Grenze International Journal of Computer Theory and Engineering , Special issue

Assessment of Hearing Perception in Occupationally Exposed Human Beings based on Gap Detection Test and Frequency Response Test

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***Abstract*—Perception of sound is one of the most fascinating aspects in Human Physiology. The present work emphasizes the ability of the human beings to perceive the sound and also provides a comparison of such a perception with respect to variations in the nature of their occupation. Two tests namely Gap detection Test (GDT) and Frequency Response Test (FRT) are used to assess the hearing perception. 44 subjects, both males and females of various age groups and with no known auditory pathological history are considered for this study. MATLAB tool is used to generate tones with varying silence intervals, intensities as well as frequencies in GDT and FRT. Both the tests are administered in a silent noise free environment. The results show a clear difference in both the tests. However, the GDT provides a clear variation with respect to sex and not with respect to the occupational exposure. But FRT distinguishes the subjects who are occupationally exposed to noise as from those who are not and fails to distinguish between males and females with respect to their perception of sound. Hence one could conclude that FRT test is better than GDT with respect to hearing perception in case of occupational exposure to sound whereas GDT provides better differentiation of subjects with respect to age as well as sex but not for occupational exposure to noise.**

***Index Terms*— Perception, Occupation, Gap Detection Test, Frequency Response Test, MATLAB.**

I. Introduction

Human hearing perception can be assessed by several approaches. While conventional tools such as audiometry fail to cater to the needs of hearing perception, innovative approaches such as GDT and FRT can be used as potential screening tools to assess the perceptive abilities of the human ear[1]. GDT can be used to assess the ability of an individual to perceive the silence intervals embedded in a sound complex. Here, random gaps are introduced to understand the hearing perception in human beings. A predefined pause is inserted between two sound complexes. If this is perceived as two sounds, then the pause length is decreased

Grenze ID: 01.GIJCTE.3.4.75

upto an extent where the subject fails to recognize this set as two different sound with gap and instead perceives the complete set as a single sound complex. This gap length is termed as the Threshold of Gap Detection and can provide abundant insight into the Auditory Temporal Resolution (ATR) which normally results in speech discrimination.[2]

The quantitative measure of the yield spectrum of a system or device in retort to a stimulus used to mark the dynamics of the system is termed as frequency response. In collation to the input, frequency response gives a measure of phase of the output and magnitude as a function of frequency. The steady-state response of the system to a sinusoidal input signal is also defined as the frequency response of a system. A critical piece the test in the field of psychoacoustics stems from the way that different listeners perceive identical sounds differently. Dissimilarities in age, gender, nationality, and many other components affect human perception. The least sound level of a pure tone that a human ear with no known pathological conditions, can hear in a sound proof environment is known as the absolute threshold of hearing (ATH). The absolute threshold associates to the sound that can be just heard by the organism. Frequencies between 20 Hz and 20 kHz can be detected by the human ear. Regardless of the sound pressure level, frequency factors outside this range, between 20 Hz and 20 kHz, are not generally considered to impact the human perception of sound. The absolute threshold of hearing is frequency-reliant and it has been shown that the ear's responsiveness is best at frequencies between 3 kHz and 5 kHz, where the threshold reaches as low as −9 dB SPL. Absolute threshold has been re-evaluated as the level, under the impact of signal detection theory, at which a stimulus will be perceived at a specified percentage (often 50%) of the time. The absolute threshold can be affected by a couple of particular factors, for instance, the subject's motivations and longings, cognitive processes, and whether the subject is adapted to the stimulus. The experiment was mapped to analyze on the basis of one parameter, frequency response, the different retention levels and conditioning of the brain. Conditioning is a learning process where on repetition of a stimulus over time the response becomes more positive according to the experimental study considered. Operant conditioning and classical conditioning are the two types of conditioning. In classical conditioning the responses are elicited by preceding stimuli, whereas, in operant conditioning the responses are strengthened or weakened using rewards or punishments respectively. [3]

