Effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure

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Register Number: 14AUD014

This Dissertation is submitted as part fulfilment

for the Degree of Master of Science in Audiology

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

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MAY 2016

CERTIFICATE

This is to certify that the dissertation entitled “**Effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure**” is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 14AUD014). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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May, 2016.

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CERTIFICATE

This is to certify that the dissertation entitled "**Effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled “**Effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure**” is the result of my own study under the guidance of Dr. Devi N, Lecturer in Audiology Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not submitted earlier in any other University for the award of any Diploma or Degree.

Mysore **Register No:14AUD014**

May , 2016

Dedicated to

The person, who is the
Greatest gift I ever had,
Came from God,
I call him "DAD"

Acknowledgement

Words are just too formal to express my love and gratitude towards you, I love you "**Mom**" and "**Dad**" from the bottom of my heart. I am blessed to have such a great parents. Mom, your goodness is higher than the mountain and deeper than a sea, you are a great friend, inspiration and a best mom any one can ask for. Thank you mom for all that you do for me, and you are loved till my last breath. Dad you are my hero, pillar of support, a man like no other. You gave me life, nurtured me, taught me, fought for me, held me in right path and most importantly loved me unconditionally. There are not enough words I can say to describe just how important you are to me, and what a powerful influence you continues to be "I love you Dad", thanks for everything you have done, you are to me what to earth, the sun is. My cute, little, handsome bro **Dhanu,** every day I thank god for giving me a brother like you. You are tremendous to me in a way you are, you hold a place in my heart that could be filled by no one else. We were born into this world in the same family, and I would not have it any other way. Thank you God almighty for an unconditional blessings and love towards my soul. For wonderful family, this is best of all blessings. I feel so blessed to experience a love like this with such an amazing family and thank you for always holding my hand.

I would like to show my sincere gratitude to my lovely guide **Devi mam** for her constant support, patience and guidance in this dissertation work. :"Thank you mam"

Life is incomplete without friends, many people will work in and out of our life, but only true friends will leave footprints in heart "**Appi,Lathika,Preeti ,Vandy,Suppy Ammu,Tina** " you guys deserve a thanks for your emotional support, motivation and valuable suggestions. Hope this self chosen family relationship continues till the end.

Special thanks to **"Samantha"** you are a great soul, thank you for bearing me ,sorry I have troubled you a lot, fought with you in my worst time, I still feel guilt for that, thank you for everything you have done for me, you were a special friend, that happened in my life and **Gatla sir,** for being a **wonderful senior** and constant support in tough situations.

Heartly thanks to **Mr.Srinivas** for the memorable and unusal help (which I have promised to be kept as confidential) **and team** who helped directly or indirectly. Your help in right time meant a lot, Thank you all.

I would like to thank **Sandeep** sir, for a care and love towards us, for arranging all the student's need based seminars. You are a great HOD of our department, we all love you sir.

You guys made a clinical postings more fun with your fighting "**Panch** and **Preeti**",you both were my best posting mates ,I definitely missed you both at times. I love my classmates (Section A), it was fun being with you all. You guys added a color to my life at AIISH.\

Last but not the least, I would like to thank **all the participants** of present study for spending there valuable time. My sincere gratitude towards all and thank you all.

Abstract

Continuous exposure to noise can cause several functional limitations of hearing, changes in frequency selectivity, temporal and spatial resolution, recruitment, and tinnitus as well as changes in hearing sensitivity (Samelli, 2004). Hence, the current study aimed to compare across lesser versus longer duration of noise exposure on frequency resolution ability in those individuals. The 45 participants were divided into three equal groups (lesser duration, greater duration of noise exposure and control group) based on their duration of working-PTCs were obtained using SWPTC software across signal frequencies from 500 to 4000 Hz in half-octave steps using forward sweep method. Testing was done after 24 hours of noise exposure. The quadratic function method was used in present study.

Results revealed significant difference was noticed among controlled and group with greater duration of occupational noise exposure in terms of estimates of Q_{10} value pattern, response area and amount of masking using f-PTCs. Among controlled and group with lesser duration of occupational noise exposure significant difference was noticed in terms of Q_{10} values at higher frequencies, tuning curves obtained at 4kHz in right ear,1kHz and 2kHz in left ear was significantly different among two different duration of noise exposure groups. Ear laterality was observed in terms of Q_{10} values at 1 kHz in lesser duration exposure and at 4 kHz in greater duration of occupational noise exposure.

However, controlled group had no significant ear difference. Results of the present study indicate that there is an effect of duration of noise exposure is one of the primary factor which contributes for change in cochlear normal mechanism which lead to reduction in frequency resolution, hearing acuity and other factors. Widened auditory filters in damaged cochlea, which is reflected by decreased sharpness of f_{tip} indicated reduction of frequency resolution among greater duration of noise exposure.

Table of contents

List of Tables

List of Graphs

Chapter 1

Introduction

Noise is among the physical exposures originated from fluctuations in air pressure and is a common exposure in many industrial settings (Kryter, 1970). Noise has several effects on human health, some include: concentration disturbance, memory loss, anxiety, depressive behavior, muscular contraction, tachycardia, and hypertension. Normal basilar-membrane responses to sound are characterized by a triad of features: high sensitivity, sharp frequency tuning, and nonlinearity (Ruggero, 1986). Continuous exposure to noise can cause several functional limitations of hearing, changes in frequency selectivity, temporal and spatial resolution, recruitment, and tinnitus as well as changes in hearing sensitivity (Samelli, 2004). Changes in frequency selectivity also cause difficulties in auditory discrimination, limits the ability of the individual to recognize sounds (Bamford & Saundes et al., 1991).

The individuals with occupational noise exposure may develop, intolerance to loud sounds and complain of tinnitus, reduced speech intelligibility, and impaired verbal communication. Exposure to high sound pressure levels can also cause irreversible hearing loss, which has serious consequences for individuals' health and quality of life.

According to Bohne (2000), there are several methods for detecting the effect of noise on hearing in an appropriate time. The duration of the exposure has a reciprocal relationship to intensity. The higher the intensity, the shorter the exposure can be and still cause permanent damage. Conversely, lower-intensity noise may be safe, even when the ear is exposed for long durations. For exposures which are equal in total energy, the scheduling of the exposure (continuous v/s intermittent) affects the magnitude of damage that the ear sustains but does not affect the pattern of damage. Rest or quiet periods between successive exposures afford some protection for the ear, as long as the periods are not too brief. With moderate-level exposures for long durations such as those found in noisy industries (</= 90 dB SPL), a few scattered sensory (hair) cells probably degenerate within the organ of corti during each day of work. In general, the noise-induced loss of hair cells is very gradual. The amount of structural damage which is present in a given ear depends on its auditory history. The longer the exposure to noise, the number of missing sensory cells in the cochlea is more (Bredberg, 1968; Bohne & Clark, 1990). One of the ways to reduce the adverse effects of noise, such as a decreased hearing acuity and a noticeable reduction in the ability to understand speech in noise is to detect about one’s frequency resolution ability.

Frequency resolution ability can be interpreted as the filtering capability of the auditory system and is important for speech recognition. A reduction in this (spectral) ability makes it difficult to distinguish speech elements like formants in vowels. The frequency resolving ability of the auditory system and the shape of the auditory filter can be measured behaviorally by masking methods.

Future scientific and diagnostic interest in frequency resolution requires an evaluation of the different methods that are available to measure it. Two supposed measures of auditory frequency selectivity a) the critical band (CB) in loudness summation and b) the psychoacoustic tuning curve (PTC). It is proposed that the PTC is a more valid measure of auditory frequency selectivity than the Critical Band in loudness summation (Bonding, 1986). The PTC can be used for two purposes: To quantify the frequency selectivity of the auditory system and to detect dead regions in the cochlea. PTCs indicate the masker level required to produce a fixed output from the auditory filter as a function of frequency. Smith et al., (1987) provided behavioral support for the contribution of the outer hair cells (OHCs) to the sensitivity and fine-tuning of the cochlea. Histological examination of the cochlea's revealed that there was complete loss of OHCs but complete retention of the IHCs in the regions corresponding to the changes of the PTCs. However, investigations documenting behavioral estimates of frequency selectivity in individual with occupational noise exposure are lacking. It is recommended that psychophysical tuning curves be measured to define the value of f(e) more precisely(Moore, Glasberg & Schlueter, 2010). The 56% agreement rate between the TEN and PTC tasks indicates that at least one of these tasks was only partially reliable as a diagnostic tool to detect dead regions (Summers et al., 2003). Threshold Equalization of Noise (TEN) test was proposed by Moore et al. (2000; 2004) for identifying dead regions. The test measures the masked thresholds of pure tones in broadband threshold equalizing noise (TEN) calibrated in dB HL; Moore et al., 2004). The TEN is spectrally shaped to produce equal masked thresholds for pure-tone probes at all frequencies between 500 and 4000 Hz in dB HL for normal-hearing adult subjects. The TEN task involves tone detection in a masking noise that is spectrally shaped to produce equal masked thresholds across the audible frequency range for normally hearing listeners. Behavioral estimates of the auditory filters can be obtained via PTCs measurement (Moore, 1978). PTCs in humans can be obtained using either simultaneous masking paradigm where masker and the probe signal are presented simultaneously or forward masking paradigm where probe follows the masker. Both these approaches provide useful measures of the frequency selectivity of the auditory system (Moore, 1978; Bidelman et al., 2014). In simultaneous masking, the effect of suppression are not seen, the signal-to-noise ratio in the frequency region of the signal is unaffected by the suppression where as in forward masking, the suppression does not affect the signal. Thus, the suppression is revealed as an increase in the slopes of the PTC. In non-simultaneous masking the masker does not suppress the signal, and so the masker is less effective (Delgutte, 1988, 1990). The tuning curve measured in non-simultaneous masking gives a more accurate indication of the tuning curve that occurs for single sinusoids. Delgutte (1990) had presented physiological evidence suggesting that simultaneous masking by intense low frequency tones (upward spread of masking) is due largely to suppression rather than spread of excitation. Thus, the PTC measured in non-simultaneous masking is likely to be closely related to BM tuning curve and neural tuning curve, while the PTC measured in simultaneous masking is likely to be broader than those curves. The PTCs obtained using forward masking are typically sharper than those obtained in the simultaneous masking (Moore, 1978).

