Auditory Temporal Resolution based Psychophysical Evaluation of healthy individuals exposed to Occupational Noise and Solvents

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Abstract: Temporal resolution often links to psychophysics and the ability of individuals to temporally resolve the sounds serve as an indication of auditory perception. The present work emphasized on the assessment of the temporal resolution and the psychophysics involved for subjects without any auditory pathological history, but with a constant exposure to noise and solvents in their work place. 44 males of age group 20 – 50 years with no known auditory disorders from two different industries, employees of Chemical Industry (CH) exposed to a combination of noise as well as solvents and the employees of Fabrication Industry (FB) with regular exposure to noise alone, in their daily routine at their work place were considered for this experiment and were made to undergo Frequency Response Test (FRT) and Absolute Threshold Test (ATT). While the results showed a clear deterioration in the auditory perception for both FRT and ATT approach, this deterioration was found to be relatively lesser in FB as compared to CH. This was attributed due to the exposure of noise in case of FB while the CH were exposed to both noise and solvents at their work place thereby proving to have a higher impact on the auditory perception in case of a combined exposure to noise as well as to solvents as compared to those with an exposure to noise alone. Hence, based on the statistical analysis of the results obtained for FRT and ATT, it was concluded that the FB have a better auditory temporal resolution than the CH.

Keywords: Psychophysics, Auditory Temporal Resolution, Frequency Response Test, Absolute Threshold Test, occupational exposure, Noise, Solvents.

1 Introduction

Auditory function is one of the most important aspect of Human Beings and is often affected due to various noise exposure in the regular living [1]. Sound and its sensation is one of the prime factor in cognitive ability of the brain. Attributes of sound being, both physical as well as psychological, have immense influence on the human understanding of the world. Auditory pathology hinders such regular functions of daily life. The threshold of hearing, assessed with the aid of a clinical audiometer, can quantify the ability of hearing [2]. The audiometry test is the most common tool used to assess the conductive hearing losses. But such tests are used to assess the pathologically affected conditions and seldom can grade the onset of hearing deterioration in normal subjects. Hence there lies a need to develop novel approaches to assess the hearing abilities in normal subjects with respect to variations in hearing perception as well [3]. For instance, the employees working in paint production plants are prone to auditory disorders due to a continuous solvent exposure. Such occupational disorders often seem to be neglected with respect to preventive medicine in developing countries such as India [4]. If such subjects are identified at the very onset of hearing perception-based deterioration, then adequate care can be provided to ensure that such exposures to solvents are reduced thereby providing them the much-needed interval so as to allow the auditory system to recover and hence avoid the damage to hearing organs [5]. Such situations are often observed in case of the employees of fabrication industries as well where a constant exposure to noise at the workplace would be the sole reason for the deterioration of hearing functions [6]. Hence the present work was confined to occupation based auditory pathology for CH and FB. The FRT and ATT paradigms were developed to assess the hearing perception of the subjects.

2 Background

Frequency Response

Frequency response is considered to be a quantitative measure of the output spectrum of a system in response to a stimulus and is often used to characterize the dynamics of a system [7]. With respect to auditory function, the frequency response can determine the ability of an individual to hear. Sound stimulus of 20 Hz to 20KHz is audible and the rest goes undetected by human beings [8]. But the sensitivity of hearing is maximum at 1KHz – 4KHz. Sound Pressure Levels (SPL) is an apt, but relative measure to assess the hearing ability. For instance, subjects can detect sounds as low as 0 dB SPL at 3 kHz but require 40 dB SPL at 100 hertz (an amplitude increase of 100). The frequency response is often depicted as a graph with frequency (Hz) at the x-axis and the SPL (dB) along the y-axis. The dB is an indicative of the maximum variation of volume level and a 3dB level is the most common gradient used in the assessment of frequency response [9]. The FRT paradigm was developed with frequency-based variations for the assessment of auditory temporal resolution.

Threshold Estimation

A precise estimation of the hearing threshold is of utmost importance in auditory psychophysical evaluations. Discrimination based approach or detection-based approaches are used in such experiments [10]. While the former technique can be used to differentiate between two given sound inputs, the latter method can be used to assess the presence of sound and not for any kind of discrimination-based tasks. Both the approaches are subjective and the feedback of the subject is used to vary the auditory stimulus [11]. Patterns such as straight line, staircase etc are commonly used. The variations of the absolute threshold value of the auditory stimulus was employed in the ATT paradigm developed. This test employed the Maximum Likelihood Method to vary the input stimulus rather than a simple staircase-based approach wherein a pure tone of a certain frequency and time period were provided to the subject through noise cancelling ear-phones. The subject was asked to indicate whether the tone was perceived or not, by simple hand gestures [12].

