Temporary Threshold Shift (TTS) for FM Tone and Steadytone at 2KHz.

Reg No: M 8608
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A dissertation submitted in part fulfillment
for the degree of Master of Science (Speech & Hearing)
to the University of Mysore

May 1988

To,

"मताजी" ...... my grandmother

CERTIFICATE

This is to certify that this Dissertation entitled: TEMPORARY THRESHOLD SHIFT (TTS) FOR FM TONE AND STEADY TONE AT 2KHz has been prepared under my supervision and guidance.

Dr.M.N.Vyasamurthy
GUIDE

CERTIFICATE

This is to certify that the Dissertation entitled: TEMPORARY THRESHOLD SHIFT (TTS) FOR FM TONE AND STEADY TONE AT 2KHz is the bonafide work on part fulfillment for the Degree of Master of Science (Speech and Hearing) of the student with Register No.8608.

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DECLARATION

I hereby declare that this dissertation entitled : TEMPERORY THRESHOLD SHIFT (TTS) FOR FM TONE AND STEADY TOEN AT 2KHz is the result of my own study under the guidance of Dr.M.N.Vyasamurthy, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

Mysore.
Date: May 1988 Register No.8608.

acknowledgments …………

“The best and the most beautiful things in this world
cannot be seen or ever touched,
they must be felt with the heart…”

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<u>INTRODUCTION</u>

Temporary threshold shift (TTS) has received a great deal of experimental attention since Urbantschitsch’s (1881) discovery of the phenomenon (Ward, 1973). It is a property of all sensory systems that exposure to a stimulus of sufficient duration and intensity produces changes in the responsiveness of the system. Some changes occur during the presentation of the stimulus and some are apparent after the end of the stimulus (Eg.Shift in threshold). Such effects are much less marked in the auditory system than they are in the visual system although large threshold shifts are often observed after exposure to stimuli of very high intensity (Moore, 1977).

TTS is defined as a reduction in hearing sensitivity resulting from exposure to noise, provided that thresholds return to preexposure levels with time (minutes, hours or days) after cessation of noise. (Rintlemann et al.1972). The most appropriate TTS measurements are those actually obtained two minutes post exposure. TTS refers to the transitory changes in hearing sensitivity induced by a fatiguing stimulus (Humes and Bees, 1978).

It is usually estimated by first determining the normal thresholds, then exposing the ears to fatiguing stimulus and finally finding the post-exposure threshold. The difference between pre and post threshold defines the severity of the fatigue (Elliott et al. 1970).

Researchers are trying to understand the mechanisms responsible for post stimulatory decline in sensitivity and its subsequent return to preexposure levels. They believe that knowledge of these mechanisms will improve our understanding of auditory physiology in normals and pathophysiology in noise induced hearing loss (NIHL). This in turn will help us to prevent NIHL and provide treatment to cases who have already acquired NIHL.

According to Fiatkoska et al (1983) the various biochemical and structural findings made to date point out that noise induced auditory fatigue, originates primarily in the cochlea and modifies the activity of neurons throughout the auditory pathways; since long hair cells have been blamed for TTS. According to Eggermont (1985) auditory fatigue may be due to metabolic processes in hair cells limiting the production rate of transmitter substance.

The range of individual differences in the amount of TTS produced by specific exposure to puretones, noise or impulse is quite large. Since exposure that produce more TTS in group of ears also tend to result eventually in more average permanent loss, it has been assumed that individual ears displaying the least TTS from a given short exposure at moderate level will be the most resistant to permanent loss from either prolonged exposure to moderate levels or short exposures at extreme levels (Ward, 1963). Therefore through various measurements of TTS one might be able to predict individual differences in susceptibility to permanent damage from high intensity sound by means of individual differences in the TTS produced by a much less intense exposure.

Although the TTS mechanisms are not very clear, attempts to unravel them has produced a lot of experimental facts about TTS. The primary factors which influence the size of TTS are intensity of fatiguing stimulus, frequency of the fatiguing stimulus, duration of the fatiguing exposure, recovery process and test frequency. If the stimulus is intermittent, interruption rate ad for impulse pulse repetition rate are also contributing factors.

Miscellaneous factors that effect TTS are resting threshold (Ward, 1963), interactive effects (Ward, 1961 a), latent and residual effects (Ward, 1960a) Harris, 1955). vibration (Morita, 1958; Yokoyama et al. 1974), Vitamin A (Ward, 1963);

oxygen (Hirsh and Ward, 1952), Salt (Cook, 1952); Iris Pigmentation (Tota and Bocci, 1967; Karlovich, 1975); Drugs (Lehnhardt, 1959), level of consciousness and central factors (Chernyak, 1958; Babighian, 1975); binaural and monoaural stimulation (Hirsh, 1958; Shivashankar, 1976), Ear difference (Glorig and Rgoers, 1965; Ward, 1967; Jerger, 1970; Weiler, 1964) etc.

Various researchers have studied TTS using steady tone (Kryter, 1950; Ward, 1962) high frequency noise (Ward, 1962; Vyasamurthy, et al. 1973), broad-band noise (Kavlowich and Wiley, 1974), low frequency noise (Mills and Lilly, 1971; Burdick et al. 1977; Mills et al. 1983), impulsive noise (Loels and Fletcher, 1968), Pop music (Jerger and Jerger, 1970; Wieler et al. 1974; Axelson and Lindgren, 1977; Lindgren and Axelson, 1983), Rock and role (Jerger and Jerger, 1970; Lindgren and Axelson, 1983) etc.

Need for the study:

As reported in the literature TTS can be affected by different types of stimulus such as pure tone, narrow band noise, broad band noise, pop music, impulse noise, high frequency noise etc.

The frequency modulated (F.M) tone shows a different spectrum as compared to the steady tone.

The sounds which we encounter in everyday life often change in frequency and amplitude from moment to moment. In the laboratory the perception of such sounds is often Studied using either frequency modulated or amplitude modulated sine waves. Such waves consisted of a carrier frequency (a sine wave) upon which same other signal is impressed. In frequency modulation, the carrier's instantaneous frequency is varied in proportion to the modulating signal's magnitude, but the amplitude remains constant. Pure tone is a sound wave whose instantaneous pressure variation as a function of time, is sinusoidal function. A simple periodic sound is called as a pure tone in common usage.

Hence the presence study was aimed at study if there is any significant difference between the TTS produced produced by the FM tone and steady tone. Further it may have theoretical implications in the field of auditory physiology.

Null Hypothesis:

There is no significant difference in TTS produced by FM and steady tone.

Definitions of the terms used in study:

Temporary threshold shift (TTS): Refers to an elevation in the threshold of hearing which recovers gradually following the noise exposure.

