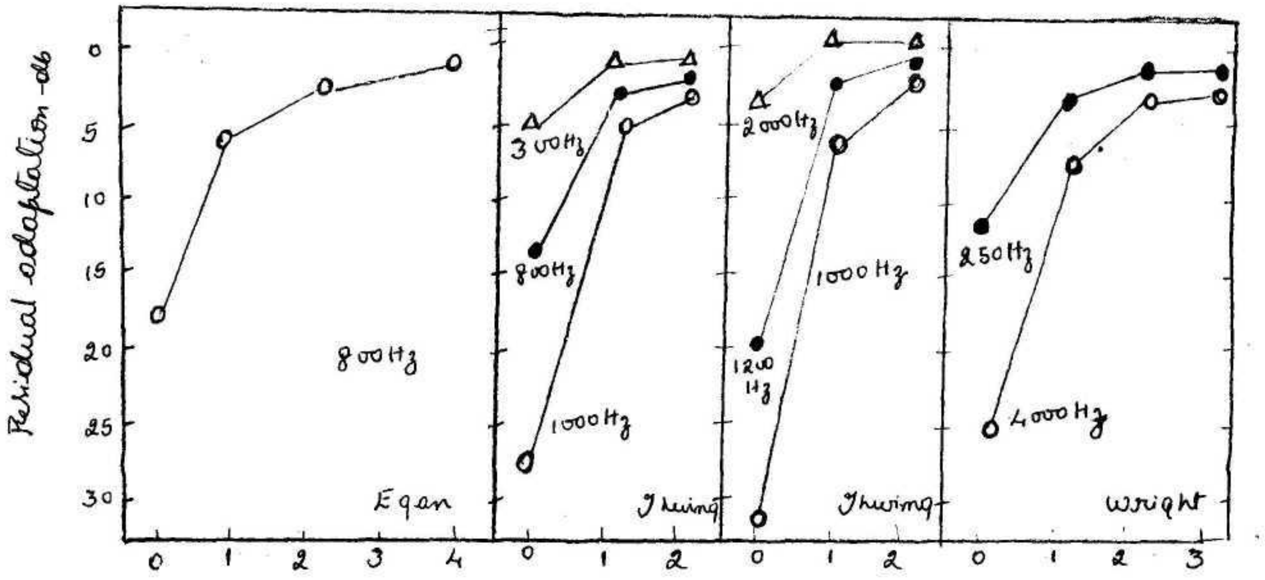


Fig.9 Comparison of the amount of adaptation obtaine
six different investigators.

3.3.2. <u>Recovery:</u>

Most of the studies using simultaneous dichotic loudness balance technique have found recovery is rapid, with far more taking place occurs during the second minute. The evidence suggests that the functional characteristics of the ear are restored by the third minute. Method of intensive localization where restimulation is minized shows the course of recovery during the first minute which includes most of the recovery is ascertained unlike SDLB test. Bekesy (1950) using this method with stimuli of 0.2 sec. duration, found that 80%

of the recovery occur during the first 5 sec. almost complete recovery occurs within 10 sec.



Time after cessation of adapting stimuli -min.

Fig. 10: Time curve of recovery from loudness adaptation. Residual adaptation is indicated on the ordinate while the abscissa represents the time after cessation of the adapting stimulus.

3.3.3. STIMULUS VARIABLES (Adapting stimuli)

3.3.3.1 Intensity:

The relation of adaptation to the intensity of the adapting stimulus is in conflict. For a continuous pure tone, Hood(1950) found a roughly linear relation over a wide range. Jerger (1957), too, demonstrated a linear relation, at least from 10 db to 60dbSL, but above this level, the function flattens out. Additionally, in those studies that investigated only two intensities (Palua 1955, Wright, 1960), there is no increase in adaptation as a function of the adapting stimuli. For those studies that have data in common (Hood, 1950; Palua, 1955; Jerger, 1957, and Wright 1960), only Hood showed a substantial increase in the degree of observed adaptation beyond the 60db level.

A general statement might be that adaptation and the intensit of the adapting stimulus are linearly related, the upper limit of this function remains in doubt.

Adaptation can be measured at intensity levels other than that of the adapting stimulus. This aspect has been investigated only by adapting the test ear at one intensity and measuring adaptation at a lower intensity. Adaptation when measured at any given intensity, is determined by that test intensity - at least when it is lower than the adapting intensity. Egan (1955) found decreasing amounts of adaptation as the test intensity was lowered. Hood(1950) offered a theoretical interpretation; he postulated that for any test intensity, there is a receptor group whose size is proportional to that intensity, the amount of adaptation, then reflects the size of the receptor group so long as the adapting intensity is equal to or greater than the test intensity.

Still another aspect of intensity - the effect of concentration of energy - can be studied by using narrow- or broad band noise for the adapting stimulus. Carterette (1956) compared several bands of noise and a 1500 Hz. tone using the methods of fixed and variable intensity, with 50, 70, and 90-dbSPL adapting stimuli. The results indicate that adaptation tends to increase as band width increases, at least for the 90dBSPL intensities. Apparently, as the available energy is spread over a broader frequency range, it adopts a larger receptor group.

3.3.3.2. Frequency:

Two aspects of the frequency parameter merit discussion. First, does adaptation vary as a function of the frequency of the of the adapting stimulus, and second, does adaptation at one frequency spread to neighbouring frequencies.

Jerger (1957) found a slight tendency for adaptation to increase as frequency increases from 125 Hz to 1000 Hz, but to remain approximately constant for frequencies from 1000 through 8000Hz.

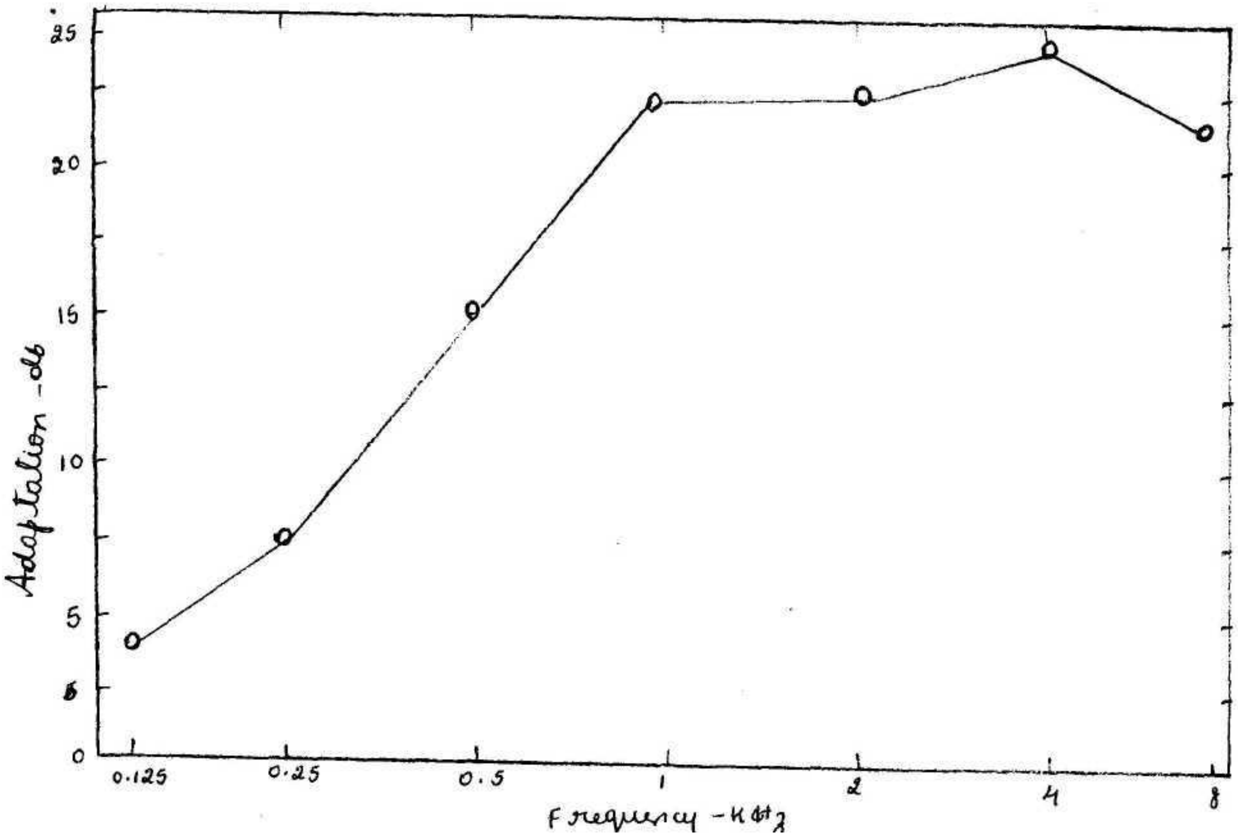
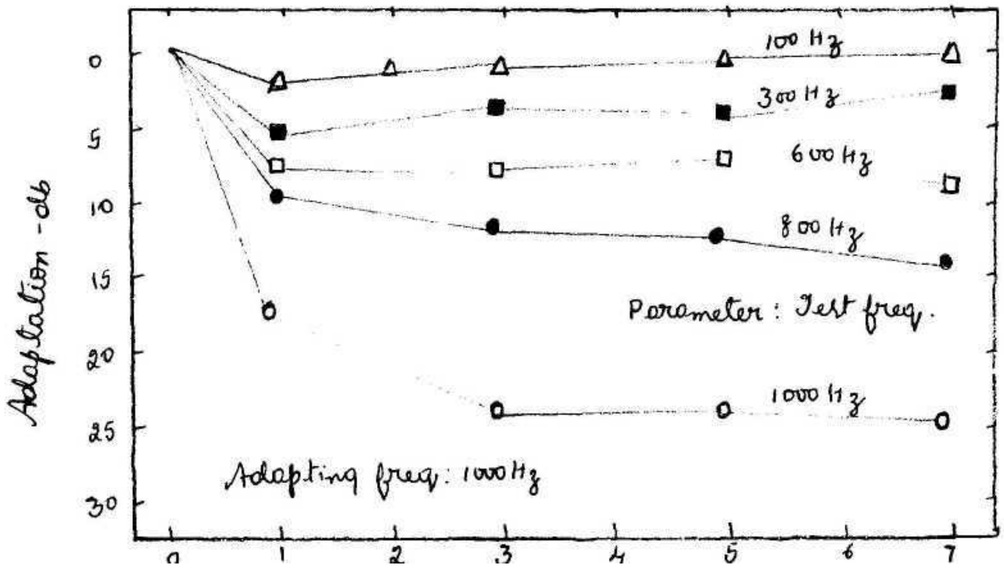


Fig.11. Loudness adaptation as a. function of frequency. The amount of adaptation is the average of 60, 70, 80 and 90 dbSPL after 5 min. exposure. [Jerger,(1957) quoted word (1963)]

Adaptation, at least for 1000 Hz. at 80 dbSPL, has its maximum effect at the adapting frequency, with continuously lower degrees of adaptation observed on both sides until at 100 Hz. and 2500 Hz., it has completely disappeared (Thwing, 1955). Thwing suggested that adaptation is proportional to the extent to which excitation patterns of the adapting and comparison stimuli overlap.

Jerger (1957) using the method of fixed intensity showed that low frequencies exhibited small amounts while high frequencies gave rise to larger amounts.



Duration of adapting stimulus - min.

Fig. 12. Temporal course of the development perstimulatory adaptation. Fig shows the results when adaptation is tested at frequencies higher than the adapting frequncy. (Thwing 1955)

When adaptation is measured at the same frequency to which ear was exposed, the effects is maximal. That is, the greatest amount of adaptation is produced at the adapting frequency.

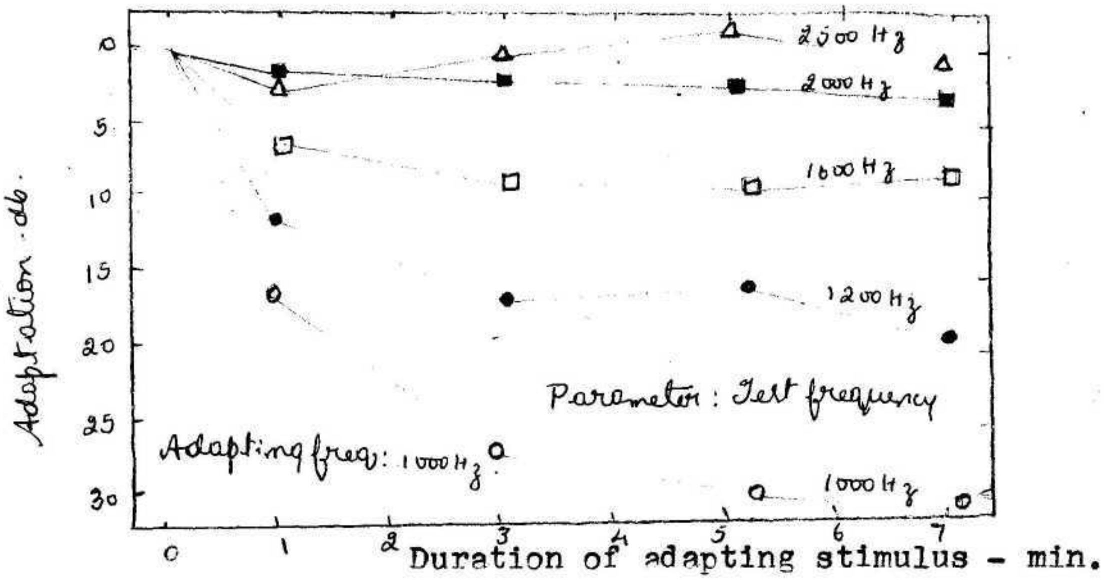


Fig :3 Temporal course of the development of perstimulatory adaptation. Figure shows the results when adaptation is tested at frequencies below the adapting frequency-Exposure: 1000 Hz. at 80dbSPL (Thwing 1955)

3.3.3.3 Continuous noise:

Noise, specifically band pass noise is usually thought of as being variable with respect to its centre frequency, its have band width and its intensity.

Carterett, (1955, 1956) using the method of fixed intensity and modified varied intensity, investigated the effects of intensity and band width upon loudness adaptation. He found a tendency for the amount of adaptation to increase as band width was increased. This increase in adaptation with increasing band width mirrors the changes in the loudness which takes place as band width is varied (Pollock 1952).

Thus, these results point out that with a fixed over-all intensity, more adaptation is obtained if the available energy is spread widely, rather than concentrated in a narrow spectral region.

The exception to this statement Is for the case of pure tone which showed more adaptation than any noise condition.

Wright (1959) investigated the effects of the simultaneous presence of noise upon the adaptation of pure tones. His study was designed to simulate an ear, demonstrating loudness recruitment In so far as it is possible to do so with simultaneous noise maskin (Steinberg and Gardner, 1935; Harris et al, 1952). In a series of experiments utilizing the method of fixed intensity, Wright showed that the Introduction of a wide hand noise increased both the initial rate and asymptotic value of adaptation for a 4000 Hz. This finding indicate that if recruitment and excessive adaptation occur together in pathological ears, then noise masking does not effectively simulate the pathology of a recruiting ear.

