TEMPORARY THRESHOLD SHIFTS
FOR
MULTIPLE FREQUENCIES

Register No 8511

An Independent project submitted as part fulfilment for
First year M.Sc. (Speech and Hearing)
to the University of Mysore

All India Institute of Speech & Hearing
MYSORE-570006.

to Manju

One who stood by me

in the weakest of the moments

CERTIFICATE

This is to certify that the Independent project entitled:TEMPORARY THRESHOLD SHIFTS FOR MULTIPLE FREQUENCIES is the bonafide work, done in part fulfilment for First Year M.So., (Speech and Hearing) of the student with Register No. 8511

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CERTIFICATE

This is to certify that the Independent project entitled: TEMPORARY THRESHOLD SHIFTS FOR MULTIPLE FREQUENCIES has been prepared under my supervision and guidance.

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DECLARATION

This Independent Project Entitled: TEMPORARY THRESHOLD SHIFTS FOR MULTIPLE FREQUENCIES is the result of my own study done under the guidance of Dr.M.N.Vyasamurthy, 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.

Mysore REGISTER No. 8511

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CONTENTS

INTRODUCTION

Temporary threshold shift (TTS) refers to any post stimulatory shift in auditory threshold (Ward, 1963) and threshold returns back to pre-stimulated levels after certain amount of time. Temporary threshold shifts are often used to predict noise induced hearing loss (NIHL) and various susceptibility tests have been devised. However, relation of TTS and NIHL has not been consistently found*

The traditional approach to studies in NIHL has been to divide the research into three main divisions, psychophysical, behavioral and animal experimentation. Various animal species have been exposed to different types of noises and the temporary and permanent threshold shifts have been determined. Based on such experiments and also on human beings, various criteria have been developed to devise what are referred to as Damage risk criteria.

The degree of TTS and recovery from TTS vary in accordance to several variables. Stimulus parameters are also effective variables. TTS for pure tones is found to be more than for noise, and the narrow band noise causes more TTS than broad band noise.

Recently, it has been shown experimentally that two pure tones cause lesser TTS and PTS (Permanent Threshold Shift) than caused by either of the tones presented singly (Cody and Johnstone, 1982). This study was done on guineapigs and both TTS and PTS was measured for single 16 KHz pure tone and for 16 KHz pure tone in combination with a lower frequency pure tone at different intensities of the second tone. The differences in TTS and PTS were significantly lesser in the latter condition. The reduced threshold shift disappears as the intensity of the second tone decrease.

The above phenomenon was explained on two tone suppression. The two tone suppression has been demonstrated earlier by many researchers by doing electrophysiological studies on auditory nerve fibres, hair cells etc. Sachs and Kiang (1968) measured spike discharges from single fibres in auditory nerve of anesthetized cats with micro electrodes and found that second tone diminishes the response of auditory nerve to the first tone if appropriate stimulus parameters are choosen. This behavior can be seen in acoustically evoked cochlear potentials also.

This study was undertaken to find out whether the results of Cody and Johnstone (1982) hold good with human subjects also. This study was a psychophysical study.

Statement of the problem:

The present study was undertaken to answer whether multiple tone exposures cause lesser TTS than single tone exposures.

Hypothesis:

The following hypothesis has been proposed: "Multiple tone exposures and single tone exposures do not produce significant difference in TTS".

Definitions of the terms used in the study:

TTS_1: Temporary threshold shift measured one minute after the cessation of fatiguing stimulus.

TTS_2: Temporary threshold shift measured two minutes after the cessation of fatiguing stimulus.

Two tone suppression: The reduction in the responsiveness of nerve fibres to one tone due to presence of other tone is called two tone suppression.

Single tone exposure: When a single pure tone is presented as fatiguing stimulus.

Multiple tone exposure: When two pure tones are presented simultaneously as fatiguing stimulus.

REVIEW OF LITERATURE

Review of literature will be covered under three main topics:

1. General information about temporary threshold shifts.
2. Two-tone suppression phenomenon, and
3. TTS as Indicative of two-tone suppression phenomenon.

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

Auditory fatigue is one of a number of terms used to describe a temporary change in threshold sensitivity following exposure to another auditory stimulus. The most common index for auditory fatigue is the temporary threshold shift (TTS) which indicates any post stimulatory shift in auditory threshold that recovers over time. Auditory fatigue is a time-linked process, i.e. it grows with duration of exposures (with minor exceptions) and disappears as a function of time since exposure.

(Ward, 1963).

Growth of TTS is dependent on several factors. All the parameters which are measurable can affect the growth of TTS. If the fatiguing stimulus is a pure tone, its frequency, intensity and duration will become relevant factors. For continuous noise, the level, band width, duration and peak factor are the salient aspects. In case of impulses and explosions, the peak intensity rise time, number of impulses and duration of exposure all determine the TTS produced. If the fatiguer is a combination of tones and noises and/or pulses, still other rules seems to apply. If the fatiguer varies over time im its characteristics, the TTS produced will be less than that produced by the same amount of energy in a steady exposure.

(Ward, 1963).

. Furthermore, the parameters are in many cases, interactive, like duration, intensity, frequency etc. effect each other in complex manner. Also there are large inter-individual variations.

(Ward, 1963).

Factors affecting TTS are the following:

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

(Ward, 1963).

For octave band noise, for recovery times less than a second and longer than 2 minutes, the TTS is proportional to the amount by which the sound pressure level exceeds some base value (75 dB for octave band noise).

(Ward, 1963) .

Exception to the rule that TTS increases with intensity occurs at very high levels (Davis et al., 1950). They observed that exposure to 130 dB SPL produced less TTS than the same exposure at 125 dB SPL which was attributed to change in the mode of stapes vibration which in turn might have been due to maximum middle ear muscle contraction.

(Davis et al., 1950)

At intensity levels around 80-120 dB SPL, middle ear muscles come into action 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 2 KHz.

(Ward, 1963) .

2. Test 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 frequencies. As one raises the level, higher frequencies are sometimes more effected. Generally the maximum TTS observed is half octave to an octave above the stimulating frequency.

