# Analysis Of Brainstem Auditory Evoked Potential Using Discrete Wavelet Transform

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***Abstract: Brainstem auditory evoked potentials (BAEP) are electrical potentials recorded in response to an auditory stimulus. Wavelet transform is adopted to extract the characteristic features of BAEP for interpretation and assessment. The results shows that there is significant difference (p<0.05) in the wavelet coefficients features in normal and abnormal BAEPs.***

**Keywords— Brainstem Auditory Evoked potentials, Discrete Wavelet transform, Wavelet transform**

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## I. INTRODUCTION

The recording of brainstem auditory evoked potentials (BAEPs) is a well established methodology in neurology, neurological surgery, and otology that reflects the synchronous neural activity generated by nuclei along the brainstem in response to an acoustic signal [i]. These signals get their name as they are generated by the activation of the brainstem pathways [ii]. This far-field potential reflects the neuro-physiological activity within the brain as a result of an auditory stimulus and is one of the best recognized electrophysiological tools used by neurologists and audiologists. A neurologist is able to assess the time taken for an auditory stimulus to travel from the point at the inner ear to the auditory cortex, as the physical audio sound is translated into a bioelectrical impulses travelling along to the brainstem. This provides an idea of accurate functioning of the auditory nerve through auditory pathway. As in the presence of acoustic neuroma, a benign tumour in the ear canal, can elongate or flatten the auditory nerve which results in the increased processing and transmission time for auditory stimuli. [iii]

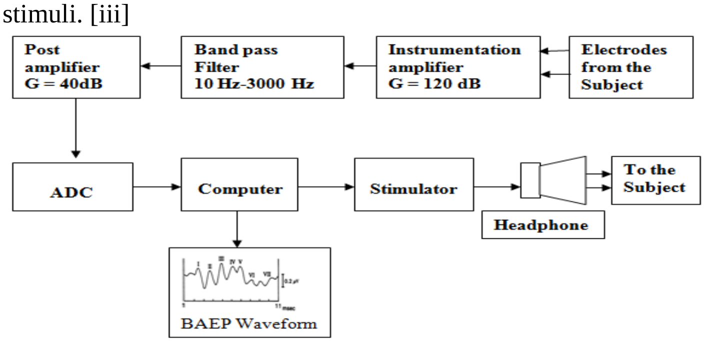



Fig. 1 Recording System of BAEP

## II. MOTIVATION

In human, deafness which is one of the sensory impairment estimated to affect one in six adults, and the ageing population being particularly vulnerable [iv]. Conventional hearing tests, audiograms, are subjective type of measurements. Automated systems for assessment of hearing using evoked potentials (EPs) has resulted in a more objective measuring mechanism. Evoked potentials indicate a change in brain electrical activity (electroencephalogram-EEG) in response to the stimulation on body's sensory mechanisms. Acoustic stimuli, in the form of clicks or tone bursts, show changes in EEG patterns for a period up to 500 ms after stimulus onset time. These patterns or signals are termed as BAEP signals which occur during the first 10ms after the stimulus [v]. The disadvantages of conventional method of interpretation of BAEP are in the management of uncooperative patients demanding considerable supporting staff, prolonged tests increasing the workload, skills and experience of physician in understanding the BAEPs. This necessitates for an automated and improved measurement and analysis system.
Our approach to this problem proposes a technique of wavelet analysis which could be later used for an automated system. As the wavelet transforms (WT) permits to do the continuous analyses in time and frequency domain on BAEP signal, the coefficients are extracted from the different levels of decomposition giving frequency and time related details of the signal [vi].