3.3.3.4 Intermittent Noise.

One of the important characteristics of the auditory system is its ability to deal with stimuli whose energy is not constant but varies as a function of time.

Carterett (1955) measured adaptation to a noise that was interrupted at rates varying from 1 to 12.4 per sec., with a 50 percent duty cycle. First, he observed that, with total energy equal to that in a continuous adapting noise, the continuous noise produced more adaptation. Second, as interruption rate increases, the degree of adaptation also increases. Carterette suggested that, as interruption rate is increased, the time for recovery is shortened, and thus cumulative effects may be produced. However, the period of adaptation Is likewise reduced. Apparently recovery processes suffer relatively more from the increase in interruption rate than do the adapting processes; thus there must be either a latency in the onset of the recovery processes or an initial recovery rate lower than the initial adapting rate.

3.3.3.5 Intermittent Tone.

Sergeant and Harris (1963) with the method of fixed intensity varied the on-and-off times of an interrupted 1000 Hz tone. The problem of energy spread was minimized by the use of relatively long signal durations.

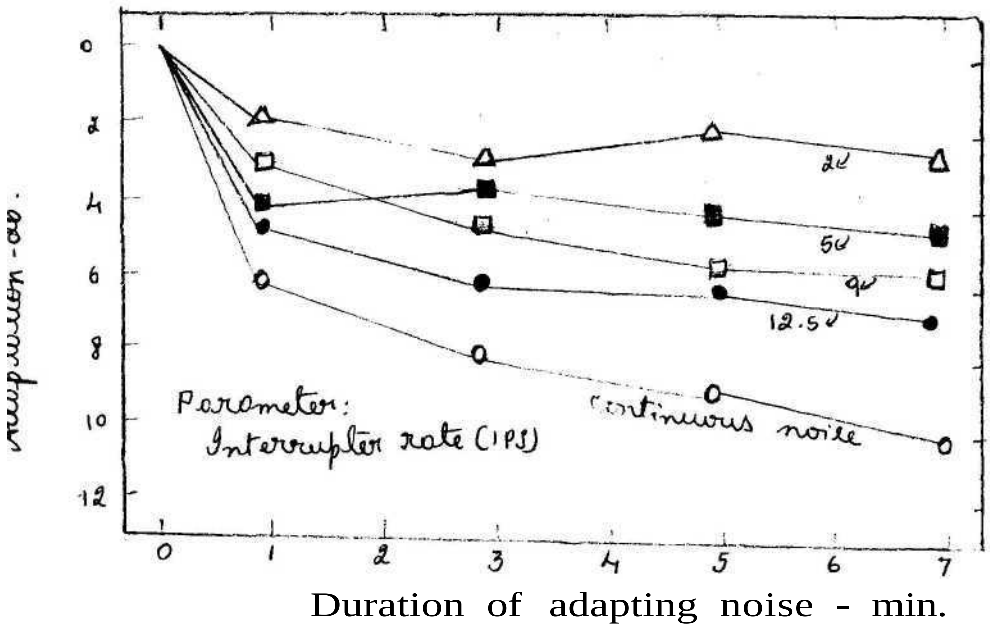


Fig. 14. {Time course of perstimulatory loudness adaptation to interrupted wide band noise. The interrupted noise was on half the time and off half the time and during the period that it was on had an intensity of 90dbSPL (burst level 90 db) Adaptation to a continuous noise of 87 db, the same intensity as the overall of the interrupted noise }[Carterette 1955]

The results of Sergeant and Harris indicate that as stimulus duration is lengthened the maximum or asymptotic adaptation increases. Further, as the silent intervals is shortened, the asymptotic adaptation also increases, probably as a result of a decreases in recovery time.

3.3.3.6 Asymptotic level:

Intensity and to a lesser extent, frequency both act to determine the temporal course of auditory adaptation and in particular to point at which its asymmptotic state is reached.

Originally, Hood (1950) reported that auditory adaptation is complete wjthin 3 to 3.5 mins. regardless of the intensity or frequency of the adapting stimuli. Later studies confirmed this finding only for intensity upto 60 dbSL of frequency upto 1000 Hz. (Herger, 1957). Above these values, the frequency effect is negligible and the degree of adaptation observed becomes primarily a function of the intensity of the adapting stimulus.

In general, for the higher intensities, the point of maximum auditory adaptation are reported beyond this point and at a considerable slower rate.

Carterette (1956) reported that adaptation was still increasing at seven minutes when the intensity of the adapting stimulus was 90 dbSPL. That the asymptote is not reached in three minutes in most studies, except at lower intensities and lower frequencies, is most likely attributable to the addition of fatigue processes.

3.3.4 Stimulus variables-(Comparison stimulus)

Auditory adaptation function may reflect the characteristics of the comparison stimulus by means of which it was derived.

3.3.4.1. Frequency difference between adapting and comparison stimuli:

Egar (1955) in an experiment designed principally to assess the relative contribution of median plane localization versus simple loudness balances with simultaneous dichotic stimulus presentation varied the frequency of the comparison stimulus independently of that of the adapting stimulus. Of course, when the frequency of the stimuli in each ear is markedly different, each stimulus is localized at Its respective ear inspite of variations in intensity. Egen's result shows that the frequency of the comparison stimulus makes little difference if a proper experimental procedure is used.

3.3.4.2 Temporal effects:

Small and Minife (1961) attempted by varying the on-and-off time of the comparison stimulus, to demonstrate the effect of adaptation in the comparison ear upto the inferred adaptation in the adapted ear. For a particular on-off time combination perstimulatory adaptation runs its usual time course, a rapid initial rate of adaptation with the function asymptoting after 5 or 6 min. of exposure. As on time is increased less adaptation is measured in the adapting ear.

The inference is that the longer the comparison stimulus is on, the greater the amount of adaptation in the comparison ear wit! the consequent Biasing of the data, This is the result for off times of 10 sec. which is very similar to off times for 20 sec. Varying the on time of the comparison stimulus for the off times of 50, 40, and 30 sec., produces no apparent effect upon the amount of adaptation measured in the adapting ear. It appears 30 sec. is enough time to allow recovery to occur in the comparison ear.

3.4. ADAPTATION IN OTHER AUDITORY DIMENSIONS.

A change in loudness is one index of the functional state of auditory system following stimulation. There are other changes.

3.4.1 Absolute threshold:

3.4.1.1. Short duration fatigue:

Amount of threshold shift increases as the intensity of the exposure stimulus increases. It also increases as a function of the duration of the exposure stimulus but only for duration less than 0.4 sec. Recovery of the threshold following exposure is a rapid and very nearly linear function of time. Indeed, following an exposure stimulus of 80 db the threshold is back to normal within 0.25 sec. Although threshold are maximally shifted at the exposure frequency, they are also shifted for neighbouring frequencies, but not in a symmetrical fashion. Test frequencies above the exposure frequency are shifted to a greater extent than those below. When the exposure stimulus is presented to one ear and the test stimulus to the other ear, no threshold shift is observed.

3.4.1.2. Long term fatigue:

Is reversible threshold shift produced by a longer and more intense than those used to produce short duration fatigue. Threshold shift increase as a function of the intensity and exposure duration but it does not reach an asymptote like short term fatigue. The size of the threshold shift continues to increase over a period of at least 5 hours. The amount of fatigue decreases as a function of the time separation between the exposure and test stimuli. However, this recovery is not monotonic with time and its rate is influenced by the frequency of the exposure and test stimuli, duration and intensity of exposure stimulus.

3.4.2 Pitch:

Bekesy (1929) observed pitch shifts which were symmetrical about the frequency region of the fatiguing tone, upward shifts above this region and downward shifts below. Ruedi and Furrer (1947) found upward shifts only if the fatiguing tone was around 1000 Hz. downward shifts only if the fatiguing tone was 6 or 7KHz and no shifts if the fatiguing tone was 4000 Hz. Davis et al. (1950) using greater intensity and durations, observed that large displacement of pitch are always upward.

3.4.3. Differential thresholds:

Bekesy (1947), Ruedi (1954) and Epstein and Schuber (1957) have used the pen excursionsat absolute threshold of a Bekesy type audiometer as their measure of the differential threshold. Their findings indicate that pen excursions decreases following stimulation. Elliott et al. (1962) also found that differential thresholds decrease following intense stimulation.

3.4.4. Temporal integration:

As the duration of a sound is decreased below a certain critical value its intensity must be increased in order to continue to elicit a threshold response. This phenomenon is terms temporal integration. Jerger (1955) has reported that following exposure to intense (overall 110 dbSPL) wide band noise, a change in the threshold time intensity relation occurs. The nature of the change is a reduction in the size of critical duration and in the slope of the function below this duration. These changes are of the same type as reported in ears purported to possess organ of corti pathology.

3.4.5. Masked threshold:

The question has been raised as to whether the masked threshold itself changes during continuous stimulation. Egan (1955) has shown that no change in masked threshold takes place under these circumstances. Thwing (1956) presented a signal continuously (1000 Hz. at 70 dbSPL) and intermittently introduced the wide band masking noise for short periods. The subject adjusted the intensity of the masker until it just masked the signal. Thwing found that the masked threshold shifted about 6 db, most of it within the first few minutes under these conditions. He relates his finding to the observation that a tone undergoing adaptation loses its "pitchiness", it becomes dull and thick. Therefore, since the tone, upon adaptation, sounds somewhat similar to a noise, it is presumably more difficult to discriminate against a noise background.

3.5 A THEORY OF LOUDNESS ADAPTATION:

3.5.1. Small (1964) discusseshypothesis dealing with only loudness adaptation. The hypothesis is based in part upon well establish neurophysiological principles, in large measure on ideas of previous investigators and to some degree is speculative. He points to few features that must be accounted for by any proposed mechanism. They are as follows.

3.5.1.1. Intensity Effects:

The amount of loudness adaptation increases as a function of the intensity of the adapting stimulus. If adaptation is measured, however, at an intensity less than that of the adapting stimulus, it is found that the amount of adaptation does not depend upon the intensity at which the ear was adapted, but only upon the intensity at which adaptation is measured.

3.5.1.2. Temporal effects:

a) Adapatation lncreses as a function of the duration of the adapting stimulus. The time taken for the adaption function to reach asymptotic depends upon the characteristics of the adopting stimulus, but rarely exceeds 6 min.

b) The amount of loudness adaptation decreases as a function of the interval between the cessation of the adapting stimulus and presentation of the comparison stimuli. This recovery is monotonic with time and its rate depends upon the amount of adaptation from which recovery is taking place. The time taken complete covery varies tremendously with experimental procedure. It may be as short as 15 sec. and almost certainly no longer than 4 mins,

3.5.1.3 Frequency effects:

maximum loudness adaptation is found at the frequency of the adapting stimulus, but the spread of adaptation to other frequencies occurs in symmetrical fashion. In addition, the effect is a peripheral rather a central phenomenon.

3.5.2 Small (1964) also tries to give explanation for the changes observed.

3.5.2.1. Intensity effects:

He postulates that a given group of receptors is not effected differentially by adapting stimuli of different intensity. To this posturation following assumptions are made.

1. neural coding for loudness in the number of fibers are activated.

2. Neural elements have different sensitivities.

3. Threshold constitutes some minimum number of active fibers, those with the lowest threshold and a 20dbSL stimulus, for ex., activate a group of greater number.

4. If the 20 dbSL stimulus is continued indefinitely, some of the neural units may become less sensitive and cease to respond to the 20 dbSL stimulus.

5. The distribution of the neural elements which cease to respond is independent of the elements initial sensitivity,

6. The number of units which cease responding as the result of prolonged stimulation is a constant proportion of the total number initially activated.

7. For ex., consider the presentation of lOOdbSL A number of units are now activated, including the units which responded to the 20dbSL stimulus as well as a number of additional units which have lower sensitivities. If following a prolonged exposure to a 100 dbSL stimulus, a 20 dbSL stimulus is presented, the same number of units will be available as would have been the case had theexposure been to a stimulus of 20dbSL. Thus, the change in loudness in a 20 dbSL stimulus will be the same whether the adapting stimulus is 20 or 100 db.

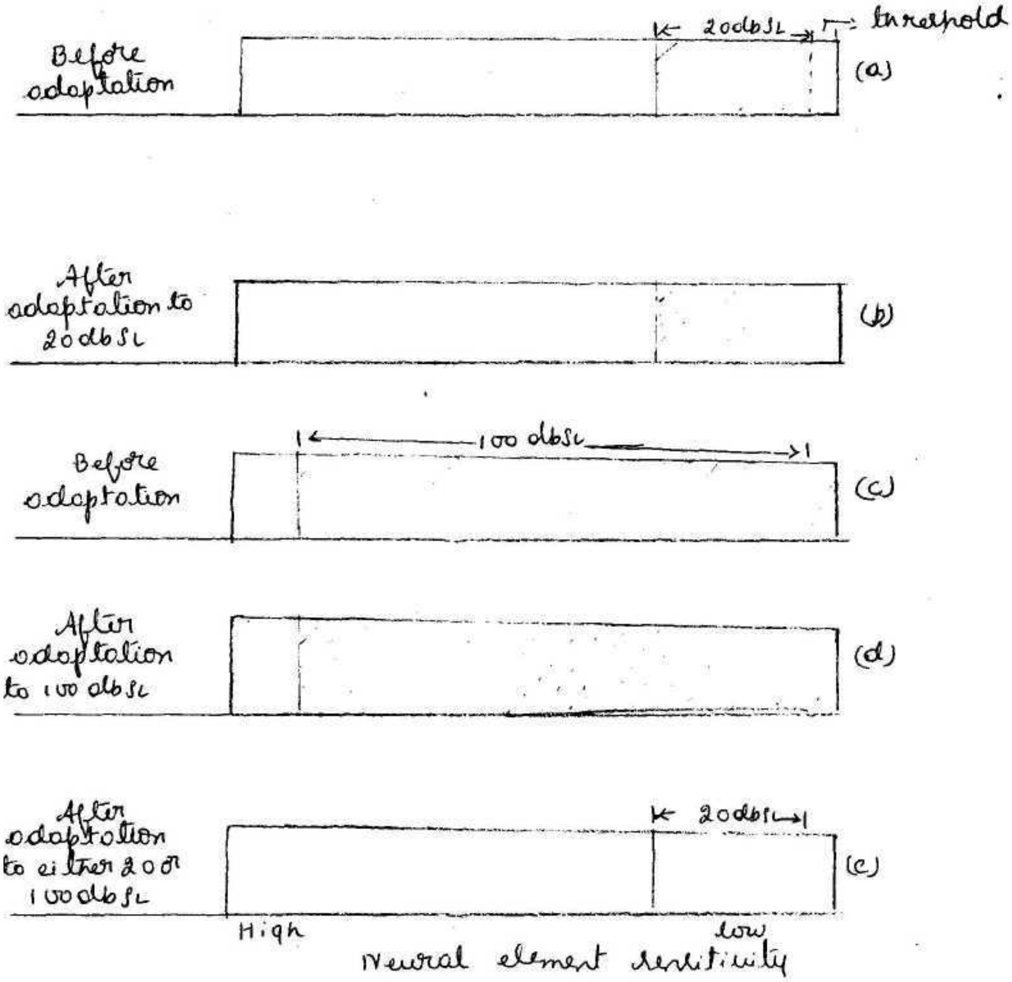


Fig. 15. Schematic representationof number of neural elements responding to stimulation. Distribution of elements sensitivity is shown on the horizontal asix while the darkness of shading indicates the density of neural element activity under various conditions.
Drawings (a) and (b) illustrate the effect of a 20 dbSL stimulus before and after adaptation while drawings(c) and (d) show the same thing with a lOOdbSL stimulas. Drawings (e) represents the response to a 20db3L stimulation after adaptation to either a 20 or 100 dbSL stimulus.