Several researchers have proposed the use of a faster method, based on Bekesy tracking (Zwicker, 1974; Summers et al., 2003; Sek et al., 2005). The method described by Sek et al (2005), in which the masker is a band of noise that is slowly swept in frequency, either upwards or downwards. The signal is pulsed on and off repeatedly while the masker is continuous; this helps to draw attention to the signal. The masker level is initially below that required to hear the signal. The masker level is increased when the participant indicates that the signal can be heard, and decreased when it is not. In this way, the masker level tracks the level required for threshold. The PTCs obtained using their method showed good repeatability and corresponded well with PTCs obtained in the traditional way. Until now, this method required specialized equipment for its implementation. The signal is presented at a sensation level of 10 dB and is pulsed on and off in a regular manner. Each tone pulse lasted for 500 ms (including rise and decay times of 20 ms each) and the gap between successive pulses is 200 ms. The center frequency of the masker swept from f_{max} to f_{min} for a forward sweep or from f_{min} to f_{max} for a reverse sweep, over a 4-min period. The rate of change of the masker center frequency is constant on a logarithmic frequency scale. For the fast method, the entire masker waveform is presynthesized, and has been implemented in software using MATLAB which can be stored on the hard drive of the PC. The software includes measures of the absolute threshold at the signal frequency and includes methods for estimating the frequency at the tip of the PTC.

The Fast PTCs measured in forward sweeps are recommended for use in clinical practice, as they give a precise estimate of centre frequency (fe) and are quick to administer. (Kluk & Moore .,2006). For the normal ears, the fast PTCs were sharper in forward masking than in simultaneous masking. For the impaired ears, the fast PTCs were similar in simultaneous and forward masking, but those in forward masking tended to be sharper at masker frequencies far removed from the signal frequency (Moore & Glasberg , 1986).

1.1 Need of the study

- Reduced frequency selectivity, which contributes to difficulty in understanding speech in noise in individuals with occupational noise exposure. The fast psychophysical tuning curve (f PTC) test is a fast computer-based method that can be used clinically to assess the frequency selectivity of the cochlea, the test takes only 4–5 min/frequency to apply; It is time saving method.

- Previous research in psychophysics using traditional PTCs as shown that the time course of recovery from forward masking is prolonged in listeners with sensorineural hearing loss (Nelson & Turner, 1980). In order to evaluate the physiological basis for the change in the time course of forward masking, evoked response recordings were obtained from the inferior colliculus of the chinchilla both before and after noise induced hearing loss. The time constants fit to the "forward-masking" function were found to be prolonged in the region of hearing loss. In general there was a strong correlation between the time constant of recovery from "forward masking" and hearing loss.

- Duration of noise exposure have adverse effect on frequency selectivity in individuals with occupational noise exposure, empirical studies behaviorally estimating frequency selectivity using fast PTC’s are limited.

1.2 Aim of the study

To investigate the effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure

1.3 Objectives of the study

- To measure Q_{10} values of frequency resolution ability using fast psychophysical tuning curves in individual with and without occupational noise exposure.
- To compare frequency resolution ability across short/early versus longer duration of occupational noise exposure and individuals without occupational noise exposure using psychophysical tuning curves.

Chapter 2

Review of Literature

Peripheral auditory system behaves as a band of band pass filters with overlapping bands. The shape and organization of the basilar membrane are in such a way that different frequencies resonate maximum at different points along the membrane. This leads to a tonotopic organization of the sensitivity to frequency ranges along the membrane, which can be modeled as being an array of overlapping band-pass filters known as "Auditory filters".

The auditory filters are associated with points along the basilar membrane and determine the frequency selectivity of the cochlea, and therefore the listener’s discrimination between different sounds. They are non-linear, level-dependent and the bandwidth decreases from the base to apex of the cochlea as the tuning on the basilar membrane changes from high to low frequency (Zwicker & Fastle, 1990). From the apex of the cochlea to the base, the degree of tuning decreases and that frequency selectivity becomes poorer (Loven, 2009).

Auditory filters are closely associated with masking, in other words masking reflects the limits of frequency selectivity. A signal is most easily masked by a sound having frequency components close to, or same as, those of the signal. Hence, it is suggested that our ability to separate the components of complex sounds depends, in part, on the frequency resolution power of basilar membrane. The frequency resolving power of the auditory system is entirely determined by the frequency selectivity apparent in the cochlear mechanics (Meyer, 1894).

2.1 Frequency resolution in individual with cochlear hearing loss

The ear is considered to be a real time spectrum analyzer where it performs an imperfect Fourier transformation on the temporal pattern of acoustic compression and rarefaction resulting in appropriate frequency coding. Hence, frequency resolution capacity of ear refers to the ability to separate the individual components in a complex signal. Besides, the frequency resolving power at the later stages of the auditory system seems to be depended upon the selectivity at the level of auditory nerve to a greater extent, being at the first stage of frequency selectivity mechanism any damage to the cochlea is vulnerable to the frequency resolution capacity of the ear which lead to crucial changes in the frequency selectivity of the ear with hearing impairment, especially cochlear hearing loss (Moore, 1982 &1986).

The frequency resolving difficulties of individuals with hearing impairment was known way back in 1930's (Moore, 1986). The first report of masking effect on people with hearing impairment was done by Hastings and Scarff (1928). The authors described masking effect on individuals with conductive hearing loss while assessing the phenomenon 'Paracusis Willisii'. The authors found that, masked thresholds increased with increase in age and absolute hearing threshold. Webster (1950) suggested poor frequency resolution as the major consequence of hearing impairment. Since then many studies have undertaken to investigate on the same and confirmed it, specifically in cochlear hearing loss (Kiang et al., 1970; Evans, 1975). The impact of frequency resolution on assessment and rehabilitation of hearing impaired as well as its importance in perception of speech has led researchers to focus more on the masking experiments to reveal the essential information on it. Since the threshold of hearing loss varies across frequencies in conductive hearing loss, the interpretation of frequency resolution might be complicated. However, the frequency resolution is presumed to be originating from sensorineural mechanism and hence studies on conductive hearing loss may not provide significant information (Nelson & Bilger, 1974).

Borg and Zakrisson (1974) reported abnormally elevated masked thresholds in animals with drug-induced stapedial muscle paresis. The elevation was significant at higher frequencies where the masker was a low frequency narrow band noise. When the comparisons are done at same sound pressure level (SPL) it reflects the differences in frequency resolution after the initial stage of cochlear mechanics (that is band pass filtering of basilar membrane) provided sensorineural hearing loss does not alter the cochlear mechanics (Moore, 1986). However, Rutten (1980) reported that the travelling wave pattern itself is altered in cochlear hearing loss. Hence, comparison at equal SPL represents changes either in the travelling-wave properties or in later stages of processing. But when comparisons are done at equal SL (Sensational levels) or loudness, the travelling wave envelope will be different since the SPLs are different. So the frequency resolution measures could be confounded with this level-dependence of the travelling wave. Hence it is desirable to compare normal and hearing impaired listeners at similar SPLs, and to pay more attention to the effects of stimulus level in both groups. Listeners can have same masked threshold but different amount of masking depending upon their absolute thresholds. If the mechanism responsible for absolute threshold and frequency resolution are different then comparison using amount of masking will become meaningless. Martin and Pickett (1970) introduced ‘Noise rejection slope’ to compare frequency resolution. This slope is calculated from a graph representing the amount of masking produced by a low pass noise masker as a function of frequency. But listeners with elevated absolute threshold could display smaller shift in threshold with masking and hence shallow slope. This will again leads to erroneous information on frequency resolution power. Hence the best approach is to report data in terms of masked threshold with mentioning of absolute thresholds.

Webster et al. (1950) reported masked threshold increased an average of 1 dB for every 10 dB absolute threshold elevation above normal (0 dB HL). They reported higher masked thresholds in females, elderly above 40 years and those without musical training. They also reported that elevated masked thresholds could be an indicator of wide critical bandwidth and poor frequency resolution. Pal’gov et al. (1973) measured masked threshold of signals with octave band of noise centered at the signal frequency. They reported that for absolute thresholds greater than 60 dB HL masked thresholds were 25 dB greater than normal. In general, higher absolute thresholds are trending towards elevated masked thresholds. However, these results are confounded with findings like high absolute thresholds upto 80 dB HL having near-normal masked thresholds and a few individuals with normal absolute threshold having masked threshold shifted by more than 10 dB.