(Ward, 1963) .

3. <u>Exposure frequency</u>: A safe generalization that can be made is that the higher, the frequency , at least upto 4 or 6 KHz, the more the TTS will be produced.

(Ward, 1963).

Pure tones are assumed to be more dangerous than octave bands of noise (Anonymous 1956) more prominently seen below 2000 Hz. This has been explained on the basis of reflex action. Pure tones produce acoustic reflex but the muscles, after an initial contraction, rapidly relax. But a noise, presumably due to its random nature, continuously rearouses the reflex. So more energy reaches cochlea when pure tones are presented. This effect is not seen at higher frequencies because middle ear reflex action is not very prominent at higher frequencies.

(Ward, 1963).

4. <u>Duration of exposure</u>: The TTS grows linearly with the logarithm of time. But 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, so the TTS gets positively accelerated.

(Selters, 1962, cited by Ward, 1963).

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. His test tone was a 20-or 30- msec, pulse of the same frequency as the exposure pulses with a delay pause of 50 msec. 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).

5. Intermittent exposures: When the exposure is intermittent or varies in level with time, the action of the middle ear muscles becomes even more important because the rests in between stimuli restore the contractile strength to the muscles. If exposure stimulus is only on a certain fraction R of the time, than the TTS produced will be only R times as great as that produced by a continuous exposure at that level (Ward et al., 1958). This relation holds for bursts ranging from a quarter of a second (Rol, 1956) upto about 2 minutes (Belters and Ward, 1962). Beyond these limits, more TTS is produced than the above relation would predict.

For noise bursts longer than 2 minutes, the net effect at the end of the exposure can be calculated by (1) equations describing the growth of TTS in a steady noise (Ward et al., 1959a) and (2) exposure - equivalent rule (Ward et al., 1959c).

For noise which varies over time in intensity we can take the average SPL value (above the base level) and calculate the TTS accordingly.

(Ward, et al,, 1958)

While the level is below the base level, the recovery proceeds just as fast as if the ear werein complete quite.

(Ward, 1960a).

Recovery From TTS:

Once a given TTS has been generated, it tends, by and large, to recover at a certain rate that depends very little on how the TTS was produced. (Ward et al., 1959b; Kylin 1960). The recovery is usually exponential in form - faster at first, slower later - so a straight line is got if TTS is plotted against the logarithm of recovery time. This holds good of recovery processes at very short times and also after about 2 minutes. Since the graphs are usually straight lines, one can predict TTS after some duration if TTS_2 is known.

(Ward, 1963)

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

(Ward, 1963)

The most well-known exception to the rule that recovery is linear in log.time is the so called "bounce" phenomenon that sometimes occurs in the first two minutes of recovery (Hirsh and Ward, 1952). Though the recovery during this time is smooth and monotonic, certain exposures produce quite different results i.e. multiphasic recovery curves are sometimes found. The TTS. may be greater than TTS when t = 30 seconds. This is explained on the basis of two processes R_1 and R_2. R_1 is supposed to be facilitatory i.e. causes improvement in threshold and R_2 causes fatigue. R_1 lasts only for one minute thus any TTS measurements during the first minute will be lesser than TTS measured just after first minute.

(Hirsh and Bilger, 1955).

A second exception to the linearity of recovery is when TTS_3 is greater than 50 dB. In such cases, recovery is very slow and, instead of being linear In log.time, recovery proceeds linearly in time (Ward 1960b). Several weeks may be required for complete recovery (Davis et al., 1950).

Miscellaneous Factors Affecting TTS:

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

1. 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 on basilar membrane, neither had any effect on the other.

(Ward, 1961a).

2. Hearing level or resting threshold: TTS is inversely proportional to hearing level i.e. if thresholds are higher, TTS produced is lower. 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 also will show less TTS than normal individuals, but only because the have less to loose, as it were (energy entering cochlea is same as in a normal hearing individual).

(Ward, 1963).

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

(Morita, 1958).

4. Latent and residual effects: Noises which fail to produce a measurable TTS_2 do not enhance to a measurable degree the magnitude of TTS produced by a subsequent exposure. Thus latent effect of stimulation are unimportant.

(Ward, 1960a).

Harris (1955) shows presence of residual effects. He restimulated his cases many times after the TTS due to previous exposu: reached zero. He found increments in TTS in every subsequent exposure.

(Harris, 1955).

5. Vitamin-A: 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).

6. Oxygen: It is known that adequate oxygen is necessary for normal functioning. But excess of 0- does not have any effect on course of fatigue as already demonstrated* Anoaia causing Increased TTS has not been demonstrated in humans but it is already shown in guineapigs. Reduction in cochlear microphonics was more when the animals were in 10% oxygen state throughout the experiment (38 minutes) than when they were in 10%. Oxygen atmosphere for only 5 minutes (preexposure period) .

(Hirsh and Ward, 1952).

7. Salt: Excessive use of ordinary salt may increase TTS (Cook, 1952). But it is only a speculation and no experimental data have been obtained in this direction.

(Ward, 1963).

8. Drugs and level of conciousness: TTS mainly being a peripheral physiological process, changes in TTS associated with changes in levels of conciousness are minor. The data in general support the lack of central involvement in TTS. It is immaterial whether subject is reading, thinking or not concentrating at all during the experiment.

(Ward, 1963).

Drugs, especially myorelaxins have effect i.e. more TTS is seen because middle ear muscles will be inoperative.

It has been shown that the locus of maximum shift was shifted down from 4KHz to 2.5 KHz when white noise was used as fatiguer and myorelaxins were administered. This also shows that middle ear muscles were inoperative.

(Lehnhardt, 1959).

9. Auditory fatigue and the sex difference: Hearing surveys invariably indicate that women have more sensitive hearing than at high frequencies by the time they reach their 20's and that the difference increase with age. (Wiscoxin state fair survey, 1954). This might be due to the fact that men are more often exposed to hazardous experiences like industrial noises, gunfire, firewords, and blows and head etc. than women.

