Estimation of Fundamental and Formant frequencies of infants' cries; a study of Infants with congenital Heart disorder

Radhika Rani L
Department of Physics, Jawaharlal Nehru Technological University Hyderabad
India
radhikarani79@gmail.com

Chandralingam S
Department of Physics, Jawaharlal Nehru Technological University Hyderabad
India
chandra_lingam@yahoo.com

Anjaneyulu T
IIT Bombay
India,
tangiralaanjaneyulu@yahoo.co.in

Satyanarayana K
Department of Biomedical Engineery Osmania University
Hyderabad,India
kjwala@yahoo.com

Abstract
A congenital heart disease (CHD) is a defect in the structure of the heart and great vessels of a newborn.CHD s are classified into Cyanotic and Acyanotic. The most common cyanotic heart disorder in infants is Tetralogy of Fallot **(TOF)**. Among Acyanotic heart disorders, Ventricular **Septal Defect (VSD), Atrial Septal Defect (ASD),** and Patent Ductus Arteriosus (PDA) are common. The present work aims at estimating the features of fundamental frequency (Mean, Maximum and Minimum) and the formant frequencies (First, Second and Third) of infant cries with TOF, VSD, ASD, PDA heart disorders. In the present study a total of 75 infant cries are investigated. The fundamental frequency and formant frequencies are estimated using frequency domain (Cepstrum) and Linear Prediction Code (LPC) methods. The results show that the fundamental frequencies of cries of infants with TOF, VSD, ASD, PDA, and healthy infant cry signal are in the range of 364Hz to 396 Hz, 435 Hz to 447 Hz, 435 to 467 Hz, 553 Hz to 584 Hz and 367 Hz to 409 Hz respectively. Such parameters provide useful information in the early diagnosis of heart disorders in infants.
Keywords; Infant cry; CHD; Fundamental frequency; Formant Frequency

1. Introduction

1.1. *Infant Cry*

Crying is the infant's most powerful means of communication. Infant crying is an expression of physical discomfort or distress [1].The major cause of crying is physiological pain. In the last few decades' fundamental and formant frequencies of different disordered infant cries were evaluated by researchers. The voice production system is responsible for the production of cry shown in figure1. Fundamentally cry sounds are produced by the vibration of vocal folds in the larynx. The frequency in which the vocal cords vibrate is called as fundamental frequency or pitch. The vocal tract modifies the sound generated at the larynx producing resonance frequencies which are formant frequencies. In order to evaluate these parameters of the infant cry, it is also important to understand how the cry is produced. Crying involves delicate coordination of a number of muscles and neural events, including the laryngeal, supralaryngeal and respiratory muscle groups and the vagal neural complex. Due to the pressure of the glottis and the air pushed from the lungs, the vocal cords can open and close very quickly, which generates vibrations in the air. The vibration is modulated by the resonances of pharyngeal/nasal/oral cavities, forming infant cry [2]. Cry signals of hunger, pleasure and birth cries were analyzed by Wasz-Hockert et al. [3]. Tenold et al. analyzed time and spectral domain characteristics of 9 full-term and 5 preterm infant cries[4]. Veurenkoski et al. analyzed 44 cry signals of infants suffering from cri-du-chat syndrome [5]. Lind et.al were tested120 samples of 30 infants with Down's syndrome[6]. The cry of infants with hypothyroidism has been investigated by Michelsson and Sirvio. The research included 40 signals recorded from 4 sick infants [7]. In another study Michelson investigated cries of infants with cleft palate which is the malformation of the orolaryngeal tracts, in this 52 signals were recorded from 13 infants[8]. Wasz-Hockert et al. studied cries of infants with metabolic disturbances, particularly cries of infants with high hyperbilurubinemia [9]. Thoden and Michelsson studied cries of infants of diabetic mothers [10]. Michelsson compared cry signals of 250 infants with asphyxia with 50 healthy full-term infants and 75 healthy preterm infants [11]. Infants with meningitis were studied by Michelsson et al. 14 infants were included in this study [12]. The investigation revealed that the frequencies of the cries of infants effected with various diseases were found to be abnormal when compared with the cries of healthy infants.