Watson and Tolan (1949) used tone on tone masking with a combination of 250/1000, 500/2000, 1000/3000 as masker/signal respectively in individuals with hearing impaired. The presentation level was increased gradually in 10 dB steps and reported that four subjects did show a less change in signal threshold with increase in masker level. At the same time de Bruine-Altes (1949) reported higher than normal masked thresholds at signal frequencies of 2000 and 4000 Hz for a 400 Hz masker. Studies on octave masking, by presenting signal one octave above of masker, have shown equivocal results that lower thresholds of octave masking in hearing-impaired (Clack & Bess, 1969) as well as no significant difference between the two groups (Nelson & Bilger, 1974).

Jerger et al. (1960) reported a greater amount of masking in hearing impaired at frequencies above and below the masker frequency at an intensity producing 30 dB of masking. In an experiment by Haebert and Young (1965), the authors used five NBN maskers at five different levels and reported greater upward spread of masking in the impaired listeners. Martin et al. (1970) further clarified that such elevation happens only for moderate-severe hearing impairment and not below that. Tyler et al. (1980) reported that pronounced upward spread of masking is generally confined to the regions of absolute threshold loss, with some exemptions (Lishowitz, 1977).

Masked thresholds are generally found to be lower in cochlear hearing impaired listeners at frequencies well below (greater than one octave) the center frequency of a NBN masker, this is nothing but the reduction in remote masking (Bilger, 1965; Keith & Anderson, 1969).

2.2. Psychophysical Tuning Curve (PTC) as a measure of frequency resolution

Psychophysical Tuning Curve is a psychophysical procedure to measure frequency resolution suggested by Chistovich (1957) and Small (1959). The measurement of Psychophysical tuning curve (PTC) involves a procedure which is analogous to physiological methods for determination of neural tuning curve. A fixed-frequency and fixed-level signal is presented just above threshold, and the level of a masker required to just mask the signal is determined as a function of masker frequency. The resultant curve is called as psychophysical tuning curve (PTC). Narrow band noise reduces the influence of “beats" caused by the interaction of signal and the masker (Kluk & Moore, 2004). One complication in interpreting PTC results is off frequency listening where, it is “The process of detecting the signal through a filter which is not centered at the signal frequency”. Listener need not attend to just one filter. There is evidence that off-frequency listening influence PTCs.

Traditionally, physiological tuning curves have been quantified in a similar manner to analogue filters. A measure of frequency resolution near the tip of the tuning curve is determined by dividing the signal frequency by the bandwidth measured 10 dB up from the tip. A similar approach was adopted by Florentine et al. (1980) and Ritsma et al. (1980) to quantify PTCs obtained from hearing impaired listeners. Bonding (1979) has chosen a slightly different approach. His measurement of tuning is defined as the distance in dB between the tip of the PTC and the level where the PTC is 1 octave wide. In this approach he assumed that the tip of the PTC was equal in level to that of the unmasked test tone (presented at 10 dB SL). Tyler et al. (1983) discovered that the level required to mask a NBN signal at the PTC tip with a pure tone masker of similar frequency was often higher than the signal level and was one of the parameters which differentiated the normal and the hearing impaired listeners.

In order to find the asymmetries in the auditory filter, Tyler et al. (1979) quantified the high and low frequency slopes of the PTCs. The slope was calculated between only two masker frequencies. Using two masker frequencies won't give a good match to the slope of a PTC obtained with several masker frequencies and this two point slope does not give a measure of frequency resolution between the two masker frequencies and does not allow for the evaluation of W-shaped PTCs. Particularly the low frequency side of PTC may be better described as curvilinear, and a single slope measure may be inappropriate. Therefore, Tyler et al. (1983) used a tip-to-tail difference score (the difference between masker level in the tail of the PTC and the masker level at the tip of the PTC). Another difference score (the maker level minus the signal level when the masker was at the frequency of the signal) was used to quantify the efficiency of the detector mechanism which depends on the detail characteristics of the signal and masker.

Leshowitz et al. (1975) and Nelson (1976) were some of the first to report PTCs measured from hearing impaired individuals. There have been several studies comparing PTCs in normal subjects and subjects with cochlear hearing loss (Hoekstra & Ritsma 1977; Zwicker & Schorn 1978; Bonding 1979). The authors reported that, normal sharply tuned PTCs in regions of normal absolute thresholds and abnormal broadly tuned PTCs in regions of elevated absolute thresholds. Most studies have found that the sharpness of tuning of PTCs decreases with increasing absolute threshold, although the correlation between threshold and the sharpness of tuning varies markedly across studies.

Moore (1978) experimented on 5 normal listeners using PTC of both simultaneous and forward masking paradigm at different level and frequency of the test tone. The obtained PTCs were similar to single neuron tuning curve when low level probe tone was used. PTCs obtained in forward masking paradigm showed sharper tip and steeper slopes when compared to simultaneous masking paradigm. Authors concluded that PTCs obtained in using simultaneous masking paradigm could be influenced by combination tones, lateral suppression and beats, whereas, PTCs in forward masking paradigm could be influenced by off frequency listening and decaying effect of the masker. Nelson and Bacon (1989) studied the temporal overshoot during simultaneous masking for normal and impaired ears in two conditions. They obtained PTCs for a 20-ms signal that occurred either at the beginning or in the temporal center or at the end of a 400-ms masker. For the normal-hearing listeners, the PTCs were sharpest when the signal was at the temporal center of the masker, and broadest when it was at the beginning of the masker. The PTCs were sharper on the high-frequency side for a signal in the temporal center of the masker. For the hearing-impaired listeners, however, the shape of the PTC was virtually independent of the temporal position of the signal. These data suggest that the mechanisms responsible for sharpening the PTC with time in normal-hearing listeners are ineffective in listeners with moderate-to-severe sensorineural hearing loss.

Stelmachowitz, et al. (1985) compared high level PTCs in normal hearing and hearing impaired. They found that tuning characteristics in normal ears (Q_{10}) independent of probe level. Also, flatter low frequency slopes were seen in HI. Low frequency slopes reflect the spread of excitation from low frequencies towards high frequencies. Results imply abnormal upward spread of masking in hearing impaired. In normal hearing listeners, problem of temporal overshoot is encountered during simultaneous masking. Davidson and Melnick (1988) compared PTCs in simultaneous masking using 2 methods:

transformed up down procedure and Bekesy tracking. More masking is to be reported in the Bekesy method which could be because of subject’s criteria for threshold.

2.3. Psychophysical Tuning Curve in individual with occupational noise exposure

Langenbeck (1950) conducted tonal thresholds in noise experiments over several years and reported the results of normal listeners, listeners with noise induced hearing loss, with head injury and with presbycusis. For normal listeners the shifts in thresholds across frequency were comparative to the increase in masker level. The same was observed in NIHL cases at frequencies were absolute thresholds were comparable to that of normal, but at higher frequencies it was elevated due to hearing loss. In general the pattern was mimicking hearing loss pattern. But in presbycusis at frequencies above around 1.5 KHz there was an abnormal elevation in masked threshold. In head injury case this abnormal shift in masked threshold was present across frequencies. However, they could not identify a clear cut demarcation for differential diagnosis. The level of noise presentation was 40 dB SPL. Tyler et al. (1982) reported more masking than normal for low level of noise but had normal masked threshold at high noise levels in two hearing impaired. This could be frequency resolution is better at high intensity in hearing impaired, which is of course contradicted to normal listeners (Scharf et al., 1977) and change in efficiency of the detector mechanism.

Tyler et al. (1982) suggested that the nonlinear growth of masking might also be better understood in terms of changes in the detector mechanism. Due to high inter-listener variability related to masked threshold and its related parameters it is unlikely to suggest that this as a tool for differential diagnosis. Elevated masked thresholds in noise may either be due to widened auditory filter or less efficient detector mechanism. No systematic differences in PTCs have been reported between cochlear losses of different origin, such as noise induced, Meniere's disease, ageing, and hereditary losses. Leshowitz and Lindstrom (1977) reported that among the participants with hereditary HL and NIHL, they examined combination tones in context of PTCs between 1kHz to 8kHz at 65 and 75dBSPL, it was noticed that in one listener with a NIHL, over masking was observed. Hoeksta (1979) noted that in some cases masker level may be 20 dB less than the signal level and observed the effect for maskers both higher and lower than the signal frequency.

Kiang et al. (1976) found that some auditory nerve fibers were hypersensitive in acoustically traumatized cats in the tails of their PTCs. That is, abnormal units respond to stimuli that were sub threshold before exposure. Over masking may also be related to the observation that the low frequency suppression region of PTCs can remain relatively unaffected in the presence of elevated thresholds. Over masking may also be related to off frequency listening. PTCs of the cochlea are a lengthy procedure typically takes at least 2hours, and the application in kids or elderly people may take even longer time. Thus, PTCs measured in the traditional way are not suitable for use in routine clinical practice (Sek et al., 2005).