TTS_o: Temporary threshold shift measured as soon as the fatiguing stimulus is ceased.

TTS_1: Temporary threshold shift measured after 1 minute of recovery time.]

TTS_2: Temporary threshold shift measured after 2 minutes of recovery time.

Fatiguing frequency: The frequency at which the ear was exposed continuously to produce the fatigue.

Fatiguing stimulus: The acoustic stimulus used to produce auditory shift in threshold.

Test frequency: The frequency at which the thresholds were determined after the ear was exposed to fatiguing stimulus.

REVIEW OF LITERATURE

The problem of auditory fatigue is still vexed with uncertainity and controversy. The problem arises from the fact that so many of the relevant parameters are interactive so that experimental results are difficult to generalize however precisely determined they are (Ward, 1963).

The auditory system is not equipped to handle prolonged exposure to high intensity sound. For reasons not clearly known, sensitivity of ear declines. The prestimulatory threshold shift is called adaptation and post-stimulatory threshold shift is called fatigue or temporary threshold shift (TTS). In case of TTS; sensitivity returns to pre-exposure levels. In the beginning, hearing may recover after exposure, but after repeated exposures, as in the case of a worker who goes to work at a noisy industrial site daily, recovery is not complete and a residual hearing impairment or a permanent threshold shift (PTS) occurs.

The most common index for auditory fatigue is the TTS which has generated a number of interesting investigations both experimented and clinical and perhaps been the most studied after effect at auditory stimulation. Both the permanent and temporary effects of noise on the human auditory system are variable (Ward, 1973; Robinson 1976; Mumes, 1980) and this is true even when the physical characteristics of the noise exposure are held constant. This variability in noise effects implies that noise may interact with other variables to produce its effects on hearing. Temporary threshold shift are often used to predict noise induced hearing loss (NIHL) and various susceptibility tests have been devised.

Following is a brief summary of the different findings reported in the available literature on TTS.

Recovery from TTS:

Recovery process from TTS seems to be dependent on fewer of the stimulus parameters than the growth process. TTS decreases after termination of noise exposure. However in many subjects, a substantial TTS could be found even after 25 minutes and more after termination of noise exposure (Axelsson and Lindgren, 1978). Recovery from TTS is faster at first and slower later. That is recovery from TTS is a linear function of the logarhithm of time following the cessation of stimulation. But Luscher and Zwislocki (1949) and Rawnsley and Harris (1952) reported that in short-term TTS, the recovery seems to be linear in time rather than in the logarhithm of time. Ward (1960) has shown that in the case of higher level exposures giving rise to TTS in the region above 40dB. The recovery process is no longer logarhithmic with time, but occurs at a steady rate of about 0.012dB/minute (Tempest, 1985).

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

Growth of TTS:

TTS generally grows with intensity of fatiguing stimulus (ward, 1963; Ward, 1965; Axerlsson and Lindgren, 1976; Moore, 1977). The growth of TTS depends on many factors. All the parameters which are measurable can affect the growth of TTS. If a pure tone is used as fatiguing stimulus, then the frequency, intensity and duration are important factors which can affect the growth of TTS. For continuous noise, the level, bandwidth, duration and peak factors are the salient aspects. In case of impulses and explosions, number of impulses, peak intensity, rise time and duration of exposure all determine the TTS produced. If the fatiguing stimulus 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 (Ward, 1963).

Doy (1970) said that in the region of 30 minutes to 2 hours, noise bands yield approximately one more dB of TTS_2 per each dB increase in level. Furthermore, the parameters in many cases, interactive, like duration, frequency, intensity etc. effect each other in complex manner. Also there are large inter-individual variations (Ward, 1963).

Factors affecting auditory fatigue:

Intensity: Generally TTS grows with intensity. The growth is linear but if one waits for the short-term (R-1) process to disappear by measuring the TTS only after 2 minutes or more, the growth of TTS with intensity becomes even more more linear (Ward, 1963).

Davis et al. (1950) noticed that TTs observed for 130dB SPL noise was less than TTS for 120dB SPL. His observation was confirmed by Trittifroe (1958), Miller (1958) and Ward (1962). The most likely explanation for this might be that the mode of vibration of the stepes may change at high levels, a change that is in turn produced by the maximum contraction of the middle ear muscles (Bekesy, 1949). At intensity levels and thus increase in the amount of energy reaching cochlea is not linear. This effect is seen more at low frequencies than at frequencies higher than 2KHz (Ward, 1963).

Test Frequency: The frequency range in which TTS occurs depends on the stimulus. In case of broad band noise, the maximal TTS will be seen at 3000-6000Hz range where as in case of pure tones and narrow band noise, maximum TTS is observed at a frequency higher than that of a TTS producing sound i.e. from 4 to 1 and 1½ octave higher (Ward, 1965).

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 frequencies. As one raises the level, however this no longer is unversally true, instead, higher frequencies are sometimes more affected than lower (Ward, 1963).

McFadden and plattsmier (1983) studied the TTS for several different test frequency following exposure to a 2500Hz tone. The intensity of the exposure tone was varied from 82 to 97dB SPL fro 5 or 10 minutes duration. In each post-exposure session, TTS was followed for four tests frequencies. In all cases TTS pattern moved upward in frequency as exposure intensity increased.

The range from 3000 to 6000Hz is most susceptible to TTS (Rintlemann et al. 1972). Most of the investigation of TTS have been concerned with effects produced by sounds in the frequency range of 500Hz to 4000Hz. Studies which have used band of noise or pure tone between 63Hz and 250Hz (Patterson et al. 1977; Burdick et al. 1977; and Mills, et al. 1983) suggests that the rules for TTS produced by mid and high frequency sound apply to TTS by low frequency sounds with exception that whereas TTS is greatest at half octave or one octave above the centre frequency or upper cut off frequency of the noise (Ward, 1962; Yamamoto et al. 1970). TTS from low fre-quncy sound is greatest in frequency region of best auditory senstivity (500Hz – 4000Hz) which can be 3-5 octave above the exposure frequency. The above charac-teristics of TTS from pure tones are also true of TTS produced by noise (Ward, 1962).

Exposure frequency: The higher the exposure frequency, atleast upto 4000Hz – 6000Hz, the greater the TTS pro-duced (Ward, 1963; Albert, 1979). Further the pure tones are assumed to be more dangerous than octave bands of noise (Anonymous, 1956). However, this was an assumption based on the critical band hypothesis (Kryter, 1950) – that if a given amount of energy were concentrated with in a single critical band, it would be more dangerous than if it were spread over several critical bands.