(Ward, 1963).

An experiment was designed to test the hypothesis that there is a difference between men and women in susceptibility to TTS. The TTS at 3KHz and 4KHz produced by one hour exposure to a noise of 1200-2400Hz at 100 dB SPL was measured on 30 normal hearing college students 15 men and 15 women. The TTS was measured at the end of the exposure and also at 17.47 and 90 minutes after cessation of the noise. Women showed slightly less TTS than men, though difference was not significant. It was concluded that no apparent sex linked difference existed between males and females in the amount of TTS experienced or in the rate of recovery from the TTS.

(Ward, 1959).

Fletcher and Loeh (1963) investigated the relationship between sex and susceptibility to TTS and found no difference between males and females in the amount of TTS experienced at 4KHz, but did discover a significant greater amount of TTS in the females at 2KHz.

Ward (1966) made various measurements of TTS from high intensity tones and noise were made on 24 male and 25 female young normal hearing adults. Significantly more TTS warn produced in males by low frequency stimuli (below l000Hz) and significantly less by high frequency stimuli (above 2800Hz). No differences between sexes in TTS from low intensity (40 dB SL) in auditory adaptation, in rate of recovery from a fixed value of TTS or in TTS produced by impulse noise could be demonstrated. Males showed about 30% more TTS than females following low frequency (700Hz and below) exposure, about 30% less TTS following high frequency exposure, with a neutral point at about 2000Hz. The females showed a greater dimontion in TTS produced by intermittent noise relative to that from a continuous noise.

These data are consistent with the hypothesis that females have more efficient middle ear muscles than males, provided that strong construction of these muscles not only reduces the transmission of low frequency energy but also enhances the transmission of high frequency sounds.

(Ward, 1966).

It was found that though males and females experienced similar amounts of TTS immediately following exposure, the females showed faster rates of recovery, even when the initial amount of TTS was held constant for each sex.

(Nerbonne and Hardick, 1971).

10. A TTS and Ear difference: Right and left ears of human beings are often shown to be having differential abilities to process auditory stimuli. Similarly, ear differences in auditory fatigue has been reported.

Glorig and Rogers (1965) found that right ear was better in high frequency and left ear in the 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.

Jerger (1976) showed similar differential effects in the TTS in the 2 ears.

Weiler et al (1974) investigated the hearing of 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 110 dB to 115 dB. Significant TTS were found in all subjects, especially in the high frequencies. The exposure had differential effects on the 2 ears at the same test frequencies.

The left ear showed a significant increase in TTS at 4KHz for the last session and a significant decrease in TTS at 500Hz and l000Hz. The right ear had significantly greater TTS at 1KHz and at 4KHz for the last exposure with an increment in threshold shift apparent in all test frequencies. The average TTS was greater at 250 Hz and 500Hz in the right ear. The left ear had more TTS than right ear at lOOOHz and 2000Hz and right ear had more TTS at 4KHz and 8KHz than the left ear. The project followed the subjects through a series of weekly exposure to rock and roll music. Mean right ear TTS was greater for the final exposure at all frequencies left ear TTS for the final session only at frequencies about 2000 Hz.

(Weiler et al., 1974).

Axelson and Lindgren (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 difference between th e right ear and left ear in that the left ear was better in the high frequency.

The microscopic physical variation between the 2 ears 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 point.

(Weiler, 1964).

11. Binaural and Monoaural stimulation in TTS: Monoaural TTS was studied following monoaural and binaural exposures under 3 experimental conditions to ascertain whether or not TTS depends upon whether one ear or both ears were exposed to sound. The results showed that the TTS for 1KHz tone is the same Whether the ear was tested alone,or both ears simultaneously.

(Hirsh, 1958).

A similar study was done to compare the TTS following monoaural and binaural exposures to three different high intensity stimuli. The maximum effect occurred at 2KHz where the binaural exposure gave less TTS as compared to monoaural exposure. This reduction in TTS was explained in terms of feedback loop and it was reported that with the increased input when the second ear is stimulated, the total activity of reflex centre also increased in middle ear muscle activity.

(Ward, 1965).

It was found that more TTS occurred when the exposure signal was 180^o out of phase in the experiment on the effect of two interaural phase conditions for binaural exposures on threshold shift.

(Melnick, 1967)

Shivashankar (1976) has reported that there is no significant difference in TTS between monoaural and binaural exposure to high frequencytones, especially at 3 KHz at TTS_2. This could be attributed to the action of homolateral olivo-cochlear bundle which might inhibit the responses of the higher centres, as crossedolivo-cochlear bundle does not play a role in adaptation mechanism at high frequency.

(Dayal, 1972).

12. TTS and articulation/phonation: TTS is reported to be less while subjects articulate during exposure.

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 atleast coincided with speech output. The occurrence of acoustic Impedance slightly before speech output would indicate that the stapedius muscle (Metz, 1946) under these circumstances is activated concurrently with the speech musculature. So the middle ear activity is part of neurological pattern in the production of speech.

Another change in peripheral auditory transmission system is alteration in the vibration pattern of the stapes which reduces the motion of cochlear fluids.

(Bekesy, 1960).

The effects of humming were studied on TTS from a 5 minutes 500Hz 118 dB SPL exposure. The experimental technique consisted of measuring hearing thresholds at 700 Hz before and after exposure, this exposure being accompanied by the performance of a specific activity such as humming. Results indicated that TTS from the exposure accompanied by humming was significantly less than TTS from exposure without any supplementary activity.

(Benquerel and McBay, 1972

Ward (1963) implied that the middle ear muscle reflex shows less adaptation and more potential for reactivation when a change or intermittent acoustic stimuli is presented to the ear. So the articulation causes continuous reactivation thus less energy reaches cochlea and thus less TTS is observed.

Shreemati (1981) has studied the effect of articulation on auditory fatigue. Subjects were asked to read a passage in exper mental condition. TTS in experimental condition was lesser than TTS in control condition in which subjects maintained silence. This effect was seen at 1KHz but not at 4KHz were middle ear reflex function is not effective.