### A. BAEP recording

In the present work BAEPs were recorded using a standard recording system (RMS EMG-EP MK-11 Version 1.1 from Recorders and Medicare Systems) in a sound proof chamber. The basic block diagram of the system is as shown in Fig. 1.BAEPs are generated by a brief click or tone transmitted from an acoustic transducer in the form of an insert earphone or headphone. The waveform response is measured by surface electrodes placed at the vertex of the scalp and mastoids. The amplitude (µv) of the signal is averaged and plotted against the time (ms). The waveform peaks are labelled as I-VII as shown in Fig. 2. The origin of BAEP waves are as follows: Wave I is produced by the action potentials generated by the auditory nerve, wave II is generated in the cochlear nucleus, III in the superior olivery complex, IV from the lemniscus tracts, V is generated in the high pons and low midbrain, VI is probably produced in the medial geniculate body and wave VII corresponds to the generator activity of the auditory relations which terminate in the auditory cortices. These waveforms normally occur within a 10 ms time period after a click stimulus presented at intensities of 70-90 dB of normal hearing level in adults [ii].

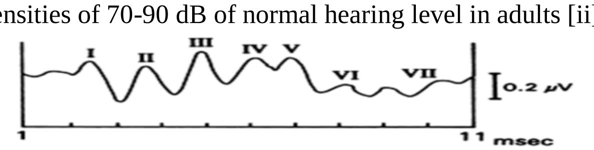



Fig. 2 Typical Normal Brainstem Auditory Evoked Potential Waveform

### B. Data Collection

The preliminary data of this study constitutes 42 male subjects (21 normal and 21 abnormal) and 42 female subjects (21 normal and 21 abnormal) between 1-70 years age group as shown in Table 1. Most of the subjects showed normal peripheral hearing thresholds of 80dB. The subjects are considered as abnormal based on the clinical symptoms and conditions, and when test shows no wave formation (peaks I-V) for the stimulation [vii].

**Table1**: Description of Subject Data

| Sl. No. | Subjects | Condition | Age in years Mean±SD | Number |
|---|---|---|---|---|
| 1. | Male | Normal | 30±20 | 21 |
| | | Abnormal | 28±18 | 21 |
| 2. | Female | Normal | 31±20 | 21 |
| | | Abnormal | 27±18 | 21 |

### C. BAEP Significance

The primary clinical application of the BAEP signals is the objective determination of hearing threshold in individuals, to evaluate the auditory organ functioning in patients who cannot participate in the behavioural testing, monitoring of traumatic brain injury patients, and intraoperative monitoring for skull base surgery.

## II.METHODS AND MATERIALS

### A. Discrete Wavelet Transform (DWT) Analysis

The WT is found to be a powerful signal processing technique used in many fields. In the past few years, wavelet methods have immensely been developed for multiscale representation and analysis of signals, and studies done on BAEP are also found [viii, ix, x]. The advantage of the WT is its ability to preserve the time and frequency information. The WT has been used in localizing and extracting the features of BAEPs and in the classification of these extracted features [xi, xii]. It has the ability to transform the signal into its frequency components in the form of scales. Since low scale values compress the wavelet and correlate better with higher frequency components of the signal and the low scale wavelet coefficients represent the fine-scale features in the input signal vector. High scale values stretch the wavelet and correlate better with the lower frequency components of the signal. The high scale wavelet coefficients represent the coarse-scale features in the input signal [xiii].

The general formula of the WT of a signal $f(t)$ is given by

$$\mathrm{WT}(a,b) = \int_{-\infty}^{\infty} f(t)\varphi^*_{a,b}(t).dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $\varphi^*_{a,b}(t)$ is the mother wavelet function, (the *"*"* denotes the complex conjugate), $a$ and $b$ are the scaling and the translation respectively. The detailed mathematical background of the wavelet theory can be found in various references [xiv]. However there are some desired features that must be met for the bases functions to be considered as wavelets as coated by [xv] i.e. they must be oscillatory and they must have amplitudes that quickly decay to zero.

The simplicity in implementation and low computational effort justifies the popularity of the DWT. Symlet wavelet (sym5) has been used in our study as it has similar looks to BAEPs and provides good localization in the structures of interest with exclusive performance. Fig. 4 shows an example of a 6 level, dyadic, decomposition of a BAEP signal.