Greater TTS are produced by pure tones than by noise bands at frequencies below 2KHz, because noise is a better stimulus for sustained middle ear muscle contraction which protects the cochlea. For high frequency sounds the amount of TTS produced is proportional to the total length of time of exposure. Intermittent exposure produces fairly complex results. For intermittent low frequency sounds, the amount of TTS produced is less because of the middle ear muscle activity. While the higher frequencies at and above, 3000 cps are resistant to TTS for only about 2 minutes 1000cps shows no TTS upto approximately 15 minutes of noise exposure (Carso, 1967). At high frequencies, the noise may even produce more TTS than the corresponding center frequency pure tone (Vyasamurthy, et al. 1974). Smith and Loeb (1968) found that higher the exposure frequency more the time to recover.

Duration of exposure:

The TTS grows linearly with the logarhithm of time. But the situation is complicated by the action of the reflex at lower frequencies. The longer the noise is on, the more the muscle reflexes and so the greater is the effective level reaching the inner ear, so the TTS gets positively accelerated (Selters, 1962).

The increase in TTS with exposure time is found under almost all conditions. The main exception is reported by

Bentzen (1953) for very short values of recovery time. Test tone used was 20 or 30 msec pulse of the same frequency as the exposure pulses with a delay pause of 50msec. Under these conditions, the TTS from moderate levels was the same for all exposure durations from 0.25 to 2 seconds (Cited by Ward, 1963).

Intermittent exposure:

The action of the middle ear muscles becomes much more important because even a short rest will at least partially restore their contractile strength.

Ward et al. (1958) have shown the relation, that if during the total exposure time (T), the exposure stimulus is only on a certain fraction (R)of the time, then the TTS produced will be only ‘R’ times as great as that produced by a continues exposure at that level. This relation holds for burst-durations ranging from a quarter of a second (Rol, 1956) upto 2 minutes (Selters and Ward, 1962). For noise bursts shorter than 0.2 sec or longer than 2-3 minutes. Somewhat more TTS is produced than as the fraction rule would predict.

Another principle applicable to the intermittent noise is that while the level is below the ‘critical level’ (the level that just fails to produce TTS lasting 2 minutes or longer) or base value recovery proceeds. Just as fast as if the ear were in complete silence (Ward, 1960a).

Ward et al. (1959 a, b) have derived some equations and one of such is in the following forms. $TTS = K_1 (S-S0) (\text{Log } T - K_2) + K_3$ where (S-S0) is the average value of the amount by which level S exceeds the base value (Negative value excluded), T is the exposure time, and K_1, K_2 and K_3 are constants. However, this form of equation holds for (1) exposure durations of 10 minutes or more (2) recovery times of 2 minutes or longer (3) exposure frequency 2000Hz or greater (4) SPLs below 125dB SPL; and (5) for intermittent exposure, burst duration of from ¼ seconds to 2 minutes.

Miscellaneous factors affecting TTS:

In addition to the parameters which have been discussed, many and their conditions might be relevant in determining the exact values of TTS. Some of them are as follows:

- Interactive effects: The course of the fatigue process at one area of the basilar membrane is relatively independent of conditions existing at other areas. It has been shown that though two noises were producing TTs at their own respective regions as basilar membrane, neither had any effect on the other (Ward, 1961a).

- Latent and residual affects: Noises which fail to produce a measurable TTS2 do not enhance to a measurable degree the magnitude of TTs produced by a subsequent exposure. Thus latent effects of stimulation are unimportant (Ward, 1960a) Harris (1955) showed presence of residual affects. He restimolated his subjects many times after the TTS due to previous reached zero. He found increments is TTS in every subsequent exposure.

Hearing level or resting threshold: TTS is inversely proportional to hearing level i.e. if thresholds are higher TTS produced is less. If a person is suffering from pure conductive hearing loss then all the energy of the fatiguer will not reach cochlea and thus he will have lesser shift than a normal hearing person when both are exposed to equal amount of noise. Individuals with pure sensory hearing loss will show less TTS than normal individuals, but only because they have less to lose, as it were. The energy entering the cochlea of such a person is no different from the normal case (Ward, 1963).

Vibration: Morita (1958) reported that when 10 subjects were exposed to 100dB white noise for 30 minutes while simultaneously being vibrated, the TTS was greater than if the 100dB noise acted alone. This might be due to lessened protective effect of middle ear muscle due to vibration.

Yokoyama et al (1974) studied the changes in the auditory sensitivity with vibration and vibration-plus-noise. No significant changes in the threshold sensitivity after exposure to vibration alone were seen. Exposure to vibration and noise simultaneously caused greater threshold shifts and longer recovery time than exposure to noise alone. They suggested that the effects of the combined noise and vibration might be the results of some disturbances of physiological homeostatis or possible mechanical interactions with its blood supply.

Oxygen: It is known that adequate oxygen is necessary for normal functioning. But excess of O2 does not have any effect on course of fatigue is already demonstrated. Anoxia causing increased TTs has not been demonstrated in humans but it is already shown in guinea pigs. Cochlear microphonics were reduced when the animals were in 10% oxygen state throughout the experiment (38 minutes) then when they were in 10% oxygen atmosphere for only 5 minutes (Hirsh and Ward, 1952).

<u>Vitamin-A</u>: In subjects having diet containing reasonable amount of Vitamin-A, administration of vitamin-A does not effect the TTS and its recovery. It is possible but not demonstrated yet, that deficiency of vitamin-A might change the course of auditory fatigue (Ward, 1963).

<u>Salt</u>: Cook (1952) speculated that excessive use of ordinary salt may cause the ear to become waterlogged and not only produce endolymphatic hydrops but also increased TTS. But it is only a speculation and no experimented data have been obtained in this direction.

<u>Iris-pigmentation</u>: Subjects with highly pigmented irises (brown) experience less TTS than those with less pigmented irises (blue) and that those with green-gray pigmentation display intermediate amount of TTs. Tota and Bocca (1967) noted high correlation between the melanin content in the strio-vascularis and that found in pigmentation of iris, they contributed their TTS difference across eye colour to the protective effects of melanin. But Karlovich’s (1975) study do not support the hypothesis that individual with highly pigmented irises (brown-eyed) are more resistant to auditory fatigue than those with less pigmentation of iris (blue eyed)

Levels of consciousness and central factors:

Wernik and Tobias (1963) reported that when subject's were required to do mental arithmetic during exposure to fatiguing stimuli, they exhibited greater TTS, than when they were required to do no task.

In an electrophysiological study, Babighian (1975) exposed rate to continuous sound. A decrease in cochlear microphonics, action potentials and impulses from inferior calliculus was found, but reduction in impulse, from inferior colliculus was more and it was concluded that central factors were involved.

Ear Difference in TTS:

During the past few years, much attention has been devoted to the study if ear difference in the processing of auditory stimuli (Davis and Weiler, 1978).