2.4. Fast Psychophysical Tuning Curve (f-PTCs): A modernized tool of traditional PTCs to measure frequency selectivity

The fast method for determining PTCs initiated by Sek et al. (2005) used f-PTC as a frequency selectivity measure, the authors used signal frequencies from 500 to 4000 Hz, in half-octave steps. The similar results obtained in both of f-PTC and traditional method. For participants with normal hearing, the two methods led to very similar estimates of the slopes and positions of the tips. An objective method has been developed for determining the tip frequency of a PTC measured using the fast method, based on fitting linear regression lines to limited segments of the PTC adjacent to the tip revealed best agreement. The direction of frequency sweep of the masker has some influence on the estimated tip frequency of the PTC, the value of estimated tip frequency was slightly higher for forward sweeps than for reverse sweeps. The magnitude of this effect is small for normally hearing subjects, but can be appreciable for hearing-impaired subjects. The standard deviation of the estimated tip frequency tends to increase with increasing rate of change of masker level. For hearing-impaired subjects, rates of change of 0.5 or 1 dB/s are recommended, which has low variability and avoid discomfort. The detection of beats can influence the shapes of PTCs when a small bandwidth (80 Hz) is used. For subjects with dead regions, this can lead to a tip of the PTC at the signal frequency even when the signal frequency falls in a dead region. A relatively wide bandwidth is recommended to minimize the influence of beat detection on the results.

Moore, Sek, Alcantara, Kluck and Wicher (2005) experimented on 10 normal listeners and 12 hearing impaired participants using fast track method, several subjects diagnosed as having dead regions using the TEN test and measurement of traditional PTCs, the PTCs determined using the fast method showed good repeatability and were consistent with the PTCs obtained using the traditional method. The authors concluded that, the fast method of determining PTCs, combined with the objective method for determining the position of the tip, may provide a useful tool for estimating the edge frequencies of dead regions in the cochlea. However, the results of the objective method should be treated with caution when the low-frequency side of the PTC is very shallow. For hearing-impaired participants with preserved low-frequency hearing, it is advisable to add a low level low pass noise to the sweeping masker, for traditional PTCs (Kluk & Moore, 2005)

Sek et al. (2007) further refined the fast method. Normal hearing participants were tested using fast method and traditional method. The shapes of the PTCs, the slopes of the low and high-frequency skirts, and the positions of the minima were very similar using both the methods. The authors used several methods of the PTC minimum estimation for comparison. Among all method, square function yielded the best results. The method gave the smallest standard deviation, the highest kurtosis and the narrowest range of the PTC minima. For an upward sweep in the centre frequency of the noise band the PTC minimum occurs at a slightly higher frequency than the tone frequency and the frequency shift is less than 3% of the tone frequency. The position of the PTC minimum does not depend on the bandwidth of the masking noise. This is true for bands of centre frequency which is equal to the centre frequency of the masking noise band.

It is evident from above literature that frequency selectivity is an essential component for individual's speech perception especially in the presence of noise. Cochlear hearing loss lead to wider auditory filters which intern affects the frequency resolution ability of an individual. Noise induced hearing loss is also one of the cochlear origin where in exposure to unacceptable noise for longer duration damages the normal cochlear function. However, empirical studies on behavioral estimation of frequency resolution abilities in individual with occupational noise exposure using f-PTCs are limited.

Sek et al., (2004) proposed a method for PTCs determination, as a very promising and faster method than the traditional one and can be used clinically. Based on studies, it was rationalized that, the f-PTC method proved to be as precise as the classical measurement of the PTC with less time consuming and therefore it should be considered as a method for frequency selectivity determination, fully equivalent to other methods.

Chapter 3

Method

The study aimed to investigate the effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure

Participants

The study was conducted on, 45 adults in the age range of 18 to 40 years (mean = 27.6 years and SD: ±2). They were equally divided into three sub – groups:

Group I: 15 participants with normal hearing sensitivity (who are not exposed to any kind of occupational noises)

Group II: 15 participants with high-level of occupational noise exposure (>85dBA), 8 hours/day for < 6 months duration.

Group III: 15 individuals with high-level of occupational noise exposure (>85dBA), 8 hours/day for above 6 months to 5 years duration.

Participant selection criteria:

- For group I and II, those young adult participants who had no complaint of hearing loss (confirmed by pure tone average thresholds of ≤ 15 dB HL in the frequencies between 250 Hz and 8 kHz for air conduction and 250 Hz and 4 kHz for bone conduction) were selected to participant in the study.
- For group III the young adults who had 4kHz notch in their estimated audiogram due to occupational noise exposure with 8hours/day for longer duration were selected.

- Who dint report of any history or complaint of middle ear problems (every participants had the presence of ‘A’ type tympanograms with acoustic stapedial reflexes present in both ears).
- OHCs functioning were confirmed through DPOAEs evaluation. Except first group who had normal DPOAEs results, second and third group had abnormal DPOAEs results which revealed abnormal OHC functioning.
- Excluded the individuals with history of psychological, neurological or neuro-psychiatric illness.
- All groups were age matched.
- Only males were chosen for the present study.
- All the participants were non-users of EPD’s, in order to infer accurate findings.

Instrumentation

- A calibrated clinical diagnostic dual channel Inventis Piano Plus audiometer was used to carry out pure tone audiometry. TDH-39 headphone transducer for air conduction thresholds and B71 Bone vibrator was used for bone conduction thresholds estimation.
- A diagnostic immittance meter (GSI TympStar) was used to assess the functioning of the middle ear system.
- Otodynamics Ltd, version 6 (ILO v6) was used to record the integrity of outer hair cells.

- SWPTC (SW stands for sweeping) software implementation of the method of Sek et al. (2005) was loaded in Sony Vaio laptop (Windows 7, 32 bit core i3 processor) to obtain PTCs.
- The presentation of stimuli was done using TDH-39 headphone transducer, which was connected to Sony Vaio laptop. The sampling rate used was 22050 Hz, which means that the highest frequency that can be generated was about 10000 Hz. Each ear was tested separately (the ear to be tested is selected in the software randomly).

Test environment

All the measurement was carried out in an acoustically treated room, where the level of ambient noise is well within the permissible limits (ANSI 1999).

Procedure:

Phase I : Noise level Mapping

The noise level mapping was collected by respective industry's safety engineer, which was based on Model P14 and P14S Type 2 Sound Level Meter. An OSHA standard (damage risk criteria) was considered to identify high intensity noise.

Phase II: Routine audiological tests

All the participants were evaluated through routine audiological tests such as pure-tone audiometry, otoscopic examination, tympanometry and otoacoustic emissions in order to ensure whether they meet the participant inclusion criteria.

- A-type tympanograms and acoustic reflexes present in both ears were included to rule out conductive pathology. Absence of any other associated problems was also confirmed.

- All the participants were informed of the test procedure and the purpose of the study.

- An oral consent regarding the same was taken from each participant.

Phase III: Measurement of frequency resolution abilities

Measurement of absolute threshold: The absolute threshold at the specified signal frequency was estimated through the Sweep PTC (SWPTC) software. This option helped to achieve the correct signal presentation level. The starting level of the signal was set in the software. It was also recommended that level of 10 dB above the anticipated absolute threshold. An adaptive two-alternative forced-choice procedure with a two-up one-down adaptive rule (Levitt, 1971) was used to measure the absolute threshold. The participant responded by ‘clicking’ on virtual buttons on the PC screen. Feedback was provided by flashing the button that was pressed, using a green flash for correct and a red flash for wrong. The resulting threshold value was shown on the screen, together with the recommended signal level for measurement of the PTC.

- Signal frequencies from 500 to 4000 Hz in half-octave steps were used. Testing was done after 24 hours of noise exposure. 24 hours of rest is due to the continuous exposure to intense noise, hearing thresholds in humans begin to deteriorate after about 1–4 hours of exposure and reach a maximum threshold shift of 10–18 dB after 8–12 hours (Mills et al., 1970; Melnick, 1976; Mills et al., 1979). With regard to recovery following such continuous exposures to noise, generally, threshold shifts that are less than 20 dB fully recover by 24hours after termination of the exposure (Mills et al., 1970; Carder & Miller, 1972; Melnick, 1976).

- Each individual was briefly familiarized regarding the procedure prior to testing. The task was to detect a sinusoidal signal, which was pulsed on and off (by default 200 ms on and 200 ms off), in the presence of a continuous noise masker whose centre frequency slowly changes, from low to high (Forward sweep). The signal frequency and level was selected in the software.
- The masker bandwidth, the initial masker level, and the rate of change of masker level were also selected in the software. Initially, the signal was presented without any masker, so that the participant knows ‘what to listen for’. Then the masker was presented, preferably at a low level so the signal remains audible.
- The participants were requested (via a box on the screen) to press and hold down the space bar whenever the signal was audible. While the space bar was pressed, the masker level was increased (at a rate of 2 dB/s).
- The participants were requested to release the space bar when the signal was not audible. While the space bar was released, the masker level was decreased. Finally, the masker level ‘tracks’ the level required just to mask the signal.

Display of results: At the end of each run, a graph was displayed of the level of the noise as a function of the centre frequency of the noise.

- A running average of this level was also shown. The masker level and centre frequency at the tip of the PTC were automatically estimated and displayed on the screen.
- All data were saved on the hard disk of the PC.