(Shreemati, 1981).

13. <u>Central factors</u>: Though TTS is thought to be a peripheral phenomenon, many experimenters have reported the presence of central factors.

A study on central factors was done in pure tone auditory fatigue. The subjects were exposed to 4000Hz at 40 or 90 dB SPL for 3 minutes under conditions of (a) mental task and (b) Revire. Subjects consistently showed greater TTS and longer recovery time when the fatiguing stimulus was present in the mental task condition. These results indicated central factor involvement.

(Wernick and Tobias, 1963).

In an electrophysiological study, rats were exposed to continuous sound. A decrease in cochlear microphonics, action potentials and impulses from inferior colliculus was found. But reduction in impulses from inferior colliculus was more and it was concluded that central factors were involved.

(Babighian,1975).

But different findings have also been reported. In a study, 12 subjects were exposed to a 4KHz tone at 100 dB SPL for 3 minutes under 2 conditions, (a) sitting guitely and (b) adding columns of the figures. Pre— and post-exposure thresholds at 5.6 KHz were determined with Bekesy audiometry using interrupted tones. No significant differences in TTS were found at any time after exposure, in fact the greatest mean difference at any time was in opposite direction. The TTS at 2 minutes 15 seconds was 14 dB for revire condition and 12 dB for the mental task. It is concluded that the efferent system need not be involved to account for any aspect of auditory fatigue.

(Ward and Sweet, 1963).

EFFECTS OF NOISE ON COCHLEAE POTENTIALS:

(a) Changes in summating potentials (SP):

It has been reported that SP DIP (recorded by differential electrodes) is much more sensitive to effects of noise than CM and AP, which suggests that marked changes can be produced in the SP even in cases where the CM is badly affected. It is reported that there is a trend towards less depression in the SP from the lower to the upper turn. In the first turn, SP is usually more depressed than CM. In the third turn, the opposite is nearly always observed, at least in the initial phase of recovery. The second turn data are immediate. Only the negative SP was investigated using tone-burst stimuli presented at levels within the linear range of the CM input-output function.

(Durrant, 1976).

Legoulx and Pierson (1978) did a study on guineapigs and found that there is a relation between the voltage of the negative SP for a given stimulus and the susceptibility to fatigue i.e. individualistic variation in amplitude of SP. They report that these variations are not know whether this is due to some cochlear pathology or normal ear features - the cochlear which show the largest negative SP are more susceptible to fatigue.

(cited by Legouix and Pierson, 1981).

(**b) Effects on endocochlear potential (EP)**:

Little research appears to have been designed to determine the susceptibility of EP to acoustic trauma.

Legouix and Pierson,(1981) have summarized the information as follows:

"As a result of prolonged exposure, no permanent changes in EP could be demonstrated (Benitex et al., 1972). However, Johnstone and Sellick, (1972) reported that EP could be potentiated following exposure to on Intense pure tone".

(**c) Effects on cochlear action potentials(CAP)**:

Since activity in auditory fibers embodies auditory information, it would be logical to relate hearing losses to a decrease of CAP. Generally CAP is more easily depressed by the action of high intensity noise than is cochlear microphonics.

(Legouix and Pierson, 1981).

Various characteristics of CAP can be altered by the effect of noise. The waveform may be modified, a result related to inactivation of a particular group of fibres or to the desynchronization of unit potentials. The CAP latency is also modified by noise exposure. When measured at the same suprethreshold intensity before and after exposure, latency is increased. When measured at threshold intensity, it is not modified.

(Smoorenburg and Van Heusden, 1979).

(d) Effects on unit responses of audiotorv nerve:

In an experiment,changes in threshold of auditory nerve in chinchillas were measured after an exposure to an octave band of noise centred at 4KHz and having a SPL of 86 dB during 5 days. After a recovery period of approximately 6 months, behavioral threshold was compared to auditory nerve fibre thresholds. The fibre thresholds were elevated upto 70 dB for units with a CF between 4 and 14KHz. Smaller shifts were seen in the behavioral thresholds. The results demonstrated that damage occurred in a cochlear region tuned about 1 octave above the centre frequency of the noise exposure.

(Salvi, et al., 1979).

(e) Changes in cochlear microphonics (CM):

Legouix and Pierson (1981) write that the depression of CM after noise exposure is a clear sign of a traumatic effect on the sensory cells and that the deterioration of these cells may result from various mechanisms that follow different time courses and some are reversible and other ate not. Further they write that some research has made use of a single electrode in contact with the round-window membrane, and the results give information about the basal turn only. Differential electrodes provide the possibility of recording the CM at various locations along the basilar membrane.

CMs have been measured in the three cochlear turns of chinchillas after fatiguing by 500Hz tone. The; third turn was more affected rather than the other turns.
(Benitez, et al., 1972).

A greater reduction of the response at high levels was reported so that the input-output curve was truncated(Tondorf and Brogan, 1952). In some particular cases, Lawrence (1958) observed a non-monotonic input-output function following exposure. Eldredge and Covell (1958) report that narrow band noises were more effective in producing CM reduction than pure tomes presented at an SPL equal to overall SPL of the noise.

2. Two Tone Suppression:

It is well known that single tones produce excitation in auditory nerve fibres, and never sustained inhibition. But if two tones are presented simultaneously, then one stimulus can affect the responsiveness of nerve fibres to the other stimulus. If relative frequencies and intensities of the tones are arranged correctly, the second tone can inhibit, or suppress.

the response to the first. This occurs despite the fact that second tone as such produces excitation and no inhibition of spontaneous activity when presented alone.

(Pickles, 1982).

Nonlinear effects result when the cochlear partition is stimulated by a sinusoid whose frequency falls in a very narrow frequency band surrounding, but not including, the resonant frequency at the point under the recording electrode. These nonlinear effects are manifested as a negative shift in the dc potential accompanied by a partial or complete suppression of the cochlear microphonic potential to a second tone presented at the same time. This suppression is best seen in the first and second turns of cochlea. It was also demonstrated that it is a mechanical interaction which is taking place.