Glorig and Rogers (1965) found that right ear was better in high frequency and left ear in low frequency when TTS was measured after exposure to noise. Ward (1967) pointed out that the same ear may also exhibit different susceptibility to different frequency bands.

Ulrich and Pinheiro (1974) randomly selected 14 teenagers who were exposed to long hours of highly amplified live rock and roll sessions. They obtained the hearing thresholds of the subjects before and 30 minutes after each rock and roll session (250-8000Hz) the sound pressure levels were ranging from 90-115dB at various positions around the stage. The loudest range of the spectral distributions was from 75Hz to 1200 Hz with a slight peak between 300Hz to 600Hz. When the post-exposure thresholds for first and last sessions were statistically compared, the left ear showed a significant increase in TTS at 4KHz for the last session and a significant decrease in TTS at 500Hz and 1KHz. The right ear had significantly greater TTS at 1KHz and at 4KHz for the last exposure with an increments in threshold shift apparent to all test frequencies.

Jerger and Jerger (1970) measured the auditory sensitivity of 2 groups of rock and roll musicians before and after (with in one hour) the concert. They found that the pre and post exposure sensitivity was fairly normal, but 14-15 years old musicians post exposure audiogram showed substantial TTS at high frequencies especially in the left ear. Over all sound pressure level was 100-116dB SPL.

Weiler et al (1974) investigated the hearing at teenagers who voluntarily exposed themselves to repeated sessions of loudly amplified pop music. Hearing thresholds were measured before and 30 minutes after exposure for 8 weekly sessions of rock and roll music with an average SPL of 110dB to 115dB. Significant TTS were found in all subjects, especially in high frequencies. The exposure had diferential effects on the 2 cases at the same test frequencies. The left ear showed a significant decrease in TTS at 500Hz and 1000Hz. Mean right ear TTS was greater for the final exposure at all frequencies about 2000Hz.

Axelson and Lindgreen (1977) determined hearing thresholds in 83 pop musicians average exposure time of 9 years and average weekly exposure time of 18 hours. In the analysis of the whole population there was a clear cut difference between the right ear and left ear in that the left ear was better in high frequency.

Binaural and Monoaural stimulation:

Dichotic exposure to certain acoustic stimuli at high intensity levels results in reduced post exposure threshold shift (TTS) relative to monotic exposure to the same stimuli (Hirsh, 1958; Loeb and Riobele, 1960; Ward, 1965; Karlovich et al 1972; Karlovich et al 1974).

Melnick (1967) found that more TTS occured when the exposure signal was 180° out of phase in the experiment on the effect of two interaural phase conditions for binaural exposure on threshold shift.

Shivashankar (1976) studied the differences in TTS between monouaral and binaural exposures to high frequency tones (2KHz, 3KHz and 4KHz) at high intensity levels (126dB SPL) for equal duration of time. It was found that there was no significant difference in TTS between monoaural and binaural exposures. This could be attributed to the action of homolateral Olivo cochlear bundle which might inhibit the responses of the higher centres, as crossed olivo chochlear bundle does not play a role in the adoptation mechanisms at high frequency (Daya, 1972).

The TTS reduces in the presence of contralateral stimulation due to efferent action (Cody and Johnstone, 1982, Sinha, 1984). In contralateral stimulation efferent action is present whereas in monoaural stimulation no efferent action will be there. This might be a possible reason for reduced TTS for binaural stimulation.

TTS and Articulation: When subject articulate during exposure then TTS is reported to be less.

Shearer and Simmons (1965) observed changes in acoustic impedance associated with moderate intensity whispering and vowel /a/ phonation. Acoustic impedance change preceded in initiation of speech sound by 65 to 100 msec. or at least coincided with speech output.

The occurance of acoustic impedance slightly before speech output would indicate that the stapedius muscle under these circumstances is activated concurrently with speech musculature (Metz, 1946). So the middle ear activity is part of neurological pattern on the production of speech. Another change in peripheral auditory transmission system is alteration is the vibration pattern of the stapes which reduces the motion of cochlear fluids (Bekesy, 1960).

Sreemathi (1981) has studied the effect of articulation on auditory fatigue. Subjects were asked to read a passage in experimental condition. TTS in experimental condition was lesser than TTS in control situation in which subjects maintained silence. This effect was seen at 1000Hz. But not at 4000Hz where middle ear reflex function is not effective.

Auditory fatigue and sex differences:

Studies of difference between males and females in temporary noise effects are scarce.

If one exposes normal hearing college students of both the sexes to the same noise the men and women show equal TTS (Ward, et al. 1959).

Several studies have shown that women have better hearing than men, even when the noise exposure has been equal in two groups. (Kylin, 1980, Dieroff, 1961).

Nerbonne and Hardick (1971) Karlovich et al (1972) reported an absence of significant difference in TTS magnitude between males and females, however the former reported a faster recovery rate in females.

There is no difference either in the initial magnitude of TTS or in recovery from it in the male and female group (Bishnoi, 1975).

Axelsson and Lindgren (1978) reported that male listeners have a broader range of TTS affecting all frequencies from 1 to 8 KHz while female listeners are only affected at 3KHz, 4KHz and 6KHz. At all frequencies males had more TTS than the females.

Chormak et al found gender difference in TTS measures with repeated noise exposure. Under these conditions of cumulative noise effects females revealed greater TTS at

4KHz then did the males. This difference may be due to hormonal difference. (Dengerink et al. 1984). Dengerink et al (1984) found that females using oral-contraceptives showed greater TTS at 4KHz than males or females who do not use oral contraceptives. Difference in TTS between males and normally cycling females were not observed.

There is not significant difference in TTS among males and females, however males showed greater amount of TTS as compared to females. There is not significant difference in rate of recovery among males and females, however females showed faster rate of recovery than males (Nigam, 1987).

Acoustical differences in Noise and Pure tone:

The only motion possible in a medium in which electrons are not free to flow is a vibration of the constituent ions or molecules. Such substances are called dielective and oscillations of its constituents is sound (Embleton, 1981). When an alternating electrical current is delivered to a electrodynamic earphone, the electricity flows in a coil placed in a constant magnetic field and produces vibratory motion of the coil, which is attached to a diaphragm, so the diaphragm also vibrates. The diaphragm produces forced oscillations of molecules in the air medium which is turn produce forced oscillations of eardrum. If one plots a graph of displacement of any of three vibrators (ear-phone diaphragm, cirmolecule eardrum) as a function of time, a sound waveform results. If this waveform is sinusoidal in shape, we call it simple periodic sound. A simple periodic sound is called as a pure tone in common usage.

If the waveform deviates from sinusoidal fashion it is called as complex sound. The waveform of a complex sound can be periodic that is the waveform after definite intervals. Music is an example of a complex periodic sound. When the waveform of a complex sound is aperiodic, that is the wave form does not show any definite repetition patternover time. Noise is an example of complex aperiodic sound. A nonsinusoidal waveform is called complex, because mathematical analysis of this wave form will yield several sinusoidal components.

