Journal of Engineering and Applied Sciences 12 (23): 7351-7357, 2017
ISSN: 1816-949X

Assessment of Psychophysical Variations in Human Beings with the Aid of Audiometry and Gap Detection Tests

[1]H.S. Sanjay, [2]S. Bhargavi and [3]N. Thangadurai
[1]Deptartment of Medical Electronics, MSRIT, Jain University, Bangalore, India
[2]Deptartment of Telecommunication Engineering, SJC Institute of Technology, Chikkaballapura, India
[3]Deptartment of Electronics and Communication Engineering, Jain University, Ramanagara, India

Abstract: Hearing problems are one of the most common issues in human beings. While there are conventional tests existing to validate the hearing ability of individuals, these tests simply fail to assess the variations in the hearing perception of normal subjects and are only useful for clinical diagnosis in case of pathologically affected subjects. The present study emphasizes on one such approach where subjects of no known auditory pathological history with variations in age and sex are subjected to Audiometry Test (AT) and then to Gap Detection Test (GDT). While the AT failed to demonstrate any kind of variations with respect to age and sex, the gap detection test was able to successfully differentiate between these parameters proving the Gap Detection Threshold (GDTh) to be a better parameter to assess the variations in age and sex for normal subjects. About 44 subjects, both males and females of age group 20-30, 30-40 and 40-50 years were considered for this experiment. The results showed that the GDTh decreases with age and also that the GDTh is better in males as compared to females in case of normal subjects and hence GDT can be used to assess the hearing perception oriented variations in subjects who are not affected by any auditory pathology.

Key words: Conventional, validate, emphasizes, clinical, auditory, perception

INTRODUCTION

Hearing is one of the most important sensory functions in human beings and more than 5% of the population is affected by hearing disorders at a global level (Basner *et al*., 2014). In India alone, more than 6% of the population suffer from sensory hearing losses and close to 4% of them suffer from profound hearing disorders (Nelson *et al*., 2005). The major problem in hearing disorders is not just the treatment but also related to the diagnosis. Periodic preventive diagnostic assessment is still far from reach of the general population in this country (Swanepoel *et al*., 2010; Tucci *et al*., 2010). While a conventional approach towards the hearing disorders have always been to consult the clinician only after one gets to feel the deterioration in hearing in their daily routine (Lennox *et al*., 2002). But the fact is that much before the realization of such a shortfall in hearing, the hearing problem would have begun to grow and would have not surfaced to such an extent. Also one more reason for this ignorance could be attributed to the fact that the conventional hearing does not need the entire range of hearing ability that human beings are privileged to have (David and Kalk, 1973). For instance, although, the hearing range spans from 20-20000 Hz, one might be exposed to sounds of range 20-200 Hz in the normal life style and hence, if there are any possibility of hearing disorders related to the frequency ranges other than this span, it often goes unnoticed unless diagnosed. But as a matter of fact such extended high frequency range can be of great use towards a plausible early assessment of hearing, even before the hearing at 20-200 Hz range gets deteriorated (Mehrparvar *et al*., 2014; Moore *et al*., 2017).

Conventional method includes the assessment of the hearing threshold of both the ears in an individual in the presence and absence of masking in order to assess the conductive hearing ability using an audiometer, this test fails to assess the perception of hearing in normal pathologically unaffected subjects. In other words, audiometry can only be used to assess whether a person is normal or abnormal, only after the onset of abnormalcy (Tremblay *et al*., 2015). Instead, if normal subjects are tested with this test, then the readings appear similar with variation in age or sex as well. Hence, there is a need to develop alternate approaches in order to assess the perception of hearing for normal subjects as well. One such approach is gap detection test which can find the

Corresponding Author: H.S. Sanjay, Deptartment of Medical Electronics, MSRIT, Jain University, Bangalore

Gap Detection Threshold (GDTh) and can be of high importance in the assessment of variations in normal subjects (Besser *et al*., 2015).