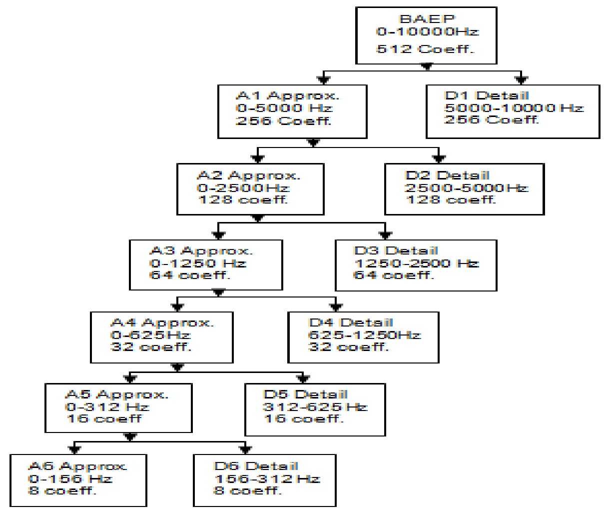


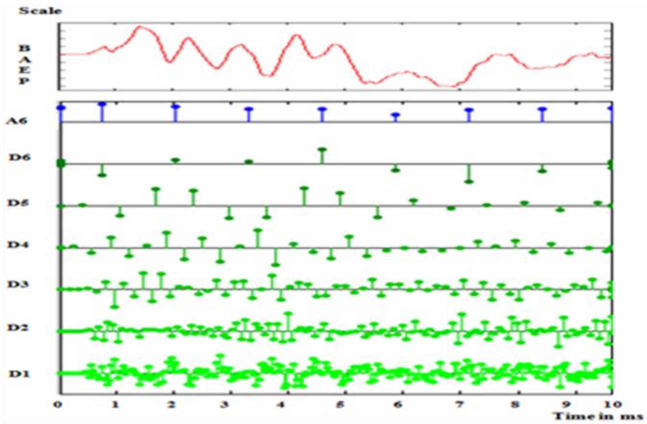

Fig. 4 Decomposition of a BAEP signal for level 6

### B. Wavelet Feature Extraction

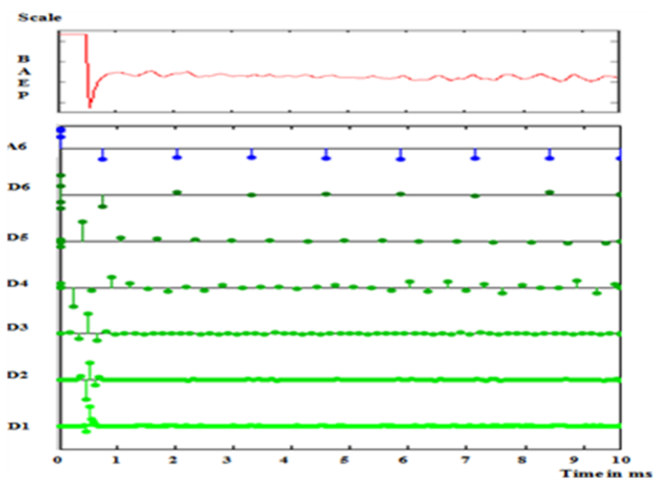
All the BAEP data taken from RMS system in ASCII format were transferred to a personal computer running the MATLAB software version 12. A personalized M-file was written to process on every BAEP data. Later the data were processed using six level discrete wavelet decomposition with dyadic scaling. The 6-level DWT is performed using the wavelet toolbox in MATLAB software. Fig. 5 shows the 6 level decomposition of the BAEP signal showing its six details, D1-D6 and its approximates A6 for (a) normal subject and (b) abnormal subject. The objective here is to extract the wavelet coefficients which contribute to the formation of peaks. The values of the coefficients form the peaks in the reconstruction of the signal. The higher coefficient values represent the normal BAEP signal with the formation of the peaks, and the lower values of the wavelet coefficients represent the BAEP without response or the peak formation representing abnormal signal.