It is reported that:

"...Similar (to that of two tone suppression) suppression effects accompanying a dc shift are obtained by artificially displacing the basilar membrane from its resting position by an assymmetrical change in hydrostatic pressure in the perilymph. (It can be concluded...)... that inhibitory effects seen in nerve fibres, stimulated by two tones simultaneously, reflect mechanical events in the cochlear partition and subsequent changes in the effective stimulating waveform triggering the auditory nerve".

(Legouix et al., 1973).

When a post stimulus histogram is plotted, the pattern of response to the suppressing tone looks like the inverse of the pattern to an excitatory one. An initial maximum of the suppression is seen the moment the suppressing tone is turned on and a prominent rebound of the activity is noticed the moment the tone is turned off. The dip in the activity at the beginning of the suppressing tone looks like the transient suppression seen at the end of an excitatory stimulus, and the activity at the end looks like the onset burst seen at the beginning of an excitatory stimulus. So it is as if the suppressing tone simply turns off the effect of the excitatory tone.

(Pickles, 1982).

This is further validated by the fact that only stimulus evoked, and not spontaneous, activity can be suppressed. Also, on average excitation and suppression differed in latency by 0.1 msec, this suggests strongly that suppression is not the result of inhibitory synapses in the cochlea as synaptic delays are not demonstrated. (Arthur, et al., 1971). So this also means that suppression cannot be due to activity of olivo-cochlear bundle which is the "feedback" pathway from the brainstem nuceli to the hair cells. (Pickles, 1982). Kiang et al., (1965) (as cited by Pickles, 1982) have shown directly by sectioning the olivocochlear bundle and still two-tone suppression was seen.

Since it is believed that two tone suppression is not the result of inhibitory synapses, the more neural term 'suppression' rather than 'inhibition' is often used, 'suppression' is only used for the process occuring in the cochlea. The interpretation of the mechanism is that the presence of one sound will affect the cochlea's responsiveness to another, perhaps by a mechanical interference in the transducer mechanism,

(Pickles, 1982).

Two-tone suppression phenomenon can be demonstrated in inner hair cells, stressing the notion that it is a cochlear phenomenon. It has been shown that the suppressing tone can reduce the response to the exciting tone when presented over a wide range of frequencies. The suppressive area is more broadly tuned than the excitatory response area and overlaps it at the tip. Stated otherwise, a stimulus can suppress even though it does not excite, and will still suppress the response to another stimulus, even though it excites when presented alone.

(Sellick and Russell, 1979)

The phenomenon of two tone suppression exists in auditory nerve fibres too. Nomoto, Suga and Katsuki (1964) did not find inhibition in every nerve fibre they studied. Thus there was some question whether all auditory nerve fibres exhibit two-tone suppression. Sachs and Kiang (1968) have shown in cats that it is found in all nerve fibres. In their study, spike discharges from single fibres in the auditory nerve of anesthetized cats (n=40) were recorded with microelectrodes. Rates of discharge were measured as a functions of the frequencies and levels of either single tone or two-tones presented simultaneously. They report as follows:

"We found that the presence of a second tone diminishes the response to the first tone if appropriate stimulus parameters are choosen. All fibres tested showed this two tone inhibition. The general characteristics of the inhibitory areas are found to be similar for a population of over 300 fibres".

(Sachs and Kiang, 1968).

Javel (1981) studied two-tone suppression in response pattern of single auditory nerve fibres in anesthetized cats (n=14). Utilizing suppression of discharge synchronization in response to low-and moderate- frequency tones as an index, it was found that (a) suppression behaves in the same manner when the suppresso tone presented alone is strongly excitatory as when it is ineffective in altering discharge rate; (b) suppression exists throughout an auditory nerve fibre's response area; (c) for fixed intensity suppressors, suppression is maximal at a fibre's characteristic frequency: and (d) suppression magnitude over a wide intensity range depends only upon the parameters of the suppressor tone and not of the ton e being suppressed. Me also states that:

"The data are in general agreement with previously published reports of suppression behavior, and they support the concept that suppression is generated primarily as a result of interactions occuring within hair cells or in the subtectorlal space".

(Javel, 1981).

If the second tone is in the suppressive area but outside the excitatory area, it will be easy to measure the suppression by measuring the total firing rate to the stimulus complex. The second tone produces only suppression and does not contribute any excitation. The overall mean firing rate will them be a measure of the activation produced by the excitatory tone and the extent to which it is suppressed.

(Pickles, 1982).

Plots of combinations of intensity and frequency necessary to reduce the mean firing rate in response to a constant axcitatory tone by a certain criterion amount (20% has been commonly taken) show the suppressive areas where they flank the excitatory areas (Sachs and Kiang, 1968; Arthur, et al,, 1971), Of course, when the suppressing tone reaches the boundary of the excitatory area it will begin to activate the fibre on its own account, and so the total number of action potentials will increase. Suppression areas plotted in this way therefore stop at, or near, the boundary of the excitatory area. All this indicates that a stimulus is able to reduce the driven response of fibres tuned to neighbouring frequencies. Two tone suppression is therefore able to increase the contrast in a complex sensory pattern, so that for instance, the peaks of activation produced by dominating frequencies will tend to stand out in stronger contrast against the background.

(Pickles, 1982).

Two-tone suppression is explained as dissipation of energy of one tone by the other tone through some nonlinear mechanism. It was attempted to explain the existence of two tone suppression by locating the nonlinear element between the stimulus input to the cochlea and the cochlear output, measured in this case as CM. The nonlinear network, consisting of three simple diode in cascade and low pass filter, was constructed to produce peak-clipping distortion similar to that seen in the cochlear microphonic of the basal turn of cochlea. The interference between pairs of tones was similar for the ear and the network.

(Engebratson and Eldredge,1968).