Once the intensity of the stimulus is great enough to excite a particular element, it is immaterial, in terms of the length of time the element will continue to fire, how much greater the intensity becomes. So it the length of time it has been firing is a cruicial factor. Under these conditions there is a recovery process going on simultaneously with the adapting process. That is, certain elements will cease firing because of prolonged activity, while others may regain their initial sensitivity and begin activity again.

Threshold is dependent in a different way upon the sensitivity of the neural elements. The decreased sensitivity brought about by exposure requires that a more intense stimulus be presented in order that the fixed number of fibers required for threshold be activated.

3.5.2.2. Frequency effects:

Loudness adaptation as proposed as a result of rendering non-functional a certain proportion of neural elements which initially responded to the stimulus. Small further proposes following assumptions to account for the symmetrical spread of adaptation from the frequency of the adapting stimulus to neighbouring frequencies.

1. Neural elements is considered as constituting a sub-population located at a particular point on the basilar membrane. This population of neural elements is on the basilar membrane or located at some place In the peripheral auditory system which is functionally connected point for point to the basilar membrane.

2. As a function of continued stimulation neural elements are locally rendered non-functional. This effect is found In the region

of the basilar membrane in which maximum displacement occurs in response to a particular frequency.

3. When a test stimulus is introduced whose frequency is different from that of the adapting stimulus, if the elements responding to the test stimulus were in part those which had responded to the adapting stimulus, the test stimulus would exhibit a loudness decrement in proportion to the degree of overlap between the two neural populations.

4. For tonal stimuli the displacement and the excitation of neural elements along the basilar membrane are not uniform. The distribution of excitation is considered in determining the amount of functional overlap.

5. As the frequencies of the test and adapting stimuli are separated, the area of overlap between populations decreases and consequently the amount of adaptation decreases. As long as the distribution of excitation along the basilar membrane is similar for each stimulus, the area of overlap will be the same regardless of whether the test frequency is above or below the adapting frequency. So, a symmetrical spread of adaptation will occur.

3.5.2.3 Localization effects:

To account for localization effects small has following assumptions.

1. Timing information is available in the form of synchronous neural discharges based on the motion of the basilar membrane and corresponding to the onset of clicks or pulses or to the positive peaks of sine waves.

2. Neural activity is functionally confined to the position on the basilar membrane which is undergoing maximum displacement and from this point that timing information arises(Schubert and Elpern,

3. This timing information is acted upon by a central factor located neural network acting as a coincidence detector as proposed by Licklider (1959).

4. Under conditions of adaptation, peripheral neural activity will be reduced because of the diminution of the population of active elements. Those elements which continue to fire will do so is a synchronous fashion, but because there are fewer of them, their summated activity will decrease in magnitude. Because of the reduced level of output from the adapted ear, the synchronous discharges will tend to be delayed in crossing synapses to a greater degree than the unadopted comparison ear. In this manner, a decrease in the level of the output of one ear, whether brought about by adaptation or by a physical decrease in the intensity of the stimulus, is equivalent to an actual time delay of the stimulus presented to the adapted ear (Flugel, 1920)

5. In consequence of this neural delay, the coincidence plane (the imaginary plane within the head at which impulses from the two ears meet) is shifted and so also is the sound image. In order to shift the sound image back to the median plane, it is necessary to raise the intensity of the stimulus in the adapted ear or, as is usually done, lower the intensity in the comparison ear.

3.5.2.4. <u>Time course of adaptation and recovery.</u>

In short term fatigue the time course is extremely rapid. A mechanism related to neural refractory periods is explanation. In TTS following intense stimuli the time course is slow. Mechanism related to large scale metabolic activity is possible exploration. In the case of loudness adaptation and recovery, the changes, although perhaps rapid than those in long term fatigue, still much too long to put in the same class as short term fatigue. Mechanism involving the depletion and resupply of metabolic reserves associated with neural activity in the peripheral portion of the auditory system is responsible.

3.6 AUDITORY ADAPTATION PRODUCED BY CONNECTED SPEECH.

Repeated listening to a single speech sound can produce a shift in categorization of subsequently presented speech sounds. For instance, repeated listeningto the syllable (p^ha) produces a shift in the boundary of a (p^ha) (ba) continuim, reflected in fewer post adaptation 'p' responses to ambiguous syllables along that continuim.

Rudnicky (1977) demonstrated that categorization of speech sounds can be influenced by the phonetic structure of connected speech.

In experiment one, subjects listened to short stories that contained a. predominance of either voiced /b/, /d/ and /g/ or voiceless/p/, /t/ and /k/ stop consonants in word initial position.

In experiment two, subjects listened to sentence containing either word initial voiced or voiceless stops. In experiment three,syllables containing the stop consonants were removed from these sentences and presented in isolation. In each of these experiments, a large adaptation effect was produced by the adapting material containing voiceless stops but not by material containing voiced stop consonants. Adaptation for sentences containing word initial nasal and affricate consonants was observed. These findings have implications in the theories of speech perception(Rudnicky 1977).

3.7. AUDITORY ADAPTATION IN VARIOUS CLINICAL GROUPS.

Not much attention has been given to this topic. The available information is very haphazard. The results obtained in different clinical groups are not comparable due to different methodology adopted with different stimulus parameters.

3.7.1 Neurotic patients:

Simeonov (1975) investigated by means of different tests of auditory adaptation among 65 neurotic patients. Functional disturbances in the hearing analysis were manifested by the audiometrically detectable deviation in auditory adaptation to a supraliminal noise stimulation with a frequency of 4000 Hz. and a 5 min duration period. He established a proportional relationship between the strength of the CNS neurodynamics and the degree of disturbance in auditory adaptation. In more severe condition of the cerebral processes auditory adaptation in the right ear was worse than in the left ear.

3.7.2. patients with bordeninp condition:

Rakhimilevich A.G.(1975) examined the auditory adaptation by Carhart's teat and after stimulation with a tone of 2000 Hz. 65 db. in intensity for 180 secs, in 156 patients suffering from different neurosis with and without speech disturbances but with normal hearing. A pathological shift of the initial threshold (by 15-30db) was revealed in 40-55% of the patients examined and prolongation of the reverse adaptation time in 50% of the cases. Pathological auditory adaptation was more frequently noted in patients suffering from neurosis with speech disturbances than in analogous patients with normal **speech.** On the basis of analysis of the data obtained, he concludes that the results of examination of auditory adaptation depended on the functional condition of the CNS which should be taken into consideration in audiological examination of patients with different forms of hearing impairment.

3.7.3. Patients with adrenal insufficiency:

Pruszewiz and Kosowiez (1972) performed auditory adaptation tests according to Feldman in a group of 29 patients with primary and secondary adrenocortical insufficiency. He found in 15 patients changes in auditory adaptation. After treatment with predmisome and cortisone, changes in auditory adaptation disappeared completely. He believes that the changes observed may be due to the effect of steriod hormones in the various parts of the hearing organ and CNS.

3.7.4. Patients with multiplesclerosis:

Hennebert (1972) recommends auditory adaptation tests on patients suffering from diverse neurological disease, mainly those affecting the brain stem. He tells that it should be a part of the test battery systematically given to every case of suspected multiplesderosis. He found the test positive in 33% of 313 case of multiple sclerosis examined between 1965-1971

* * * *

3.8 SISI test and adaptation:

Changes in the differential sensitivity to intensity (DLI) were thought to provide a new and reliable test in audiological differential diagnosis 20 years ago. On the basis of their findings Jerger et al (1950)designed a new test using suit sustained stimulation, to replace the conventional DLI tests. In this test the subject attempts to distinguish 1 db pulses of 200 msec. duration presented at 5 sec. Intervals in a continuous 20dbSL tone. The number of the recognized pulses (percent) was termed as 'Short increment sensitivity Index'.

Jerger and his associates later reported (1961, 1962) results of the SISI test in normal hearing and in conductance, cochlear and retrocochlear deafness. It was concluded (1961) that values above 55% were positive, those between 20-55% questionable and those below 20, negative. The test retest trials by Jerger (1962) showed a slight practice effect: the performance tends to be somewhat better on the retest. The largest test-retest difference occurred at 4000 Hz.(12.3%)

Several other variables of the SISI procedure in normal individuals have been Investigated, ex. changes in the pulse intensity, in the SL and in the number of pulses presented.

From the result of suprathreshold adaptation test (Palva and Palva, 1963; Karja, 1968) it is known that even at 20dbSL, marked adaptation can develop quite rapidly even in normal ears. In the SISI procedure, the sustained test tone lasting for 1 min. 40 sec. must also be subject to similar adaptation.

Rehko (1971,1975) undertook a study to determine the effect of this suprathreshold adaptation upon the SISI scores in normally hearing subjects, subjects with conductance hearing defects and subjects with perceptive hearing defects.

Afterthe conventional SISI bad been administered, the test ear was adapted for 3 min. with a sustained 20 dbSL tone. SISI score of between 250 and 6000Hz were obtained immediately afterwards.

The statistical disperson of both the pre and port adaptation valves were found to be large. Adaptation caused no significant change in either direction in the SISI scores, some of which increased and some decreased. About 15% of normals, *22%* of conductive hearing loss group were positive.

In the post adaptation SISI test, the adaptation had reduced the loudness level in the test generally by more than 10db at frequencies above 1000 Hz. This as such had no effect upon the perceptual SISI values. It agrees with the contention of Jerger (1959) that use of a continuous tone in the SISI would not introduce factors that would unfavourably affect the results.

CHAPTER - 4

ELECTROPHYSIOLOGICAL CORRELATES

4.1 INTRODUCTION.

Change in loudness or absolute threshold is one index of the functional state of the auditory system following stimulation. TTS observed behaviorally is accompanied by electrophysiological changes. This has been revealed by recent studies conducted by Gisselson and Sorensen, (1959): Benitz et al. (1972); Eggermont and Spoor, (1973); Sohmer and Pratt, (1975); R.Price, (1976), Charles Woodford, (1977); Pratt et al., (1978).

4.2. COCHLEAR MICRQPHONICS.

Loss of sensitivity and a loss of maximum voltage in cochlear microphonics has been observed. Benitz (1972) exposed chinchileas for 2-3 days to an octave band of noise centered at 500 Hz. at 95 dbSPL. Cochlear microphonics responses were measured about 5, 24 and 48 hours after exposure from 3 cochlear turns. The average CM_1 function after 5 hr. of recovery showed 12 db loss of sensitivity, 6 db loss of maximum voltage and the SPL for maximum voltage is shifted about 6 db higher.

In CM_2 there was a loss of sensitivity of 24 db, a loss of maximum voltage of 15 db and the SPL for maximum is shifted to 4 db higher levels.

CM_3 showed 48 db loss, loss of maximum voltage of 16 db, the apparent shift of maximum to higher SPLs was about 19 db. Both magnitude and sensitivity of CM were reduced in all three turns in animals with TTS. This reduction is graded from less severe at the base to more severe at the apex.

It is clear that CM is not normal and that there has been loss of maximum voltage resulting in depression of the function and loss of sensitivity reflected in the shifts to higher sound pressure required for maximum CM. The average shift of 6 or 4 db in the first and second turn, respectively, were clearly smaller than the shift of about 19 db in the third turn.

The most significant finding is the absolute decrease in the CM input-output function. These decreases contribute to the effective loss of sensitivity at given SPL. This must be either of dysfunction in the hair cell modulating mechanism or in the electrochemical source of energy to be modulated.

CM represent very closely the electrical equivalent of sound energy upto a given intensity (Davis et al. 1958) after which follows a decrease interpreted as being due to auditory fatigue. For the guinea pig the transitional limit at 500-2000 Hz. was 95db human threshold (Gesselson and Sorensen 1959) for the cat it was 75-90 db at 250-3000 Hz .(Hughson and Witting 1935).

Pratt et al.(1978) studied CM recorded by means of surface electrodes, before during and after white noise induced TTS in human volunteers. They found behavioral threshold shift was not accompanied by a change in amplitude of CM. When the stimulus intensity was decreased by the amount of TTS, a large reduction in CM amplitude was observed even though a TTS of this amount was accompanied by a reduction in CM amplitude.

4.3 ACTION POTENTIALS

Benitz (1972) could not see any synchronised action potential after 5 hr. of recovery in chinchileas even when the wide band clicks were presented at levels 90 db. above normal normal visual detection level. The N_1 peak voltage was about 3 Uv at normal VDL. One of the ears that had recovered for 24 hour failed to show a response. Benitz could not find any explanation for this failure to see action potential. Near the VDL these action potential functions show losses of sensitivity that are 10-12 db greater than the behavioral TTS and then grow more slowly than normal for higher sound levels.

The absence of any whole nerve AP response to the wide band click at levels 90 db above normal threshold clearly implies some additional dysfunction of synaptic mechanism or in the primary neurons. Whole nerve AP may be absent either because the individual neurons do not respond or the individual neurons are responding without the degree of synchrony required by the method of recording. The changes are long lasting (Benitz et al. 1972).

Sohmer and Pratt (1975) noted TTS observed behaviorally is truly accompanied by a neural decrement expressed as an N_1 amplitude decrease and latency increase.

No auditory fatigue could be demonstrated after exposing guinea pig ear to short pure tone (one sec.) under 95 db Gisselson and Sorensen 1959). Longer stimulation with increasing intensity upto 130 db produced a clear decrease in the amplitude of the cochlear potentials. The recovery time after high intensity stimulation for less than one minute was from one to 5 min., it increased with decreasing stimulus duration. The effect was independent of the frequency of the stimulating tones (500, 1000, 2000 Hz.). Stimulation with white noise (130db) particularly affected low frequency recovery. Noise containing frequencies 5000-20,000 Hz. depressed cochlear potentials more than white noise of the same intensity.

Derbyshire and Davis (1935) have shown adaptation in the Up of the auditory nerve. They showed fast equilibration which was complete within 2 secs. or less and in addition the familiar slow equilibration which was complete in about 7 min. Recovery required about 30 secs. No auditory adaptation was demonstrated in the cochlear potentials registered from the round window.

The response of a single auditory nerve fiber was measured by Galamkos and Davis (1943) . The auditoryfibre responded to a continuous adequate stimulus by a train of impulses which were initially numerous but declined rapidly. Auditory adaptation being complete in a few tenths of a sec. The amplitude of the AP also diminished to some extent.

At the level of the superior olivery complex, auditory adaptation to a 10 sec., pure tone appeared as a decline of the firing rate but not as a change in the number of activated neurons (Goldberg et al. (1964).