II. Background

The human hearing process relies on the ability of the neural system and the ear to detect and process deflections or variations in sound pressure. Data on acknowledgement of the auditory nerve to sound stimulus are useful both to comprehend the functionality of the ear, and to assess the performance of the brain, with respect to perception in various tasks against that of an impeccable onlooker operating on auditory-nerve information. The cerebral cortex of the brain is divided into four sections, viz., occipital lobe, temporal lobe and parietal lobe, and frontal lobe. The frontal lobe is located at the forefront of the brain and is linked with motor skills, reasoning, expressive language, and higher level cognition. Near the central sulcus, at the back of the frontal lobe, lies the motor cortex. This area of brain accepts information from diverse lobes of the brain and it then employs this information to carry out various body movements. [4] A component of the brain also called as the somato-sensory cortex is positioned in this lobe and is important to the processing of the body's senses. The temporal lobe is set at the bottom section of the brain. This lobe is also the place of the primary auditory cortex, which is essential for investigating sounds and the language we hear in the environment. The hippocampus, whose main function relates to storage of short and long term memories, is also placed in the temporal lobe, which is why this portion of the brain is also heavily related with the origination of memories. The occipital lobe is positioned at the underside of the brain and is linked with investigating visual stimuli. The principal visual cortex, which receives and investigates information from the retinas of the eyes, is located in the occipital lobe. The segment of the temporal lobe, known as the primary auditory cortex, is the main cog in the mechanics of the brain that helps in processing auditory information in humans and other vertebrates. Performing rudimentary and elevated functions in hearing, it is a segment of the auditory system. The processing of auditory information is accounted by the many small neurons situated in the brain. By experiencing distinctive sound-related pathways, the signals are decoded into sounds that we are well versed with and make sense to us. A natural method of taking in sound through the ear and having it move to the language section of the brain to be deciphered is known as Auditory Processing. The intricacy of the human ear can be inferred from its ability to interpret a broad assortment of frequencies from the deepest baritones to the shrillest pitch of an insect. Hair cells are spread across a leveled surface called the basilar membrane, which is rolled and tucked into the inner ear called the cochlea. The cells that detect these sounds, also called sensory cells, interpret the detected sounds and are identified by their thread-like clumps on the apex of the cell structure. These thread-like structures form levelled association with the basilar membrane of the inner ear or cochlea. Each of the 16,000 hair cells present is restricted to a frequency range. According to the frequencies they recognize, these cells are arranged in the order of varying frequencies along the basilar membrane. [5,6] One end has those that senses low pitches while the other end has that which detects high pitches. The sensitivity of the ear differs notably with frequency. The investigated range of frequencies that the ear is most sensitive to is 2 kHz to 5 kHz. The sensitivity peaks at the range, 3.5 kHz to 5 kHz, which is an attribute of the ear canal's resonance. Our hearing sensitivity declines at frequencies above 10,000 Hz. [7]