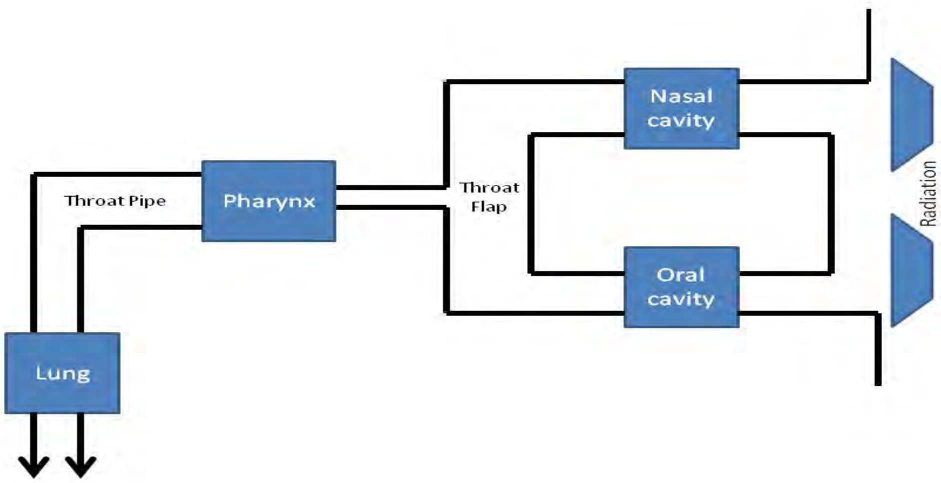

Fig. 1. Human voice production system

1.2. ***CHD congential heart disorder***

Congenital heart disease is the most common type of cardiac disease affecting infants. Any defect of the heart or the major blood vessels that is present at birth is called congenital heart disease. About one in every 120 babies has some congenital heart defect. CHDs are classified into Cyanotic and Acyanotic heart disorders. The primary symptom of cyanotic congenital heart disease is blueness of the infant's skin at birth. Tetralogy of Fallot (TOF) belongs to cyanotic heart disorder. Congenital heart disease that does not cause bluish skin is called Acyanotic. Acyanotic disorders include Ventricular Septal Defect (VSD), Atrial Septal Defect (ASD) and Patent Ductus Arteriosus (PDA) [13]. Congenital heart defect may occur with an associated genetic abnormality; an illness afflicting the mother during fetal heart development and in some cases medication taken by the mother during pregnancy. The symptoms of CHD effected infants are exhibit shortness of breath, cyanosis, chest pain, syncope, sweating, heart murmur, respiratory infections, under-developing of limbs and muscles, poor feeding, or poor growth, build up of blood and fluid in lungs, feet, ankles and legs. The diagnostic techniques to identify CHDs are heart murmur, Electrocardiogram (ECG), Chest X-Ray, Blood tests, Echocardiography (Cardiac ultrasound), Cardiac Catheterization [14].

2. Method

Figure 2 shows the flowchart of cry signal analysis. The first stage is recording of cry signals in hospitals and the second stage is analysis.This stage consists of Preprocessing, Processing and Evaluation. The author used MATLAB software for analysis of infant’s cry signal and estimated fundamental and formant frequencies.

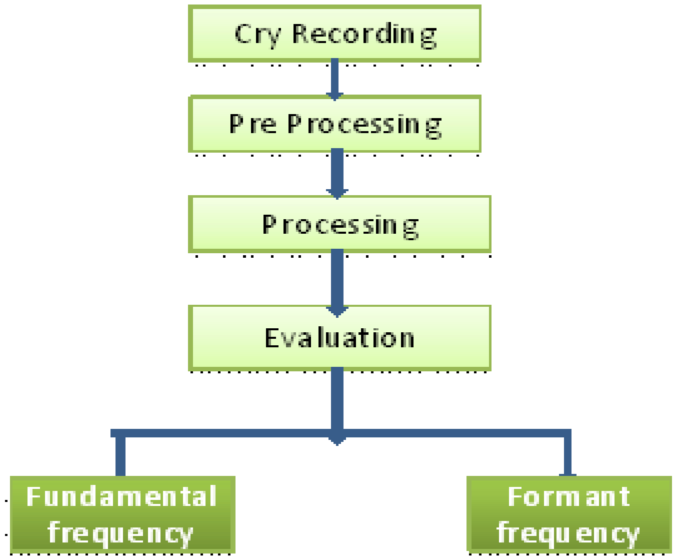

Fig. 2. cry signal analysis

2.1. *Cry recording*

A total of 75 cry signals were analyzed, out of which 60 infants(18 TOF,20 VSD,11ASD,11PDA) having congenital heart disorder, (confirmed through medical examination) were recorded at Innova Children's Heart Hospital, Hyderabad and 15 Normal infant cry signals were recorded at hospitals and houses. The babies were 1-12 months old. The length of the cry signal was 40-60 sec. The author used a digital camera (CANON-A3100 IS) in order to recognize the infant and the circumstances of crying. The sampling frequency of the cry signal was 44,100 Hz. The distance between the microphone and the mouth of the infant was 1m.