### C. Selecting the wavelet variables

During the analysis, few wavelet coefficients appear repeatedly at particular scales in the BAEPs with peak formation, which contribute to the wave I, II, III, IV and wave V. While the same is not frequent in the abnormal BAEPs as they are without peak formation. The locations of the wave I, III and V are mainly considered in our study, as these are most prominent waves used routinely for diagnosis. Therefore, the number of times the wavelet coefficients appear in the different range and its absolute values are taken as the relevant feature that significantly distinguishes the normal and abnormal BAEPs.




(a)




(b)

Fig. 5 BAEP and its six level decomposition for (a) normal subject (b) abnormal subject

The BAEP is recorded for the period of 10ms after the stimulus is applied. This has given 480 data points in the recorded period of time. The location of the wave I, III and V then are found to be at X= 80, 180 and 280 corresponding to the time in ms at t=1.7, 3.9 and 5.7 ms respectively. As the peak latencies may change from one subject to another, a range of time in which peaks formation may occur has been considered.$Y_{D4}$ =4, $Y_{D5}$ =8 and $Y_{D6}$=16 are taken as the half length of the time series for scales D4, D5 and D6 respectively, as these are the minimum distances between the wavelet coefficients at these scales [iv]. Hence to extract the coefficients at the significant locations, the range of the coefficients present in the scales at D4, D5 and D6 are taken at the ranges [$X-Y_{D4}$ , $X+Y_{D4}$], [$X- Y_{D5}$ , $X+Y_{D5}$] and [$X-Y_{D6}$ , $X+Y_{D6}$], respectively. The frequency contents of the scales D1 and D2 are very high and they do not contribute to the frequency content information of wave I, III and V, only the D4, D5 and D6 details are considered as they have the lower frequency information as shown in the Fig. 4. Table II shows the relevant variables used in the study. AD41 represents the absolute values of the wavelet coefficients from D4, AD51 from D5 and AD61 from D6 for wave I, AD43 represents the absolute values of the wavelet coefficients from D4, AD53 from D5 and AD63 from D6 for wave III and AD45 represents the absolute values of the wavelet coefficients from D4, AD55 from D5 and AD65 from D6 for wave V. The quantitative parameter of the wavelet analysis, the coefficients are determined to distinguish the normal and abnormal signals. The statistical significance of the coefficients to differentiate signals between the male and females are evaluated by t-test.

## III. RESULT AND DISCUSSION

The aim of the study was to investigate the effect of the wavelet transform on the BAEP signals. The result of this study contains the information about the variation in the wavelet coefficients in normal and abnormal subjects, and also in male and female subjects. The total number 84 subjects BAEP data analysed in this work is as shown in Table I. Wavelet coefficients at different scales details are obtained in the different interval corresponding to the peaks I, III and V. The approach is to identify those wavelets coefficients which are most significant for representing the BAEP with peaks and distinguish the BAEPs without peaks. A wavelet function was used, to extract the wavelet coefficients from the reconstructed signal. The test signals were decomposed into 6 levels using the DWT.

The extracted wavelet coefficients corresponding to the BAEPs with the normal peak formation to the stimulus were found to have larger values. At each band D4, D5 and D6 the details of levels 4, 5 and 6, the wavelet coefficients of the signal are calculated using the symlet5 mother wavelet, and is tabulated as shown in Table III for normal and abnormal subjects. Comparisons of wavelet coefficients for male and female subjects for left and right ear are as given in Table IV and V respectively. Descriptive statistical study is carried out for the most clinically significant waves I, III and V. Statistical difference were considered significant if the *p*-value was less than 0.05. The normal standard values of BAEPs were considered from Chiappa et al. [ii], and Misra and Kalita [xvi].