Chemical Industries

Chemical industries often involve a large amount of solvents, which are toxic to the human ear. Exposure to these, along with a large amount of industrial noise collectively causes damage to the hearing functions which are irreversible eventually. These chemicals are known to cause Sensorineural Hearing Loss, in which the inner ear and the auditory nerves are damaged. Exposure to a combination of different chemicals can also result in hearing loss [13]. Anti-inflammatory medication also has an adverse affect on the human ear. Although more than 700 chemicals have been identified to be toxic to human ears, very few have been studied in depth and this is often neglected in industries. Presence of noise from the machines at chemical industries such as chilling plants, air compressors, vacuum pumps and fluid bed driers result in a compounded effect on the human hearing due to a combined exposure to solvents as well as industrial noises [14].

Fabrication Industries

Fabrication industries house machinery emanating high intensity noises while being operated. Most common equipment in such industries include those for Drilling, Grinding and Filing tasks. Workers exposed to such machinery in their daily job routine are often prone to occupational noises which are harmful to the auditory system. While many such issues go neglected unless the individual senses a loss of hearing, much could be done if an early detection of the same is achieved where preventive approach could be employed to avoid the irreversible damage to hearing function [15].

3 Materials and Methods

Subjects

The present work encompassed two sets of 44 random ubiquitous individuals of the age group 20-50 years. The first group was the employees of a popular chemical industry which used solvents in their daily jobs with more than 3 years of work experience at the factory, thus having definite exposure to solvents as well as to noise from machines commonly used in the chemical industry (CH). The other set comprised of employees of a popular fabrication industry, with more than 3 years of work experience in the operation of the machines used for drilling, grinding and filing tasks (FB). The subjects chosen had no history of any hearing dysfunction till date. Written informed consent was obtained from the subjects before the administration of the tests. Both CH and FB were subjected to FRT and ATT before the commencement of their work shift in the morning (8.00 am to 10.00 am) [16]

Experimental Paradigm

The Frequency Response Test (FRT) and Absolute Threshold Test (ATT) were administered in a silent noise free environment with the aid of Sony vio laptop with windows 8 operating system and Panasonic HD headphones. MATLAB tool was used to generate the sound complex and the analysis was done using SPSS software. FRT was conducted with the aid of hearing test tool and ATT was conducted with the aid of Psychoacoustics tool in MATLAB.

The response of the subject for these tests were tabulated to evaluate the auditory temporal resolution thereby assessing the auditory psychophysical abilities of the subjects considered.

Frequency Response Test (FRT)

The FR can assess the dynamics of a given system and provides an insight into the magnitude as well as the phase of the system as compared to the input. In general, the steady-state response of the system to a sinusoidal input signal is considered to be the FR. With respect to Psychoacoustics, the listeners are known to perceive a similar sound as “NOT SO SIMILAR” which makes it seem different to different subjects. Perception is affected by many factors such as gender, age, working environment, pathology and many more inherent features. The FRT was designed to assess the frequency response of the ear so as to determine the threshold of hearing. The test was based on a fundamental principle that the ear has a non-flat frequency response which indicates that, a set of tones, while retaining the volume to be constant, when played at different frequency values will sound as if they have been played at different volume levels. Hence individuals hear certain tones better than others. This is attributed to the fact that the hearing mechanism of every individual is unique due to which there seems to be a difference in the response of different individuals to different frequencies. The FRT paradigm encompassed a frequency range of 0 to 16000 Hz due to the hearing constraints in human beings. Each frequency was played across amplitudes ranging from 10 to near 0 dB. These amplitudes were multiplied by a factor of 0.707 which is an equivalent of 3dB decrement because that is the Just-Noticeable-Difference (JND) for an average human ear. Hence, 26 intensity levels were fixed for each frequency to be played and tested for the assessment. The 26 intensity levels stored in an array rounded off to four decimal points were 10, 7.0794, 5.0118, 3.54813, 2.5118, 1.7782, 1.2589, 0.8912, 0.6309, 0.4466, 0.3162, 0.2238, 0.1584, 0.1122, 0.0794, 0.0562, 0.0398, 0.0281, 0.0199, 0.0141, 0.0100, 0.0070, 0.0050, 0.0035, 0.0025, and 0.0017. The frequency sets were from 10 Hz to 16000 Hz in steps of 10 Hz with a total of 1600 values. Each frequency value starting from 10 Hz was played using the tone function of MATLAB with a maximum of 26 levels each, as mentioned prior, depending on the subject’s responses to generate tones. The test began from the maximum level and continued as the values decreased. The sound function of MATLAB was used to play the generated tone. At each frequency, till the subject responded positively (tone perceived) the level decreased to the last 26th level and moved on to the next frequency and started from the 1st level again. If the subject responded negatively (tone not perceived) at a particular level for a given frequency value, the control moved onto the next frequency level while having set the level back to one. This way the subject’s threshold of hearing was determined at every frequency and plotted simultaneously. So, if the result said the subject heard up to level 26 at 3500 Hz, it indicated that the levels below 26 were below the threshold of hearing and the level thus obtained corresponded to -4 dB because it would then be the approximate threshold of hearing at 3500 Hz for a subject of normal hearing. Using this convention, the rest of the thresholds were plotted at various frequency values by subtracting the count at each frequency from 3500 Hz and multiplying the difference by 3 and then, adding the result with -4 dB, to get an array of the dB levels to plot the equi-loudness curve. For instance, if the audible tone level was found to be 21 for 3500 Hz, 18 for 1000 Hz and 5 for 100 Hz, then the graph was plotted based on the below mentioned approach [17].