Pfeiffer (1970)modifled the cochlear microphonic model of Engebratson and Eldredge (1968) by enclosing the nonlinear section between linear band pass filters. This modifications gave the model a band pass property similar to that of a cochlear nerve fibre. This model has clear two-tone inhibition properties similar to those observed experimentally. Also there is no necessity to assume elaborate neural interconnection in order to produce the inhibition phenomenon. the states:

"In fact, in view of the analysis, it is clear that suppression is inhe-rent to the system and thus inhibition, if equated to suppression, is a result of the narrow-band system and not cause of it. The degree of suppression depends highly on the amount of filtering by the output bandpass filters of the suppressing signal. Although suppression is seem when input and output filters are identical, the degrees of suppression obtained more closely replicate inhibition observed from cochlear nerve fibres when the input filter has both a wider bandwidth than the output filter; and a less sharp cut-off on the low frequency side".

(Pfeiffer, 1970)

Sachs and Kiang (1969) have tried to give a mathemetical expression relating rate of discharge to parameters of a two-tone stimulus. The rate of response is written as the sum of a "spontaneous" part and a driven part. The driven part of the response to two-tones is a weighted sum of the driven parts of the responses to the individual tones presented alone. The equation is:

$$r(P_{cf},f_c,P_2,f_2) = R_{sp}+R(P_{cf},f_c)g(P_2/P_{cf}, f_c,f_2)+R(P_2f_2)$$

Where the inhibitory multiplier "g" has the same form is all regions; whether excitatory or inhibitory.

the L.H.S of the equation is the driven activity.

R is the spontaneous activity of a fibre.

R(P_f_) is the response of the fibre at level p.

(Sachs and Kiang, 1969).

There is some psychoacoustical evidence that two-tone suppression is not greatly influenced by the presence of a temporary threshold shift, smoorenberg (1980) has shown that two-tone suppression exists in a desensitized cochlea.

3. Two-Tone Suppression as indicated by reduced. TTS:

Recently it has been shown that two-tone suppression phenomenon can be studied by noticing the temporary threshold shifts produced by single tones and two tones presented simultaneously. Cody and Johnstone (1982) did study on anesthetized guineapigs (n=48) and report the following findings:

(1) "The combination of two pure tones delivered simultaneously reduces the TTS or PTS compared with the desensitization produced if the tones are presented alone.

(2) The reduction in desensitization is reciprocal, that is, both the primary and the secondary tone reduce the desensiti-, sation due to either tone presented alone.

(3) Although the maximum TTS due to the primary tone is initially the same after either a primary tone delivered alone or with a secondary tone, the recovery rate from that TTS is more rapid after a dual tone exposure",

(Cody and Johnstone, 1982).

METHODOLOGY

1. SUBJECTS:

Twelve subjects were selected (6 males and 6 females) in the age range of eighteen to twenty-one years. They were all otologically normal i.e. they never had any history of trauma or infection. The selection of subjects was done mainly on random basis. Hearing sensitivity of all the subjects were within 20 dBHL (ANSI,1969) for frequencies 500, 1000, 2000 and 4000Hz. None had reported exposures to high levels of noise for long periods.

2. EQUIPMENT:

The equipment used was clinical audiometer Beltone-200-C. The earphones were TDH-39 housed in MX41/AR ciroum aural cushion. The audiometer is a two channel equipment which enables presentation of two different frequencies at desired intensities into the same earphone.

(i) The attenuator was different for both channels.

(ii) The frequency selector is different for both channels,

(ill) A button on both panels enables as to give tones continuously.

3. TEST ENVIRONMENT:

The experiment was carried out in soundtreated room at the Audiology Department, All India Institute of Speech and Hearing, Mysore.

(a) Power Source: The power supply to the audiometer was stabilized

(b) Location of the instrument: It was a two-room situation. The audiometer was kept in the first room on a table and the subject sat in the second room on a comfortable Chair facing the observation window.

(1) Humidity was neither too high nor too low and both subject and experimenter were comfortable.

(ii) It was away from noisy, drafty or excessive vibration area.

(ill) The lighting was by incandescent lamps but shaded so diffuse lighting was present.

(iv) Central air cooling system was in operation.

4. PROCEDURE:

Prior to every test, the stabilizer output was checked to ensure that voltage remained within desired limits.

Instructions: The subjects were instructed to respond for pulsed-pure tones, whenever given. They were asked to listen quitely to fatiguing stimulus without talking. Again after fatiguing, they were asked to respond to pulsed-pure tones for threshold measurements*

The subjects were comfortably seated in the second room. Then thresholds for both the ears were determined using pulsed-pure tones of frequencies l000Hz, 2000Hz and 4000Hz. The ear with better thresholds was preferred for experiment (only one ear of each subject was tested). If both the ears had similar thresholds, right ear was preferred.

Then they were exposed to fatiguing stimulus in the following manner:

(i) Single tone exposure and TTS measurement.

(11) Multiple tone exposure and TTS measurement.

So subjects were exposed to either l000Hz tone at 100 dBHL or 2000Hz tone at 100 dBHL (6 subjects were exposed to lOOOHz and 6 subjects were exposed to 2000Hz tones). This constituted the single tone exposure. They were exposed continuously for 10 minutes. Then threshold measurements were done again one minute and two minutes after the fatiguing stimulus was ceased (TTS_1 and TTS_2 respectively).

The multiple tone exposure pardigm consisted of presenting both lOOOHz and 2000Hz pure tones to the same ear simultaneously at 100 dBHLs for 10 minutes duration. After fatiguing, again thresholds were determined for pulsed-pure tones one minute and two minutes after cessation of fatiguing stimulus (TTS_1 and TTS_2 respectively).

Thus each subject was tested twice, but they were never tested twice on the same day i.e a minimum duration of 24 hours elapsed between the two sittings. This was done so as to enable complete recovery from earlier exposure.

The TTS measurements were done only after one minute so as to avoid the bounce phenomenon. (Hirah and Ward, 1952).

So, schematically, the testing procedure of both the groups can be shown, in following steps.