2.2. *Database*

The recorded infant cries (.avi) were transferred into a PC and converted into .wav files. The infant's database contains the following information.

- **Details of the Infant;** Name, Date of birth, Gender, Address and Telephone number of the Parents
- **Medical Observations**; Type of heart disorder, other diseases existing
- **Details about the cry record;** Date of recording, Place of recording, Length of cry signal, Sampling frequency, Type of recording device, File name of the cry signal

3. Analysis

3.1. *Data Preprocessing*

The infant cry signal is preprocessed before estimating the fundamental (F0) and formant frequencies (F1, F2, F3). In the preprocessing stage, the cry signals were pass band filtered in the range of 200Hz-5,500Hz and resampled at 11,025Hz. In the next step, for each cry signal the first five cry units were segmented in frames of 25ms and the six parameters [F0(Mean),F0(Min),F0(Max) F1, F2 and F3) extracted from each frame. This procedure was applied for all cry signals.

3.2. *Estimation of Fundamental Frequency*

The Fundamental Frequency (F0) detection is an important part of investigation. The fundamental frequency is the lowest useful frequency component in the spectrum. The most common fundamental frequency characteristics used are the mean, maximum and minimum fundamental frequency. Cepstrum analysis is used to calculate F0. Cepstrum analysis is a form of spectral analysis where the output is the Fourier transform of the log of the magnitude spectrum of the input waveform [15]. The cry signal was divided into 5 successive units which were in 25ms size. The Cepstrum analysis was applied for each unit. Fig. 3 shows the stages in the Cepstrum analysis algorithm.

3.3. *Estimation of Formant Frequencies*

The Formant Frequencies are vocal tract natural resonance frequencies. Formants are frequency ranges that characteristically contain a concentration of the acoustic energy. The author used linear prediction code method to estimate first three formant frequencies (F1, F2, and F3) [16]. Linear Predictive Coding (LPC) is one of the most powerful analysis techniques .The Linear prediction Code method was applied for each unit. Fig. 4 shows the formant frequency estimation.

4. Results

Cries of 75 infants were analyzed and classified into 5 groups based on their medical condition. They are Normal, TOF, VSD, ASD, and PDA. Fundamental and Formant frequencies were estimated for all groups

4.1. *Estimation of Fundamental Frequency*

Table 1. shows the results of mean, maximum and minimum fundamental frequencies (F0) and standard deviation of all groups. In 15 signals of normal cries the maximum fundamental frequency was about 409 Hz, and the minimum 367 Hz. For 18 TOF cry signals the following values were estimated; a maximum fundamental frequency of 396 Hz, a minimum fundamental frequency of 364 Hz. 20 VSD cries of infants was characterized by a maximum fundamental frequency of 447 Hz and a minimum frequency of 435Hz. 11 infant cries with ASD disorder were estimated to have a maximum fundamental frequency of 467 Hz and a minimum fundamental frequency of 435 Hz. A maximum fundamental frequency of 569 Hz and a minimum fundamental frequency of 553 Hz were found with 11 PDA disorder infant cries.

Table 1. Comparative analysis of Fundamental frequency (F0)

S.No	Clinical condition	No of cries	Mean of FO	SD	Max of FO	SD	Min of FO	SD
1	Normal	15	383.2771	32.023	409.0367	39.583	367.3231	35.839
2	TOF	18	378.9967	35.311	396.4126	38.673	364.4904	35.42
3	VSD	20	440.6283	44.982	447.3907	46.459	435.886	46.816
4	ASD	11	452.5954	32.99	467.5849	40.84	435.054	42.54
5	PDA	11	569.0063	40.601	584.8199	40.713	553.1137	39.79

FO-Fundamental frequency (Hz)

4.2. *Estimation of Formant Frequencies*

Table 2.shows the results of mean values of first, second, third Formant frequencies (F1, F2 and F3) and standard deviation of all groups. The F1, F2 and F3 in normal cries were 684Hz, 1315Hz and 2174. For the group of TOF disorder infants it was 775Hz, 1472Hz and 2392Hz, For infants with VSD disorder it was 948Hz, 1606 Hz and 2564Hz. Table 2. depicts that infants with ASD disorder have 890Hz, 1553Hz and 2483Hz as formant frequencies and for those with PDA disorders it was found to be 814 Hz, 1592Hz and 2479Hz.