In DWT, with multi resolution, the wavelet transform is repeatedly performed on the signal until all resolution levels are obtained. This decomposes the BAEP into scale coefficients, also referred to as wavelet coefficients to low frequency and higher frequency components. The scale values gives the information of the degree to which the wavelet is compressed or stretched. Low scales values compress the wavelet and correlate better with the high frequency components. Low scale coefficients represent the fine scale in the input signal. High scale values stretch the wavelet and correlate better with the low frequency content of the signal which represents the coarse-scale features in the input signal. The larger wavelet coefficients hence, reflect the combined effect of the large variation of the signal and a good matching of shape between the signal and the wavelet. From the literature, the BAEP frequency analysis have showed that a relatively high energy, low frequency component at 200Hz or below, a mid energy component in the 500-600Hz region, a low energy, high frequency component in the 900-1000Hz region and a minimal spectral energy above 1500-2000Hz were observed [xvii]. Considering the above criteria the coefficients at details at level 4, 5 and 6 are noted, since these levels would decompose the signal at 625Hz, 312 Hz and 156 Hz respectively as shown in Fig. 4 that are responsible for the formation of the peaks I, III and V. The lower scales give the details corresponding to the higher frequency components of the signal and the higher scales correspond to the lower frequency components. Using DWT, the original signal is decomposed into components of lower frequency. Hence, the larger values of wavelet coefficients are observed for the BAEPs corresponding to the normal peak formation to the stimulus and the smaller values for the BAEPs without peak formation or the abnormal BAEPs. An example of a BAEP and its DWT results are shown in Fig. 5. The average results of the wavelet coefficients of BAEP are shown in Tables III, IV and V. The null hypothesis considered was that the means of the wavelet coefficients of normal and abnormal are not significantly different from one another.

Table II. Variables extracted from wavelet analysis

| Number | Variable | Significance |
|---|---|---|
| 1. | AD41 | Absolute value of wavelet coefficients in the interval $[X-Y_{D4}, X+Y_{D4}]$ at scale detail D4 for wave I |
| 2. | AD51 | Absolute value of wavelet coefficients in the interval $[X-Y_{D5}, X+Y_{D5}]$ at scale detail D5 for wave I |
| 3. | AD61 | Absolute value of wavelet coefficients in the interval $[X-Y_{D6}, X+Y_{D4}]$ at scale detail D6 for wave I |
| 4. | AD43 | Absolute value of wavelet coefficients in the interval $[X-Y_{D4}, X+Y_{D4}]$ at scale detail D4 for wave III |
| 5. | AD53 | Absolute value of wavelet coefficients in the interval $[X-Y_{D5}, X+Y_{D5}]$ at scale detail D5 for wave III |
| 6. | AD63 | Absolute value of wavelet coefficients in the interval $[X-Y_{D6}, X+Y_{D6}]$ at scale detail D6 for wave III |
| 7. | AD45 | Absolute value of wavelet coefficients in the interval $[X-Y_{D4}, X+Y_{D4}]$ at scale detail D4 for wave V |
| 8. | AD55 | Absolute value of wavelet coefficients in the interval $[X-Y_{D5}, X+Y_{D5}]$ at scale detail D5 for wave V |
| 9. | AD65 | Absolute value of wavelet coefficients in the interval $[X-Y_{D6}, X+Y_{D6}]$ at scale detail D6 for wave V |

Since the calculated *p*-value was less than 0.05, it indicates that there is significant statistical evidence in support of rejecting the null hypothesis. In other words, the means of the two categories are significantly different. Hence the wavelet coefficients extracted as the salient features contribute significantly to differentiate the normal and abnormal BAEPs. The wavelet coefficients calculated for gender difference did not show significant difference. Since only absolute values of the wavelet coefficients for the peaks I, III and V are calculated in the range, and the *p*-values in Table IV and V has not shown any significant difference in the wavelet coefficients with respect to gender difference.