Literature review: The ability of the human brain to resolve a given sensation temporally results in the perception of psychophysical variations of any type in an individual (Law *et al*., 2014). Auditory temporal resolution relates to the ability of an individual to perceive the variations in the sound presented at a given instant (Carlile *et al*., 2016). Hearing perception is entirely dependent on this factor ans is hence an important parameter in the assessment of hearing perception of normal subjects. This is because, two individuals can perceive a similar sound in different manner. While a given type of music may be perceived as loud by one, the other might feel the same to be pleasant. Hence perception differs from one individual to another even in case of no pathological history and is a very common phenomenon in human beings. (Bestelmeyer *et al*., 2014).

Audiometry Test (AT): AT is often used to assess the hearing threshold by testing the response of an individual to the intensity and frequency variations of sound. A specialist termed as audiologist runs this test. AT process is simple, non-invasive and subjective. This test can assess the functionality of external and the middle ear as well. This test is generally done with pure tones and hence called as pure tone AT where for a preset frequency, intensity of the sound is varied and the subject is asked to respond, whether that particular sound was heard or not heard by either pressing a switch or by hand signals. This process is repeated for different frequencies. The test is administered in a sound proof room with the subject seated inside and the audiologist with the equipment sitting outside with a clear view of the subject through a glass window. A chart of the frequency vs. intensity is plotted called the audiogram on a logarithmic scale. This audiogram is used to assess the frequency ranges at which the subject is not able to hear and accordingly, hearing aids are designed to counter the same. Although, AT has options to measure the sound till 800 Hz, most of the normal conversations happen between 200-500 Hz and hence the rest could be neglected as they do not participate in daily conversations. The intensity of normal conversation too is around 30 dB in general (Svensson *et al*., 2015; Daniel and Feeney, 2014).

GAPS: The concept of a gap/pause in hearing can be described as the time between the existence of a sound/noise and its absence or vice versa. By understanding how the brain recognises such gaps, it is possible to understand how, a given individual is able perceive a new sound from among other existing sounds or recognise that a sound which was present has suddenly stopped. This further enables in the analysis and comprehension of the entire function of hearing due to the auditory cortex. Primary auditory cortex neurons are believed to be associated in the processing of such onset-offset patterns of ambient sounds. Hence, the ability of a person to detect gaps introduced in a given sequence of sounds gives abundant information about his/her auditory functions. With the understanding of the normal patterns of auditory function, it is possible with the same tests to determine the subject's abnormality in hearing loss/malfunction (Braga *et al*., 2015).

Gap detection and normal auditory functions: It can be postulated that there is an optimal gap between two sounds which if detected, denotes normal auditory function and if not detected, denotes some abnormality. There is a minimum gap between two separate sounds, the detection of which aids in the decision making as to the auditory function of the subject being normal or abnormal.

Gap detection tests are run using various approaches. But the important aspect here is that two sounds are given and a gap is introduced and the subject is asked to respond when he perceives this gap. Many variations with respect to sound namely broadband or narrow band noise or the duration of gap can be introduced. The ability of an individual to perceive such a sound complex as two separate sounds, i.e, sound with a gap/pause is termed as gap detection threshold. This ability is related to the temporal integration of the auditory cortex which is defined as the rate of response of the auditory system to sudden variations in the sound intensity. Deficits in the ability of gap detection are generally associated with hearing loss (Lister, 2016; Yalcynkaya *et al*., 2009).

Temporal resolution: The ability to assess the silence intervals/pauses between two sound complexes helps to ascertain the gap detection as well in many related applications. In other words, the gap detection Threshold is a very common approach to estimate the ability of temporal resolution in an individual. Deficits in this task can affect the speech understanding and comprehending specifically in crowded and noisy environments (Douglas *et al*., 2016). These can also result in hearing disorders. Gap detection is easier when the sounds have normal periodic sinusoidal variations. But this drastically reduces for random variations in sounds. As the intensity reduces, gap detection becomes difficult, especially in pathological subjects. But even in case of normal individuals, gap detection task becomes tougher in the presence of background noise (Spiousas *et al*., 2017).