Estimation of tip frequency: The software offered several methods for estimating the frequency at the tip of the PTC (and the sharpness of tuning of the PTC).

- The quadratic function method was used in present study, as it had the smallest 95% range, a high success rate in f -tip estimation and the best test-retest reliability. For fast PTCs measured for signal frequencies from 500 to 4000 Hz using an upward-sweeping masker, author suggested that the normative range of ftip to be - 3% fs to 10% fs with a test-retest reliability of 5% fs. (Myers & Malicka, 2014)

If f-tip estimation was not done through quadratic function method then other methods were used. Fast-PTC methods resulted in similar estimates of tuning as compared to published notched-noise data. (Karolina, 2011) Fast PTCs showed potential for clinical use due to a high success rate with minimal training required. Filter sharpness was quantified from PTCs by measuring the Q10 factor of the auditory filter. Q10 dB value is defined as the centre frequency divided by the bandwidth at the 10dB down points.

Chapter 4

Results

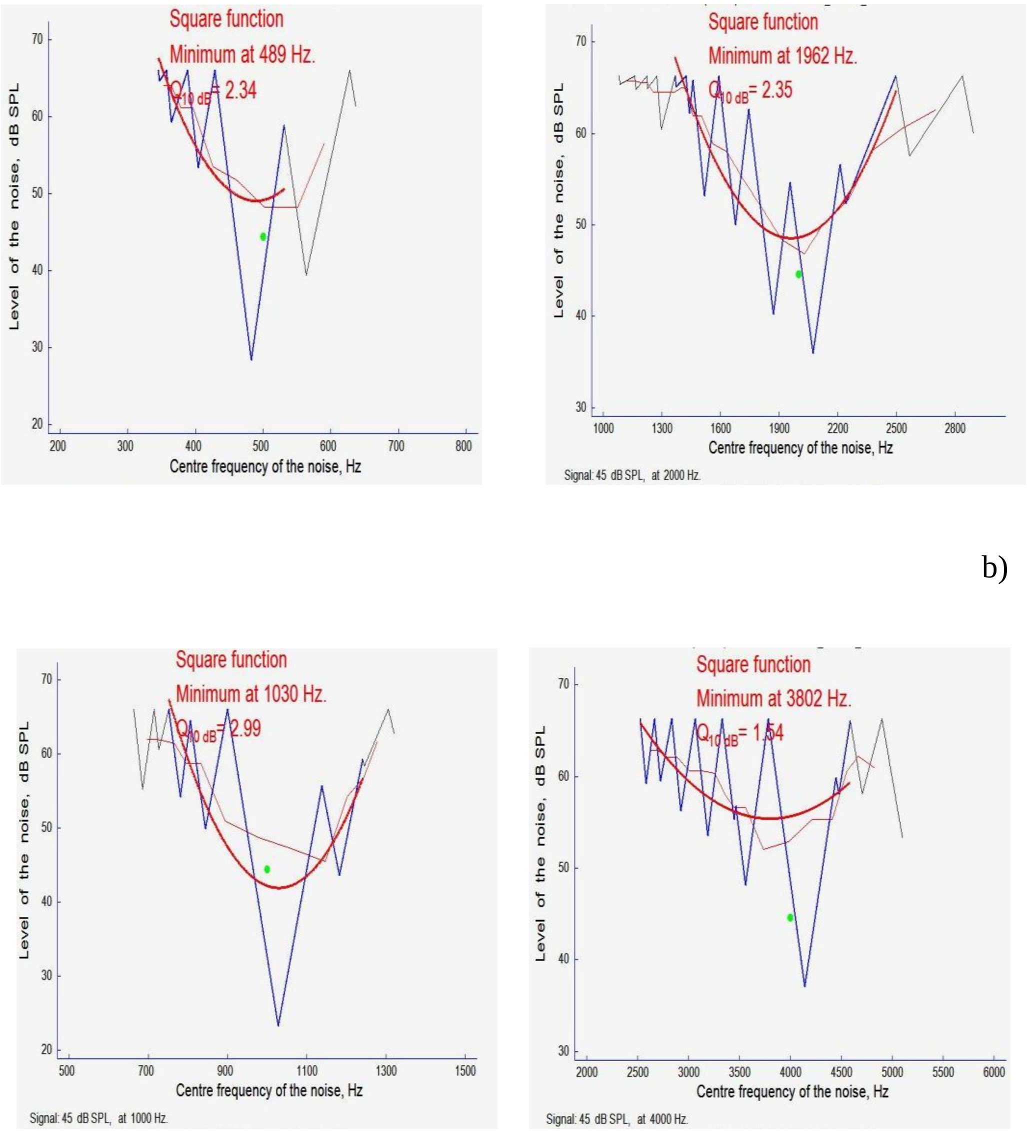
Data obtained to investigate the effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure were analyzed using the Statistical Package for Social Sciences (SPSS) software, version.20. Tests of normality: Shapiro-Wilk normality test was done in order to determine the probability distribution. The data obtained in all frequencies were found to possess a normal distribution (*p*>0.05) except few non –normal data *(p* <0.05*)*. However, non-parametric statistics was chosen for analysis. The data were analyzed using descriptive and inferential statistics. In descriptive statistics, mean, median and standard deviation (SD) for Q10 values across frequencies of all groups were calculated.

4.1. Mean, median and SD between groups across all frequencies:

Table 4.1.

Mean, SD and Median for Q_{10} Values across Frequencies of Group I

Ear	**Frequency**	**Mean**	**SD**	**Median**
Right ear	500Hz	1.95	.24	1.92
	1000Hz	2.25	.40	2.22
	2000Hz	1.87	.36	1.96
	4000Hz	2.02	.25	1.99
Left ear	500Hz	2.02	.33	1.96
	1000Hz	1.98	.32	1.95
	2000Hz	2.08	.35	2.01
	4000Hz	1.96	.39	1.84



a) b)

c) d)

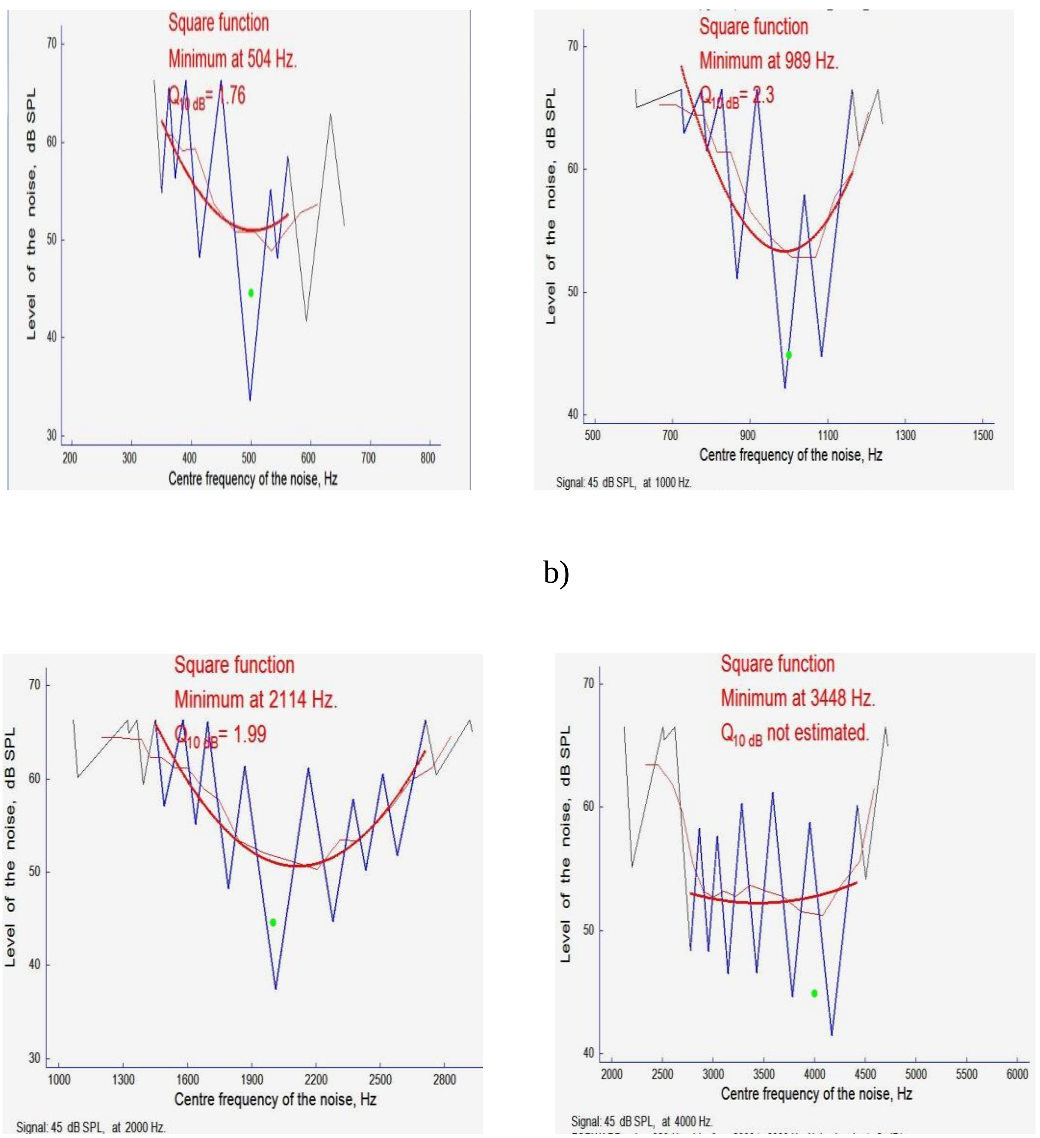
Graph 4.1. A graphical representation of Q10 value across frequencies of one participant among group I a) 500 Hz b) 1KHz c) 2 KHz d) 4KHz

The above four graphs represents the group I samples across frequencies using square function method to estimate Q10 values in SWPTC software.