Low frequencies are heard less well than high frequencies. Frequencies at and below 30 Hz are hard to distinguish. There is a production of a 'feeling', than a sense of sound at lower frequencies. Lower frequency tones are transmitted mainly through conduction of bone. The cochlear fluid acts as a channel for the transmission of vibrations caused by frequencies. The audible frequencies that fall under the higher frequency range start the genesis of the transmission process by causing the skull to vibrate in parts. These vibrations are carried onto the otic capsule, which is a bony casing that encloses the inner ear, through the cochlear fluid channel. The otic capsule undergoes compression. The vibrations set up in the perilymph of the scala vestibule, as the round window membrane is more freely flexible than the stapes footplate, are not cancelled out by those in the scala tympani, and the resultant movements of the basilar membrane can stimulate the organ of Corti. Due to the process' main focus on compression, the transmission is known as compression bone conduction. The skull moves as a rigid body at lower frequencies viz., 1,500Hz and below. As the ossicles are less affected, they move less freely than the cochlea and the margins of the oval window because of their inertia, their loose coupling to the skull, and their suspension in the middle-ear cavity. The final result is that the oval window moves with respect to the footplate of the stapes, which gives the same effect as if the stapes itself were vibrating. This form of transmission is known as inertial bone conduction. Hearing impairment, also known as hearing loss, is a total inability or partial inability to hear. A deaf person has little to no hearing. Hearing loss may occur in both or one ear. In children hearing problems can affect the ability to learn spoken language and work related difficulties can be observed in adults. Loss that occurs when there is a problem conducting sound waves anywhere along the route through the outer ear, middle ear (ossicles) or tympanic membrane (eardrum) is known as conductive hearing. Loss that occurs when the sensory hearing cells in the cochlea dies or is damaged is known as high-frequency hearing loss. These hairs are responsible for translating the noises the ears collect into electrical impulses, which the brain eventually evaluates as recognizable sound. The lower part of the cochlea is where the high-frequency sounds are perceived, because of this, hearing loss typically effects the higher frequencies before it affects the lower frequencies. [8,9] Some of the cause/reasons for high frequency hearing loss include exposure to noise, aging, Ototoxicity and related pathology. Damage to the hair cells specific to the inner ear may cause an irreparable loss of hearing. These cells act as transmission channels that ensure no loss of sound from the outer ear passage to the brain during the process of hearing. The ability of the person to hear can be seriously affected if the hair cell is damaged. People suffering from low frequency hearing loss, also referred to as a "reverse slope audiogram" showcase selective hearing and are unable to hear frequencies below 2 KHz. As mentioned above, selective hearing in this case, allows frequencies in the higher range of normal hearing to be heard. Hence, this cannot be considered as a case of conversational hearing loss. Hence, these individuals are able to take part in conversation as opposed to those who suffer from a complete loss of hearing. The main cause for low frequency hearing loss strands to be a mutation that occurs at the Wolfram Syndrome gene and hence, aptly named, Wolfram Syndrome 1. However, this can also be caused by Mondini dysplasia, Meniere's disease and an unforeseen loss of hearing. [10]

III. Materials and Methods

Subjects: The subjects for both GDT and FRT included normal males and females of no known auditory pathology. The control set included the subjects who were not occupationally exposed to noise or aromatic chemicals. The control set was further divided into age groups of 20-30, 30-40 and 40-50 years. The conditioned set included the subjects of age 20-40 years who were exposed to various types of auditory exposures in their routine work place. This set was further divided into the subjects who were working in chemical industries and those working in fabrication industries. In order to probe into the positive training and conditioning aspects, if any, another set of subjects known to be professional basket ball players were also considered for this study due to the fact that auditory perception is an important aspect of basketball sports. Overall three sets of subjects, normal subjects (Control set), chemical and fabrication industry employees (negatively conditioned set) and basketball players (positively conditioned set) were are considered for both GDT and FRT tests

A. Gap Detection Test

In this experiment a sound-gap-sound protocol is used. Based on a pre-defined peak value, the ramp and cosine waves are generated using MATLAB toolbox. The Product of the up-ramp and the cosine wave is obtained. A white Gaussian noise is generated and then the mirror image of the product of up-ramp and the cosine wave is taken. The up-ramp, Gaussian noise and the down-ramp are concatenated (intermediate waveform). After this the first half of the Gaussian noise is generated and the gap length is assigned. By using an array of zeros a gap sequence/silent interval is created. Inserting this gap sequence at the central point of the intermediate waveform (Final waveform), gives the final waveform which is provided as an input for the subject to hear, via earphones. The gap length is varied based on the subject's response to the tone, which is done by multiplying or dividing it by a factor prefixed factor, say k. The gap length is decreased by a factor 'k' if the subject is able to detect the gap, else it is increased. The turn-points are considered to calculate the geometric mean, which gives the value of the gap detection threshold in terms of milliseconds (after converting the scale in terms of time in MATLAB). This is repeated until desired number of turn-points are obtained (The present experiment includes 8 turn points to calculate the geometric mean of the GDT). To respond as to whether the individual perceived the gap or not, he/she is asked to press 1 or 0 respectively, according to which the gap widens or narrows down.