MATERIALS AND METHODS

Subjects: About 44 subjects of no known auditory pathology were considered as subjects for this experiment. The age groups selected for both males and females were 20-30, 30-40 and 40-50 years and were subjected to both AT and GDT and the results were tabulated to conclude upon any possible variations seen with respect to age and sex. Both these tests were conducted in a noise free environment from 8.00-10.00 a.m. time slot only to avoid any possible fatigue which could have affected the results if done later during the day. Adequate care was taken to ensure that the subjects were not under the effect of any type of illicit drugs during the experimentation.

Experimental paradigm

Audiometry Test (AT): The threshold of hearing of an individual is found using an audiometer. The devices comprises of a simple hardware with a headphone used to provide audio inputs to the subjects and a bone vibrator. A feedback switch is provided for the subject to respond. The hardware consists of a tone generator and an audio amplifier. The present test used a standard clinical audiometer (Pamtronics make-PAM010) as shown in Fig. 1 to acquire the hearing threshold with the aid of air conduction test. Pure tones with variations in intensity (-10 to 100 dB with a step of 5 dB) and frequency (250, 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz) ranges have been used for the test. As the sound with these variations is provided, the subject is asked to respond whether the tone was heard or not and based on these values an audiogram was plotted and compared for all the sets of subjects. This method is followed for both left and right ears for every subject. The AT paradigm does not include the aspects of masking due to the fact that the present test is being conducted for normal subjects and that masking is more important in cases of abnormality and during bone conduction rather than during air conduction related tests.

Fig. 1: PAM 010 audiometer unit used to measure the hearing threshold

Gap Detection Test (GDT): GDT aids in the assessment of the perception of silence intervals between a predesigned sound complex. This is the simplest method to study the auditory behavior with respect to random gaps which can be graded to conclude on the hearing perception based analysis. In this test, the auditory input is provided as a pause embedded between the sound and the subject is asked to respond if he/she is able to identify the pause in which case, the sound complex is perceived as two sounds with a pause in between. If so, the length of the pause is reduced till an extent where he/she cannot perceive this input as two sounds with a pause, instead is perceived as a single sound with the pause/gap going unperceived. The time interval of such a gap, after which the perception of gap ceases, is concluded to be the Gap Detection Threshold (GDTh) which is an important tool to grade the Auditory Temporal Response (ATR). If the ATR is in the normal range, the subject is said to be possessing normal hearing abilities, else abnormal. Previous research suggests that the normal GDTh is 0-20 msec and any value above this range hints at a possibility of the temporal processing disorder and difficulty in speech discrimination.

A simple approach to design a gap detection test as developed in the present experiment would be to use 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

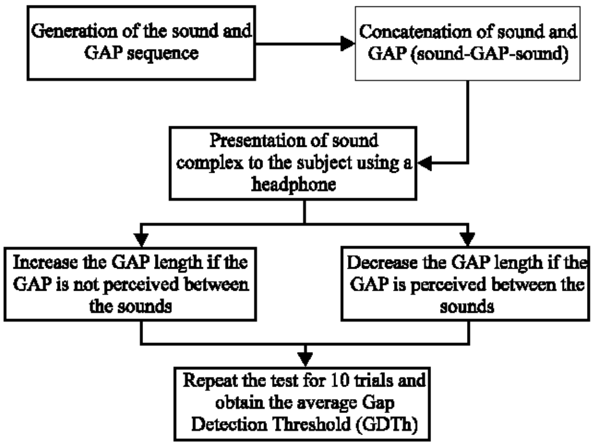

Fig. 2: Protocol designed for gap detection test paradigm

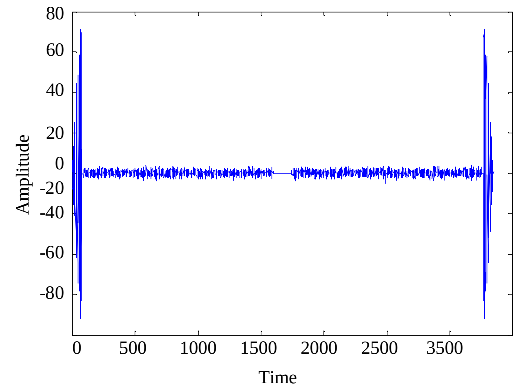

Fig. 3: Sample sound complex (sound-gap-sound) generated in MATLAB; x-axis: time of the test (msec) with a sampling rate of 8000 samples per second; y-axis: amplitude of sound in dB