At 3500 Hz	21 tone levels	[3x {21-21} – 4] = -4 dB
At 1000 Hz	18 tone levels	[3x {21-18} – 4] = 5dB
At 100 Hz	5 tone levels	[3x {21-5} – 4] = 44dB

Absolute Threshold Test (ATT)

The Absolute Threshold (AT) of Hearing is defined as “The minimum sound level of a pure tone that an average human ear with normal hearing can hear with no other sound present”. AT signifies the sound that is “JUST HEARABLE” by the individual. Conventionally, human beings can perceive the sounds of frequencies in the range of 20Hz – 20 KHz. Any sound above or below this range goes unnoticed and are not known to influence the hearing perception in any ways, irrespective of the pressure level of the sound being perceived. AT is relative to frequency of the sound and it is also a fact that the human ear is the most sensitive at frequency levels of 1 KHz – 5 KHz at which the hearing threshold goes up to -9 dB SPL. The AT can vary based on various factors such as the adaptability of the subject to the given sound and the cognitive ability of the individual as well.

Maximum Likelihood Procedure (MLP)

Although conventional staircase-based variation of the sound input is provided in normal hearing tests where the intensity or the frequency is varied in either incremental / decremented order, a better approach to vary the parameters of sound such as intensity and frequency is based on the Maximum Likelihood Procedure (MLP). MLP is a unique approach depending on two aspects namely Stimulus selection policy and Maximum Likelihood Estimation. In the resent paradigm, the psychometric parameters were hypothesized as per the requirement so as to arrive at an efficient result. The parameters, termed as hypothesis functions in the present approach were considered as α (Array of mid-points of all the hypothesis), β (Slope of the psychometric function), γ (False alarm rate) and λ (Attention lapse rate in the subject). While α was the only entity which varied throughout the experiment, with every trial, β, γ and λ remained the same throughout the experiment. A generic MLP based Adaptive N-Altered Forced Choice (nAFC) detection approach was designed for the estimation of absolute threshold. The process began with the provision of an auditory input above a predefined threshold value. The intensity of this sound was varied based on the MLP approach as the experiment progressed. The response was noted as the intensity below which the subject could not perceive the sound input. The likelihood of each of the hypothesis being defined as the psychometric function was estimated using equation 1.

$$L(\mathrm{Hj}) = \sum_{i=1}^{n} \mathrm{C} \log \mathrm{H(xi)} + \mathrm{W} \log [1- \mathrm{H(xi)}] \quad \text{--------} \quad \text{(Eq 1)}$$

Where L(Hj) was the Likelihood of the j^{th} hypothesized function, i being the trial number, C was the exponent denoting the correct responses (which was equal to 1) and W was considered to be the exponent used to denote the wrong responses (which was equal to 0).

After the likelihood was calculated for all hypothesis, the ones with the highest occurrence was considered to be same as that of the psychometric function of the subject and was identified by its midpoint, α. The selection policy employed to choose the stimulus for the next trial involved the setting of the threshold at the end of the previous trial using the p-target (the psychometric function to be considered), given by equation 2.

$$x = \alpha - \left(\frac{1}{\beta}\right) \times \log[\frac{1-\lambda-\gamma}{p-target-\gamma} - 1] \quad \text{-------} \quad \text{(Eq 2)}$$

Where *x* was the stimulus value (threshold) estimated for next trial.

The ATT was used to assess the threshold of the perception of the sound with respect to the intensity of the subjects. Here the pure tone sound generated using MATLAB was presented to the subjects and the intensity was varied as per the response of the subject with respect to whether he/she was able to perceive this sound. The Present experiment used the MLP approach to vary the intensity of the sound given as input to the subject. A pure tone of 1 KHz was given to the subject for 500 msec. This tone was gated off and on with two raised cosine ramps of 10 ms each. 3 blocks with 15 trials each were considered. In each of these trials, the subject was provided the sound and asked if the same was heard or not. The subject was made to press 0 if the sound was not heard and 1 if heard in the keyboard. The hypothesis was fixed to be 100. As defaults, the initial mid-point was set as 110 dB FS and the last mid-point was 30 dB FS. The slope (β) was set as 1 and gamma (γ) was 0, the p value was 0.631 at the beginning. The first block of sound was given at 30 dB FS. Based on the subject response, as positive or negative, the psychometric function was calculated based on equation 1. Using the result of equation 1, the threshold value of the stimulus for the next trial was calculated using equation 2. The complete duration of the test was 3 minutes. The ATT encompassed an intensity range of 30 – 100 dB in the present experiment. The results were tabulated to assess the intensity-based variation of both CH and FB to conclude on the auditory temporal resolution of the subjects due to occupational exposure. [18]