Table 4.2.

Mean, SD and median for Q_{10} values across frequencies of group II

Ear	**Frequency**	**Mean**	**SD**	**Median**
Right ear	500Hz	2.58	0.59	2.45
	1000Hz	2.96	0.98	2.63
	2000Hz	2.89	1.20	2.52
	4000Hz	2.66	1.10	2.28
Left ear	500Hz	2.63	0.96	2.46
	1000Hz	2.10	0.44	2.11
	2000Hz	2.53	0.87	2.36
	4000Hz	3.01	1.38	2.49



a) b)

c) d)

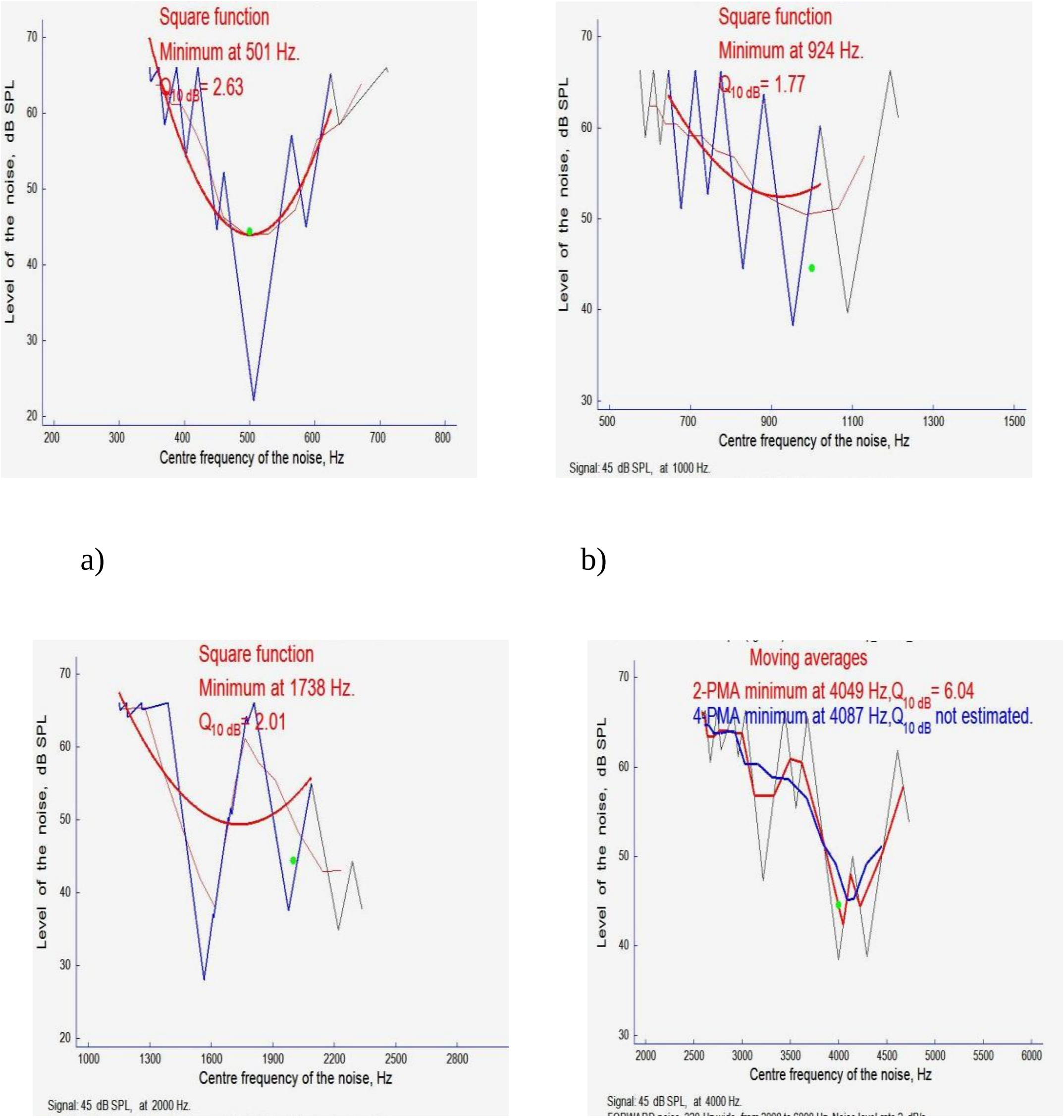
Graph 4.2. A graphical representation of Q10 value across frequencies of one participant among group II a) 500 Hz b) 1KHz c) 2 KHz d) 4KHz

The above four graphs represents the samples obtained from group II across frequencies using square function method to estimate Q10 values in SWPTC software

Table 4.3.

Mean, SD and median for Q_{10} values across frequencies of group III

Ear	**Frequency**	**Mean**	**SD**	**Median**
Right ear	500Hz	3.23	1.73	3.06
	1000Hz	3.08	.87	2.86
	2000Hz	3.95	2.49	3.15
	4000Hz	5.73	4.31	4.46
Left ear	500Hz	3.42	1.69	2.73
	1000Hz	3.31	1.15	3.63
	2000Hz	4.11	2.25	3.48
	4000Hz	3.81	1.98	3.34



a) b)

c) d)

Graph 4.3. A graphical representation of Q10 value across frequencies of one participant among group III a) 500 Hz b) 1KHz c) 2 KHz d) 4KHz

The above four graphs represents the samples obtained from group III across frequencies using square function and moving averages method to estimate Q10 values in SWPTC software.

From the Tables 4.1, 4.2 and 4.3, it could be noted that mean and median of Q_{10} value was greater for group III followed by group II and I, which infers that the frequency resolution ability is better for individuals who are not exposed to occupational noise. With respect to frequencies that were tested, the Q_{10} values were increasing as and when the frequencies increases from low to high. From the graph 4.1, 4.2 and 4.3, it could be noted that, group I had better sharpness at centered frequency in all tested frequencies, group II had better sharpness at centered frequency except at 4kHz, group III had better sharpness at centered frequency except at 4kHz.

4.4. Comparison of Q10 values between groups across all frequencies:

Kruskal Wallis test was done for comparing Q10 values across all frequencies between three groups.

Table 4.4.

Comparison of Q10 values between groups across all frequencies

Frequencies (Hz)	χ^2	
	Right ear	**Left ear**
500	14.00**	16.74**
1000	9.17*	12.10**
2000	14.54**	17.94**
4000	18.60**	14.31**

Note: $p < 0.01$** and $p < 0.05$*

Results of table 4.4 revealed that, among all groups there were significant difference ($p < 0.05$) across all frequencies in terms of Q10 values for both ears. Hence, paired comparison were done using Mann-Whitney U test.

4.5.1. Pairwise comparison of Q10 values across all frequencies between group I and II

Mann-Whitney U test was administered to compare the Q10 values between the groups I and II across all frequencies tested.

Table 4.5.1.

Results of pair wise comparison in terms of Q10 values across all frequencies between group I and II

Frequencie	**|Z|**	
	Right ear	**Left ear**
500	3.31*	2.94**
1000	2.28*	0.41
2000	2.96*	1.34
4000	2.67*	3.00**

Note: $p < 0.01$** and $p < 0.05$*

Mann-Whitney U test results as in above Table 4.5.1. Revealed that there was significant main difference *(p* <0.05*)* present in terms of Q10 values across all frequencies except left ear 1000 and 2000Hz.

4.5.2. Pairwise comparison of Q10 values across all frequencies between group I and III

Table 4.5.2.

Results of pair wise comparison in terms of Q10 values across all frequencies between group I and III

Frequencies (Hz)	|Z|	
	Right ear	Left ear
500	3.05**	3.67**
1000	2.84**	3.17**
2000	3.42**	4.14**
4000	3.86**	3.33**

Note: $p < 0.01$** and $p < 0.05$*

Mann-Whitney U test results as in above Table 4.5.2. revealed that there was significant difference *(p* < 0.05*)* present in terms of Q10 values across all frequencies.

4.5.3. Pairwise comparison of Q10 values across all frequencies between group II and III

Table 4.5.3.

Results of pair wise comparison in terms of Q10 values across all frequencies between group II and III

Frequencies (Hz)	|Z|	
	Right ear	Left ear
500	0.99	1.74
1000	0.58	2.77**
2000	1.09	2.75**
4000	2.46*	1.12

Note: $p < 0.01$** and $p < 0.05$*

Mann-Whitney U test results as in above Table 4.5.3. revealed that there was significant main difference *(p* <0.05*)* present in left ear Q10 values of frequencies 1000 and 2000Hz and in right ear 4000Hz. However, other frequencies had no statistically significant difference *(p* >0.05*).*

4.6. Comparison across frequencies within right and left ear of all groups

Friedman's test was done to compare across frequencies within right ear of all groups.