For a complex sound, these sinusoidal components are such that frequency of each component is an integral multiple of the lowest frequency. That is why such components are called harmonics. For a complex aperiodic sound, the frequencies of sinusoidal components are not related in any manner.

If the sinusoidal components of a complex aperiodic sound are such that their amplitude are varying constantly and unpredictably, we call such a noise complex, aperiodic, random noise or random noise in short. If a random noise contains several components over a wide frequency range, in fact as many components, as its generator (earphone diaphragm can produce, and if the amplitudes of its components at various time instants are normally distributed (amplitude US time graph of each component is a bell shaped curve). We call it white noise or broad band noise. Although the amplitude of its components is varying constantly and unpredictably, the total energy of all frequency components will be equal for a given unit of time. The frequency range of broad band noise may extend from frequencies less than 200Hz to frequencies above 5000Hz, the exact range depending on the frequency response of earphone diaphragm. If a broad band noise is filtered to obtain a specified band of frequencies, all other characteristics remaining unaltered a narrow band noise results. The waveform of a narrow band noise shows less deviation from sinusoidal waveform compared to a broad band noise. A narrow band noise may have different band widths.

Difference in TTS for Noise and Pure Tone:

Scientists have used various types of noise stimuli like high frequency noise bands, low frequency noise bands, which frequency noise band (broad-band), impulse noise, pop music etc.

Ward (1962) reported that a high frequency noise band a high frequency pure tone of equal SPL and duration produce same amount of TTS.

Vyasamurthy et al. (1973) reported that high frequency noise band produces greater amount of TTS than a high frequency pure tone. Two experiments were conducted. In one experiment the ear was exposed to narrow band noise centered at 4KHz. The second experiment was conducted after enough time-gap to allow recovery f5rom fatigue caused in first experiment. Both noise and tone were delivered at a level of 105dB SPL for a duration of one hour. In both the experiments TTS_o for noise 54dB, retested) and pure tone (31dB, retested) were significantly different, Mean TTS_o for noise being greater than Mean TTS_o for pure tone.

In cases of broad band noise, the maximum TTS will be seen at 3KHz-6KHz range where as in the case of puretones and narrow band noise maximum TTS is observed at a frequency higher than that of TTs producing sound, i.e. from ½ to 1 and 1½ octave higher (Ward, 1965). TTS apparently involves areas on the basilar membrate. At low levels of stimulation maximum effect is produced at the stimulation frequency less at adjacent frequency with the increase in intensity, the high frequencies are more affected than the lower (Ward, 1963).

Karlovich and Wiley (1974) studied the effects of contralaterally presented broad band noise and 4000Hz pure tone on TTS produced by 1000Hz. They found that broad-band noise produced greater reduction in TTS compared to 4000Hz pure tone.

They conducted 3 experiments. In 1st experiment they exposed one ear to a 1000Hz pure tone at 110dB SPL for 3 minutes. They measured TTS_2 at 1414Hz. Mean TTS_2 was 14dB. In IInd experiment they exposed one ear to 1KHz pure tone at 110dB SPL for 3 minutes and simultaneously exposed the contralateral ear to a broad band noise at 100dB SPL. They measured TTS_2 (in the ear exposed to 1000Hz) at 1414Hz and found a Mean value of 10.5dB. In IIIrd experiment they exposed one ear to 1000Hz pure tone at 110dB SPL for three minutes and simultaneously exposed the contralateral ear to a 4000Hz pure tone. TTS_2 was measured in the ear exposed to 1000Hz at 1414Hz and mean value was 13.5dB. In IInd and IIIrd experiment acoustic reflex in the ear exposed to 1000Hz pure tone was due to both 1000Hz pure tone acting through ipsilateral reflex are and broad band noise or 4000Hz pure tone acting through contralateral reflex pathways. TTS2 in experiment IInd and IIIrd were reduced due to contralateral noise or 4000Hz pure tone. In experiment II TTS2 reduced by 305dB and in experiment III TTS2 reduced by only 0.5dB (average). Obviously broad band noise produced more reduction in TTS than 4000Hz tone.

Kryter (1950) observed that pure tones below 2KHz produce more TTS than corresponding octave bands of noise. Low frequency noise bands were considered less hazardous than low frequency pure tones. He gave critical band hypothesis to explain why low frequency pure tone produce more TTS than low frequency octave noise bands. According to the hypothesis, if a given amount of energy were concentrated within a single critical band it would be more dangerous than if it were spread over several critical bands eg. over an octave. Ward (1962) verified the above hypothesis.

Ward (1962) conducted 2 studies. In one study he found that a very narrow band of low frequencies ($1/8^{th}$ octave band width) produces consistently less TTS than a pure tone at the same frequency despite the fact that both stimuli are less than a critical band width.

In another study he used 600-1200Hz octave band noise and 850Hz pure tone. When noise and tone were presented for equal duration at equal SPl, the low frequency noise band produced less TTS than the low frequency pure tone.

Mills and Lilly (1971) employed low frequency noise band of 660-710Hz and a low frequency pure tone of 710Hz. 6 normal hearing subjects and 6 stapedectomized subjects who had the tendon of the stapedius muscle sectioned during the course of a vein-plug stapedioplasty were studied. For both the groups noise and tone were presented at 110dB SPL for 10 minutes. TTS_2 was measured at 1000Hz which is half-octave above both the exposure tone and upper-cut off frequency of noise. They found that TTS for low frequency noise and tone did not differ signify-cantly in stapedectomized patient. In normal hearing subjects with intact stapedius tendon low frequency pure tone produced more TTS than low frequency noise band. In stapedectomized subjects without an acoustic reflex low frequency pure tone and low frequency noise band produce same TTS.

Loeb and Fletcher (1968) exposed their subjects an different test days to 166dB (peak-normal-incidence) impulses 34, 58, 72 and 96/msec in duration spaced 1 sec. apart. For each pulse duration, the subjects were first exposed to one pulse, then the number of pulses was doubled on successive days until the temporary threshold shift (TTS) following exposure exceeded 30dB. Intercorrelations of number of impulses required to criterian TTS at each duration were obtained; they were highest when durations were similar. At the largest pulse duration a median of only four impulses was required to achieve criterian, some individuals exceeded criterian at one impulse, while other required hundreds. Maximum shift was at high frequencies (10-15KHz) and relatively independent of impulse duration.