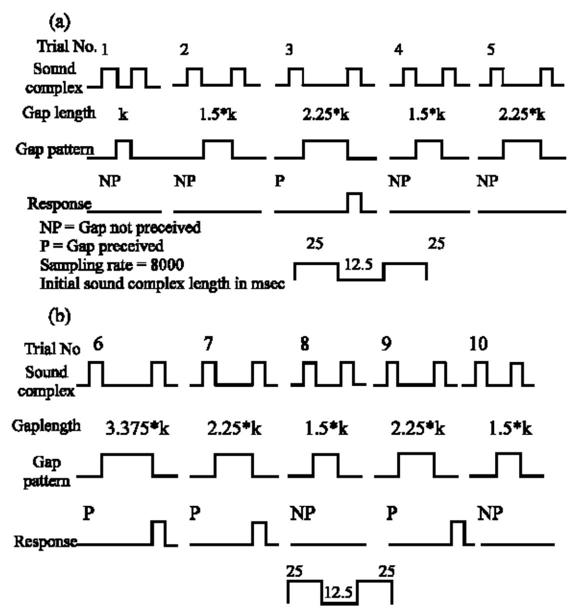

Fig. 4: a, b) Timing diagram for gap detection protocol (trial no 1-5)

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 GDTh). 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. The setup comprises of a windows based system with a MATLAB tool installed. The white noise is used to stimulate the subjects via. a simple headphone and the response of the subject to this set of sound is noted. A laptop would ensure the smooth conduction of this test even during the absence of a power socket (remote locations). MATLAB is a very simple tool which runs on a windows platform with greatly aids in the visualization of the signals in time and frequency domain and is used for waveform and pulse generation including sine, cosine and gaussian pulse that are played on a PC-based audio output device. MATLAB provides a simple approach to analyze various mathematical models and saves a lot of time with computations. The complete protocol is depicted in Fig. 2 and 3 depict a sample sound complex used in the present paradigm. The GDTh values obtained are analyzed with age and sex being the discriminating factor. Mentioned in Fig. 4 is a sample case of GDTh protocol run on a subject illustrated with the help of a timing diagram for the paradigm for 10 iterations. While Fig. 4a represents a sample case for the first five trials, Fig. 4b represents a continuation of the same for trial number 6-10.

RESULTS AND DISCUSSION

The AT is used as a screening tool due to its wide acceptance by clinicians all over the world in order to

Table 1: Audiogram recordings obtained for conditioned and control set; left ear (frequency Hz)

Intensity (dB)	Males (20-30 years)	Males (30-40 years)	Males (40-50 years)	Females (20-30 years)	Females (30-40 years)	Females (40-50 years)
125	30	25	35	35	30	35
250	25	20	30	30	20	30
500	20	25	30	20	30	30
1000	25	20	30	30	25	20
2000	35	20	25	30	30	25
3000	30	30	20	40	30	25
4000	20	20	30	30	25	35
6000	20	25	30	30	15	40
8000	20	25	35	40	40	40

Table 2: Audiometry readings (dB vs. Hz) obtained for conditioned and control; set-right ear (frequency Hz)

Intensity (dB)	Males (20-30 years)	Males (30-40 years)	Males (40-50 years)	Females (20-30 years)	Females (30-40 years)	Females (40-50 years)
125	25	30	30	30	35	30
250	25	20	25	30	25	30
500	25	30	30	25	30	20
1000	25	25	35	35	20	20
2000	20	20	25	30	30	20
3000	20	30	25	45	35	30
4000	30	20	35	40	30	30
6000	25	35	25	30	20	40
8000	20	30	25	30	35	35

assess the hearing threshold. Each subject was made to undergo this test three times and the average value was noted. The grand average for all the subjects of every type for both males and females was obtained and analyzed for the presence of any variations so as to verify whether any possibility of differentiations of subjects based on this test was possible. The averaged audiogram plotted for the different categories of subjects are provided for a better comparison. Table 1 provides the audiogram for the left ear and Table 2 includes the audiometry recordings obtained for the right ear. The results tabulated in Table 1 are represented pictorically in Fig. 5

A statistical analysis of the hearing threshold provided in Table 1 and 2 is mentioned in Table 3 left ear and Table 4 right ear.