B. Frequency Response Test

The test is based on the fundamental principle that the ear has a non-flat frequency response which means a set of tones, while keeping the volume constant, when played at different frequency values will sound as if they are being played at different volume levels. It is what makes each of us hear some tones better or worse than others because each individual's ear has been made differently and hence the difference in response to different frequencies. The program considers the frequency range to be tested from 20 to 2000 kHz since that is the region of hearing for humans. Each frequency is played across amplitudes ranging from 10 to near 0. These amplitudes are multiplied by a factor of 0.707 which is an equivalent of 3dB decrement because that is the Just-Noticeable-Difference for an average human ear. Hence, we get 26 levels for each frequency to be played and tested for the threshold of hearing. The frequency values considered in Hertz are 10, 20, 40, 60, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1200, 2000, 3000, 3500, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000, 15000 and 16000. Each frequency value starting from 20 Hz is used in the tone function of MATLAB with a maximum of 26 levels each depending on the subject's responses to generate tones. It starts from the maximum and goes on decreasing. The sound function of MATLAB is used to play the generated tone. At each frequency as long as the subject keeps responding positively (tone heard) the level will decrease to the last 26^{th} level and move on to the next frequency and start from the 1^{st} level again. If the subject responds negatively (tone not heard) at a particular level in a frequency value the control moves onto the next frequency level while having set the level back to one. This way the subject's threshold of hearing is determined at every frequency and plotted simultaneously. So if the result says the subject heard up to level 26 at 3500 Hz, it means the decremental values are levels below the threshold of hearing. That level obtained corresponds to -4dB because that is the approximate threshold of hearing at 3500 Hz for a subject of normal hearing. Using that assumption to plot the rest of the thresholds at all other frequencies, the detected level at each frequency is subtracted from the count at 3.5k Hz, then the notable difference between the two is multiplied by 3, and the product is added with -4 dB, to obtain a sequence of the dB levels to plot the frequency-loudness graph that can be compared to the absolute threshold of hearing graph of a normal hearing subject. For example, if the highest count was 25 for 3.5 kHz, and for 90 Hz it was counted as 8 audible tone levels and for 900 Hz you counted 20 audible tone levels, it would be plotted -dB at 3.5 kHz, 3*(25-8)-4=47 dB at 90 Hz and 3*(25-20)-4=11 dB at 900 Hz.

IV. RESULTS AND DISCUSSIONS

A. Gap Detection Test

The gap detection paradigm is used to assess the GDT of the subject with respect to age, in the present case. Once the GDT of an individual is obtained, as per the protocol mentioned prior, it is tabulated with respect to age. Every individual is made to undergo three trials and the GDT obtained for every trial is averaged and the descriptive Statistics for the results obtained for Gap Detection Test paradigm is as shown in Tables 1-4. The overall GDT value obtained is given in Fig 1.

TABLE I: OVERALL ANALYSIS - AGE WISE (MSEC)

Age (Years)	N	Range	Mean	Std. Deviation	Variance	Kurtosis		Mean Ranks Friedman Test	Chi square
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error		
20 - 30	44	3.52	4.3839	.99930	.999	-1.295	.702	1.05	64.682
30 - 40	44	3.86	7.1789	.88805	.789	2.427	.702	2.25	
40 - 50	44	6.99	7.8143	1.34354	1.805	1.817	.702	2.70	

TABLE II: OVERALL ANALYSIS – AGE WISE FOR MALES (MSEC)

Age (Years)	N	Range	Mean	Std. Deviation	Variance	Kurtosis		Mean Ranks Friedman Test	Chi square
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error		
20 - 30	44	2.31	4.25	.76125	.580	-1.603	.953	1.00	33.091
30 - 40	44	3.86	6.8523	.94423	.892	4.783	.953	2.05	
40 - 50	44	3.48	7.54	1.18539	1.405	-1.701	.953	2.55	

TABLE III: OVERALL ANALYSIS – AGE WISE FOR FEMALES (MSEC)