## IV. CONCLUSION

In this paper wavelet transform is used as a time-frequency analysis tool and applied to extract the features to distinguish the normal and abnormal BAEP signals. The wavelet features are also analysed in male and female subjects in different age groups. From the results it is evident that the wavelet coefficient values are significantly higher in the normal subjects when compared with abnormal subjects. However, the wavelet coefficients did not show any significant difference between male and female subjects. The study helps in better diagnostic decisions and treatment procedures for different pathological conditions in men and women in different age groups. In future work based on the wavelet coefficients as features a robust and accurate automated diagnostic system based on artificial neural network (ANN) can be developed for detection of neurological diseases leading to hearing loss.

## REFERENCES


i. *Jane Hornickel, Erica Knowles and Nina Kraus, "Test-retest consistency of speech-evoked auditory brainstem responses in typically-developing children", Hearing Research, 284, Jan 2012, pp. 52-58*

ii. *Chiappa.K.H (1990) Evoked Potentials in Clinical Medicine, 2nd Edition, Raven Press, New York.*

iii. *Joerg-Christian Tonn, Hans-Peter Schlake, Roland Goldbrunner, Christian Milewski, Jan Helms, Klaus Roosen, "Acoustic neuroma surgery as an interdisciplinary approach: a neurosurgical series of 508 patients", Journal of Neurosurgery Psychiatry, vol 69,pp.161–166,2000*

iv. *Rui Zhang, Gerry McAllister, Bryan Scotney, Sally McClean, "Combining Wavelet Analysis and Bayesian Networks for the Classification of Auditory Brainstem Response", IEEE Transactions on Information Technology in Biomedicine, vol.10, July 2006,No.3,pp.458-467*

v. *Arnaud Jacquin, Elvir Causevic, Roy John and Jelena Kovacevic, "Adaptive Complex Wavelet-Based Filtering of EEG for Extraction of Evoked Potential Responses", IEEE Transactions Biomedical Engineering, 2005,pp.393-396*

vi. *J. L. Maglione, M. Pincilotti, R. C. Acevedo, C. E. Bonell and G. Gentiletti "Estimation of the Auditory Brainstem Response's wave V by means of Wavelet Transform", in Proceedings of the 25th Annual International Conference of the IEEE EMBS Cancun, Mexico,2003,pp.2631-2634*

vii. *S. Rahbar, M.D.Abolhassami "Auditory Brainstem Response Classification Using Wavelet Transform and Multilayer Feed-forward Networks", Proceedings of the 4th IEEE-EMBS International Summer School and Symposium on Medical Devices and Biosensors, St Catharine's College, Cambridge, UK, Aug. 19-22,2007,pp.128-131*

viii. *J. Robert Boston, "Spectra of Auditory Brainstem Responses and Spontaneous EEG" IEEE Trans. Biomed. Eng, vol. 28, no 4, April 1981, pp.334-341*

ix. *Ying Sun,Zhao-Xue Chen, "Fast Extraction Method of Auditory Brainstem Response Based on Wavelet Transformation", in Proceedings of the 2007 International Conference on Wavelet Analysis and Pattern Recognition, Beijing, China, 2-4, ,Nov. 2007, pp.1862-1864*

x. *Wayne J. Wilson and Farzin Aghdasi, "Fast Fourier transform analysis of the auditory brainstem response effects of stimulus intensity and subject age, gender and test ear", in Proceedings of the Africon '99: 5th Africon Conference in Africa, 1999, pp.285-290*

xi. *Sandhya Dass, Mallikarjun S.Holi,and K. Soundara Rajan, "A Comparative study on FFT,STFT and WT for the Analysis of Auditory Evoked Potentials", International Journal on Engineering Science and Technology, vol 2,(issue 11), Nov2013, pp.636-641,.Available at* [*http://www.ijert.org/browse/volume-2 2013/november-2013-edition?start=80*](http://www.ijert.org/browse/volume-2%202013/november-2013-edition?start=80)

xii. *S. Rahbar, M.D.Abolhassami "Auditory Brainstem Response Classification Using Wavelet Transform and Multilayer Feed-forward Networks", in Proceedings of the 4th IEEE-EMBS International Summer School and Symposium on Medical Devices and Biosensors, St Catharine's College, Cambridge, UK, Aug. 2007,pp.128-131*

xiii. *Torrence, C. and G.P. Compo. "A Practical Guide to Wavelet Analysis", Bull. Am. Meteorol. Soc., 79, 1998, pp. 61–78*

xiv. *Daubechies, I. Ten Lectures on Wavelets,*

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ISSN:2319-6890)(online),2347-5013(print)
01 Jan. 2016