Table 2. comparative analysis of Formant frequencies (F1,F2 and F3)

S.No	Clinical condition	No of subjects	Mean of F1(Hz)	SD	Mean of F2(Hz)	SD	Mean of F3(Hz)	SD
1	Normal	15	684.352	53.841	1315.353	47.047	2174.968	39.52
2	TOF	18	775.98	50.1	1472.82	63.139	2392.081	62.971
3	VSD	20	948.68	58.411	1606.594	30.807	2564.613	39.609
4	ASD	11	890.0855	36.61	1553.109	53.048	2483.084	51.047
5	PDA	11	814.1909	34.084	1592.804	32.099	2479.578	34.918

F1; First Formant frequency (Hz); F2; Second Formant frequency (Hz) F3; Third Formant frequency (Hz);

5. Discussion and Conclusion

Cries of infants were analyzed and classified according to their type of disorder to establish possible differences in Fundamental and Formant frequencies. Fig 5, 6 and 7 represented the distribution of mean, maximum and minimum values of fundamental frequencies of all groups. Fig 8, 9, and10 represented the distribution of First, second, Third Format frequencies of all groups. From these graphs the author concluded that the range of fundamental frequencies of 15 normal cries were 367Hz to 409Hz with a mean of 383Hz.The First, Second, Third formant frequency values of this group were 684Hz, 1315Hz and 2174Hz. 18 infants with TOF disorder were studied and the fundamental frequency range was estimated to be 364 Hz to 396 Hz with a mean of 378Hz. The First, Second, Third formant frequency values of this group were 775Hz, 1472Hz and 2392Hz. The findings showed that the range of fundamental frequency was 435Hz to 447Hz with a mean value of 440Hz for 20 infants suffering from VSD disorder. The First, Second and Third formant frequency values of this group were 948Hz, 1606 Hz and 2564Hz. 11 infants who suffered from ASD were tested. The findings concluded that the range of fundamental frequency was 435Hz to 467Hz with a mean value of 452Hz. The First, Second, Third formant frequency values of this group were890Hz, 1553Hz and 2483Hz. infant cries with PDA disorder have been investigated. The findings showed that the range of fundamental frequency of The First, Second and Third formant frequency values of this group were 814 Hz, 1592Hz and 2479Hz.

Author concluded that in the groups of infants with ASD and PDA disorders was considerably large F0 (Mean) value when compared with normal infants, indicating a greater variability of the F0. VSD group of infants showed significantly less F0 (Mean) representing a less variability in FO. In TOF disorder group of infants no major changes in the fundamental frequency were found and further investigations needs to be done. The First, second, Third Formant frequencies (F1, F2, F3) of TOF, VSD, ASD and PDA groups differed significantly from normal cries.

The author found significant difference between normal cry and CHD disordered cry. In Normal cry the voice quality, pitch, loudness are sensibly agreeable and perceptible to the listener. CHD affected cry has deviation in quality, pitch, loudness that may indicate illness. Infant crying is a wealthy source of information. Crying provides information about the biological integrity of the infant. These kinds of studies are important for the diagnosis of congenital heart diseases at early stages.