4 Results and Discussions

Frequency Response Test (FRT)

The Frequency Response (FR) obtained for both CH and FB are plotted in figure 1

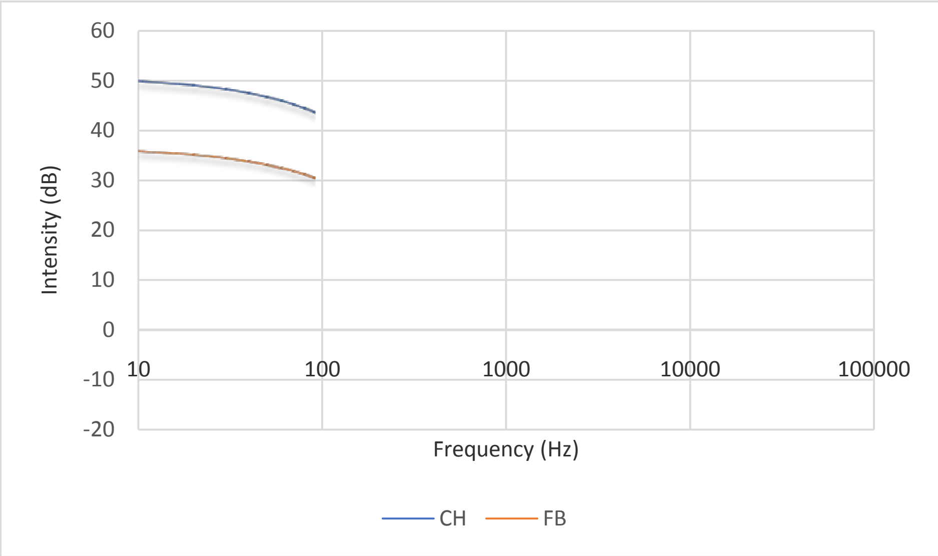

Figure 1: FR patterns for CH and FB

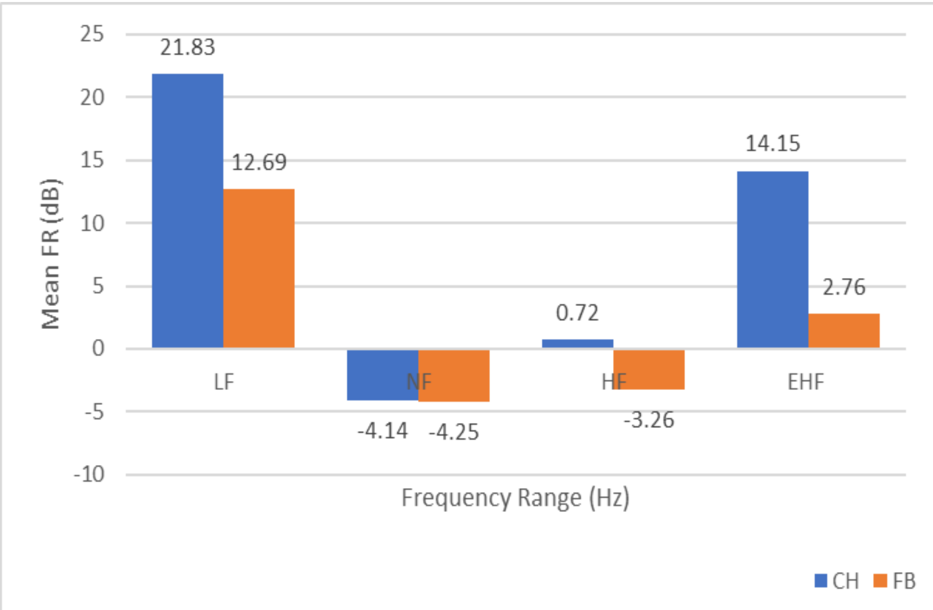

Figure 2: Mean FR of CH and FB

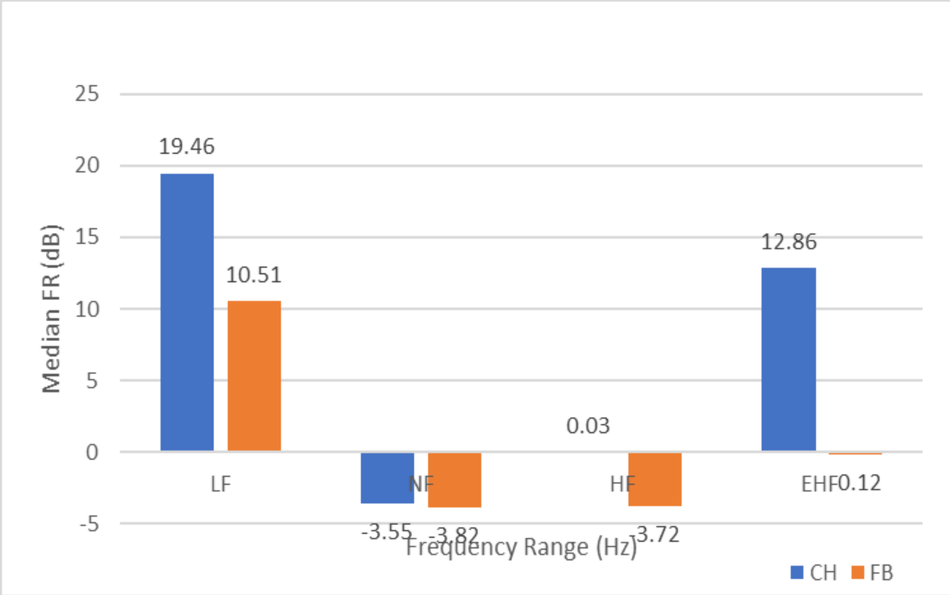

Figure 3: Median FR of CH and FB

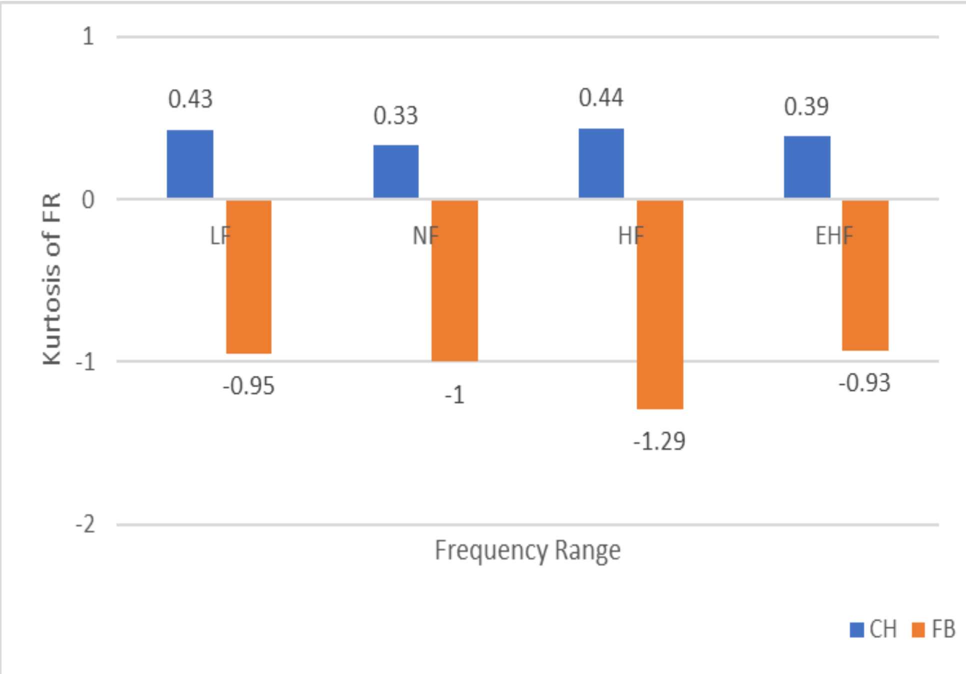

Figure 5: Kurtosis values of FR obtained for CH and FB

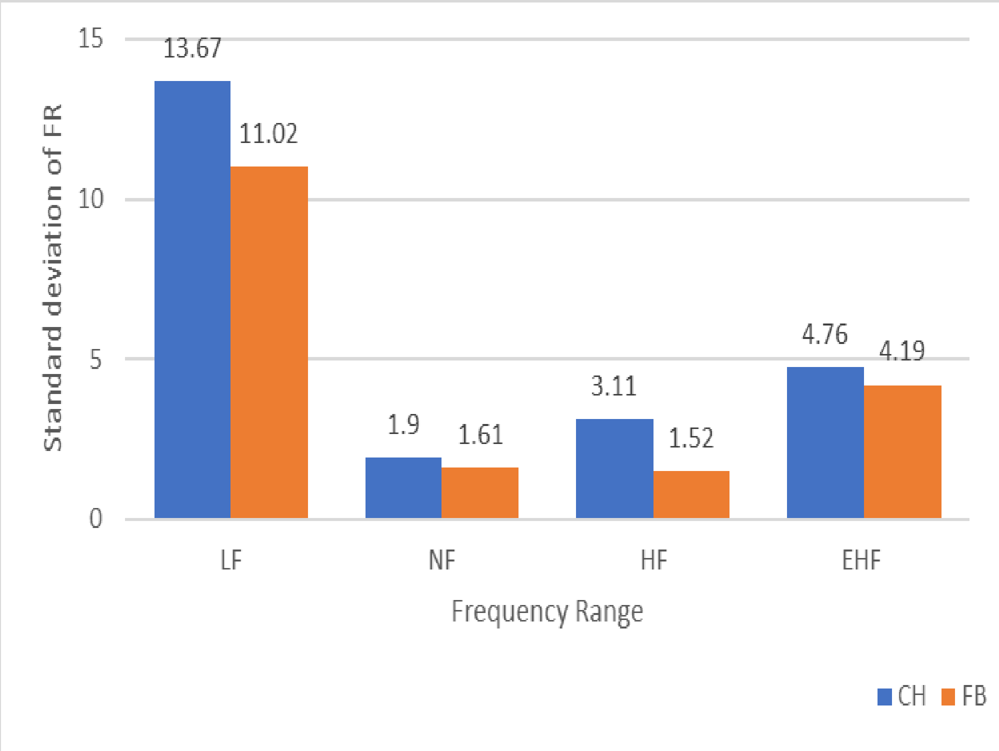

Figure 4: Standard Deviation in the FR of CH and FB

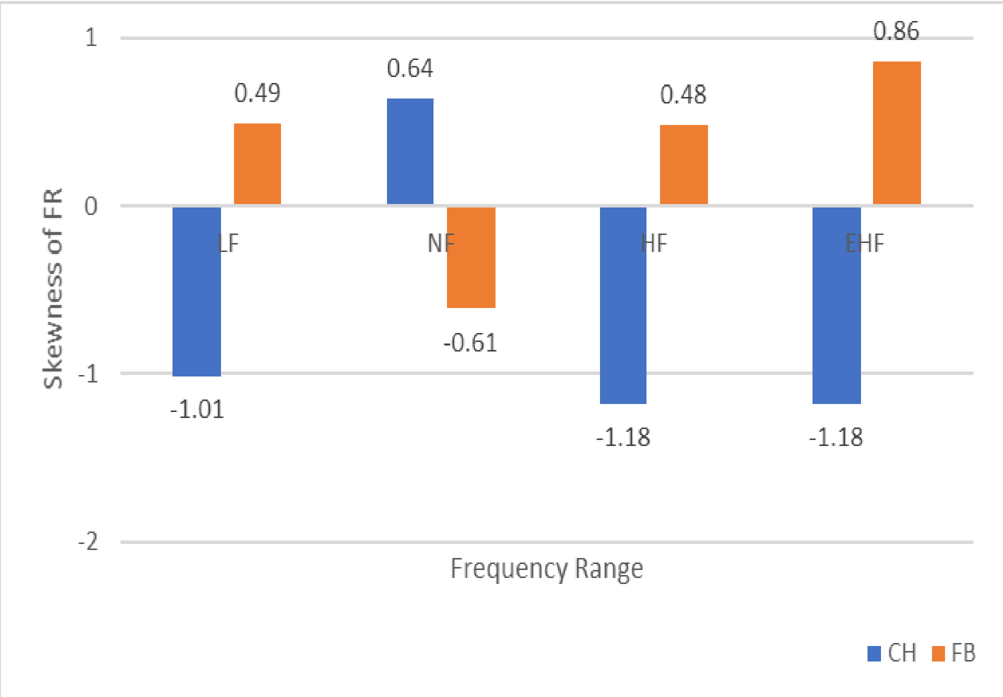

Figure 6: Skewness of the FR of CH and FB

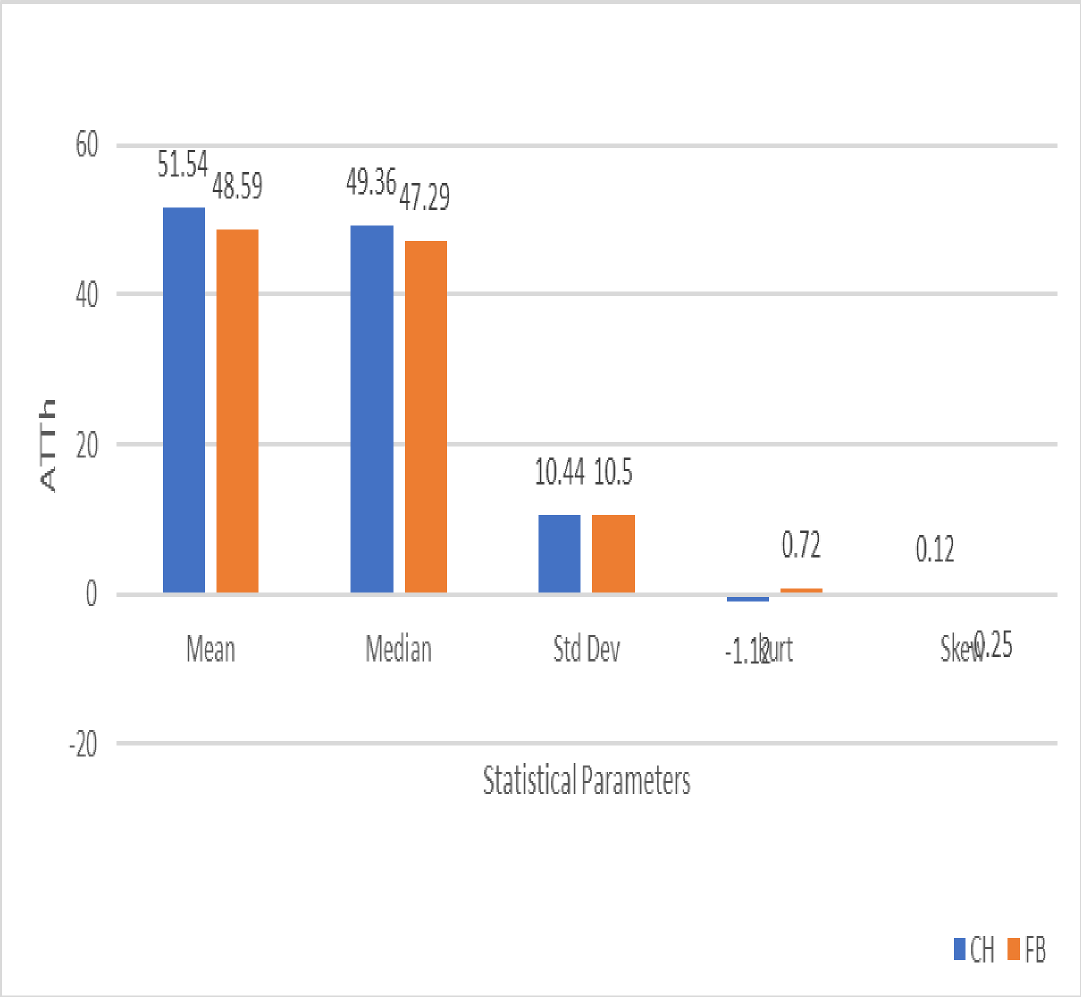

Figure 7: Statistical analysis of the ATTh values obtained for CH and FB

Table 1: Statistical analysis of the FR obtained for CH and FB

Chemical Industry (CH)					
	Mean	***Median***	***Std Dev***	***kurtosis***	***Skew***
LF	21.83	19.46	13.67	-1.01	0.43
