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Breathe Sound Analysis: A New Approach for Diagnosis

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Abstract:

This paper presents a new approach of breath sound analysis by recording exhalation and inhalation sounds with microphone placed in a pipe. The aim of this study is to understand the differences in inspiration and expiration signals of male and female subjects, differences in breath signals of healthy non-smokers and smoker subjects, differences in the breath signals of healthy and well controlled asthma patients. These differences were studied by comparing different signal parameters like Peak Frequency, significant frequency range, Power and the frequency at which maximum power occurs, Power Spectral Density and the frequency at which Maximum Power Spectral Density occurs. Exhalation and Inhalation sounds generated from mouth in a pipe arrangement were evaluated for testing and recorded for 45 subjects. Online microphone sound recording with developed experimental set up and computer based data analysis has been carried out according to physical parameters, the body mass index i.e. height and weight, gender, diseases and smoking habits. Frequency analysis carried out using Fast Fourier Transformation helps in extracting peak frequency and significant frequency range of the recorded sound signal. Significant difference in maximum Power Spectral Density (PSD) has been found in healthy men and women. This study discusses the possibility of modern lung examination through breath sound analysis which involves the study of exhaled air sound signal available from mouth in a pipe arrangement.

Keywords — **Spirometer, Fast Fourier Transform, Power spectral density, Sound Signal Power, Body Mass Index, Linear regression.**

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I. INTRODUCTION

The breath sounds at mouth occurs due to vibrations induced in the walls of air tract by air velocity and turbulence at the lobar or segmental bronchi level [1]. Breath sounds show different characteristics depending upon ventilatory cycle (expiration and inspiration) [1].

Many attempts have been carried out for the recording of the sound generated in the lung system due to passage of air in the large airways of the respiratory system. These vibrations may be heard or recorded easily with the aid of a stethoscope or a microphone for basic diagnosis [2]. Analysis of the lungs sounds includes finding out the characteristics of breath sounds, intensity and vocal resonance [3]. An absence or a decrease in lung sounds can mean: an increase in thickness of chest wall, over inflation of a part of the lungs (due to emphysema), reduced air flow in some part of the lungs (due to Asthma), fluid or air in or around the lung system (due to pneumonia, pleural effusion and heart failure) [4]. Abnormal breath sounds may arise due to acute or chronic bronchitis, asthma, pulmonary edema, tracheobronchitis, pneumonia, etc. It has been observed that Asthma, Chronic Obstructive Pulmonary Disease (COPD) are the leading causes of mortality and morbidity and are attaining alarming proportions that require more objective and quantitative ways for the detection and diagnosis of both the disease and the therapeutic outcomes [5]. A frequent or a daily analysis of lung sound spectra could help to identify patients with different diseases, before the appearance of any radiologic abnormality, for e.g. patients with an incipient pneumonia [6].

Literature surveys reported until now have used many methods of digital recording of lung sound. Digital sound recording with subsequent frequency analysis is a very reliable and quantitative method for an objective assessment of lung diseases [6]. Also it is observed that a Fast Fourier transformation (FFT) has been used to calculate a sound power spectrum [7]. Earlier studies have used different parameters to characterize the frequency spectrum such as median frequency [8, 9], quantile frequencies [8], frequency with the highest power [10] and the power of frequency bands [6, 7]. To obtain a dynamic image of respiratory sound distribution Guntupalli et al. [11] came up with a microphone array that covers the person's whole back. Thus, an automated classification of recorded breath sounds through electronic auscultation helps to prevent the shortcomings of the manual auscultation methods which have the limitations of inherent inter-listener variability [12].
This study discusses the possibility of modern lung examination through breath sound analysis which involves the study of exhaled air sound signal available from mouth in a pipe arrangement. Due to the air pollution and smoking habits, lung disorders such as Asthma, Chronic Obstructive Pulmonary Diseases are increasing rapidly.

Respiratory diseases need to be diagnosed using different lung capacity measurement devices. Different sensors are used for sensing the exhaled air flow and volume such as thermistor, ultrasonic sensors, bellows, turbine etc. A new method for breath sound analysis using a microphone has been explained in this paper.