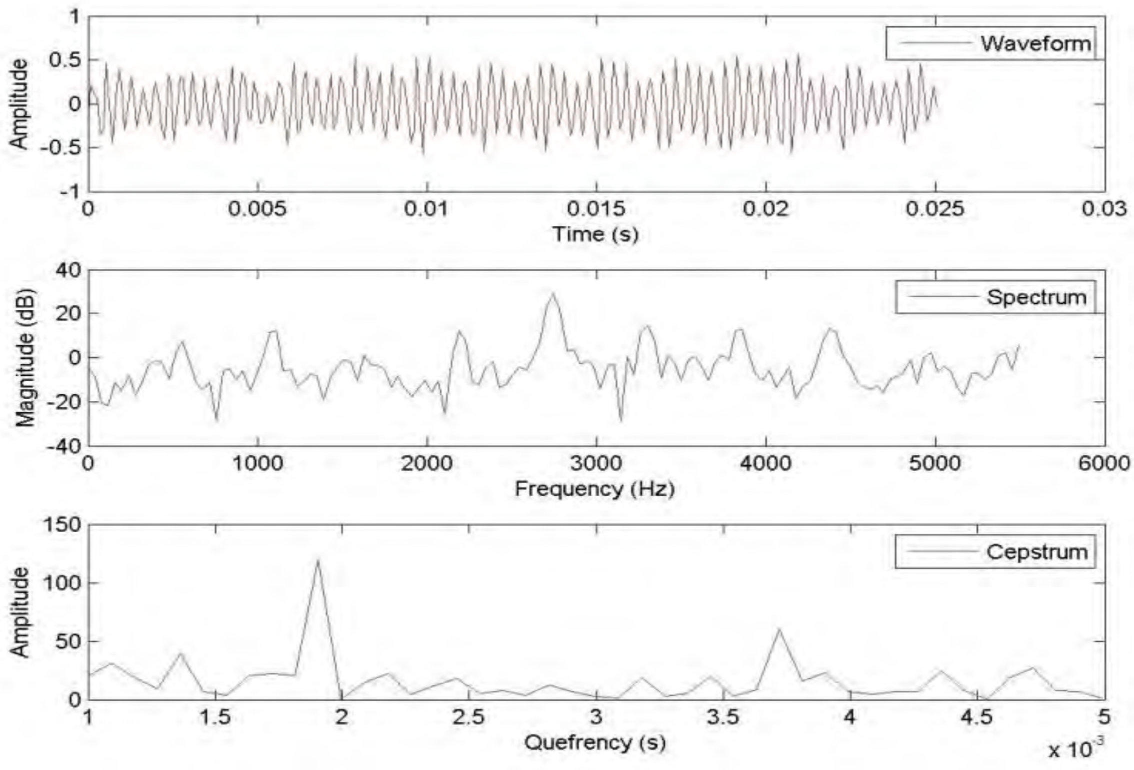

Fig. 3. Cepstrum Analysis

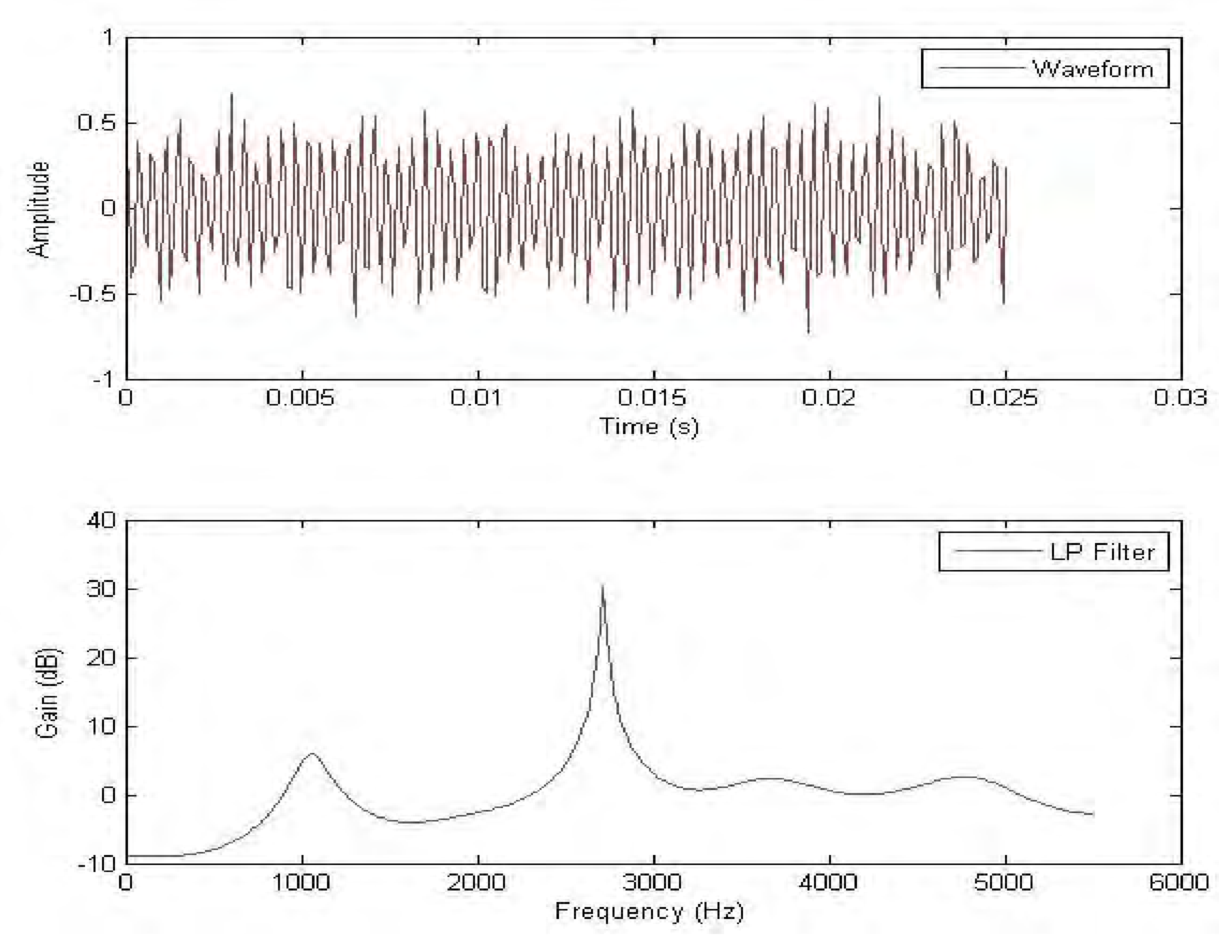

Fig. 4. Estimation of Formant frequency

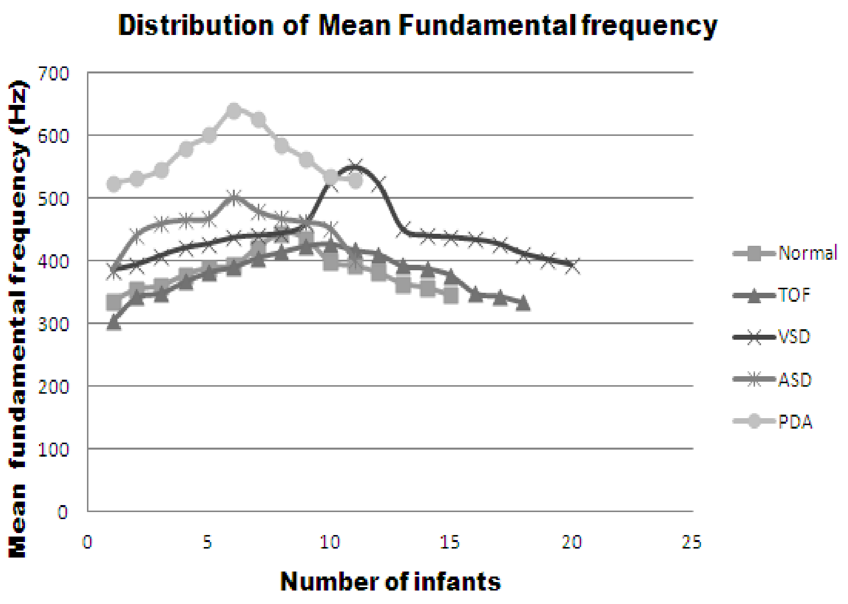