NF	-4.14	-3.55	1.9	0.64	0.33
HF	0.72	0.03	3.11	-1.18	0.44
EHF	14.15	12.86	4.76	-1.18	0.39
Fabrication Industry (FB)					
	Mean	***Median***	***Std Dev***	***kurtosis***	***Skew***
LF	12.69	10.51	11.02	-0.95	0.49
NF	-4.25	-3.82	1.61	-1	-0.61
HF	-3.26	-3.72	1.52	-1.29	0.48
EHF	2.76	-0.12	4.19	-0.93	0.86

Based on the response curves obtained, a polynomial equation was derived for a fourth degree as mentioned in equation 3 and equation 4. A detailed statistical analysis of the frequency response was performed and is tabulated in Table 1 after classifying the ranges into 10-1000 Hz (Low Frequency-LF), 1010-6000 Hz (Normal Frequency-NF), 6010-10000 Hz (High frequency-HF) and 10010-16000 Hz (Extended high frequency-EHF).

		R^2	
CH	$y = 5E\text{-}13x^4 - 5E\text{-}09x^3 + 2E\text{-}05x^2 - 0.058x + 44.34$	0.974	Eq 3
FB	$y = 4E\text{-}13x^4 - 4E\text{-}09x^3 + 2E\text{-}05x^2 - 0.043x + 28.89$	0.896	Eq 4