Age (Years)	N	Range	Mean	Std. Deviation	Variance	Kurtosis		Mean Ranks Friedman Test	Chi square
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error		
20 - 30	22	3.52	4.5136	1.19581	1.430	-1.782	.953	1.09	34.636
30 - 40	22	2.93	7.5055	.70694	.500	5.163	.953	2.45	
40 - 50	22	6.99	8.0805	1.46377	2.143	2.797	.953	2.86	

TABLE IV: GAP DETECTION TEST PERFORMED FOR SUBJECTS WORKING IN INDUSTRIES AS COMPARED TO THE NORMAL SET OF SUBJECTS

	Normal	Chemical	Fabrication	Basketball
N	44	44	44	44
Age	20-40 years	20-40 years	20-40 years	20 – 40 years
Range (msec)	6.45	6.5	6.8	5.9

B. Frequency response Test

A total of 44 subjects, both males and females of age group 20-30 years all of no known history of auditory pathology were considered for the data acquisition. The experiment was conducted from 8.00 am – 10.00 am thereby minimizing the possible effects of fatigue due to various time bound factors such as stress and work pressure. The intensity response thus obtained is compared for males and females and among the 1600 frequency values, mentioned in the Table 5 is a set of response of the subjects at certain important frequency values.

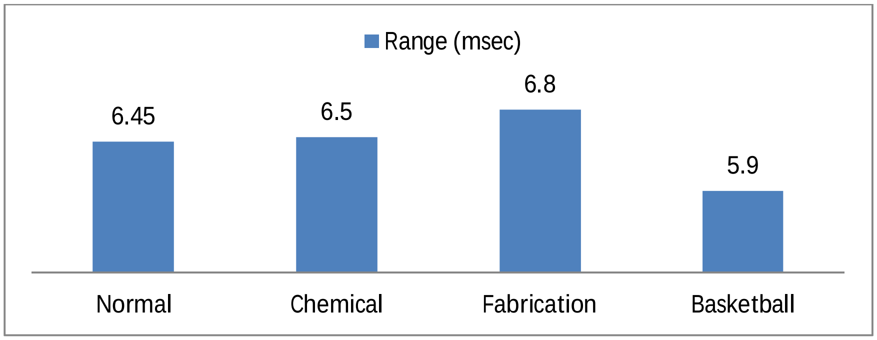

Fig 1: GDT results for various types of subjects

TABLE V: FR TEST FOR NORMAL SUBJECTS (SPL) BOTH MALES AND FEMALES

N	44	44
Frequency (Hz)	Males	Females
3000 Hz	-2.6366	-3.5723
3500 Hz	-1.3761	-3.3820
4000 Hz	-1.0284	-3.4702
13500 Hz	-0.9343	-2.3682

The results obtained for the frequency response test for both conditioned and the control data set were tabulated and plotted on a logarithmic scale as shown in Fig 2 (blue – normal subjects and red – conditioned subjects). The polynomial curve fit was performed for the normal and conditioned set of data and the equations were derived, as mentioned in table 6.