In the inferior colliculi, the response to white noise was slower than that of the cochlear nueleus (Theirlow et al. 1951) but in most cases the response dropped practically to zero in a few sec.s. A slow electrical component, such as that measured by Galambos (1952) from the medial geniculate body also become evident and it remained unchanged during 15 min. stimulation.

In an elaborate study coats (1964) confirmed the results of Derbyshire and Davis (1935). He further observed that the amount of depression of the amplitude is dependent on the intensity of the signal upto a level of 60 db re 0.0002 microbar this effect gradually increasing; with greater intensities the depression falls fairly rapid off to a minimum . It was further emphasized in his study that the intensity as such has no effect on the rate of recovery. In contrast increasing duration of the signal significantly slowed the rate of recovery.

4.4 AUDITORY EVOKED POTENTIALS.

The recovery of the auditory cortex (Rosenblith et al. 1950) occurred parallel to the first neural component measured from the cochlea, the test tone being a click of 0.1 sec. duration and the stimulus a 510 Hz tone at 115dbSPL sustained for 60 sec.

Benitz et al. (1972) observed auditory evoked potentials, 45-50 min. after exposure to the wide band click in one ear 40db and in the two ears 50db above control VDL. These responses were noticed at a time when action potential could not be elicited at levels 90 db above normal VDL.. It 24 hour and 48 hour after the end of exposure the auditory evoked response was clearly more sensitive.

The efferent auditory bundle have been found to affect cochlear function and these findings shed new light on the auditory adaptation problem, The crossed efferent diuo-cochlear bundle described Rasmeessen (1942, 1953) the i divocochlear bundle and the direct efferent bundle from the refcicular formation to the cochlea constitute the peripheral part of the efferent system originating from the CNS. Electrical stimulation of the efferent bundle resulted in a decrease of the auditory adaptation of the efferent bundle (Galambos, 1955, 1956; Dermedt and Mechelle, 1958)

Activity set up in the olivo cochlear pathways by a tone stimulus was studied by Fex (1962) and pfalz (1962). They found that most of the neurons of both the direct and crossed bundle were characterized by a well defined beat frequency by a definitely fixed threshold and regular function. Fex stated that, the crossed bundle responded mainly to stimulation of the ear into which it passed, the direct bundle responded to contralateral stimulation.

Interesting observation regarding the relation between the efferent bundles and auditory adaptation was made by Leibbrandt (1964 and 1965). When AP were measured from the round window in the guinea pig, there was normally auditory adaptation which wag complete in 75-100 msec, the stimulus consisting of 2 msec. impulses at 10 msec. intervals and the SPL being 60db at 500Hz. If the procaine was injected into the Internal auditory meatus, the drop in action potential failed to occur. He considered the failure of the auditory adaptation due to blockin? of the efferent bundle.

SUMMARY:

TTS observed behaviourally after acoustic stimulation has been accompanied by electrophysiological changes. Loss of sensitivity and a loss of maximum voltage in cochlear microphonics has been observed. TTS observed behaviourally is truly accompanied by a neural decrement expressed as an N_1 amplitude decrease and latency increase. But these results are mostly based on animal studies.

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CHAPTER - 5.

LOCUS OF ADAPTATION AND FATIGUE

5.1. INTRODUCTION.

From where auditory adaptation and fatigue originates is a debatable question. Obviously, anything that affects any part of the auditory chain can produce a shift in threshold. For ex., all the following could concievably be involved in TTS. residual middle ear muscle activity; displacement of the territectorial membrane relative to the basilar membrane; change in chemical environment of the hair cells; swelling of hair cells, making stimulation more difficult mechanically; an increase in internal noise as far ex., due to increased blood flow or an audible tinnitus; changes in or results of efferent activity at the basilar membrane, ordinary poststimulatory decrease in nerve excitability which could occur in the eighth nerve, cochleaa nucleus, lateral lemniscus, inferior colliculus, medial geniculate or auditory cortex.

5.2 PERIPHERAL V/s CENTRAL.

Till recent time the accepted site for* the origin of auditory adaptation and fatigue was peripheral auditory system. This idea was not established with supportive facts. But it was accepted from indirect views.

Recent reports have added more perplexing facts regarding the cochlea and TTS. These results indicate that the cochlea is perhaps not the only site of adaptation and fatigue (Bagibhian, 1972).

5.3 CENTRAL AUDITORY SYSTEM.

Changes in auditory sensitivity unaccompanied by hair cell loss have been demonstrated in cats and Monkey by Elliott (1961) and by Hunter Duwas (1971).

Eldredge and Miller (1969) and Ward and Durall (1971) showed in contrast to the above, that considerable hair cell destruction may be accompanied with only a slight TTS.

Ward et al.(1972) found that animals with only a small area of normal hair cell in the apex can respond normally to very weak high frequency tones. Such disparity between hair cell presence and behavioral threshold is quite amazing, even if one can identify, as shown by Lim (1972) near normal in appearance but no functional hair cell.

A similar lack of correspondence between audiograms and pathology has been reported by Nenitz et al. (1962) and by Bredberg (1968). Bredberg (1972) described normal appearing hair cell associated with permanent threshold shift, as well as a normal threshold despite a 35% loss of inner hair cell and a *45%* of outer hair cell in an 81 year old.

This disparate findings suggest that central factors, in addition, to peripheral ones, play an important role in auditory adaptation and fatigue.

In recent years, several investigators have been interested in the effect that performance of some sort of directed activity during fatigue exposure periods on TTS. The activity may have been completely mental as in trying to solve simple arithmetic problems (Wernick and Tobias 1963, Ward and Sweet 19634 Riach and Sheposh 1964) or may involve some sensory task such as tracking a light (Bell and Stern 1964) or performing a similar auditory task, such as listening for Interruptions in a signal, listening to a narration (Fricke 1966) or tracking threshold (Collins and Capps 1965, Smith and Loeb 1967).

The issue of Central influence on auditory fatigue was raised when Wernick and Tobias (1963) reported that mental activity in the form of mental arithmetic curing a pure tone exposure resulted in more auditory fatigue than the same exposure during reverie(REV). These same findings have been reported in two other experiments (Capps and Collins 1965 , Collins and Coppa 1965) when the original conditions were replicated. When the conditions were changed slightly, however, manipulation of the level of mental activity ceased to result in differences in the amount of auditory fatigue (Bell and Sten 1964, Collins and Copns, Riach and Sheposh, Ward and Sweet 1963, Price 1968).

Klockwoff (1961) reported evidence that distraction of listener's attention from the aural sphere alter the middle ear muscle reflex whether the reflex eljcited by cutaneous of acoustic stimulation.

Later Bell (1966) investigated the effects of task performance upon the acoustic reflex. He had three conditions:

1. reduced attention: operationally defined as performance of an non-auditory task.

2. neutral attention: defined as no task performance.

3. increased attention: defined, as performance of an auditory task. He measured the acoustic impedance of the middle ear as an indication of the reflex activity. He reported that performance of either task caused a decrement in the acoustic reflex, ie., decreased acoustic impedance with the non-auditory task causing

the larger decrement. This was observed for all three levels of stimuli. He concluded that the performance of the task itself was the more important factor rather than type of task.

Durrant and Shallop (1972) studied the effect of differing states of attention on acoustic reflex activity on TTS. They found impedance measures can be altered by attention of the subject. The results indicate the involvement of some central factor in the activity of the middle ear muscle.

Peter and Elliott (1970) measured auditory adaptation using successive and simultaneous presentation of heterphonic stimuli in order to determine if auditory adaptation is more a central than a peripheral phenomena. The similarity in trend between heterphonic and homophonic delayed balances with 1 sec. comparison tones suggests that the auditory fatigue shows little if any loudness decrement when binaural interaction are reduced or eliminated. Thus the shifts observed with simultaneous balances involving a tracking procedure probably reflect slowly developing changes in binaural interaction and consequently, central rather than peripheral changes.

Babighian et al. (1975) obtained cochlear potentials (cochlear microphonics and whole nerve action potentials) and inferior colliculus electrical responses were simultaneously obtained before, after excessive sound exposure. In General, sound exposure produced a greater reduction of the collicular evoked response than of CM or AP. The results based on evoked responses and single neuoiral responses reveal that there is a central involvements in auditory fatigue.

Capps and Collins (1965) presented a possible resolution to the problem raised by the failures to find a central influence on fatigue when they found that the specific type of task used for the mental activity was critical. Some mental tasks, such as auditory threshold tracking or written language division, produced either negligible or *very* slight effects, whereas mental activity consistently produced significant differences.

5.4 **PERIPHERAL**.

The pathologic physiology associated with asymptotic TTS, electrophysiological correlation which are associated with TTS, show the locus of auditory fatigue is peripheral.

5.4.1. Middle ear muscle:

It seems quite likely that auditory fatigue is not due to contraction of middle ear muscle. This can be shown on several grounds.

The middle ear muscle shows an activation threshold of about 70dbSPL (Wever and Vernon, 1956; Dallas, 1964, Borg and Moller, 1968) whereas auditory fatigue is quiet evident for exposure tones at lower sound levels.

The middle ear muscle have almost no effect on middle ear sound transmission at frequencies above a few kilohertz(Wiggers, 1937; Wever and Vernon, 1955) whereas adaptation is evident at high frequencies as it was at low frequencies.

Any effect of the middle ear muscle should be the game for different fibers exposed and tested under the same conditions. Auditory fatigue and adaptation is unchanged by the administration of gallamine triethiodide which ghould eliminate middle ear muscle contraction (Young and Socks, 1973).

Furthermore, since the muscles act in concert bilaterally they could only lead to bilateral fatigue. Based on loudness and matching experiments, we know fatigue can be limited to one ear.

Auditory fatigue has been demonstrated when the intensity of the stimulation is too near absolute threshold to cause middle ear muscle reflexes.

Therefore psychophysical data are not consistent with what would be expected if the middle ear muscle were involved.

5.4.2 Cochlea:

Report by Ward and Sweet, (1963); Bell and Stern, (1964), Riach and Steposh, (1964); and Copper and Collins (1965) have supported the view that auditory fatigue has its origin in the cochlea.

Benitez (1972) have shown changes in the cochlear anatomy following noise exposure in chinchillas. These changes were scattered loss of outer haircell in an area from about 8mm to about 13 mm from the round window end of the basilar membrane and the cells organ of corti were missing to an extent.

The loss of sensitivity for cochlear microphonic in the second and third turn bears a closer numerical correspondence to the TTS measured in behavioral experiments.

5.4.3. Auditory nerve:

Earlier studies said the decrement in response to the test tone is simply dependent on the response of the fiber of adapting tone (Smith, 1977; Harris, 1977) Abbas (1979) has shown the decrement in response seen in each group of fibers will depend upon the response of that group to the adapting tone.

A study was conducted to study or investigate the peripheral auditory system involvement in auditory fatigue. In the cochlea of the test animal, the total action potential as an overall neural answer to click stimulation was used to measure adaptation, The auditory adaptation can be found in a decrease of amplitude of the action potential under several circumstances (Kupperman). He measured the input-output curve when the intensity of the stimulus was varied was measured. It was found that there was a decrease of the successive action potential with a factor after about 45dbSPL with a maximum of about 75dbSPL. Because of this fast occurrence of auditory adaptation, Ruprermsn wanted to prove that this auditory adaptation is strictly related to cochlear function itself and cannot be influenced by the efferent fibers from the central auditory system. To observe the influence of the crossed and uncrossed efferent fibers, the neuclear cochlearis at the same side was removed by a special section technique. Although the cochlea was now without any central influence the typical cochlear auditory adaptation was still there, The differences were that that the area of the action potential was strongly enlarged, the input-output curve was now linear. There was no adaptation when the intensity was increased. The influence of the crossed fibers could be measured by carefully reacting the olivocochlear bundle in the floor of the fourth uentricle. It resulted in an increase of sensitivity at threshold levels. There was no influence on the area of the action potential. The conclusion can be made that there is a strictly cochlear fast auditory adaptation due to positive potentials in the vicinity of the hair cell and a central ipsilateral auditory adaptation that influence the input-output function of the cochlea. The bundle of Rasmussen has only a function in the signal to noise ratio at threshold levels.

It is found that after the generation of a single action potential a positive after potential is measurable. During their occurrence a second generated action potential is always smaller. The amplitude of the second action potential is related to the amplitude ofthe first action potential, or to its total area. Also when another positive potential in the cochlea such as the positive summating potential. The action potential generated during this time is always smaller. This proves that there is a typical local cochlear process that is responsible for a fast kind of auditorv adaptation.

Wever and Small (1963) both argue that auditory fatigue as an early neural affair. Continuous stimulation is known to diminish the rate at which a given nerve fibers responds, and if loudness is coded by the total number of impulses per unit time, when loudness certainly should decline during stimulation. Moreover as intensity increases and fibers thereby are forced to fire earlier and earlier in their relative refractory periods, their excitability becomes impaired the effects of forcing are cumulative.

4.4.4. Hair Cell and nerve synapse:

Pratt et al. (1978)recorded cochlear microphonics potentials by means of surface electrodes, before during and after white noise induced TTS in human volunteers. The behavioral threshold shift was not accompanied by a change in amplitude of cochlear microphonics. These findings indicate that in humans the site affected by the noise exposure and which probably give rise to the TTS is central to the site of generation of cochlear microphonics. In an earlier study, Action potential generated in the auditory nerve was found to be of lover amplitude and longer latency during TTS and it is thus proposed that the site affected is peripheral to the generation of conducted action potential. The synapse between the hair cell and the auditory nerve fibers is the most likely candidate to be the affected site.

The pathologic physiology associated with asymptotic TTS is most probably peripheral because the loss of sensitivity for cochlear microphonic in the second and third turn bears a closer numerical correspondenceto the TTS measured in behavioral experiments than do the measured shifts of action potential response. The shift in sensitivity for action potential were for too large. Since the exposure to noise did not change the de endocochlear potential, disorder must be in the hairwell modulating mechanism. The larger changes in synchronised action potential responses imply some synaptic or neural dysfunction in addition to the lots of cochlear microphonic (Benites, 1972)

Recent work by Russell and Sellich (1977) measuring the intrecochlear intracellurlar potentials of cochlear hair cell, indicates that the tuning of inner hair cell potentials is similar to that of an auditory nerve fiber tuning curves. Studies using other methods of decreasing the fibre's response have observed concomitant changes in the tuning curve. It is observed that measure of response decrement due to the adapting tone was constant across test frequency. Thus there are other manipulation affect the tuning of the system, the findings are consistent with a view of adaptation taking place at thehair cell synospe after the response of the fiber has been determined.

We cannot at present specify a particular site of the adaptation and fatigue process in auditory nerve fibers. In fact, Smith (1979) has suggested that there may be several phenomena involved in adaptation, some seen at low levels and short durations (Smith, 1977; harris; 1977) and others seen at higher levels and longer duration (King et al. 1965) Young and Sachs, 1973). Studies of invertibrate auditory system indicate that adaptation takes place at the synapse between the hair cell and efferent nerve fiber(Furukowa and Ishis, 1967) Flock and Russel, 1976).