Fig. 5. Number of infants vs mean Fundamental frequency

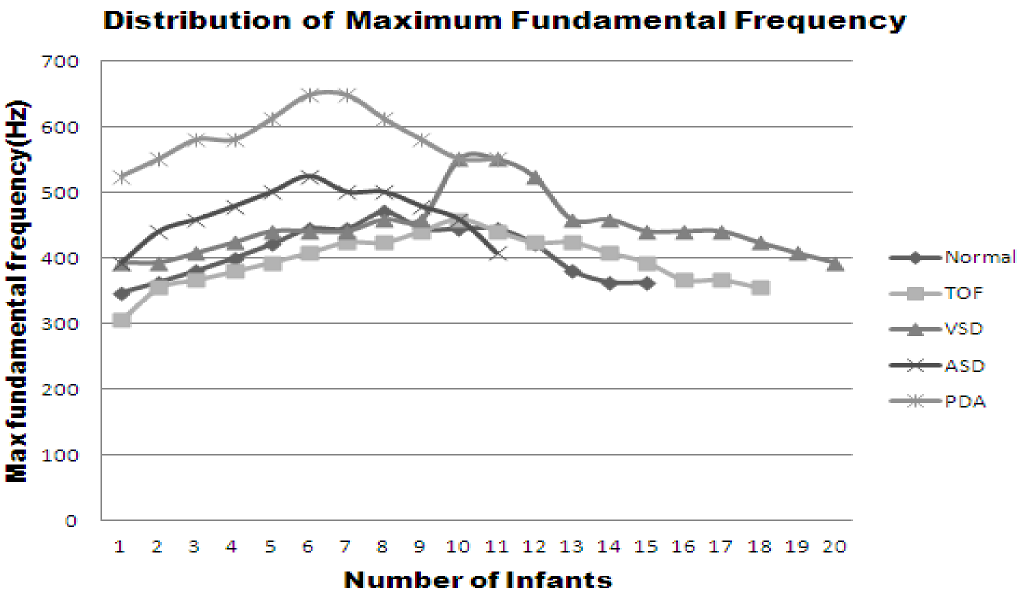

Fig. 6. Number of infants vs Maximum Fundamental frequency

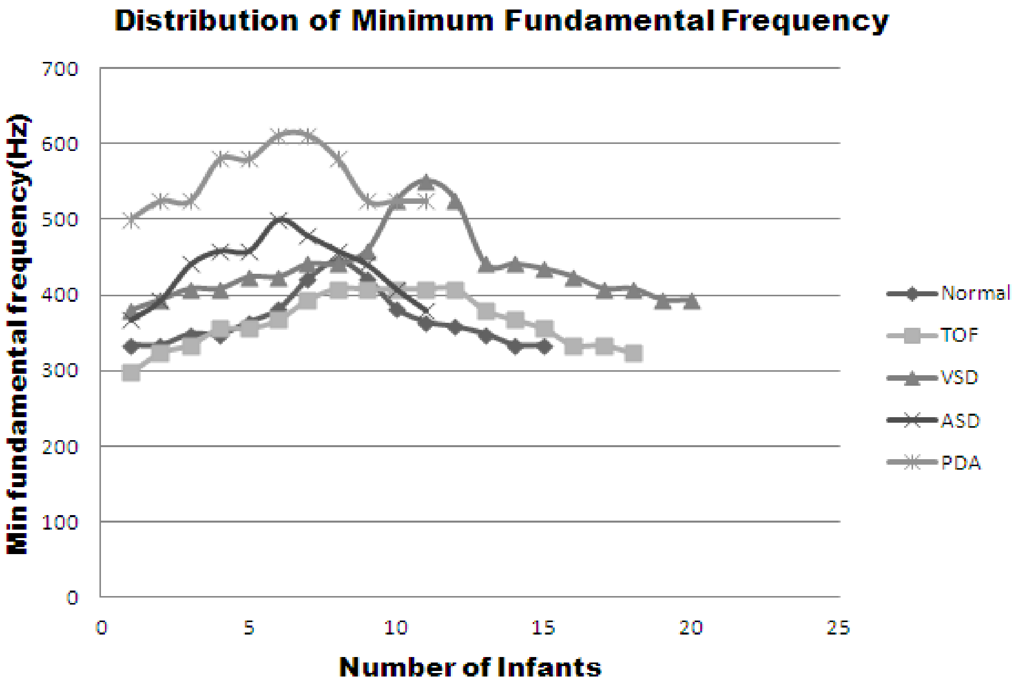