Lindgren and Axelsson (1983) conducted a study to determine the possible individual differences in TTs after repeated controlled exposure to non-informative noise and to music with equal time, frequency and sound-level characteristics. In their study, 10 voluntary subjects were exposed to 10 minutes of recorded pop music on 5 occasions. On 5 other occasions these subjects were exposed to noise with level, frequency and time discrimination characteristics measured in octave band steps equal to those of the music. Measurements of TTS showed almost equal sensitivity to the two stimuli in 4 subjects where as six subjects demonstrated marked differences in sensivitity. Differences were always due to more TTS after exposure to the non-musical noise stimulus. In their discussion authers state that high sound levels that are experienced as unbearable, unpleasant and unnecessary would then induce more hearing loss than sounds at excessive levels but with positive emotional content.

Kumar and Rangamani (1981) studied TTS_2 for pure tones and warble tones. The study was done using 10 subjects to know the effect of warbling on the temporary threshold shift measured after 2 minutes. The results showed a significant difference between the TTS2 for warble tone and the TTs2 for pure tone. No explanation for this significant difference was given.

From the review of literature TTS, we can see that there is no pertinent literature available on TTTS for pure tones and frequency modulated tone and hence this study has been proposed to be undertaken with the hope that it might throw some light on this area.

METHODOLOGY

Subjects:

Ten subjects in the age range of 17 to 23 years, with a median age of 20 years took part in this study. The selection of subjects was done on a random basis and met the following criteria:

1. They should not have any history of ear discharge, tinnitus ear ache, headache, giddiness, exposure to loud noise or any other otologic complaints.

2. Hearing sensitivity within 20dB HL (ANSI, 1969) at frequencies from 250Hz to 8000Hz at octave intervals.

Instrument used:

The Grason-Stattler Audiometer (GSI-16) with TDH-50P earphones with supra aural cusions was used. the audiometer was calibrated according to the specifications given by ANSI 1969; ISO:1975. The audiometer has frequency modulation of $\pm 5\%$ of centre frequency at a rate of 5Hz.

Test environment:

The study was carried out in an acoustically sound treated 2 room situation. The ambient noise level present in the test rooms were below the permissible ISO-1964 maximum allowable noise level.

Procedure:

All the subjects were screened at 20dBHL (ANSI-1969) at frequencies from 250Hz to 8000Hz at octave intervals to find out the presence or absence of a hearing loss in both the ears.

Thresholds were established for the right ear at 4000Hz using Modified Hughson-Westlake procedure with pulsed pure tone and frequency modulated tone separately.

Each subject was tested in two sessions. In the Ist session each subject was exposed to 2KHz pure tone at 110dBHL for 10 minutes. TTS2 was determined at test frequency i.e. 4000Hz, one octave higher than the fatiguing frequency IInd session was similar to session I except for the fatiguing stimulus. Here each subject was exposed to 2KHz frequency modulated tone at 110dB HL for 10 minutes. A rest period of seven days was given between the two sessions for the complete recovery to occur.

The data obtained was subjected to relevant statistical analysis.

RESULTS AND DISCUSSIONS

For each subject TTS_o, TTS_1 and TTS_2 was calculated for both pure tone and frequency modulated tone. Table-1 shows the raw rate for TTS_o, TTS_1 and TTS_2; as well as mean and standard deviation for steady tone. Table-2 shows the raw data for TTS_o, TTS_1 and TTS_2; as well as mean and standard deviation for frequency modulated tone.

The mean TTS observed for the steady tone stimulus was 35.5dB (S.D.-3.69); 31dB (S.D.=3.94); and 27.5dB. (S.D.=4.03) for TTS_o, TTS_1 and TTS_2 respectively.

The mean TTS observed for the frequency modulated tone stimulus was 35dB (S.D.5.77), 30dB (S.D.5.77) and 28dB (S.D.4.58) for TTS_o, TTS_1 and TTS_2 respectively.

The difference between the means for steady tone and frequency modulated tone was tested for its significance by using Wilcoxon matched-pairs signed ranks test.

No significant difference was observed between the TTS_o, TTS_1 and TTS_2 at .01 level of significance with a t-value of 12, 18.5 and 20 respectively.

Discussion:

The present study was aimed to study the difference between the TTS produced by steady tone and frequency modulated tone. The results indicate that there is no significant difference in the amount of TTS produced by steady tone and frequency modulated tone.

Kumar and Rangamani (1981) studies TTS_2 for pure tone (steady tone) and warble tone (frequency modulated) tone at 1000dB SPL with fatiguing frequency of 2000Hz and test frequency of 4000Hz. They reported a significant differrence in the amount of TTS_2 produced by the two stimuli.

However the results of present study is not with agreement with the above study. The controversy still lies that whether there is a difference in the amount of TTS produced by steady tone and warble tone which may due to the methodological differences between the two studies. The present investigation studied the TTS at stimulus intensity of 110dBHL whereas the earlier study by Kumar and Rangamani (1981) used the stimulus intensity of 100dBSPL.