5.5. EFFERENT BUNDLES.

Activation of the efferent olivocochlear bundle is the other possible mechanism. Such activation has been shown to inhibit the sound induced discharge of auditory nerve fibers (Fex, 1962, Wiederhold and Kiang 1970). It is unlikely the olivocochlear responsible .

Kiang and Sachs (1965) severed the eigth nerve of a cat including both the crossed and uncrossed olive cochlear bundle and recorded in the peripheral stump, the perstimulatory rate decline over the first few msec. of a 40 msec. tone burst and the transient reduction of spontaneous activity immediately after the stimuli were unaffected. Thus these short term adaptation effects are not caused by divocochlear bundle activity.

Fex(l962, 1965) showed that when activated by prolonged sound, many divocochlear bundle fibers showed some decrease of their discharge rate with time and post stimulatory decrease in their responsiveness.

Wiederhold and Kiang (1970) showed that the inhibition of auditory nerve fibers induced by direct electrical stimulation of the crossed olivo cochlear bundle decreased with time during a maintainted stimulus(ie., the inhibited fiber's discharge rate increased with time). These responses patterns taken together imply that the olivo cochlear bundle would be expected to produce a perstimulatory rate suppression which is maximum near stimulus onset, rather than the observed that in many of their experimental animals, crossed olivo-cochlear bundle activation did not inhibit the spontaneous activity of single nerve fibers. Following sound exposure, however, spontaneous activity is always reduced.

Thus, known characteristic of the inhibition of auditory nerve fibers, activity produced by the divocochlear bundle differ in several respects from the adaptation known.

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SUMMARY

We cannot at present specify a particular site of the adaptation and fatigue process in auditory system. Middle ear muscles and efferent bundles as the site has been ruled out on the basis of varied observation. Many results point the locus as peripheral probably at the synapse between the hair cell and afferent nerve fibers. Central factor in auditory fatigue, according to recent results can be ruled oat. The reason is specific type of task used for mental activity is critical. So it has been shown central factor as an artifact.

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CHAPTER. 2.

MEASUREMENT

6.1. INTRODUCTION.

In order to measure the decay of loudness sensation during acoustic stimulation a great number of psychoacoustic experiments have been developed.

The methods used for measuring auditory adaptation are based mainly on changes in 3 psychophysical entities, ie.

1. On perstimulatory threshold shift and post stimulatory threshold shift.

2. The decrease in loudness of suprathreshold stimulus.

3. Decline of masked puretone threshold as measured by an intermittent masking tone.

Of these perstimulatory threshold adaptation is the best known (Schubert, 1944; Hood, 1954; Palua and Carhart, 1957; Jerger et al. 1958; 1960, Palua and Palua, 1961, 1963) and it has also proved a practical test in the diagnosis of perceptive hearing impairments (Riger and Fos, 1962; Johnson, 1956; Sorensen, 1962; and Palva and Palva, 1966).

As regards perstimulatory suprathreshold adaptation in which the number of inner ear and auditory tract units involved in the hearing process is greater than at threshold level, highly variable results have been recorded. The other unadapted ear of the test subject has often been used as a reference without paying sufficient attention to the functional change caused by the comparison tone in the control ear (Wright,l960; Palua 1964). This source of error can be eliminated by using a suitable interrupted comparison tone, consisting of short impulses eliciting a response corresponding to normal even in the adapted ear (Hood 1950, 1955). Because of this the adaptation of the control ear due to cross hearing of a strong stimulus becomes insignificant from the point of view of measurement, and on this basis the test can be applied reliably not only to the study of normal ears at high intensities but also to cases of unilateral hearing loss.

One must consider the stimulus magnitude employed. Actually most investigators, no doubt in an effort to demonstrate the phenomenon in a optimal manner, used intensities of 80 db. to 100 db. and higher. Such intensities may have exceeded the safe limits of physiological stimulation and may have caused considerable discomfort on the part of the test subject. Moreover tinnitus occurs frequently after such high level exposures. Several authors reported that some of their subjects showed threshold shifts persisting for 24 hours or more. Such shifts were manifestations of acoustic trauma which should not be confused with auditory fatigue. It appears necessary to avoid such potential source of error and to confine experiment condition to safe physiological levels. It might also be admirable to employ large number of test subjects without previous experience in psychophysical testing, instead of using a small number of highly trained subjects as most other experimenters have done.

Referring to the many publications we can distinguish two major procedures, each divided in several methods according to their peculiarities. This will provide the opportunity of showing which difficulties actually arose and to what extent the imperfection of these procedures limits the reliability of the measurements.

Upto the present time the following procedures for measuring auditory adaptation have been developed.

1. Monaural procedures:

a) The threshold under masking (Luscher and Zwislocki, 1949 Feldman, 1957; Langenbeck and Kietz, 1959; Schaefer, 1959).

b) The threshold tone decay test (Carhart, 1957; Bosatra, 1960).

c) Bekesy audiometry (Jerger, 1960).

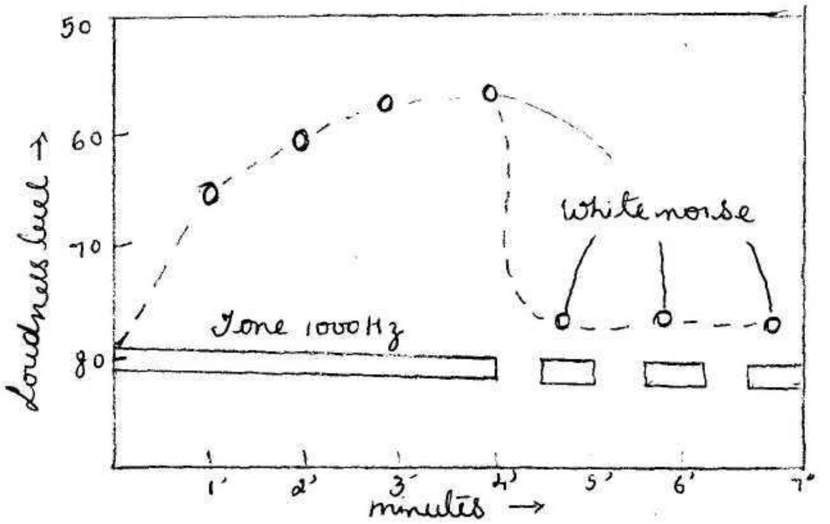

Fig. 16. Threshold under masking (Feldman)
The subject is presented a pure tone and after one minute of sustained stimulation the same ear is offered a few seconds, necessary for attenuating the white noise to a level that permits just hearing the pure tone through the white noise. After four minutes of sustained pure tone stimulation the recovery from this functional state is measured with short duration tones and white noise.

2. **Binaural procedures;**

a) Post-stimulatory comparison method (Pattie, 1927; de Mare, 1939; **Wood, van Gool, 1952; Egan** and Thwing, 1955).

b) **Perstimulatory comparison method, divided** into simultaneous dichotic balance methods (Hood 1949) and Localization methods (Wright, 1960)

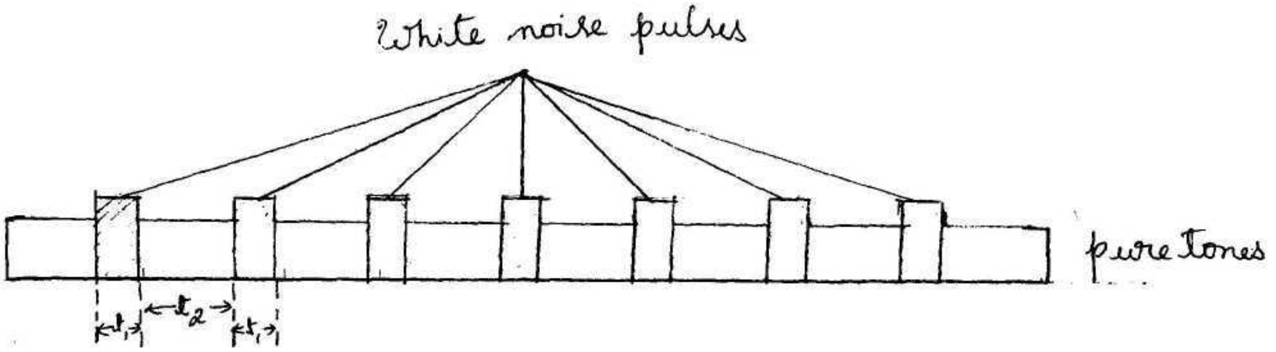

Fig.17. The Kietz-Longenbeck test.
One ear is offered a pure tone (sustained stimulation) together with a series of white noise pulses, of which the duration t_1 and the interval t_2 can be varied. Duration of t_1 and t_2 in relation to the intensity of both signals are measured when the pure tone in between the white noise pulses is just above the level of audibility.

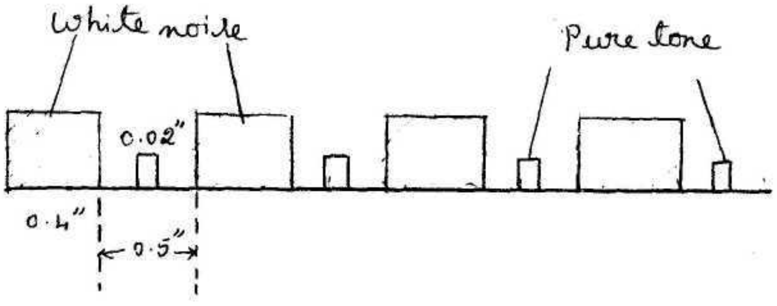

Fig. 18. Initial adaptation or residual masking (Luscher and Zwislocki)
The adaptation is measured as a function of the intensity of the pure tone pulse just below hearing level in relation to the interval between white noise and white pure tone pulses.

6.2. MONAURAL PROCEDURES:

6.2.1. Threshold under masking:

According to German authors (Langenbeck et al., 1959), this procedure without making use of a comparison or control ear, represents the best way to measure loudness decay specifically in pathological conditions.

In the method of Feldman, ie., measuring the loudness decay by masking the pure tone stimulation by a white noise, the decrease of the intensity of the masking noise (interrupted) in decibels represents the amount of loudness decay.

The Kietz-Longerbeck test is a variant of the white-nooise threshold audiometry. A sustained pure tone *f.* stimulation is masked in the same canal by interrupted white noise pulses 0.4 sec. in length with an interval of 0.04 sec. The Intensity of the pure tone is varied in one decibel steps until the subject can hear the tone in the intervals.

In the test procedure of Luscher and Zwislocki the audibility of a pure tone signal is matched in relation to the masking effect of white noise pulses. In an extensive experimental study Schaefer (1960) used this method in a great variety of parameters.

In clinical application monaural procedures has its use. But it is doubtful in its importance in measuring the decay of loudness as such.

Concerning the quantitative results of these methods it can be said that the amount of loudness decay as measured by the method of Feldman and plotted as a function of intensity of the adapting signal appeared to be slowly progressive, depending on the intensity. As the picture (fig. 16) shows, at 800 db ref 0.0002 microbar the loudness decay lies somewhere between 20 and 30 dbs, besides a dependence on frequency and bandwidth of response tone and noise. The same can be said of the results of the Kietz-Largerberk test, but here and in the Luscher and Zwislocki experiments there are more variables, which influence the results.

Moreover phenomena such as masking and auditory fatigue are identified with loudness decay. Thus it is obvious that in the test of Feldman, Longenbeck and of Luscher and Zwislocki different aspects of the charge in functional state of the auditory organ are measured. Therefore, these tests are less reliable for detection of pathological conditions of auditory adaptationthan the threshold tone decay test, where no masking and fatigue is present.

6.2.2. Threshold tone decay test:

By this procedure the test person's hearing of a sustained pure tone at near threshold intensity is determined. First, the threshold of the frequency tested is measured by presenting short tone pulses. Then the same frequency is offered as a sustained tonal stimulation, a few decibels louder than the threshold intensity. The auditory sensation of a pure tone as well as the all or non-hearing of that tone as a function of duration of the tonal signal are pointed out to the subject. Normally under these conditions a subject Is able to hear a pure tone as such beyond one minute of sustained presentation. Threshold tone decay test has proved to be very useful and reliable in the differential diagnosis of perceptive deafness.

6.2.3. Bekesy audiometry:

More or less based on the same principle as the threshold tone decay test, the Bekesy audiometry can produce diagnostic cues by revealing different rates of loudness decay Lundborg (1952) in his monograph, dealt principally with the amplitudes of the audiometric tracings. In an attempt to analyse auditory disorders found by Bekesy audiometry. Jerger showed that most tracings of 434 Beckesy audiograms could be placed into one of four categories (1960). The basis for categorization is the relationship between tracings of periodically interrupted and of continuously tonal stimuli.

6.3. BINAURAL PROCEDURES:

Most of the methods of measuring auditory adaptation and auditory fatigue have utilized two ears. The ear receiving the sustained sound is called the adapting ear and the ear used to estimate the amounts of adaptation is called the comparison ear. The methods may be classified on the basis of whether loudness is assessed during the course of adaptation (perstimulatory adaptation) or simply at the termination of the auditory stimulus (post stimulatory).

6.3.1. Post-stimulatory comparison method:

In this method the loudness sensations of the acoustic signals at each ear are compared, after cessation of the adapting stimulus is the stimulus causing a decay of loudness in the ear under testing conditions.

6.3.1.1. Alternate binaural Loudness balance.

The testing run is divided into three periods. In the initial period of the stimulus is alternately presented to the two ears each presumably in a normal or unadopted state. The intensity of the stimulus in the comparison ear is adjusted until the loudness is balanced or equal in both ears. The second segment is the adapting period during which a stimulus is applied continuously to the adapting ear. During the final period loudness balances are obtained in the same fashion as during the initial period, except that now one of the ears presumably has undergone adaptation. If so, this adaptation will be reflected in the fact that for equal loudness the comparison stimulus is reduced in intensity compared to that required during the initial balance's. This method clearly attempts to measure post stimulatory adaptation since loudness is eliminated not during, but before and after adaptation. The use of alternate binaural loudness balances has the drawback of recovery occurring in the adopting ear each time the stimulus is turned off. So far the final period the state of adaptation in the adapting ear is not constant. This method either as described, or in a slightly modified presentation has been utilized by Pattie (1927), de Mari (1939), Davis et al. (1950), Hood and Egan and Thwing (1955).

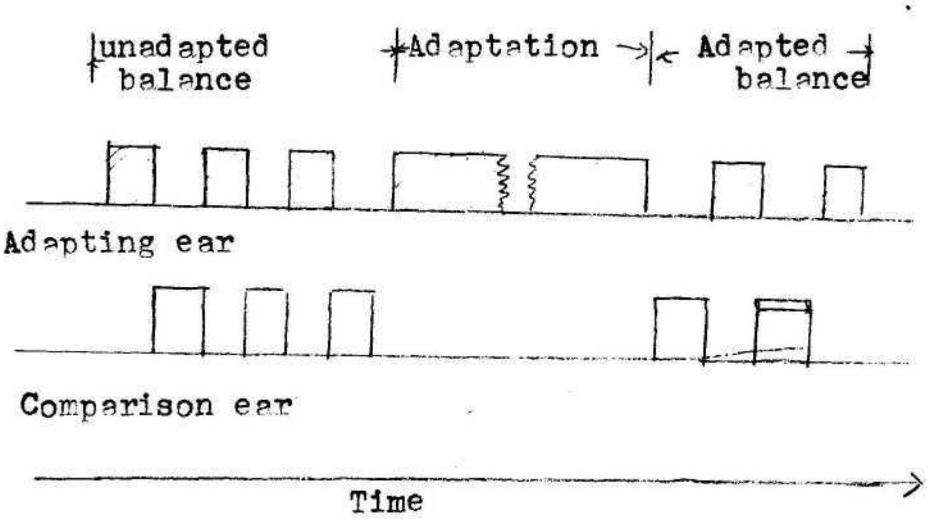

Fig. 19.Schematic representation of the method of alternate binaural loudness balances. The darkened areas show the time during which a stimulus is on. Stimuli are never simultaneously present at both ears, The comparison stimulus is varied until a balance is obtained. Utilized by Pattie (1927), de Mart (1939), Davis et al. (1960), Hood (1950) and "Egan and Thwing (1955).