Fig. 7. Number of infants vs Minimum Fundamental frequency

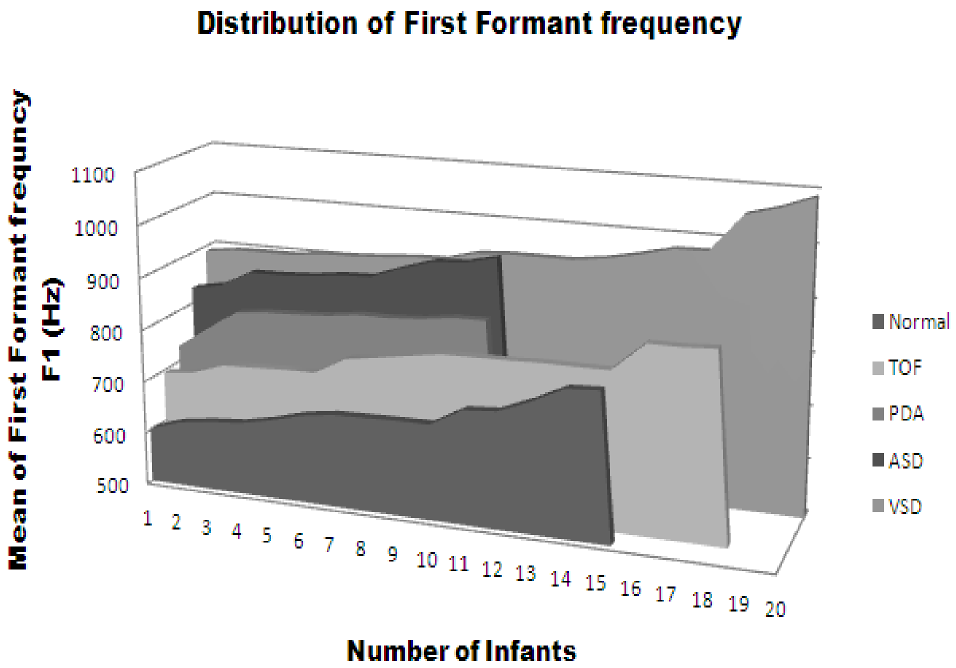

Fig. 8.Distribution of First Formant frequency

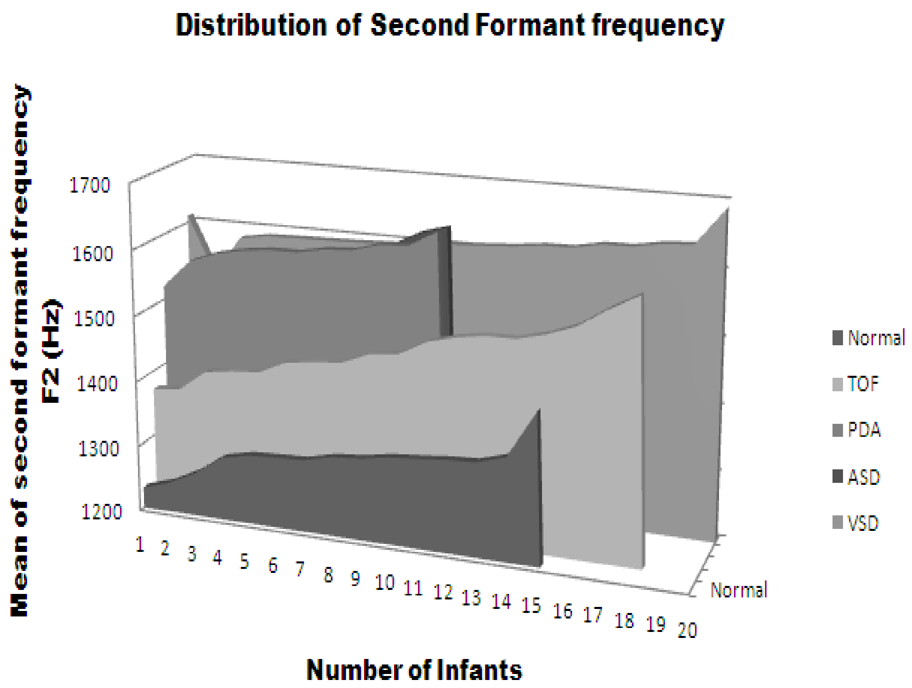