Table 4.6.

Results of Comparison for Q10 values across frequencies within right and left ear of all groups

Group	χ^2 (Asymp. Sig) Right ear	 Left ear
I	7.24 (0.06)	0.20 (0.97)
II	4.92 (0.17)	6.75 (0.08)
III	5.00 (0.17)	5.16 (0.16)

Results as in above Table 4.6 revealed that there was no significant difference (*p* >0.05) across frequencies within right and left ear in all three groups.

4.7. Comparison between ears within frequencies of all groups

Wilcoxon signed-ranks test was administered to compare between left and right ear within each frequency of all groups.

Table 4.7.

Results of comparison between ears within frequencies of all groups

Group	R-L500Hz	R-L1kHz	R-L2kHz	R-L4kHz
I	0.39	1.93	1.64	0.79
II	0.96	2.89**	0.76	0.56
III	0.14	0.90	0.17	2.15*

Note: p < 0.01** and p < 0.05*

Results as in above Table 4.7 revealed that group II had significant difference (p <0.05) between right and left ear at frequency of 1000Hz. However, all other frequencies had no significant difference (p <0.05) Also note that, group III had statistically significant difference (p <0.05) between right and left ear at frequency of 4000Hz and rest all other frequencies had no statistically significant difference (p >0.05). Group I had no statistically significant difference (p<0.05) between right and left ear across all frequencies.

Chapter 5

Discussion

Behavioral estimates of the auditory filters can be obtained via psychophysical tuning curves (PTCs) measurement (Moore, 1978). The impact of frequency resolution on assessment and rehabilitation of hearing impaired as well as its importance in perception of speech has led researchers to focus more on the masking experiments. There have been several studies comparing PTCs in normal subjects and with cochlear hearing loss (Hoekstra and Ritsma 1977; Zwicker and Schorn 1978; Bonding 1979).

Since frequency resolution is affected in individual with occupational noise exposure due to cochlear damage. Several studies have been performed to assess the methods for detecting the effect of noise on hearing in an appropriate time. Researchers have proposed the use of a faster method, based on Békésy tracking as a rationalized method of traditional PTCs (Zwicker, 1974; Summers et al., 2003; Sek et al., 2005). Sek et al., (2005) showed that PTCs obtained using faster method showed good repeatability and corresponded well with PTCs obtained in the traditional way. Fast PTCs measured in forward sweeps are recommended for use in clinical practice, as they give a precise estimate of fe and are quick to administer (Kluk & Moore ., 2006). For the impaired ears, the fast PTCs were similar in simultaneous and forward masking, but those in forward masking tended to be sharper (Moore & Glasberg., 1986) .

By estimating the Q10 value of f -min on individual with occupational exposure with greater and lesser duration of noise exposure using fast PTCs, results in the current study provide an evidence for poor frequency resolution in individual with occupational noise exposure.

Workers' hearing health has received growing attention in the recent decades, since the problems found are not limited only to hearing loss. Researchers have reported that, due to stress the extra-auditory effects of noise, temporary threshold alteration, tinnitus and other symptoms could also look into extensively. In the present study, PTCs were estimated using forward sweep in faster method. The result across participants, the frequency resolution ability was affected more in individual with occupational noise exposure as duration of noise exposure increases. This is consistent with findings of previous psychoacoustic studies (Mariola & Kowalska, 1998; Mahendra & Sridhar, 2008; Harrison, 2012; Kesar, 2014) where in they discussed about important factors to be considered in individual with occupational noise exposure .The current study estimated Q10 values of PTCs tip at various centre frequencies using SWPTC software.

Extensively analyzing the results, it could be noted that among group with greater duration (6months-5years duration) of occupational noise exposure at high-level (>85dBA) for 8hours/day and controlled group who had no previous history of occupational noise exposure, among these groups, the Q10 values of all frequencies been tested had statistically significant difference. This could attribute that the cochlear damage due to longer duration of noise exposure must have led to the elevated thresholds, broader PTCs and thereby reduction of frequency selectivity. Elevated masked thresholds compared to normals may either be due to widened auditory filter or less efficient detector mechanism. Out of 15 participants, 6 participants showed W-shaped PTC pattern. This is consistent with findings by Hoekstra and Ritsma (1977) on NIHL.4 participants' f-PTC results exhibited shift in tip of f –min at 2kHz and 4kHz, this could be speculated as off-frequency listening. Over masking may also be related to off frequency listening, there is a linear relation between NIHL and hair cell loss, but with residual low frequency hair cells (Fetcher, 1998). The sharpness in tip of f–min at centre frequencies was affected among group with greater duration of noise exposure. Since absolute thresholds, middle ear and outer hair cell status are important factors to be considered as behavioral estimates while correlating psycho acoustical results.

Pooling the 15 participants absolute thresholds and DPOAEs results, group with long term occupational noise exposure exhibited notched audiograms (3-6kHz) and mean thresholds at 4kHz was </=30dBHL and out of 15 participants, 8 individuals had reduced DPOAE amplitudes at higher frequencies and 7 participants had absence of DPOAEs across all frequencies. The explanation for reduction in DPOAEs could be that short noise exposures may cause damage to the early, more active stages of cochlear transduction. As the noise exposure continues, further damage may be induced at additional, later stages of the cochlear transduction cascade (Fraenkel, Freeman & Sohmer,

2010). The controlled group exhibited sharper tip and narrower f-PTCs, absolute thresholds within normal limits and normal DPOAE results across tested frequencies. The duration of the exposure has a reciprocal relationship to intensity. The higher the intensity, the shorter the exposure can be and still cause permanent damage. Conversely, lower-intensity noise may be safe, even when the ear is exposed for long durations. For exposures which are equal in total energy, the scheduling of the exposure affects the magnitude of damage that the ear sustains but does not affect the pattern of damage. Rest or quiet periods between successive exposures afford some protection for the ear, as long as the periods are not too brief. With moderate-level exposures for long durations such as those found in noisy industries (</= 90 dB SPL), a few scattered sensory cells probably degenerate within the organ of corti during each day of work. In general, the noise-induced loss of hair cells is very gradual. The amount of structural damage which is present in a given ear depends on its auditory history.

Outer hair cells (OHCs) are more sensitive to noise than inner hair cells (IHCs). With longer exposures or a more intense noise, there is further loss OHCs, IHCs, and supporting cells such as the outer and inner pillars. If the cell loss is confined to a narrow region of the organ of Corti, a 'focal' hair-cell lesion develops. Once IHC reaches moderate proportions, there is a beginning loss of myelinated nerve fibers within the osseous spiral lamina (Bohne et al., 1987). These myelinated fibers are the peripheral processes of the spiral ganglion cells. Hair cell and supporting cell losses within a focal lesion can gradually progress to involve 100% of the cells over a variable length of the organ of corti. A lesion in which no recognizable cells of the organ of Corti remain on the basilar membrane is termed an 'OC wipeout' by Bohne and Clark (1989). Eventually, the spiral ganglion cells which originally innervated the degenerated portion of the organ of Corti are progressively lost, including their central processes which form the auditory portion of the eighth nerve (Nadol and Xu, 1992). The longer the exposure, the greater the number of missing sensory cells (Bredberg, 1968; Bohne and Clark, 1990).

Among findings obtained from group with lesser duration of noise exposure (<6months) of occupational noise exposure at high-level (>85dBA) for 8hours/day and controlled group. The 15 participants of group with lesser term occupational noise exposure had normal absolute thresholds in all tested frequencies except 4kHz(</=20dBHL) and DPOAEs results exhibited reduced amplitude at 4kHz among 6 participants, inspite of near normal thresholds in pure tone audiometry and 4 participants with reduced DPOAE amplitude and elevated threshold at 4kHz, rest of the participants had normal DPOAEs across all frequencies. OAE recording techniques can be used for assessment of noise damage, as the most extensive noise-induced changes occur in the cochlea, involving the OHCs, which seem to be particularly vulnerable to noise. OAE recording techniques are simple, non-invasive, and they provide objective information and they are available in routine clinical practice. OAEs are characterized by a high sensitivity in detecting subtle changes of the OHCs and this property makes them very valuable in identifying early noise induced change, even before any notable shift in the audiometric thresholds. Although there is a

high inter-individual variability\ OAEs may also provide an insight into functional aspects of noise damage, which are less described in the literature (Borca, 2007).