6.3.1.2 <u>Delayed Balance?</u>

This procedure represents the ultimate simplification of the This procedure represents the ultimate simplification of mulus first aprears in the adapting ear, then upon its cessation at the end of the adapting period the stimulus 3s introduced

at the end of the adapting period the stimulus is introduced

briefly in the comparison ear. Alternating with a rest period, the entire process is repeated but with each repetition the intensity of the comparison stimulus is varied until it is judged as being equal in loudness to the terminal portion of the adopting stimulus. For this method the amount of adaptation is perhaps best defined as the difference in the obtained loudness balance and that balance resulting when the adapting stimulus is of the same duration as the comparison stimulus. A difficulty test detracts from this otherwise straightforward method is that of specifying precisely what time segment of the adapting stimulus is used in loudness matching.

The validity of these methods depends on the independence of the two ears. A dependency could result from cross-conduction of sound from the adapting ear to the comparison ear or from neural interaction. Since the delayed balance method and the alternate binaural balance method employ stimuli that are in fact not presented simultaneously to the two ears, measure loudness adaptation directly, that is, by loudness balances uncontaminated by localization effects.

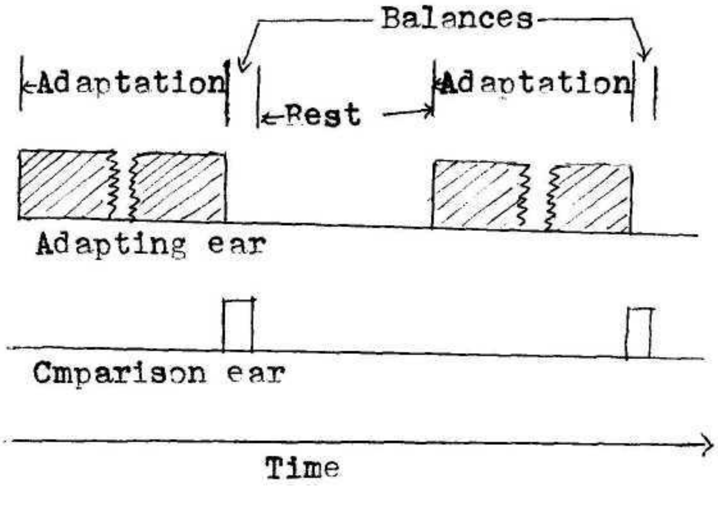

Fig. 20. Schematic representation of the method of delayed balance. The darkened areas show the time during which a stimulus is on. Each run is repeated after an appropriate rest period. Each time a run is repeated the intensity of see page 141

of the comparison stimulus is varied and another judgement is made by the listener. Stimuli are never simultaneously present at both ears. There is only one balancing period after the adapting period (Van Goold(1952)

6.3.2. The perstimulatory comparison method:

This method in advantage to the alternate binaural loudness balance offers the opportunity to study the loudness decay during the presentation of the sustained acoustic-stimulation.

6.3.2.1. Simultaneous dichotic balance:

6.3.2.1.1. Tracking and fixed intensity:

Within the broad category of simultaneous dichotic balances are found the methods of tracking, fixed intensity and varied intensity. Simultaneous dichotic stimulus presentation, involves presenting the comparison stimulus concurrently with the adapting stimulus.

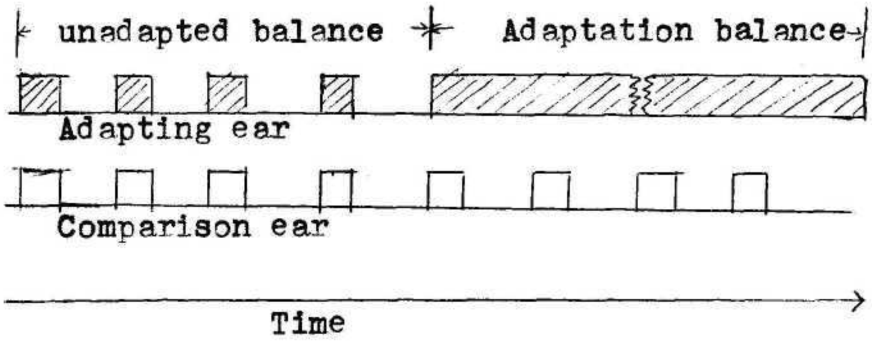

Fig.21. Schematic representation of the methods of fixed and tracking. 2 methods follow the same temporal paradigm and both involve simultaneous dichotic balance stimulus presentation. The basic difference is that with the method of fixed intensity only one balance is obtained during presentation of the comparison stimulus, while the tracking procedure calls for continuous bracketing which is automatically recorded (Hood 1950).

The tracking method developed by Hood (1950) and used In modified, form by PalVa (1955) and Small and Finifie (1961) differs from the method of fixed intensity only in the manner In which the magnitude of the comparison stimulus is varied. With the tracking method the comparison stimulus, when it is presented, is varied continuously in a bracketing fashion about the intensity necessary for a balance. On the other hand, the method of fixed intensity requires that only a single balance be obtained each time (usually 10 to 20 Sec.) that the comparison stimulus occurs (Egan, 1955 and Thwing, 1955; Jerger, 1957; Wright, 1959; Sergeant and Harris, 1963).

The method of tracketing and fixed intensity, involves two parts. During the first segment the stimuli occur simultaneously for brief durations in both ears. For each occurrence a balance is made by adjusting the comparison stimulus. During the second segment the adapting stimulus is on continuously. At regular intervals the comparison tone is presented briefly, and balances are made in the same manner as in the first segment, perstimulatory adaptation is manifest by the difference between the amperage of the preadapting balances contracted with balances obtained during the adapting period.

6.3.2.1.2 <u>Varied Intensity.</u>

Egan (1955) was of the opinion that the method of fixed intensity might encourage the formation of a loudness standard within the subject. Because of this, the subject, balancing partly on the basis of his constant internal standard rather- than the adapting stimulus, would probably show less adaptation than was actually occurring. Egan's method of varied intensity was an attempt to minimize this source of bias. The essential feature of this method is that the stimulus in the adapting ear is presented at different intensities each time a balance is obtained. The adapting stimulus is maintained at a constant level except during the balance intervals. The amount of adapta-

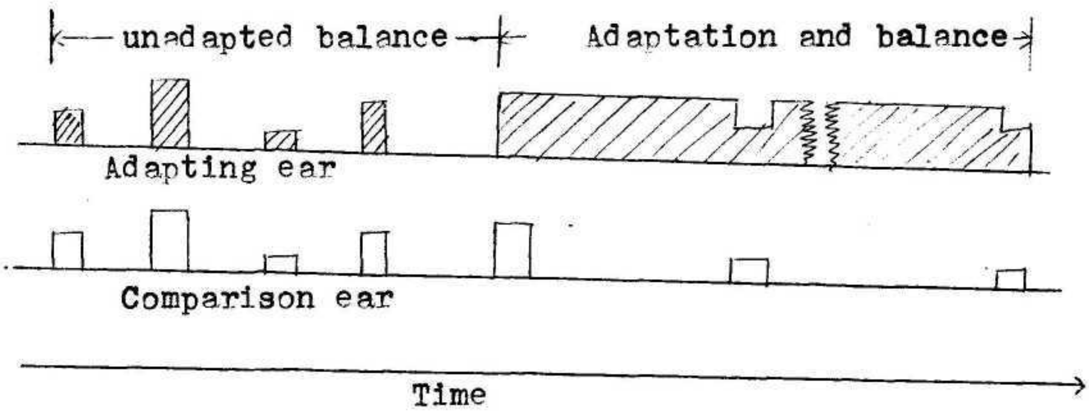

Fig.22. Schematic representation of the method of varied intensity. The darkened areas show the tme during which a stimulus is on. The different heights of the on-of? markers represent the various intensities at which the adapting stimulus is presented for a simultaneous dichotic balance. The intensity of the adapting stimulus remains constant at a given level during the interval Allowed fof a balance and remains at a fixed level during the period when balances are not being made. (Wittich, pilot study 1960).

tion for each intensity of the adapting stimulus tested is given by the difference between the balance obtained during the adapting portion of the run and the preadapting balance made at that same intensity. Carterette (1955), and Thwing (1955) and Egan and Thwing (1955) utilized a modification of this method in which the stimulus in the adapting ear was varied during the preadapting balances, but kept constant during the adapting segment of the test run.

6.3.2.1.3 <u>Assumptions in simultaneous dichotic balance method.</u>

It is necessary to assume that the stimulus presented to the comparison ear incurs negligible adaptation. It is quite obvious that any adaptation occurring in the comparison ear will bias the data in such a way that adaptation in the adapting ear is underestimated. In order to minimize adaptation in the comparison ear, comparison stimuli are made as brief as possible and usually raised in an ascending fashiong from a low intensity for each balance.

Other assumption is that localization effects either do not influence loudness judgments or that judgments based on localization yield the same results as those based on loudness. When identical stimuli are presented by earphones to each ear simultaneously they tend to fuse into a single sound image which appears in a plane midway between the two ears. This sound image may be shifted from the median plane by varying the relative phase (Zwislocki and Feldman 1956) or intensity (Mills 1960) of the stimuli or both. In the typical simultaneous dichotic balance, the phase relation remains constant, but the intensity is varied and, as it is varied, not only does the stimulus loudness change, but also the location of the sound image. If a listener is instructed to balance the stimuli in terms of loudness, a tacit assumption is made that the apparent location of the sound source has not influence on the resulting judgement. On the other hand, if a listener's instructions are to obtain a median plane balance, in order for this procedure to yield a measure of perstimulatory loudness adaptation, it is necessary to assume when the sound image is located at the median plane that the loudness at each ear is equal.

6.3.2.2. Localization methods:

When identical stimuli are presented by ear phones to both ears simultaneously they tend to fuse into a single sound image, which is heard in a plane somewhere in or around the head between the ears. On this principle (Van Bekesy 1929) Wright(1960) developed the median plane'localization test.'

6.3.2.2.1. Asymptotic Localization:

First, median plane localizations are determined in the unadapted state by presenting the stimuli simultaneously in both ears. The intensity of the 1-sec. comparison stimulus is varied randomly from one presentation to the next and for each prsentation the listeners reports the location of the sound image as left, right or centered. Next,the stimulus is presented continuously to the adapting ear and after 7 min. the comparison stimulus is presented in the same manner as in the first or unadpted segment of the session. By using the 7 min. of continuous stimulation it is assumed that the adapting ear will have reached its asymptotic or steady state value of adaptation and that further stimulation will not alter its functional state. The mean intensity of the comparison stimulus necessary for a median plane localization is obtained from the distribution of judgements based on the unadapted condition. A. similar estimate

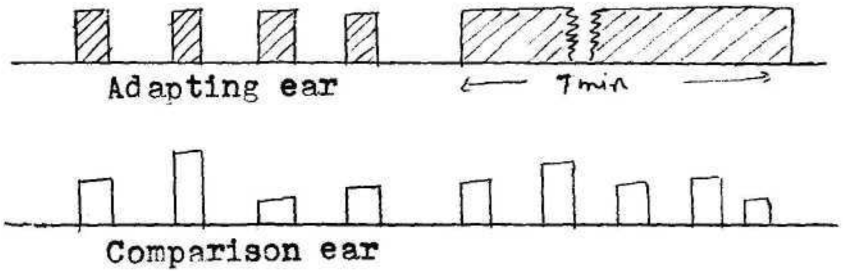

Fig.23. Schematic representation of localisation method (Wright 1960). Both ears are offered pure tones of the same frequency (250, 500, 1000, 4000 Hz.) In the initial balance the Uones are simultaneously offered to both ears to obtain a median plane localization of the sound image within the head of the subject. After seven minutes of sustained tone stimulation of one ear, a scores of tone pulses is *ottered* to the other ear in order to obtain once more a median plane localization of the sound image.

is obtained from the data gathered after the adapting ear has reached its asymptotic state and the difference between the two presumably represents the amount of adaptation. Wright reports that for a 500 hz., 90dbSPL tone, 50db of adaptation occurred, a considerably larger amount than reported under similar conditions witft any pther crocednw

6.3.2.2.3 Moving Phantom:

A modified form of earlier method is moving phantom method described by Wright (1960). It is similar to the method of asymptotic localization in that the stimulus if first sustained in the adapting ear for 7 mins. in order for that ear to adapt completely. Next, a stimulus is presented to the comparison ear at a fixed intensity. If the intensity of the comparison stimulus is the same as the adapting stimulus the sound image will initially be localized toward the comparison ear, but as time progresses, the comparison stimulus will move toward the median plane. The time, from the initial presentation until the sound image reaches the median plane, is recorded. Thus, instead of manipulating, the intensity of the comparison stimulus until a median plane localization is obtained, the intensity of the comparison stimulus is fixed and the time for the sound image to reach the median plane is determined. There is no way to transform the time measure to the more traditional intensity measure and for this reason results obtained with this method are difficult to compare to those obtained with others.

6.3.2.2.4 Intensive and phase localization:

Both these methods are similar with respect to the temporal presentation of the stimuli. The first part of the intensive localization method is concerned with obtaining median plane localization with both ears in an unadapted condition. This is done by presenting the stimuli briefly to both ears. The listner indicates whether sound image is to the right or left of the median plane. After an appropriate rest period the procedure is repeated but with intensity of the the comparison stimulus adjusted to a different value. Eventually an intensity of the comparison stimulus is found which yields a median plane judgment. During the second part of the procedure the adapting stimulus is presented, then turned off, but turned back on simultaneously with the comparison stimulus. The difference between the intensity of the comparison stimulus for a median plane balance in the adapted and unadapted state is taken to the amount of adaptation.

Flugel (1920) used the same mode of stimulus presentation in a method of phase localization. Instead of adjusting the intensity of the comparison stimulus Flugel used stimuli of identical frequency in each ear and varied the phase of the comparison stimulus to obtain centering of the sound image.

These two methods measure correctly recovery from adaptation since measurements taken during 'adaptation' involve a re-stimulation of the adapting ear after an intervening period of silence. The method of phase localisation does not give the index of adaptation in a dimension other than intensity.