The mean value is conventionally equal to the average response of the subjects at given frequencies. If the mean value is higher, it hints at a lesser perception of sound at a given frequency range. In the present case, the mean FR seemed similar for both CH and FB at NF (CH = -7.14 and FB = -7.26 in NF). Due to the fact that most of the conversations happen at NF range, the subjects concluded themselves to be normal and did not foresee any auditory problems in their normal auditory conversations.

But the mean FR was significantly different at LF, HF and EHF ranges which seldom would be encompassed during the normal conversations in general. A comparative pictorial depiction of the variations in mean FR is given in figure 2.

The median is the location of the center value of a group of numbers in a statistical distribution and gives the central behavior response for all frequency ranges with respect to the responses of a given set of subjects. If the median value is lower, the FR is said to be better which then denotes the betterment in the ability of the FR of all the subjects considered. The median FR of CH and FB is given by figure 3 from which it is evident that the median values are lower for FB as compared to CH in LF range (CH = 19.46 and FB = 10.51 in NF).

The standard deviation denotes the variations of the responses with respect to the average response value obtained. Therefore, it can conclude that a lower standard deviation value is better when compared to a higher standard deviation.

The Standard deviation of FR for CH and FB is given in figure 4 from which it is evident that FB was found to be having a lower deviation than CH due to the fact that FB was exposed to only noise whereas CH was exposed to a combination of noise and solvents at their work place. Also the deviation was less in NF and HF for both FB and CH. But this deviation increased in LF and EHF comparatively.