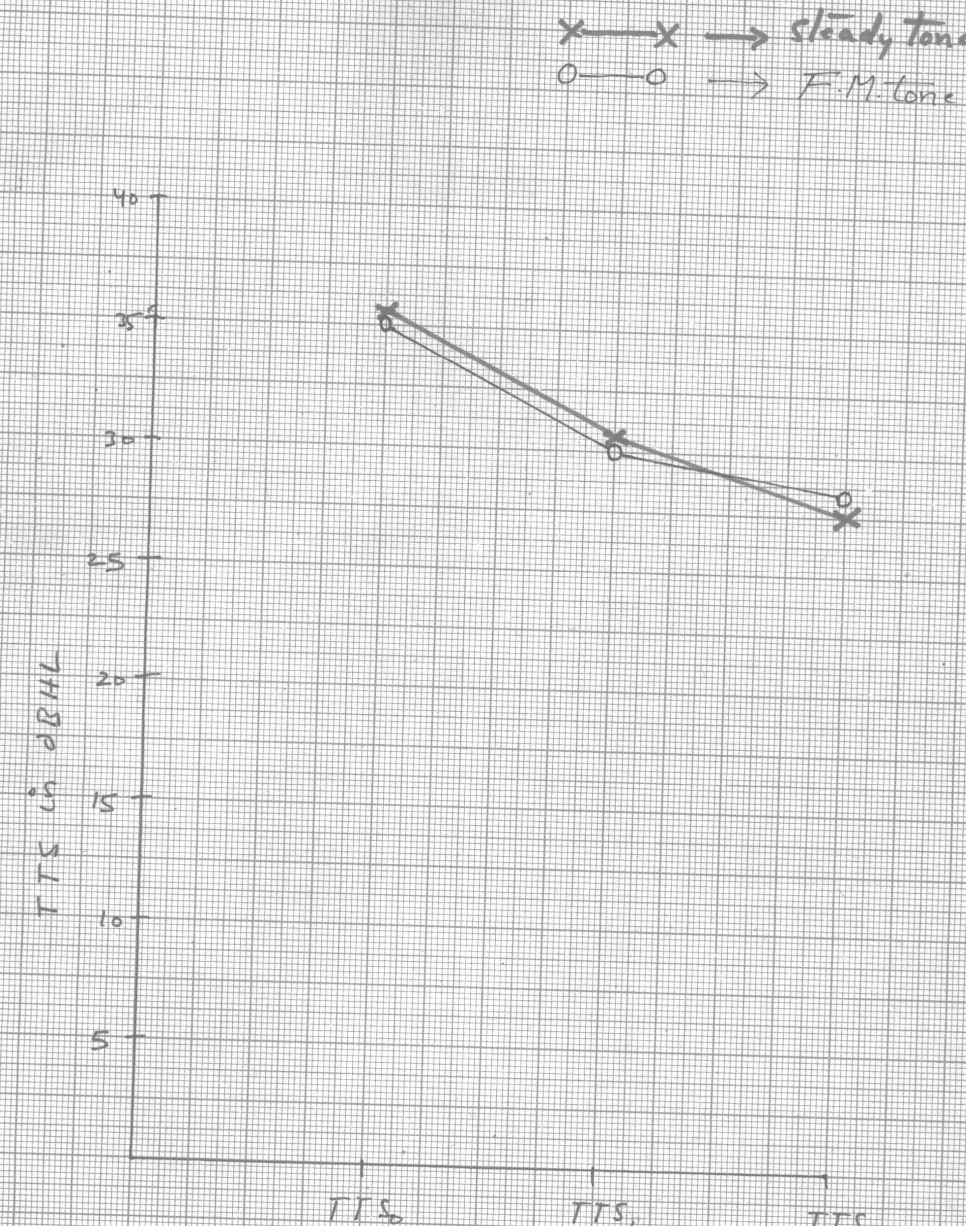
To study the amount of TTS produced by steady tone and frequency modulated tone further investigation with differrent test fatiguing frequency and stimulus intensity should be carried out.

Table-1: Temporary threshold shift in dBHL (TTS_o, TTS_1, and TTS_2) at 4KHz (Fatiguing stimulus 2KHz for steady tones).

Subjects	TTS_o	TTS_1	TTS_2
1	30	25	25
2	35	35	20
3	40	35	35
4	30	25	25
5	40	30	30
6	35	30	30
7	35	35	30
8	35	30	25
9	40	35	25
10	35	30	20
Mean	35.5	31	27.5
Standard Deviation	3.69	3.94	4.03

Table-2: Temporary threshold shift in dBHL (TTSo, TTS1 and TTS_2) at 4KHz (fatiguing stimulus 2KHz) for frequency modulated tone.

Subjects	TTS_o	TTS_1	TTS_2
1	35	30	30
2	30	30	25
3	45	40	35
4	30	30	30
5	45	40	35
6	35	25	25
7	30	25	25
8	35	30	30
9	35	35	20
10	30	25	25
Mean	35	30	28
Standard Deviation	5.77	5.77	4.58



Mean values of TTS0, TTS1 and TTS2 for FM tone and steady tone.

SUMMARY AND CONCLUSION

The present study was aimed to test the following null hypothesis.

"There is no significant difference in the amount of TTS produced by steady and frequency modulated tone".

Ten subjects in the age range of 17 to 23 years with a median age of 20 years were given a exposure of 2KHz steady tone and frequency modulated tone at 110dB HL for 10 minutes. All subjects were screened at 20dB HL (ANSI: 1969) at frequencies from 250Hz to 8000Hz at octave intervals to find out the presence or absence of hearing loss in both the ears. Thresholds were obtained at 4KHz for pre exposure and post exposure for both the stimuli. TTS_o, TTS_1 and TTS_2 were calculated for each subject. Wilcoxon matched-pairs signed rank test was used to examine the statistically significant difference between the two stimuli.

The findings of the present study indicated that there is no significant difference in amount of TTS produced by steady tone and frequency modulated tone and hence the null hypothesis has been accepted.

Limitations of the study:

1. Small number of subjects were tested.
2. Only one frequency i.e. 2KHz was used as fatiguing stimulus
3. Only one intensity level i.e. 110dBHL was used as fatiguing stimulus.
4. The frequency modulation of $\pm 5\%$ of the centre frequency at a rate of 5Hz was only used.

Recommendation for future research:

1. The same experiment can be carried out on large sample.
2. Different fatiguing frequency (i.e. low as well as high) can be used to study the phenomena of TTS produced by steady tone and frequency modulated tone in depth.
3. Different intensity levels can be used in future investigations.
4. Higher frequency modulation can be used in order to highlight the amount of TTS produced by such stimuli.

BIBLIOGRAPHY

Axelsson and Lindgren (1978) "Temporary threshold shift after exposure to pop music". Scan.Aud. Vol.7, 127-135.

Babighian, G. et al (1975) "Central Auditory Fatigue". Audiology, Vol.14, 72-83.

Bhatt, S., (1987) "Ear difference in temporary threshold shift for monaural stimulation", Independent Project, A.I.I.S.H. University of Mysore.

Bekesy Von, G., (1979) "The resonance curve and the decay period at various points on the cochlear pertition", J.Acoust. Soc.Am. Vol.21, 245-254.

Bishnoi, G.D., (1975) "Distribution of individual suscep-tibility for noise induced hearing loss as measured using Wilson's Test in Indian Popul-tion". Unpublished Master's Dissertation, University of Mysore.

Burdick, C.K. et al (1977) "Threshold shifts in chinchillas Exposed to low frequency noise for nine days". J.Acoust.Soc.Am. Suppl.1. 63-S.95.

Chernyak, R.I. (1958) "Alteration in the adaptation of the hearing to silence with relation to the duration of a preliminary loud noise", Biofizika 3, 75-86.

Corso, J.F. (1967) "The experimental psychology of sensory behaviour". New York, Holt, Rinehart and Winston, Inc, 371-336.

Davis, H., et al. (1950) "Temporary deafness following expo-sure to loud toens and noise". Acta Otolaryngol. Suppl.No.88.

Dayal, S.V. (1973) "A study of crossed olivo cochlear bundle on adaptation of auditory action potentials". Laryngoscoope, Vol.82, 693-711.

Dengerink, J.E. et al (1984) "Gender and oral contraceptive effects on temporary auditory effects of noise Audiology, Vol.23, 411-425.

Eggermont, J.J., (1985) “Peripheral auditory adaptation and fatigue – A model oriented review. Hearing Research, Vol.18, 1, 57-71.

Elliot, N., and Winifred, R.F., (1970) “Fatigue and Adaptation in Foundation of Modern Auditory Theory”. Jerry V.Tobias (Ed) New York, Academic Press.