Group-I:

1. Threshold measurement at l000Hz, 2000Hz and 4000Hz - pulsed tones were used.
2. Exposure to lOOOHz continuous tone at 100 dBHL for lOminutes.
3. Threshold shifts were measured using pulsed pure tones at 2000Hz.
   _ after one minute of recovery time (TTS_1)
   - after two minutes of recovery time (TTS_2)
4. A rest of minimum of one day was given.
5. Again the subject was exposed to lOOOHz and 2000Hz continuous tone at 100 dB HLs for 10 minutes.
6. Threshold shifts were measured using pulsed-pure tone at 2000Hz
   - after one minute of recovery time (TTS.)
   - after two minutes of recovery time (TTSg)

Group-II:

1. Threshold measurement at lOOOHz, 2000Hz and 4000Hz - pulsed-pure tones were used.

2. Exposure to 2000Hz continuous tone at 100 dBHL for 10 minutes.
3. Threshold shifts were measured using pulsed-pure tones at 4000Hz.
   - after one minute of recovery time (TTS_1).
   - after two minutes of recovery time (TTS_2).
4. A rest of minimum of one day was given.
5. Again the subject was exposed to l000Hz and 2000Hz continuous tones at 100 dBHLs for 10 minutes.
6. Threshold shifts were measured using pulsed-pure tones at 4000Hz.
   - after one minute of recovery time (TTS_1)
   - after two minutes of recovery time (TTS_2)

RESULTS AND DISCUSSION

The data obtained were subjected to relevant statistical analysis and the results obtained are summarised in two tables (Table-III and Table-IV) .

Table-I and Table-II: show as the raw data obtained. By Inspection,of the raw data, we can make out that multiple tone exposure cause lesser TTS than single tone exposure. But this was not a consistent finding as all individuals tested did not show the reduction in TTS.

Table-Ill and Table-IV show as the statistical interpretation of the data obtained. The results can be summarized as follows:

Information from Table-III:

(i) The difference in the means of TTS. in (i) single tone exposure and (ii) multiple tone exposure was significant at .05 level (t=2.42) but not at .01 level.
Here single tone exposure was presentation of l000Hz pure-tone at 100 dBHL for 10 minutes duration and multiple tone exposure was presentation of l000Hz and 2000Hz pure tones at 100 dB HLs for 10 minutes duration and threshold measurements were done at 2000Hz.

(ii) The difference in the means of TTS_2 in (i) single tone exposure and (ii) multiple tone exposure was significant at .05 level (t=2.42) but not at .01 level.

Here single tone exposure was presentation of lOOOHz pure-tone at 100 dB HL for 10 minutes duration and multiple tone exposure was presentation of lOOOHz and 2000Hz pure-tones at l00dB HLs for 10 minutes duration and threshold measurements were done at 2000Hz.

Information from Table-IV:

(ill) The difference in the means of TTS_1 in (1) single tone exposure and (ii) multiple tone exposure was significant at .01 level (t=3.79).

Here single tone exposure was presentation of 2000Hz pure-tone at 100 dBHL for 10 minutes duration and multiple tone exposure was presentation of lOOOHz and 2000Hz pure-tones at 100 dB HLs for 10 minutes duration and threshold measurements were done at 4000Hz.

(iv) The difference in the means of TTS_2 in (i) single tone exposure and (ii) multiple tone exposure was significant at .01 level (t=3.17).

Here single tone exposure was presentation of 2000Hz at 100 dB HL for 10 minutes duration and multiple tone exposure was presentation of lOOOHz and 2000Hz at 100 dB HLs for 10 minutes duration and threshold measurements were done at 4000 Hz.

DISCUSSION:

The major findings of this study are:

(1) The multiple tone presentation (i.e. combination of two pure tones) causes lesser TTS than single tone presentation.

(ii) The reduction in TTS is reciprocal, that is, both the tones (lOOOHz and 2000Hz) reduce the TTS due to the other tone presented alone.

These findings are similar to the findings reported by Cody and Johnstone (1982) who did similar experiments on guineapigs. They recorded N_1 thresholds as indicative of TTS. They also reported that multiple tones cause lesser TTS than single tones, that this is shown reciprocally (i.e. both the primary and the secondary tone reduce the ETS due to either tone presented alone) and that the recovery rate from TTS is more rapid after a duel tone exposure.

Cody and Johnstone (1982) try to explain this finding in light of two-tone suppression phenomenon. They suggest that energy from one-tone is being dissipated by the presence of the other ton e through some nonlinear mechanism. Since this finding holds good in human subjects too, the some or similar mechanism might be operating in human auditory system. This type of non-linear behavior is seen in acoustically evoked cochl ear potentials or in the behavior of single auditory neurons. (Cody and

Johnstone, 1982). For single fibres, the presence of a second tone reduces the firing rate of the fibre to a tone located at the characteristic frequency (Sachs and Kiang, 1968). When cochlear microphonics are measured, a reduction in the relative amplitude of CM to the primary tone in the presence of secondary tone is noticed. The secondary tone can be located at frequencies above or below the primary ton e although lower frequency tones are reportedly more effective. (Legouix et al., 1973).

In the present study also it can be noticed that reduction in TTS is more when lower frequency tone (1000 Hz acts as a secondary tone and higher frequency tone (2000Hz) as a primacy tone than when higher frequency tone (2000Hz) acts as a secondary tone and lower frequency tone (1000Hz), acts as a primary tone. The t values are higher in the former condition (t-3.79 for TTS_1 and t=3.17 for TTS_2) than in the latter condition (t=2.42 for both TTS. and TTS_2).

Engebretson and Eldredge (1968) locate the nonlinear element between the stimulus input to the cochlea and the cochlea output. Two-tone suppression is also found in the receptor potentials of inner hair cells in the basal turn in cochlea in gulneapigs. (Sellick and Russell,1979). Rhode (1977) has shown by Mossbauer effect that the two tone suppression manifest as nonlinear mechanical behavior of the squirrel monkey basilar membrane.

The reduced TTS due to multiple tone exposures may explain, at least partially, why broad or narrow band noise exposures tend to be less damaging than pure-tones (Hunter-Duvar and Bredberg, 1974). Many tones, being present in a noise, can cause more suppression, thus less TTS is seen. Also Cody and Johnstone(1982) have reported that N. threshold recovery rates are faster in multiple tone exposures.