The kurtosis measures the sharpness of a given distribution. This also gives the tiredness of a dataset. A normal distribution has a kurtosis value of 3. Here positive values indicate a peaked distribution while negative values have a flatter distribution. The kurtosis of the FR for CH and FB is depicted in figure 5. It was observed that the kurtosis of the FR was relatively flat for both CH and FB at LF, HF and EHF. But surprisingly, the kurtosis was extremely different at NF for CH and FB (CH = 0.64 and FB = -1). This indicates that the kurtosis can be used as a differentiating parameter to assess the variations between FB and CH at NF. Also, the peakedness of kurtosis could be attributed to a combined exposure of employees to noise and solvents which was not the case for FB.

The skewness of the FR gives the characteristics of the degree of asymmetry around the mean of a distribution.

In the present case, the skewness was greater than 0, which means there was an asymmetric trail which extended towards positive values. Both CH and FB exhibited similar skewness in the LF regions (CH = 0.43 and FB = 0.49) but in the HF and EHF regions, the values seemed to vary. The largest variations were seen in the NF region (CH = 0.33 and FB = -0.61). This indicates that skewness can be used as an effective tool to differentiate the FR of CH and FB in NF.

Absolute Threshold Test (ATT) results

The intensity-based variations termed as the ATTh (Absolute Thresholds) were obtained for CH and FB. The statistical analysis of the ATT results have been tabulated in table 2.

Table 2: Statistical parameters of the ATT results

ATTh	*CH*	*FB*
Mean	51.54	48.59
Median	49.36	47.29
Std Dev	10.44	10.5
kurt	-1.12	0.72
Skew	0.12	-0.25

The mean values obtained for the ATTh of CH and FB demonstrate a better perception of sound in the morning by FB as compared to CH not only due to the nature of their occupational exposure, but also due to the fact that their work shifts would not have begun yet (CH = 51.54 dB and FB = 48.59 dB). The median values obtained for the ATTh of CH and FB provided an indication that the FB was better than CH in this case as well (CH = 49.36, FB = 47.29).

The standard deviation was also found to be analogous with the median. But the deviation was almost similar in both CH and FB thereby eliciting very less difference with respect to the deviation from the mean. (CH = 10.44 and FB = 10.5). The kurtosis values of CH were found to be more peaked than FB thereby supporting the fact that CH have a higher deterioration of ATTh as compared to FB (CH = -1.12 and FB = 0.72). The skewness of the ATTh was found to be deteriorated for CH than FB. (CH = 0.12 and FB = -0.25) thereby substantiating the previously depicted results. The statistical parameters obtained for the ATTh are depicted in figure 7.

5 Conclusion

From table 1, it was evident that the FB have a better FR than CH with respect to the statistical analysis performed at various ranges. Both mean and median were able to elicit the difference between CH and FB at LF and EHF regions. But the standard deviation was similar for almost every range and failed to probe any differences between CH and FB. But the kurtosis and skewness depicted a large variation of FR between CH and FB at NF. Hence it was concluded that the FRT was able to successfully differentiate between CH and FB at certain frequency ranges. However, no single statistical parameter was able to provide a stronger variation in FR between CH and FB at every frequency range. From table 2, similar conclusions were drawn. The statistical analysis of the ATTh obtained for CH and FB supported the patterns of variations seen in CH and FB for FRT.

Overall, it was inferred that the FB has a better hearing perception than CH due to the fact that the CH are exposed to a combination of noise and solvents. These results could be used to assess the onset of deterioration of hearing perception in such employees. Once such an onset is observed, as a preventive measure, it is apt to shift such an employee to the position where exposure to noise and solvents are lesser till the time the ATTh and FR values improve. Such a measure can avoid permanent damage to hearing organs and thereby function as a better preventive measure and avoid the occupational disorders with regard to chemical and fabrication industries. With regard to the FRT and ATT paradigms developed, the statistical analysis of FRT and ATT revealed a clear difference between CH and FB with respect to their auditory temporal resolution. But further studies need to be carried out in order to probe the reinforced learning-based aspects in the deterioration as well as the improvement in the hearing perception. Although the present experiment was confined to FRT and ATT, more experiments need to be conducted in order to have a better insight into industrial exposure. Also, similarly exposed subjects such as traffic police and paint industry workers too need to be assessed in order to further strengthen the usefulness of the presently developed paradigm

Acknowledgements: The authors wish to thank Centre for Medical Electronics Research, MSRIT for helping with data collection. Data collection as well as the analysis was conducted with the aid of MedNXT Innovative Technologies, Bangalore. The authors wish to thank them as well. MATLAB based tools such as Hearing Test tool (Developed by Dr Samir Rawashdeh) and psychoacoustics toolbox (developed by Dr Massimo Grassi) have been used for the present work. Also, the authors hereby clarify that there was no financial interest associated with this work and the authors also wish to hereby declare that there was no conflict of interest of any kind regarding the publication of this paper.

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