Fig. 9.Distribution of Second Formant frequency

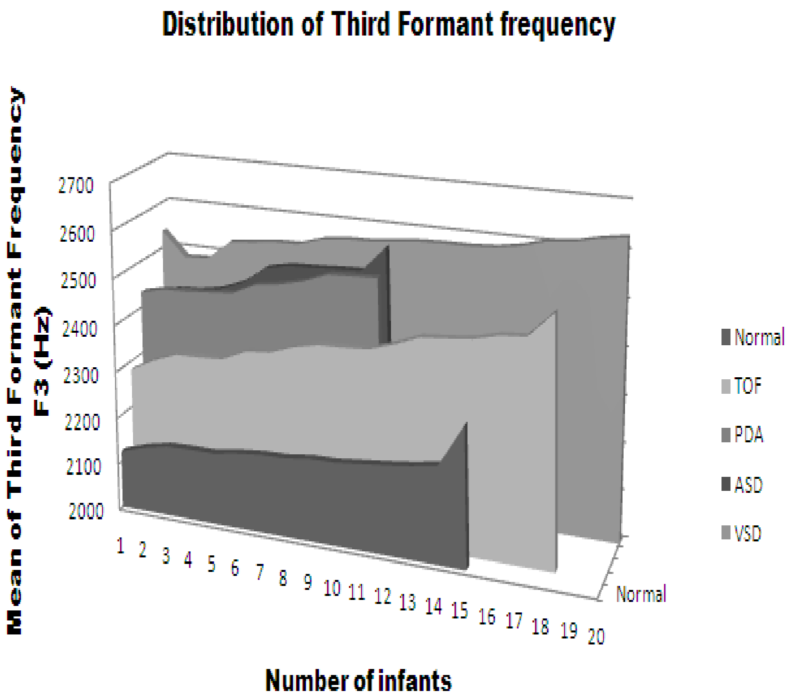

Fig. 10.Distribution of Third Formant frequency

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