Cody and Johnstone (1982) cast doubt on the equal energy hypothesis for damage risk criteria predictions in light of the existence of a cochlea nonlinearity measured as reduced TTS. Equal energy hypothesis states that exposures of equal total energy (the product of power and time) are equally dangerous, (however the equal energy hypothesis is not applicable when exposures are intermittent in nature). Both the present study and the study done by Cody and Johnstone (1982) show that traumas delivered at the same intensity for the same time can produce signiftantly less TTS depending on frequency multiples. So it shows that the potential of a noise in producing TTS not only depends on the intensity of the acoustic trauma but also the spectral content or more specifically the spectral density.

Table-I: Raw data obtained with Group-I

Subjects	F.S. 1KHz 100 dB, 10 minutes, TTS at 2KHz		F.S. 1KHz + 2KHz, 100 dB 10 minutes. TTS at 2KHz	
	TTS_1(dB)	TTS_2(dB)	TTS_1(dB)	TTS (dB)
1	20.0	20.0	0	0
2	20.0	20.0	20.0	20.0
3	25.0	25.0	15.0	15.0
4	20.0	20.0	20.0	20.0
5	30.0	30.0	20.0	20.0
6	25.0	25.0	20.0	20.0
	17.48	50.50	17.48	50.60

F.S. - Fatiguing stimulus

V- Co-efficient of varation

Table-II: Raw data obtained with group-II.

Subjects	F.S. 2KHz, 100 dB, 10 minutes, TTS at 4KHz		F.S. 1KHz + 2KHz, 100 dB 10 minutes. TTS at 4 KHz	
	TTS_1 (dB)	TTS_2 (dB)	TTS_1(dB)	TTS_2(dB)
1	20.0	20.0	10.0	5.0
2	20.0	15.0	10.0	10.0
3	25.0	25.0	20.0	20.0
4	15.0	15.0	10.0	10.0
5	15.0	15.0	15.0	15.0
6	25.0	20.0	20.0	15.0
	22.35	34.67	25.62	41.92

F.S - Fatiguing stimulus

V- Co-efficient of varation

Table-III: Mean, Standard Deviation, variance and t scores for TTS_1 and TTS_ values of Group-I

	TTS_1 (S)	TTS_1 (M)	TTS_2 (S)	TTS_2 (M)
Mean	23.33	15.83	23.33	15.83
σ_n	3.726	7.312	3.726	7.312
σ_{n-1}	4.082	8.010	4.082	8.01
V	17.48	50.60	17.48	50.60
t	2.42		2.42	

S - Single tone exposure condition.

M - Multiple tone exposure condition.
V- Co-efficient of varation

Table-IV: Mean, Standard Deviation, variance and t scores for TTS_1 and TTS_2 values of Group-II.

	TTS_1 (S)	TTS_1 (M)	TTS_2 (S)	TTS_2 (M)
Mean	20.0	14.16	19.16	12.50
σ_n	4.08	4.887	4.487	4.787
σ_{n-1}	4.472	4.915	4.915	5.244
	22.35	34.67	25.62	41.92
t	3.79		3.17	

S - Single tone exposure condition.

M - Multiple tone exposure condition.

V- Co-efficient of varation

SUMMARY AND CONCLUSIONS

Temporary threshold shift refers to any post stimulatory shift in auditory threshold which is recovered after some period of rest. TTS depends on many factors like Intensity, duration and frequency characteristics of the stimulus. It is known that noise produces lesser TTS than pure tones.

Cody and Johnstone (1982) showed experimentally that multiple tone exposure causes lesser TTS than single tone exposure and also that recovery is faster in the former condition. These findings have been explained as indicative of two-tone suppre-ssion.

Two tone suppression has been experimentally demonstrated by many researchers (Sachs and Kiang, 1968; Suga and Katsuki, 1964; Javel, 1981).

The present study was aimed at finding out whether human beings also show lesser TTS when exposed to multiple tones than when exposed to single tone exposure.

The Beltone 200-C(Clinical Audiometer) with TDH-39 ear-phones housed in MX41/AR circumaural cushions, calibrated according to the specifications given by ANSI, 1969 was used for this study. 12 normal hearing subjects (6 males and 6 females) were tested in the study and divided into two groups I and II.

Group-I was exposed to:

(i) l000Hz tone at 100 dB HL for 10 minutes and TTS was measured at 2000Hz (single tone exposure condition).

(11) l000Hz and 2000Hz at 100 dB HLS for 10 minutes and TTS was measured at 2000Hz (Multiple tone exposure condition).

Group-II was exposed to:

(i) 2000Hz tone at 100 dB HL for 10 minutes and TTS was measured at 4000Hz (single tone exposure condition).

(ii) lOOOHz and 2000Hz at 100 dB HLs for 10 minutes and TTS was measured at 4000Hz (multiple tone exposure condition).

CONCLUSIONS:

1. The TTS. and TTS_2 in multiple ton e condition in Group-I was significantly lesser than TTS_1 and TTS_2 in single tone condition (t=2.42 for both TTS. and TTS_2 so it is significant at .05 level but not at .01 level).

2. The TTS_1 and TTS_2 in multiple tone condition in Group-II was significantly lesser than TTS_1 and TTS_2 in single tone condition (t=3.79 for TTS_1 and 3.14 for TTS_2 both significant at .01 level).

The reduction in the TTS in multiple tone exposure is explained on the basis of two-tone suppression. The suggested explanation is that energy from one tone is being dissipated by the presence of the other tone through some nonlinear mechanism.

The reduced TTS due to multiple tone exposures may explain, at least partially, why broad or narrow band noise exposures tend to be less damaging than pure-tones (Hunter-Duvar and Bredberg, 1974). So the damage risk criteria based on equal energy hypothesis needs some modification as the present study and study by Cody and Johnstone (1982) show that potential of a noise in producing a TTS not only depends on the intensity of the acoustic trauma but also the spectral content or more specifically the spectral density.

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