It was noted that, except Q10 values of 1 and 2 kHz in left ear, rest all other frequencies exhibited statistically significant difference. f-PTC results exhibited normal pattern of PTCs with narrower and sharper tip of f min. However slightly elevated thresholds, broader and less sharper tip could be observed among 12 out of 15 participants ,only at 4 kHz frequency. The sharpness in tip of f –min at centre frequencies was not much affected among group with lesser duration of noise exposure. It could be accredit that, the sequence of change starts with an elevation of threshold of the sharply tuned tip region of tuning curve, especially at higher frequency; the low frequency “tail” thresholds are not initially changed. For neurons with high characteristic frequency (CF) there is a lowering of CF during the exposure and a gradual enlargement of the bandwidth of the response area. With continued noise exposure, thresholds at all frequencies become elevated, and eventually the neuron can become totally unresponsive. There is generally more damage to outer hair cells than inners. This could be the result of outer hair cell stereocilia being more firmly attached to the tectorial membrane than those of the inner hair cells and thus more excessively displaced by mechanical vibrations in the cochlea. There are also metabolic theories suggesting that outer hair cells are more susceptible to the metabolic exhaustion effects of acoustic trauma. Note also that while a small degree of disarray of stereocilia can exist after some months, generally cells damaged beyond a certain point (as yet undefined) degenerate completely, leaving the conspicuous gaps in the reticular lamina as reviewed by Harrison(2012).However, it could also noted that ,in terms of Q-10 values at 1and 2kHz in left ear there was no statistical difference, we could speculate that the mid frequency has least affect from noise exposure hence no significant difference of Q10 value were observed among two respective groups. It is possible that, the working plants are located in buildings such that the noise generator machines are closer on one side of ear and farther than the other, The issue of ear laterality has been discussed by many authors who state that NIHL is usually bilateral. The individual susceptibility, direction of noise source and frequency composition of noise also plays a major role in our findings (Boger et al., 2009).

Interestingly, the findings of comparison among group with lesser and greater duration of noise exposure in terms of Q10 values revealed statistically significant difference in Q10 values of 1kHz,2kHz in left ear and 4kHz of right ear. Rest all other frequencies had no significant difference. Based on the notion that, the greater elevated threshold among participants of greater duration of noise exposure than the other group especially at 4 kHz, in analyzing the mean values of audiometric thresholds according to frequencies starting at 3k Hz and the time of exposure, we observed that the longer the time of exposure, the greater the degree of hearing loss, in all the frequencies, when compared among themselves. This must have contributed for their significant difference of Q10 value at 4kHz in right ear. The pattern of f-PTC also varied among these two respective groups that the w-shaped PTC and off frequency listening were not noted among participants of lesser duration of noise exposure. Amount of masking, response area and sharpness of f-min tip also varied between two groups at higher frequencies.

Some event was observed in this study, that there was statistically significant difference in Q10 values of 1 kHz, 2 kHz in left ear, since the highest prevalence of NIHL notch happened in both ears. However, the left ear proved to be slightly more prone to it than the right ear. As far as a possible asymmetry, some authors report that the left ear is more vulnerable to noise-induced damage, however, there was no evidence for such statement. Another study considered that male adult hearing is about 4 dBHL lower on the left ear, when compared to the right one. This has also been observed in clinical practice, it is possible to perceive that during audiometry we have a better right ear response when compared to the left ear. The possible physiological mechanisms responsible for this difference seem to be unknown (Boger, Branco and Ottoni, 2007).However, across all tested frequencies in all groups there was no statistical difference observed in terms of Q10 values presumption was that, the pattern, amount of masking, response area and sharpness varied across frequencies, but in the present study the significant difference were not pronounced in all tested frequencies. The important factors could be the wide range in susceptibility to noise induced hearing loss has intrigued researchers and hearing conservationists alike. Some of these differences in variability have been attributed to various intrinsic factors such as eye color, gender, age, etc. However, a review of controlled research shows that the influence of these intrinsic variables is relatively small and cannot explain the wide range of hearing loss observed in demographic studies (Donald, 1993). Furthermore, uncontrolled variables or unrecognized drug and noise interaction may obscure the relation between noise exposure and hearing loss.

It was also noted that, the controlled group had no ear asymmetry in terms of Q10 values across all frequencies however other two groups showed ear laterality. Group with lesser duration of noise exposure had ear difference presented in Q10 value of 1kHz and greater duration group had ear laterality seen at 4kHz,rest all frequencies had no ear difference in terms of Q10 values. The possible physiological mechanisms responsible for this difference seem to be unknown. There are some studies where in this issue has observed. These findings are consistent with few studies (Boger, 2007; Axelsson' G. Aniansson & O. Costa, 2009).In their studies, they could also notice the ear asymmetry which was in contrast to the notion of bilateral symmetry in NIHL cases.

Based on above discussions and speculations with respect to the null hypothesis of current study findings hence proved, it could be noted that there is an effect of duration of noise exposure on frequency resolution ability in individuals with occupational noise exposure. Hence intensity, frequency composition of exposed noise and duration of noise exposure has an important role in case of diagnostic aspects of individual with occupational noise exposure.

Chapter 6

Summary and Conclusion

Peripheral auditory system behaves as a band of band pass filters with overlapping bands. The shape and organization of the basilar membrane are in such a way that different frequencies resonate maximum at different points along the membrane. This leads to a tonotopic organization of the sensitivity to frequency ranges along the membrane, which can be modeled as being an array of overlapping band-pass filters known as "auditory filters”. Normal basilar-membrane responses to sound are characterized by a triad of features: high sensitivity, sharp frequency tuning, and nonlinearity (Ruggero,1986).Continuous exposure to noise can cause several functional limitations of hearing, i.e., changes in frequency selectivity, temporal and spatial resolution, recruitment, and tinnitus as well as changes in hearing sensitivity (Samelli,2004).According to Bohne (2000), the duration of the exposure has a reciprocal relationship to intensity. Hence it is one of the major factors to be considered while speculation of cochlear damage due to occupational noise exposure.

The cochlear damage lead to changes in frequency selectivity also cause difficulties in auditory discrimination, limits the ability of the individual to recognize sounds (Bamford & Saundes et al., 1991). Psychophysical Tuning Curve is a psychophysical procedure to measure frequency resolution suggested by Chistovich (1957) and Small (1959). Fast Psychophysical Tuning Curve (f-PTCs) is a rationalized tool of traditional PTCs to measure frequency selectivity.

Sek et al., (2005) used f-PTC as a frequency selectivity measure and could obtain the similar results in both of f-PTC and traditional method.

Hence, the current study aimed at exploring implication of f-PTC in individual with occupational noise exposure and also to compare across lesser versus longer duration of noise exposure on frequency resolution ability in those individuals.45 participants were divided into three equal groups (lesser duration, greater duration of noise exposure and controlled group) based on their duration of working condition (months/years).f-PTCs were obtained using SWPTC software across signal frequencies from 500 to 4000 Hz in half-octave steps using forward sweep (low to high) method. Testing was done after 24 hours of noise exposure. At the end of each run, a graph was displayed of the level of the noise as a function of the centre frequency of the noise. The software offered several methods for estimating the frequency at the tip of the PTC. The quadratic function method was used in present study, as it had the smallest 95% range, high success rate in f -tip estimation and the best test-retest reliability. If f -tip estimation was not done through quadratic function method then other methods were used.

Appropriate statistical analysis was carried out and the current study revealed the following:

- Estimates of Q10values and sharpness of tuning curves among participants with greater duration of noise exposure had abnormal findings using f-PTC method

- Significant difference was noticed among controlled and group with greater duration of occupational noise exposure in terms of pattern ,response area and amount of masking using f- PTCs
- Among controlled and group with lesser duration of occupational noise exposure significant difference was noticed in terms of Q 10 values at higher frequencies.
- Tuning curves obtained at 4kHz in right ear ,1kHz and 2kHz in left ear was significantly different among two different duration of noise exposure groups
- Ear laterality was observed in terms of Q10 values at 1 kHz in lesser duration exposure and at 4 kHz in greater duration of occupational noise exposure .However, controlled group had no statistically significant ear difference.
- Significant differences in terms of Q10 values across all frequencies among three groups with respect to ears were not observed.

Results of the present study indicate that the duration of occupational noise exposure has greater effect on change in frequency selectivity in individual who are exposed to occupational noise. The duration of noise exposure is one of the primary factor which contributes for change in cochlear normal mechanism which lead to reduction in frequency resolution, hearing acuity and other factors. Widened auditory filters in damaged cochlea, which is reflected by decreased sharpness of f-tip indicated reduction of frequency resolution among greater duration of noise exposure.

Clinical implication

- The present study explores the clinical implication of f-PTC as a tool for psycho acoustical measure in diagnosis of individual with occupational noise exposure with greater time efficiency.
- Since effect of duration of noise exposed has been noticed in the study , subtle changes observed in f-PTC identifies the hidden abnormalities of OHCs ,early diagnosis of NIHL or early detection of ears with normal absolute threshold but susceptible to the effects of noise can prevent hearing loss could be identified and can avoid from extension to speech frequencies. These factors can be used while counseling NIHL individuals.
- Studies of interrelationships between auditory functions suggest that frequency resolution is an important determinant of auditory disability and is correlated with speech discrimination in noise .This study provides better understanding of speech recognition difficulties among individuals with occupational noise exposure.

Future direction

The present study investigated the effect of duration of noise exposure on f-PTCs in individual with occupational noise exposure, future studies could be carried out to find out effect of other magnitudes such as level and frequency composition of noise exposure in NIHL individuals could be considered to investigate their frequency resolution. Since studies using f-PTCs are not done extensively, there is a greater need to standardize this method across wide varieties of ear pathologies and exploration of f-PTCs across various factors and correlation with behavioral measures could be carried out.

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