From Fig. 5, it is evident that the audiogram plotted males as well as for females of various age groups are similar and do not demonstrate any notable variations and hence the AT test fails to assess the variations in hearing patterns of normal subjects who are not suffering from any known auditory pathology. Although, the standard values of a normal hearing subject ranges from 0-20 dB at all given frequencies, there are instances where in the values obtained are out of the standard range. This initiates the need to develop further phases in order to assess the variations in a better manner for normal subjects with respect to their conditioning in terms of their occupation as well. The statistical analysis too fails to bring out any variations with respect to age or sex.

The gap detection paradigm is used to assess the GDTh of the subject with respect to age in the

Table 3: Statistical analysis for the hearing thresholds obtained for the left ear

Sex/Age	Mean	Min.	Max.	SD	Median
Male					
20-30	43.78	25	72	17.27	40
30-40	42.56	22	70	14.81	45
40-50	50.56	30	78	15.79	50
Females					
20-30	49.45	30	74	14.84	48
30-40	50.33	30	70	14.38	50
40-50	55.78	40	76	12.87	58

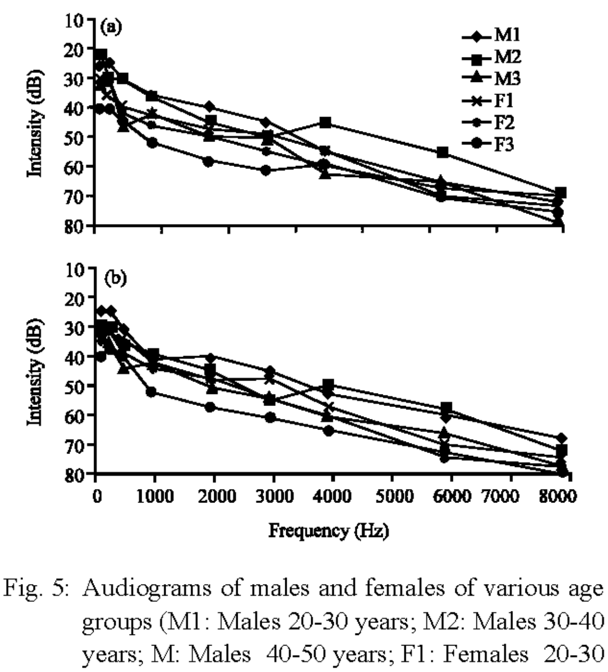

Fig. 5: Audiograms of males and females of various age groups (M1: Males 20-30 years; M2: Males 30-40 years; M: Males 40-50 years; F1: Females 20-30 years; F2: Females 30-40 years; F3: Females 40-50 years); a) Audiogram-left ear and b) Audiogram right ear

Table 4: Statistical analysis for the hearing thresholds obtained for the right ear

Sex/Age	Mean	Min.	Max.	SD	Median
Male					
20-30	43.22	25	68	14.90	42
30-40	46.22	30	72	13.99	45
40-50	51.11	30	78	15.17	50
Female					
20-30	48.55	32	74	15.74	48
30-40	51.67	32	78	16.36	48
40-50	56.11	38	80	14.93	58

Table 5: Overall GDTh analysis-age wise for males

Age (years)	N	Range	Mean	SD	Variance	Mean ranks friedman test	Chi square
20- 30	44	2.31	4.25	0.76	0.58	1.00	33.09
30- 40	44	3.86	6.85	0.94	0.89	2.05	
40-50	44	3.48	7.54	1.18	1.40	2.55	

Table 6: Overall GDTh analysis-age wise for females

Age (years)	N	Range	Means	SD	Variance	Mean ranks Friedman test	Chi square
20-30	44	3.52	4.51	1.19	1.43	1.09	34.63
30-40	44	2.93	7.50	0.70	0.50	2.45	
40-50	44	6.99	8.08	1.46	2.14	2.86	