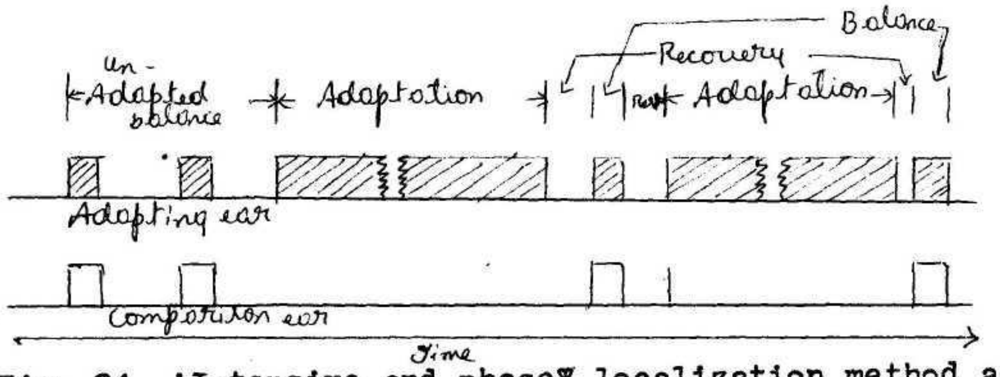

Fig. 24. 'Intensive and phase' localization method according to Van Bekesy (1929) and Egan and Thwing (1955) which can be considered as a combination of both post-and-perstimulatory procedures.

Recently Takashi Tsuiki published his investigations with a procedure, which might be called variant of Wright's method. A pure tone of a given frequency is divided into two channels. The intensity is one of them is constant throughout the test period, the one conducting to the test ear. The other channel through an automatic interruptor and a Bekesy type attenuator is passed into the control ear. Thus the comparison tone is interrupted periodically with a repetition period of 2500 msecs. with a duty cycle of 70%. Both tones are in phase and therefore the phanton sound moves to and from within the head between both ears in proportion to the interaural loudness - differences. The subject regulate the Intensity of the comparison tone by means of a push-button connected to an automatic reversing attenuator of the Bekesy type in order to get the phanton sound localized in the centre of their head. The results are recorded by a pen writer. Tsuiki demonstrated clearly a considerable amount of loudness decay to occur in the first five secs.

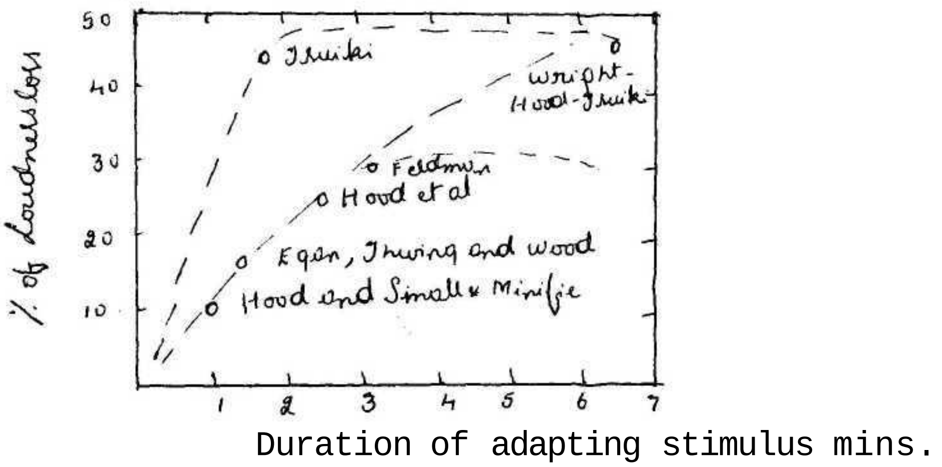

Fig.25. Loudness decay plotted as the function of duration of the conditioning stimulus. On the ordinate loudness decay is plotted as a percentage of loudness loss; values are to be considered as representative for different sensation levels.

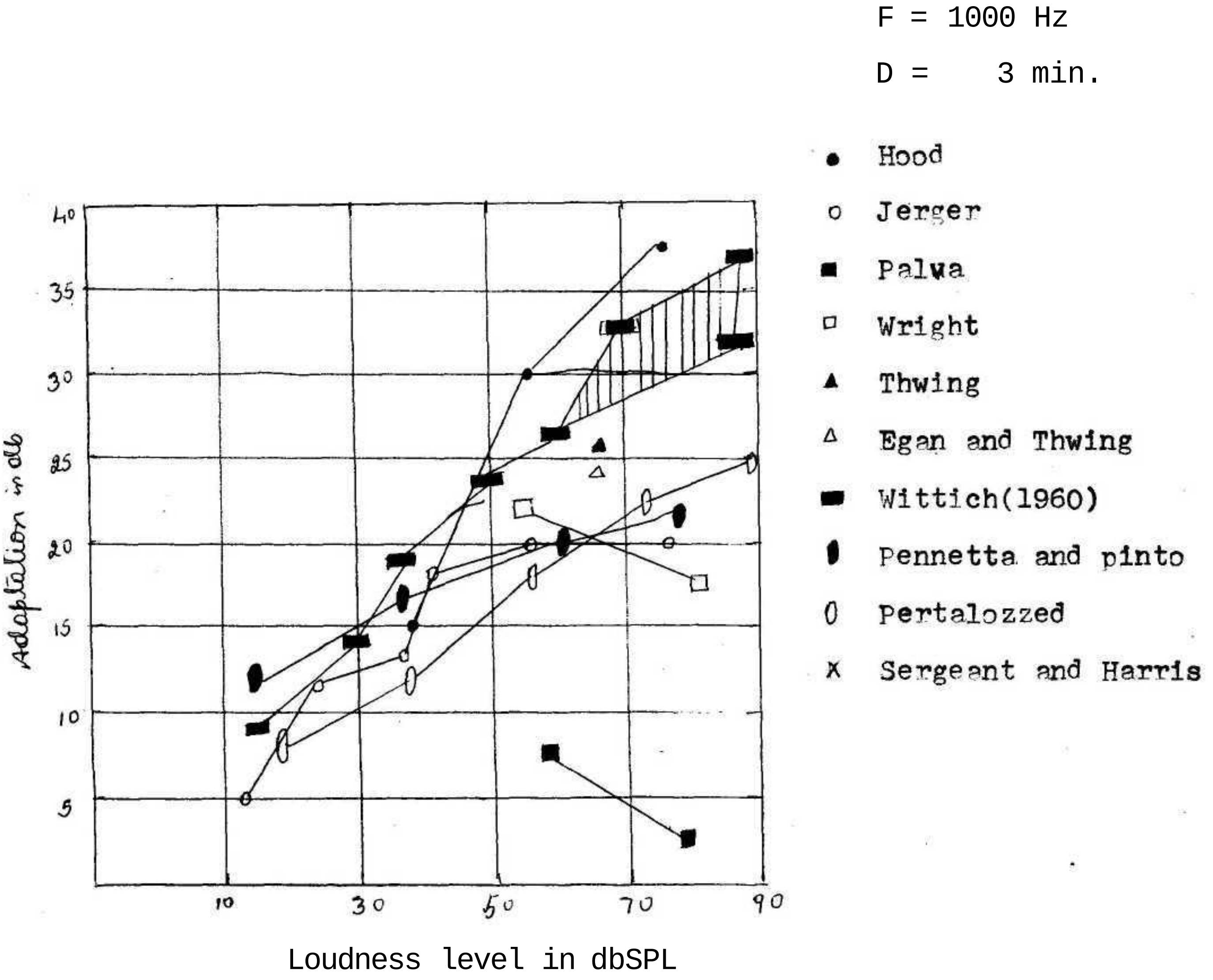

Fig. 26 Comparison of results obtained by 10 investigation. All points represent adaptation for a 1000 Hz. tone for 3 mins. of sustained stimulation.

6.4 MONAURAL AUDITORY ADAPTATION AS MEASURED BY SIMPLE REACTION TIME.

It has been well established in the reaction time literature that there is an inverse relationship between a human subjects reaction time and the intensity of the acoustic reaction time stimulus (Woodworth and Schlosberg 1954). Reaction time procedures have been utilized in several studies which have investigated auditory intensity phenomena in humans and monkeys (Gregg and Brogden, 1950; Moodey, 1970, 1973; Pfinget et al.1973)

It is known that loudness is the psychological correlate of intensity (Fletcher and Munson 1933, Woodworth and Scholarberg and others). It is also known that as stimulus intensity increase the subjects reaction time decreases. Based on this knowledge it would seem logical to assume that as stimulus is perceived at a louder sensation level, the subject is able to respond more quickly to the stimulus and vice versa.

Assuming then, that, there is some relationship between loudness and reaction time it would seem appropriate to infer that auditory adaptation can cause a decrease in the subjects perceived loudness of an auditory stimulus which would result in longer reaction time. The use of a reaction time procedure does not require the use of a comparison tone and therefore, eliminates the possible contamination of auditory adaptation data by localization effects and contralateral ear adaptation. In addition, it is not required to form any type of subjective loudness standard because he is not responding to intensity perse but rather to the presence or absence of a given stimulus.

Davis and Weiler (1976) compared pre and post reaction time measures following 7 min. of monaural auditory adaptation. The adapting stimulus utilized was a 500 Hz. pure tone presented at an intensity level of 50 dbSPL for a period of 7 mins. The pre and post adaptation reaction time measures were obtained for the frequencies 400, 800 and 1000 Hz. at intensity levels of 50, 60, 70dbSPL. The results revealed time measures for all of the frequencies and intensities tested and would suggest time measures can be utilized in the study of auditory adaptation phenomena.

Iodice (1959) has constructed a test for the determination of auditory fatigue. This test consists of following parts:

1. Determination of the AC and BC threshold at 1024 and 4096 Hz.

2. fatiguing by these frequencies at l00dbSPL intensity, for 5 mins. and determination of the thresholds after 2 mins. rest.

3. 20 mins. rest.

4. Vocal audiometry with logotomes. Using this technique a study has been made of 40 subjects sub-divided into several groups. From the findings in general the conclusion is drawn that the method makes it possible to test both the sensitivity to sound trauma and to determine what acoustic sectors are more electrically exposed to such trauma. The possibility of determining anatomo-functional sectors that are particularly susceptible to sound trauma renders this method of examination socially interesting as well. But detailed information regarding this test is not available.

....

6.5. Objective method of determining recovery period and asymptotic period.

Vyasamurthy (1977) gave a definition of adaptation which led Vidya (1976) to determine the recovery period and asymptotic period objectively. The definition runs as "....the difference between the intensity of the post adapted stimulus and the intensity of the rag preadopted stimulus which produces the same magnitude of reflex as that of the post adapted stimulus"

To determine recovery period:

For this following are the steps.

a) measure auditory acoustic reflex threshold at adapting frequencies.

b) Recovery time at the adapted frequency is determined after adaptation. Recovery time is the time taken to get the same magnitude of the acoustic reflex for the same intensity of the stimulus after the ear was adapted with the adapting stimulus, the same stimulus (i.e., adapted frequency) was presented at acoustic reflex threshold, at intervals of 10 see. until the balance meter needle was as same as the pre adapting acoustic reflex threshol Recovery time is the interval between the cessation of the adapting stimulus and the introduction of the same stimulus at acoustic reflex threshold at which balance meter needle deflection is as same as the deflection of the balance meter needle before adaptation.

(Fig. see 151 b)

To determine asymptotic period:

a) Measure acoustic reflex threshold at adapting frequency.

b) Determine recovery time at the above frequency after adapting the ear for 7 mins.

(Fig. see 151 b)

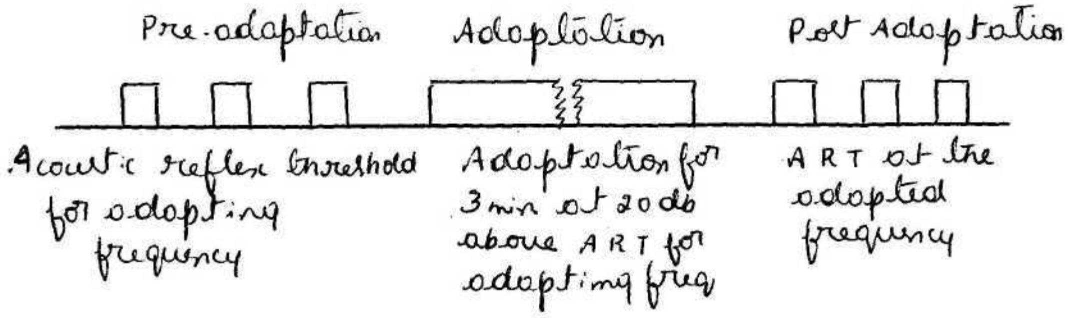

Fig. 27

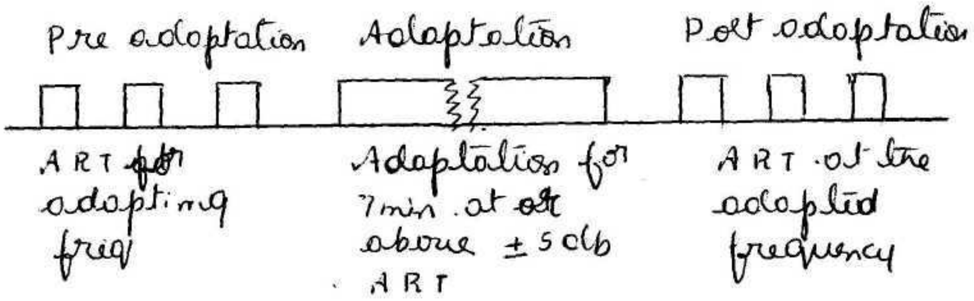

Fig. 28

Using this objective method Vidya (1976) has found following facts.

1. Recovery time at ane actave higher than the adapting frequency is more than when measured at the adapting frequency. This leads to the conclusion that adaptation is more at a frequency one octave higher than the adapting frequency. In this study it is assumed that greater the recovery time greater would be the adaptation.

2. Adaptation reached asymptotic state at about 7 min. when the adaptation level was at or ±5 db acoustic reflex threshold of the normal hearing subjects.

3. Recovery time progressively increased from 1000Hz. to 4000 Hz.

ex: recovery time was 18.5 sec. at 1000 Hz., 52.5 sec. at 2000 Hz. and 230 see. at 4000 Hz.

4. Recovery periods appear to have reached a steady state from 420 sec. of exposure time.

SUMMARY.

The relationship between adaptation and auditory threshold can be studied either as a perstimulatory change by recording, as function of time, the stimulus intensity required for obtaining the threshold, or it can be studied as the behaviour of threshold after stimulation. Both monaural and blnaural procedure have been used to measure adaptation and fatigue.

Monaural procedures include threshold under masking, threshold tone decay test and Bekesy audiometry. Blnaural procedures can be divided Into poststimulatory comparison method which include loudness balancing method and perstimulatory comparison method which includes simultaneous dichotic balance method and localization method.

Simple reaction time measurement for monaural auditory adaptation is also used. Objective method of determining recovery period and asymptotic period from loudness can also be used successfully

CHAPTER.7

APPLICATIONS.

7.1 INTRODUCTION.

At present, we can see no immediate widespread clinical application of adaptation and fatigue measurements. We do not know whether the most applicable might be short time or long time exposures, for high or low intensity, etc.