*Philadelphia, PA: Society for Industrial and Applied Mathematics (SIAM), 1992*

*xv. A. P. Bradley and W. J. Wilson, "On wavelet analysis of auditory evoked potentials," Clin. Neurophysiol., vol. 115, 2004, pp. 1114–1128*

*xvi. Chengyong Zhao, Mingfeng He, Xia Zhao, "Analysis Combined of Transient Waveform Based on Short Time Fourier Transform and Wavelet Transform", International Conference on Power System Technology – POWERCON, ,Nov 2004, pp.1122-1126*

*xvii. Wayne J. Wilson and Farzin Aghdasi, "Discrete Wavelet Analysis of the Auditory Brainstem response effects of subject age, gender and test ear, IEEE Transactions Biomedical Engineering, vol. 6,1999, pp.291-2966*

*xviii. Misra and Kalita, (2006) Clinical NeuroPhysiology, 2nd Edition, Elsevier Publishers.*

**Table III.** Comparison of Wavelet coefficients for normal and abnormal subjects

| | BAEP | Wave I | | | Wave III | | | Wave V | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **AD41** | **AD51** | **AD61** | **AD43** | **AD53** | **AD63** | **AD45** | **AD55** | **AD65** |
| Left | Normal | 4.04±2.26 | 11.3±8.82 | 31.15±14.93 | 3.57±2.26 | 10.31±5.59 | 26.8±12.83 | 3.9±2.22 | 9.86±5.52 | 29.6±14.1 |
| | Abnormal | 1.97±1.59 | 4.26±2.07 | 5.24±2.58 | 1.62±1.18 | 3.17±2.14 | 4.38±2.42 | 1.82±1.33 | 3.32±1.91 | 4.83±2.54 |
| | *p*-Value | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** |
| Right | Normal | 4.6±2.34 | 12.7±7.76 | 28.95±18.31 | 4.37±2.84 | 10.07±5.94 | 30.4±15.91 | 4.00±2.53 | 9.06±4.62 | 30±13.91 |
| | Abnormal | 1.96±1.66 | 3.49±1.95 | 4.78±2.53 | 1.89±1.35 | 2.98±1.98 | 3.98±2.21 | 1.82±1.32 | 3.38±2.44 | 3.8±2.12 |
| | *p*-Value | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** | ***p*<0.01** |