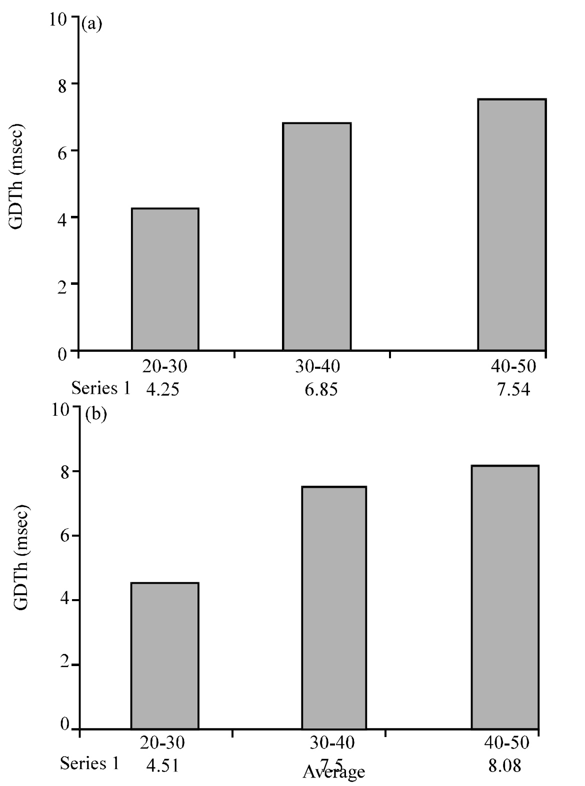

Fig. 6: a, b) The GDTh obtained for males and females of various age groups (a-b) Average GDTh for females

present case. Once the GDTh 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 GDTh obtained for every trial is averaged. The averaged data is mentioned in Table 5 and 6 as provided below. Also the descriptive Statistics for the results obtained for the GDT paradigm are mentioned along with.

Along with the mean values obtained, one could also infer similar results from the other statistical parameters calculated as depicted in Fig. 6. In case of standard deviation, the deviation from the mean value seems to be very less and is hence an acceptable aspect to differentiate between every dataset. However, for females of 20-30 and 40-50 years, the standard deviation is higher than the rest of the datasets. On similar lines, the variance is acceptably less for the datasets except for females of 20-30 years and both males and females of 40-50 years. Also the mean rank fredman test results provide a substantial proof to depend on the results obtained in GDT. Also the χ^2-test predicts the results to be around 35% by chance which proves the occurrence of the obtained results for sure by about 65% to be definitive and not due to any kind of coincidence.

CONCLUSION

The audiometry results clearly indicate a similarity between the readings obtained. This means that a simple test such as audiometry can although assess the hearing thresholds of pathologically affected subjects, simply fails to differentiate between normal subjects with respect to their age and sex. Hence, it can be concluded that AT cannot be used to differentiate between the psychophysical aspects of normal healthy individuals and hence further investigations are necessary to infer about the same. Conversely, the most important inference that could be drawn from the GDT analysis is that GDTh 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. 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. Also, it is very evident that GDT is better than AT to assess the psychophysical variations in normal human beings without any auditory pathological history with respect to auditory temporal resolution and hence can be used to probe into hearing perception oriented aspects. Also, the same could be extended to subjects who are occupational exposed to noise such as those working in fabrication industries to assess whether the same pattern could be observed in such subjects as well in order to assess the plausible degradation of the auditory perception due to their occupational exposure.

ACKNOWLEDGEMENTS

The researchers wish to thank Jain University for providing a constant support during the present research. 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 researchers wish to thank them as well. Also, the researchers hereby clarify that there is no financial interest associated with this work and the researhers also wish to hereby declare that there is no conflict of interest of any kind regarding the publication of this study.

REFERENCES

Basner, M., W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen and S. Stansfeld, 2014. Auditory and non-auditory effects of noise on health. Lancet, 383: 1325-1332.