Fiatkowska, M.O., et al. (1983) “Studies on temporary effect of noise on the auditory function in man”. Scand.Audiol. Vol.12, 295-298.

Glorig, A., et al (1957) “1954 Wisconsis state fair hearing survey sub-committee on noise”. Quoted by Nerbonne and Hardick (1971).

Hirsh, I.J., and Bilger, R.C., (1955) “Auditory threshold recovery after exposure to pure-tones”. J.Acoust.Soc.Am. Vol.27, 1186-1197.

Hirsh, I.J. (1958) “Monoaural temporary threshold shift following monoaural and binaural exposure”. J.Acoust.Soc.Am. Vol.30, 912-914.

Humes, L.E., (1970) “Temporary threshold shift for masked pure tones”. Audiology, Vol.19, 335-345.

Jerger,J., and Jerger, S., (1970) “Temporary threshold shifts in Rock and Roll Musicians”. J.Sp. Hg.Res. Vol.13, 218-224.

Karlovich, R., and Wiley, T., (1974) “Spectral and temporal parameters of contralateral signals altering temporary threshold shift”. JSHR, Vol.17, 41-50.

Karlovich, R.S., (1975) “Comments on relations between auditory fatigue and Iris-pigmentation”, Audiology Vol.14, 238-243.

Kryter, K.D.,(1950) “The effects of noise an man”, KSHD Monograph supplement No.1

Kumar, P.J., and Rangamani, G.N., (1983) “TTs2 for pure tone and warble tone.” Hearing Aid Journal, Jul-Dec 1983.

Lehnhardt. E., (1959):Quoted by Ward (1963) in Modern Development in Audiology. Jerger (Ed.) New York, Academic Press.

Loeb, M., and Fletcher, J., (1963) “Temporary threshold shift for ‘normal’ subjects as a function of age and sex”. J.Aud.Research. Vol.3, 65-72.

Loeb, M., and Fletcher, J., (1968) “Impulse duration and TTS”. JASA, Vol.44, 1524-1528.

Lindgren, F., Axelsson, A., (1983) “TTS after exposure to noise and music of equal energy”. Ear. Hear. July-Aug. 4(4) 197-201.

McFadden, D., and Plattshier,H.S., (1983) “Frequency patterns of TTS for different exposure intensitites”. J.Acoust.Soc.Am. Vol.74, 1178-1184.

Melnick, W., (1967) “Effect of two interaural phase conditions for binaural exposures on threshold shift”, JASA, Vol.42, 179-184.

Mills and Lilly (1971) “Temporary threshold shifts produced by pure tones and by noise in absence of acoustic reflex”, JASA, Vol.50, No.6, Part-2, 1556.

Mills, et al. (1983) “Temporary threshold shifts produced by exposure to low frequency noise”, JASA, Vol.73, 918-923.

Moore, C.J., (1977) “Introduction to the psychology of hearing”, London, The MacMillan Press, Ltd.

Mortis, M., (1958) “Quoted by Ward (1963) in Modern Development in Audiology, Jerger (Ed), New York, Academic Press.

Murthy, M., (1987) “TTS at high frequency noise and at high frequency prue tone” Independent Project, A.I.I.S.H., University of Mysore.

Nerbonne, M.A., and Herdick, F.S., (1971) “Further observations on temporary threshold shfit and sex”, J.AuduResearch. Vol.11, 279-285.

Nigam, R., (1987) “Sex differences in auditory fatigue”, Independent Project, A.I.I.S.H., University of Mysore.

Rintlemann, W.F., Lindberg, R.F., and Smitley, E.K., (1972) “Temporary threshold shift and recovery ptterns from 2 types of rock and roll music presentation”. JASA, Vol.51, 1249-1255.

Rol, C., (1956) “Auditory fatigue following exposure to steady and non-steady sounds”. Thesis, Univ. of Leiden, cited by Bishnoi (1975).

Shivshankar, N., (1976) “Temproary threshold shifts following monoaural and binaural exposure to high frequency puretones”, Master’s Disservation, University of Mysore.

Siegel, S., (1956)”Nonparametric – statistics for the Behavioural Sciences”, New York, McGraw-Hill.

Sinha, P.K., (1985) “Temporary threshold shift and efferent Action”, Master’s dissertation, A.I.I.S.H., University of Mysore.

Smith, R.P., and Loeb.M., (1968) “Recovery from TTS as a function of test and exposure frequencies”. J.Acoust.Soc.Am., Vol.44, 252.

Sreemati (1981) “Effect of articulation on auditory fatigue” Master’s dissertation, A.I.I.S.H., University of Mysore.

Tempest, W., (1985)”Temporary threshold shfit”, in Tempest W., (Editor) “The Noise handbook”, London, Academic Press, (65).

Tota and Bocci (1967) Quoted by Karlovich (1975) Audiology, Vol.14, 238-243.

Wlvich, R.F., and Pinheiro, (1974) “Temporary hearing losses in teenagers attending repeated rock and roll sessions”. Acta Otolaryngol. Vol.77, 51-55.

Vyasamurthy, M.N., et al. (1973) “Vertification of critical band hypothesis to explain the discrepancy in amounts of TTS produced by noise and tones when presented at equal intensity and for equal duration”. JAIISH, Vol.4, 131-134.

Ward, W.D, Glorig, A., and Sklar, D.L., (1959) “Suscepti-bility and sex”, J.of Acoust.Soc.Am. Vol.31, No.8, 1138-1142.

Ward,W.D., Glorig, A., and Sklar, D.L., (1959b) “TTS produced by intermittent exposure to noise” J.Acoust.Soc.Am. Vol.31, 791-794.

Ward, W.D., (1960a) “Latent and residual effects in TTs” J.Acoust.Soc.Am. Vol.32, 497-500.

Ward, W.D., (1960b) “Recovery from high values of TTS”. J.Acoust.Soc.Am., Vol.32, 135-137.

Ward, W.D., (1961) “Non-international TTS”, J.Acoust. Soc. Am., Vol.33, 512-513.

Ward, W.D., (1963) “Auditory fatigue and masking”. In Jerger,J., (Ed) Modern Development in Audio-logy. New York, Academic Press.

Ward, W.D., (1966) “Temporary threshold shifts in males and Females”. J.Acoust.Soc.Am., Vol.40, 478-485.

Yamamoto, et al. (1970) “Critical Bandwidth with respect to temporary threshold shifts”. J.Acoust.Soc. Am., Vol.48, 978-987.

Yokoyama, et al (1974) “TTS produced by exposure to vibra-tion noise, and vibration-plus-noise”. Acta. Oto-Laryngol. Vol.78, Vol.3, 207-212).