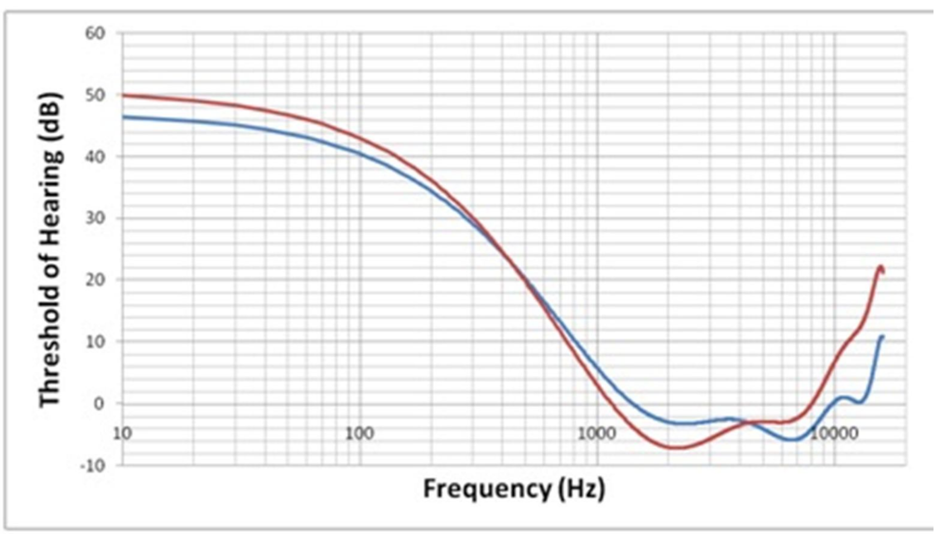

Figure 2: Frequency response for normal and conditioned subjects for the frequencies 10 – 16000 Hz

TABLE VI: POLYNOMIAL EQUATIONS DERIVED FOR THE FREQUENCY RESPONSE DATA FOR NORMAL AND CONDITIONED SUBJECTS

Conditioned $R^2 = 0.974$	$y_c = (5X10^{-13})x^4 - (5X10^{-9})x^3 + (2X10^{-5})x^2 - 0.058x + 44.34$
Control $R^2 = 0.946$	$y_n = (4X10^{-13})x^4 - (4X10^{-9})x^3 + (2X10^{-5})x^2 - 0.047x + 40.45$

A comparative analysis for the unconditioned and conditioned set of subjects with respect to FR test is as given in Table 7.

TABLE VII: FR BASED ANALYSIS FOR CONDITIONED AND UNCONDITIONED SET OF SUBJECTS (N=44) (SPL)

Frequency (Hz)	**Normal-males**	**Normal-females**	**Chemical**	**Fabrication**	**Basketball**
3000 Hz	-2.64	-3.57	-5.79	-4.23	-4.57
3500 Hz	-1.38	-3.38	-4.90	-3.03	-3.67
4000 Hz	-1.03	-3.47	-4.50	-2.53	-3.01
13500 Hz	-0.93	-2.37	-2.42	-0.42	-2.32

V. CONCLUSIONS

A. GDT Paradigm

The most important inference that could be drawn from the analyses was that GDT increases with age. This means that the ability of a human being to perceive and detect the silence interval between sound complex decreases with age. In other words, the GDT value of an individual increases with age. Also the auditory perception is better in males than in females. This provides a strong hint that the temporal resolution is better in males than in females and that the ability to temporally resolve decreases with age in both males and females. But at the same time, GDA fails to differentiate between unconditioned and conditioned set of subjects.

B. FRT paradigm

From the results, there seems to be very less difference between the males and females at important values. As mentioned in the protocol, hearing level can be calculated at any frequency value. Also the frequency response successfully differentiates between conditioned and control set of data. However, there is no definite variation pattern in case of chemical industries and fabrication industries. This suggests that FRT cannot be used to assess the variations with respect to the type of conditioning or in other words, this test cannot be used to differentiate between chemical industries and fabrication industries, but can only be used to differentiate between the control set and conditioned set of subjects. Also for the FR test conducted on conditioned set, one could infer that the polynomial fit obtained for the frequency response data illustrates a correlation of more than 90% for both the datasets with regard to the polynomial equation. Also this equation can easily be used to create a mathematical model to replicate similar datasets for further analysis.
From the obtained results, it is very evident that the GDT can be used to differentiate between males and females whereas FRT can be used to assess the occupational aspects of the subjects. However, there is a need to assess the internal variations in different types of occupational exposure as well which needs to be probed into with the aid of further experimentation.

ACKNOWLEDGEMENTS

The authors wish to thank Jain University for providing a constant support during the present work. Also credits to Centre for Medical Electronics Research, MSRIT for helping with data collection. The analysis of the data has been conducted with the aid of MedNXT Innovative Technologies, Bangalore. The authors wish to thank them as well. Also the authors hereby clarify that there is no financial interest associated with this work and the authors also wish to hereby declare that there is no conflict of interest of any kind regarding the publication of this paper.

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