Besser, J., J.M. Festen, S.T. Goverts, S.E. Kramer and M.K. Pichora-Fuller, 2015. Speech-in-speech listening on the LiSN-S test by older adults with good audiograms depends on cognition and hearing acuity at high frequencies. Ear Hearing, 36: 24-41.

Bestelmeyer, P.E., P. Maurage, J. Rouger, M. Latinus and P. Belin, 2014. Adaptation to vocal expressions reveals multistep perception of auditory emotion. J. Neurosci., 34: 8098-8105.

Braga, B.H.C., L.D. Pereira and K.Z. Dias, 2015. Normality tests of temporal resolution: Random gap detection test and gaps-in-noise. Rev. CEFAC., 17: 836-846.

Carlile, S. and J. Leung, 2016. The perception of auditory motion. Trends Hearing, 20: 1-19.

Daniel, B.P. and M.P. Feeney, 2014. 24 Misuse of Insert Earphones during Pure-Tone Audiometry. In: Adult Audiology Casebook, Valente, M. and M. Valente (Eds.). Thieme, Stuttgart, Germany, ISBN:9781604068504, pp: 344-344.

David, M.K. and C.E. Kalk, 1973. A Strategy for Evaluating Health Services. Vol. 2, National Academies Press, Washington, USA., Pages: 192.

Douglas, C., J. Noble and S. McAdams, 2016. Auditory scene analysis and the perception of sound mass in ligeti's continuum. Music Percept. Interdiscip. J., 33: 287-305.

Law, J.M., M. Vandermosten, P. Ghesquiere and J. Wouters, 2014. The relationship of phonological ability, speech perception and auditory perception in adults with dyslexia. Front. Hum. Neurosci., 8: 482-493.

Lennox, N., V. Prasher and M. Janicki, 2002. Health Promotion and Disease Prevention. In: Physical Health of Adults with Intellectual Disabilities, Prasher, V. and M. Janicki (Eds.). Wiley, Hoboken, New Jersey, ISBN:9781405102193, pp: 230-251.

Lister, J.J., 2016. Marking time: The precise measurement of auditory gap detection across the lifespan. J. Acoust. Soc. Am., 140: 3328-3329.

Mehrparvar, A.H., S.J. Mirmohammadi, M.H. Davari, M. Mostaghaci and A. Mollasadeghi *et al*., 2014. Conventional audiometry, extended high-frequency audiometry and DPOAE for early diagnosis of NIHL. Iran. Red Crescent Med. J., 16: 1-6.

Moore, D., L. Hunter and K. Munro, 2017. Benefits of extended high-frequency audiometry for everyone. Hearing J., 70: 50-52.

Nelson, D., R. Nelson, M. Barrientons and M. Fingerhut, 2005. The global burden of occupational noise-induced hearing loss. Am. J. India Med., 48: 446-458.

Spiousas, I., P.E. Etchemendy, M.C. Eguia, E.R. Calcagno and E. Abregu *et al*., 2017. Sound spectrum influences auditory distance perception of sound sources located in a room environment. Front. Psychol., 8: 969-984.

Svensson, U.P., O. Kvaloy and T. Berg, 2015. A comparison of test-retest variability and time efficiency of auditory thresholds measured with pure tone audiometry and new early warning test. Appl. Acoust., 90: 153-159.

Swanepoel, D.W., J.L. Clark, D. Koekemoer, J.W. Hall III and M. Krumm *et al*., 2010. Telehealth in audiology: The need and potential to reach underserved communities. Intl. J. Audiol., 49: 195-202.

Tremblay, K.L., A. Pinto, M.E. Fischer, B.E. Klein and R. Klein *et al*., 2015. Self-reported hearing difficulties among adults with normal audiograms: The beaver Dam offspring study. Ear Hearing, 36: e290-e299.

Tucci, D.L., M.H. Merson and B.S. Wilson, 2010. A summary of the literature on global hearing impairment: Current status and priorities for action. Otol. Neurotol., 31: 31-41.

Yalcinkaya, F., N.B. Muluk, A. Atas and R.W. Keith, 2009. Random gap detection test and random gap detection test-expanded results in children with auditory neuropathy. Intl. J. Pediatr. Otorhinolaryngology, 73: 1558-1563.