**Table IV.** Comparison of wavelet coefficients for male and female subjects in different age group for Left Ear

| Age in years | Gender | Wave I | | | Wave III | | | Wave V | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **AD41** | **AD51** | **AD61** | **AD43** | **AD53** | **AD63** | **AD45** | **AD55** | **AD65** |
| 1-20 | Male 10±6 | 3.96±2.08 | 9.30±3.89 | 23.29±12.74 | 3.52±1.46 | 7.75±4.11 | 21.48±9.14 | 3.88±2.11 | 7.55±2.97 | 20.08±9.71 |
| | Female 8±6 | 4.58±2.64 | 12.66±8.27 | 23.82±20.37 | 4.97±1.96 | 9.36±2.18 | 22.58±14.6 | 3.49±2.08 | 14.3±7.4 | 19.53±8.91 |
| | *p*-Value | ***p*=0.63** | ***p*=0.34** | ***p*=0.95** | ***p*=0.27** | ***p*=0.37** | ***p*=0.86** | ***p*=0.74** | ***p*=0.04** | ***p*=0.91** |
| 20-40 | Male 34±4 | 4.49±2.97 | 16.2±12.6 | 32.3±11.6 | 3.44±2.39 | 8.65±4.09 | 23.79±6.81 | 4.41±2.53 | 7.36±4.5 | 31.1±10.9 |
| | Female 34±6 | 6.21±2.61 | 16.73±10.55 | 37.83±10.01 | 4.93±2.79 | 16.3±7.91 | 37.57±17.8 | 6.16±2.08 | 12.9±6.34 | 42.26±12.6 |
| | *p*-Value | ***p*=0.27** | ***p*=0.93** | ***p*=0.54** | ***p*=0.30** | ***p*=0.04** | ***p*=0.08** | ***p*=0.18** | ***p*=0.08** | ***p*=0.17** |
| 40-70 | Male 54±8 | 4.04±1.43 | 7.59±9.76 | 28.03±17.7 | 4.02±2.23 | 10.4±4.8 | 23.79±16.6 | 3.92±1.87 | 9.44±4.68 | 23.72±20.1 |
| | Female 55±10 | 2.9±1.34 | 8.21±4.28 | 25.07±11.18 | 2.21±1.13 | 9.92±6.23 | 22.77±11.8 | 4.13±2.78 | 8.12±3.78 | 22.88±11.1 |
| | *p*-Value | ***p*=0.14** | ***p*=0.88** | ***p*=0.71** | ***p*=0.18** | ***p*=0.86** | ***p*=0.89** | ***p*=0.87** | ***p*=0.75** | ***p*=0.92** |

**Table V.** Comparison of wavelet coefficients for male and female subjects in different age group for Right Ear

| Age in years | Gender | Wave I | | | Wave III | | | Wave V | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **AD41** | **AD51** | **AD61** | **AD43** | **AD53** | **AD63** | **AD45** | **AD55** | **AD65** |
| 1-20 | Male 10±6 | 4.29±1.76 | 12.30±7.39 | 20.91±7.27 | 4.13±2.4 | 10.35±5.5 | 25.57±13.27 | 4.55±2.19 | 8.43±3.33 | 22.24±8.66 |
| | Female 8±6 | 5.13±3.65 | 17.15±7.45 | 29.47±22.8 | 7.17±2.95 | 11.04±6.4 | 21.01±14.49 | 4.79±3.65 | 8.29±5.08 | 23.48±7.49 |
| | *p*-Value | ***p*=0.59** | ***p*=0.24** | ***p*=0.36** | ***p*=0.05** | ***p*=0.83** | ***p*=0.83** | ***p*=0.88** | ***p*=0.95** | ***p*=0.78** |
| 20-40 | Male 34±4 | 4.72±2.9 | 14.64±11.5 | 29.08±11.3 | 3.75±2.07 | 9.99±4.44 | 26.32±7.87 | 4.47±2.55 | 12.07±6.04 | 33.46±9.73 |
| | Female 34±6 | 3.94±2.26 | 16.41±8.12 | 44.39±26.5 | 4.04±3.65 | 14.66±11.12 | 47.2±22.29 | 3.8±2.17 | 11.9±6.94 | 35.14±18.8 |
| | *p*-Value | ***p*=0.58** | ***p*=0.74** | ***p*=0.18** | ***p*=0.85** | ***p*=0.33** | ***p*=0.03** | ***p*=0.60** | ***p*=0.81** | ***p*=0.83** |
| 40-60 | Male 54±8 | 3.76±1.95 | 7.91±4.93 | 23.25±16.4 | 3.91±1.77 | 10.8±6.46 | 25.41±16.38 | 2.78±2.46 | 8.01±3.3 | 19.87±7.59 |
| | Female 55±10 | 5.66±2.58 | 10.10±3.21 | 20.44±18.6 | 3.14±1.22 | 7.41±6.12 | 23.26±14.4 | 4.63±2.85 | 9.67±4.23 | 29.49±19.96 |
| | *p*-Value | ***p*=0.14** | ***p*=0.34** | ***p*=0.76** | ***p*=0.35** | ***p*=0.33** | ***p*=0.79** | ***p*=0.21** | ***p*=0.43** | ***p*=0.25** |