7.2 EFFECT OF AUDITORY FATIGUE ON THE AUDIOGRAM.

There is no doubt that if one presents a tone at 100db or more for 1 min. or more, an effect will be produced on the audiogram that is measured subsequently. On the other hand it is clear that exposure of the order 10 sec., which is usual for the beginning of an audiometric test, with moderate intensities will not produce auditory fatigue effects, provided that the audiogram is measured at least some secs, after the cessation of such an orienting tone.

In audiometry we should be particularly worried about auditory fatigue at the same frequency as that of stimulation. Such auditory fatigue at moderate intensities is important on frequencies above 800 Hz. and even then for ex. at 2000 Hz., the effects do not become appreciable until the sensation levels exceeds about 80 db(Hood 1950). In cases of severe hearing loss, we have to present at least the first tones at much higher intensities in order to be sure that the patient knows what to listen for. Although the amount of auditory fatigue from such intensities will depend on the type of hearing loss, a precautionary pause after such a tone before the threshold would be advisable.

7.3 '<u>KIETZ TEST</u>'.

Attempts to use ultra short term TTS as a clinical tool have occurred in America, but in Germany the 'Kietz test' enjoys some popularity.

Loingenbeck (1959) succeeded in simultaneous determination of auditory adaptation and fatigue. This method is called Kietz test. It consists of the following steps.

1. The curve of the auditory threshold of the patient is determined.
2. A noise audiometric curve is measured.
3. A noise audiometric curve with the use of time switch, which causes a periodical interruption of the noise so that noise pulses (instead of a continuous noise) of 0.4 sec. duration with intervals of 0.04 sec. duration are obtained, which superimpose the audiometer tone as continuous tone.

He carried out Kietz test eighty times. In healthy subjects the curve measured with the time switch halves the distance between the auditory threshold curve and the normal noise audiometric curve. The same is found in pure disorder of sound condition.

In disorder of the inner ear the pictures are more complicated. A pathological auditory fatigue is often found. If for instance, it is found in the region of the lower frequencies, it is characteristic of Menieris disease. Whereas such a pathological fatigue in the higher frequencies regions generally indicates a degenerative impairment of hearing.

After an old acoustic trauma the test may sometimes be normal, in other cases, It may show a pronounced pathological auditory fatigue.

In simple impairment of hearing of old age and in endogenouse heredity deafness the Kietz test is normal.

It is pointed out that disorder of the inner ear with verified pathological auditory fatigue are definitely more serious than those of the same severity, but without pathological auditory fatigue, especially with regard to hearing of speech.

7.4. SHORT TERM TTS.

Only a few attempts have been made to use short term TTS in clinical test battery.

Lierle and Reger (1955) exposed patients with various types of loss to 36© 20dbSL. In Sn loss cases their threshold shifts were more persistent than those of normals. In conductive loss cases '20dbSL' probably does represent about the same energy entering the cochlea for the patient as for the normal, would expect, therefore, that the adaptation should also be same. However, this does not seem to be the case. Although a 3 min. exposure at 20dbSL produces the same initial TTS In conductives as in normals, the conductives recover more slowly (Epstein et al. 1962) Katz and Epstein (1962) suggest that this may be associated with the relative disuse, that is, non-exposure to sounds of high loudness, of these ears; To support this view Katz gave the 20 dbSL test to normals after an ear-plug had been worn in the ear concerned for 5, 10 or 15 hrs. He found a 10db greater TTS in the ear that had been 'deprived' of stimulation for 15 hours. But any type of conductive loss will apparently produce this 'disuse' phenomenon, 3ince there were no difference between otosclerosis and nonotoscelerosis (Epstein et al. 1962) so there seems to be of little diagnostic value in this area.

7.5 TTS PARADIGM FOR ASSESSING SOUND TRANSMISSION IN THE AUDITORY SYSTEM DURING SPEECH PRODUCTION.

Voiced vowel production impedes transmission and reduces the energy delivered to the cochlea from a fatigue stimulus. This is evidenced as the reduced TTS magnitudes associated with this condition. 2 potential mechanism are proposed to account for the alteration in sound transmission during voiced vowel production. One mechanism involves possible middle ear muscle contraction and the other concerns alteration in the normal vibratory mode of the stapes caused by vertical vibrations of the skull during phonation (Karlovich and Luterman 1970).

Von Bekesy (1960) has called the attention to some unique middle ear structural and physiologic consideration in man and other mammals that might be important in reducing the bone conducted sensitivity of the ear to the organisms self-vocalization. He pointed out that the stapes foot plate in man is elliptical in shape and inserted into the oval window so that its long axis is at right angles to the vertical axis of the neck. During the transmission of externally generated air borne sounds, the stapes rotates about a vertical axis through the posterior crus, thus producing a maximal displacement of the cochlear fluid. One of the mechanisms for reducing transmission of bone conducted feed back during speech production proposed by Von Bekesy has shown that the vibration amplitude of the skull during voice vowel production is maximal In the vertical direction and maximal in the onterior-posterior as well as in lateral direction. He then pointed out that, because of the large vertical amplitude of skull vibration during phonation, these vibrations are communicated to the incus which in turn causes the stapes to rotate its long axis through the footplate, thus producing a minimal fluid displacement in the cochlea. This vibratory mode of the stapes also occurs when excessive sound pressure at the threshold of feeling are presented by air conduction.

Rotation of the footplate of the stapes about its long axis during each of the voiced vowel production has been responsible for attenuating transmission of energy to the cochlea from the air conducted fatigue stimulus. Such an intermittant alteration in vibratory mode of the stapes might have been responsible for producing the reduced TTS magnitudes during voiced vowel condition relative to the non-voiced and whispered condition. The reduction in transmission could have occurred without involvement of the middle ear muscle or possible in conjunction with such involvement. Von Bekesy (1960) however, did not state whether the middle ear muscle were involved in the function of this mechanism.

7.6 TTS PARADIGM; EVIDENCE FOR AM INFORMATION PROCESSING CHANNEL SELECTIVELY SENSITIVE TO FREQUENCY CHANGES:

The notion that sensory information is processed in parallel channels has been much discussed in recent years. The various types of psychophysical evidence that have been cited for the evidence that have been cited for the existence of such channels were succintly listed by Blackemore and Sutton (1969) in the following cases:

a) programme attenuation of the magnitude of sensation during adaptation,

b) selective threshold elevation following adaptation to changing size,

c) the existence of a negative after effect and

d) distortion of perception after adaptation.

The auditory cortex of cats contains neurons that respond much more strongly to changing stimulus frequency than to changing stimulus intenslty(White field and Evans 1965). If analogous exist In human auditory cortex, then they might form a basis for a psychophysical channel selectivity sensitive to changing frequency.

Exposure to an frequency modulated tone elevates frequency modulated threshold but not amplitude modulated threshold. This holds for a wide range of frequency deviation (F = ±0.4Hz. - ±30Hz at least) provided that modulation of frequency is low (f_m = 2 Hz.) but if f_m is somewhat higher (ex. 8Hz) the finding only holds for small frequency deviations. Frequency modulated threshold can rise with time upto an adapting duration of at least 1200 sec. though the build up depends on frequency deviation. Exposure to an amplitude modulated tone elevates amplitude modulation tone, but not frequency modulated tone threshold, over a wide range of modulation depths. Quasi frequency modulated adapting tones resemble frequency modulating adapting tones have identical power spectra. Exposure to a pure tone produces no difference between frequency modulated tone and amplitude modulated tone threshold elevation. These data can be explained If the human auditory pathway contains separate information processing channels for amplitude modulated and frequency modulated signals whose sensitivities do not overlap even with suprathreshold stimuli.(Regan and Torsley 1979). Frequency modulated channel(but not the amplitude channel) is sensitive to changing difference between signals from different sites along the basilar membrane.

Because frequency modulated tone depresses auditory sensitivity to frequency changes, but not to amplitude changes, whereas exposure to an amplitude modulated tone depresses auditory sensitivity to amplitude changes but not to frequency changes. We can argue that information as to changing frequency and information as to changing amplitude are processed in separate psychophysical channels,

7.7. USE OF TTS IN THE DERIVATION OF DRC FOR NOISE EXPOSURE.

A set of damage risk criteria (DRC) developed for the U.S.Army were published in 1960 by Kryter et al. These criteria cover both continuous and intermittant exposures to steady noise - noise only vaguely defined as being without pronounced peaks - for bursts of half a second or longer. Their development was prompted by the recent demonstration that the equal energy hypothesis was much too conservative. Equal energy assumption states that all exposures involving a given total amount of energy in a given octave band are equally noxious. However, since these different exposure patterns have been shown to lead to different values of TTS (Word et al. 1958, 1962) it seems highly unlikely that they should produce equal noise induced permanent threshold shifts(NIPTS). Instead it is more reasonable to assume that daily noise exposures that produce equal values of TTS will eventually result in equal values of NIPTS, especially since the rate of recovery from a given value of TTS_2 depends little on how the TTS was produced (Ward et al. 1959).

The equinoxiousness of exposures that produce given TTS was the fundamental assumption involved in a new criteria, once agreement had been reached on the octave band levels permitted for an 8 hour daily exposure to steady continuous noise, it was a relatively simple matter to derive, from recent studies on TTS produced by intermittent or interrupted exposures, three sets of equal TTS contours.

The first set shows the levels permitted for single exposures to a steady noise from 2 min. to 8 hr. These can also be used to evaluate the noxiousness of noises that vary with time but never drop below a 'minimum TTS' value. The minimum TTS value level of an octave band noise is that SPL below which the slight TTS produced does not increase with time, it is about 75dbSPL for the Octave bands from 300 to 4800Hz. (Ward et al. 1959). Thus if a noise alternate regularly between 88 and 100 dbSPL in 1200-2400 Hz octave band, it will produce the same TTS_2 as a steady 94dbSPL noise. The average level is what is important here, not the average energy.

The other sets of curves deal with noise that fluctuate above and below the 'minimum TTS value'. One set covers noise bursts ranging in duration from about half a sec. to *2* mins. with noise bursts as short as this, the TTS produced is almost, proportional to the fraction of the time exceeds the 'minimum TTS' level(Ward 1962)

The third set of criteria cover repeated noise bursts and and intervening quiet periods longer than 2 min. In this case,the criteria are presented in terms of the necessary duration of rest periods if the TTS from repeated exposure at a given level and duration is not to exceed the criterion TTS_2 at the end of the day.

In all eases, more energy - in some, considerably more can be tolerated in a fluctuating, intermittent or interrupted noise then in one at a constant level. In addition to the curves described, a set of single exposure criteria have been presented for use when the exposure stimulus is a tone instead of a noise.

How much hearing loss is to be expected if these criteria are faithfully followed is a question usually put. In regard to the average NIPTS,Glorig et al. (1961) have shown that the average TTS_2 produced at 4000 Hz. in normal young adults by an 8 hour exposure to 4 industrial noises happens to be nearly identical to the NIPTS resulting from 10 year or more of normal industrial exposure to the same noises. So the relation is linear.

Industrial deafness:

No words need be written to emphasize the importance of this practical problem. It remains a problem that commands the attention of many clinical and experimental workers today. Industry is getting noisier, and hearing losses that result from such noise are becoming more numerous. Very few controlled studies on the relation between permanent hearing loss end the conditions of stimulation are available. This is undoubtedly due to the difficulty in obtaining experimental listeners. The tremendous literature on the nature of permanent hearing loss that is found in actual practice affords little by way of an analysis of the important dimensions of stimulating sounds

Certain stimulus dimensions have been teased out of industrial surveys. The relation between hearing loss and duration of exposure for ex. was obtained from two groups of workers , one of which had been employed in noisy work for 15 to 20 years and the other for 20 to 25 years by Rosenblith. The average hearing loss for the latter group was about 10db more severe above 2000Hz. Rosenblith also measured the average hearing loss for three groups of workers, namely, boilermakers, blacksmiths, and ironsmiths, and machinists, in order to relate hearing loss to intensity of stimulation. The average noise levels to which these groups were exposed for more than 15 years were 90, 80, 75 db. respectively. The results show hearing loss increases as the intensity increases.

Work on prophylaxis goes on in several directions,

1. Many attempts are being made to find in appropriate test to determine a man's susceptibility to permanent hearing loss as a result of prolonged exposure to noise. This has been discussed in detail in earlier chapters.

2. A second attack on the problem has to do with the use of ear plugs.

3. A third direction has to do with the engineering aspects of making working environments more quiet.

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SUMMARY:

Decreased response to sustained stimuli is a common feature of all receptors of the sensory system. It can beobjectively demonstrated, for instance by electrophysiological methods, as a decline in the rate of discharged impulses per time unit. The phe-

phenomenon is known as adaptation and, according to Ranke's theory, its essential object is the production of a purposeful balance between stimulus and response to stimlation(Ranke, 1955; Keidel, 1961). Adaptation, however, is not merely a peripheral event, it seems to occur in the central nervous system too (Keidel, 1959, Keidel et al, 1960).

Adaptation in the human ear is easily demonstrable as a shift in threshold of hearing, or as a decline in loudness of suprathreshold stimuli; or it may appear in the form of changes in sound quality, sound localization, and in masked pure tone threshold. In animal experiments the phenomenon shows Itself as a diminution in the auditory nerve action potentials and a reduction of the number of action potentials of individual nerve elements.

The concept "auditory adaptaion" was suggested by de Mare' in 1939. Upto the last few years, however, the terminology has varied. All the following terms have been used interchangeably; auditory fatigue and its German equivalent "Ermudung" (Bekesy, 1929; Schubert, 1944; Hood, 1950), physiological fatigue (Hood 1950), and in electro physiological studies, equilibration (Derbyshire and Davis 1935).

Even though adaptation and fatigue may occur parallely, they should be clearly separated from each other. Auditory fatigue follows intensive stimulation in the normal ear, the maximum change taking place one half to one octave above the pure tone stimulus. The degreee of fatigue increases continuously with the duration and the intensity of stimulation, or a balance is not reached until at abnormal sound intensities. Recovery is slow; it is related to the

the degree of fatigue an, if the stimulus is strong enough, an irreversible change may result. Pure adaptation quickly attains a definite level in relation to the stimulus and there is no further increase; the greatest change take place at the stimulus frequency. Recovery is rapid and does not depend appreciably upon the amount of adaptation (Zwislocki and Pirodda 1952; Kietz I960; Zwislocki, l960; Hood 1960; Dishoeck, 1954; 1960).

The methods used for measuring human auditory adaptation are based mainly on changes in three psychophysical entities, i.e., on per and post stimulatory threshold shift, the decrease in loudness of suprathreshold stimulus, and decline of masked pure tone thre shol as measured by an intermittent masking tone. Of these, perstimulatory threshold adaptation is the best known (Schubert, 1944; Hood, 1954; Palua, 1956; Carhart, 1957; Jerger et al, 1958; Jerger, 1960; Sorensen, 1960; Palua and Palua, 1961, 1963) and it has also proved a practical test in the diagnosis of perceptive hearing impairments (Reger and Kos, 1952; Johnson, 1956; Sorensen, 1962; Palua and Palua, 1966; Palua et al, 1967).

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