II. SENSORS USED FOR LUNG SOUND RECORDING

Most commonly two types of transducers are used for lung sound recording and analysis reported in literature. One of them is the electret microphone with coupling chamber. These electret microphones are very compact and are easily available for audio recordings [13]. The coupling chambers used with these microphones are similar to stethoscope bell. The overall frequency response of the sensor is found to be affected by different sizes and shapes of coupling chambers. Those setups with smaller and conical shape are found to be more sensitive to higher lung sound frequencies and therefore are very susceptible to ambient noise [14, 15].
The other transducers which are widely used in lung sound analysis are contact accelerometers. They are calibrated on a vibration table so their output is quantified. Contact accelerometers may exhibit internal resonances, are more expensive, often fragile, than electret microphone [7].
Hence in this study electret microphone placed in a pipe arrangement is used for breath sound analysis.

III. METHODS

A. Subjects

30 non-smoker healthy subjects (male-13, female-17), 10 smoker healthy male subjects and 5 known self reported asthma male patients has been recruited in the study. Due to lack of female smokers in Indian community, female smoker subjects were not included in the study. A subject who did not have any symptoms and were not aware of suffering from any disease has been considered as healthy. Smokers recruited in the study typically reported to have been smoking for last 3-4 pack years. The asthma patients recruited in the study fall under the category of mild and well controlled asthma and reported to have been taking regular medications after been medically diagnosed previously. The readings for asthma patients did not include any wheeze event and none of them had asthma exacerbation in the last 6 months. All the subjects provided the written informed consent before the study participation. The study was approved by the Independent Research Ethics Committee, Pune, India. The subjects were recruited from known contacts based on convenience.

B. Measuring Methods

Figure 1 shows the schematic arrangement of recording set up which consists of electret (electrostatic capacitor) microphone, which eliminates the need for a power supply [15], placed in a pipe with a mouth piece. Figure 2 shows the detailed geometry of the experimental set up.

American Thoracic Society' (ATS) guidelines have been followed in the selection of mouthpiece and pipe [16]. The audio signals have been recorded at a standard sampling rate of 44100 Hz [17] using Audacity 2.1.0 software; which is a free, open source, cross-platform software for recording and editing sounds.

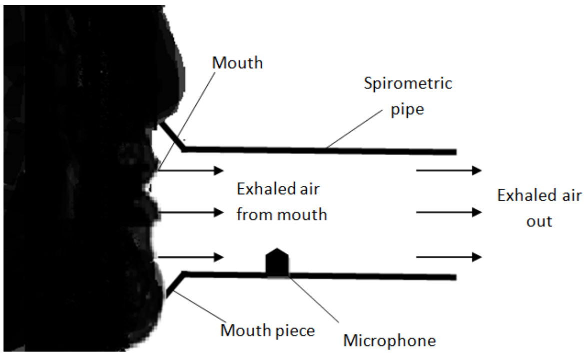

Fig. 1 Schematic arrangement of exhalation in spirometric pipe.

In the proposed arrangement, mouthpiece is placed close to the mouth of a subject, under test. Care has been taken with placement of assembly such that the exhaled air is directly forced in the pipe, without any pressure loss [18]. The sounds have been recorded by breathing (only through mouth) in the mouth piece in a sitting position in a quiet room.

The subjects were made to breathe with airflow through the pipe following spirometric procedure, provided the readings were taken only if the subjects didn't perform any rigorous physical work just before the experimentation. Thus the subjects were made to record in a calm and normal breathing notion which helped us to acquire readings in standardized way.

It has been assumed that the influence of sounds originating from the mouth or experimental setup tube was the same for all the subjects. Noise was removed from the signals by observing the power spectrum. Exhaled air sound recorded near mouth consists of frequency distributed from 200 to 2000 Hz similar to normal sound signal. In the range of lower frequencies (<100 Hz), heart and muscle sounds overlap; this range must therefore be filtered out for the assessment of exhaled air sounds [19]. To reduce the influence of heart and muscle sounds, as well as noise, the signals were band pass-filtered using a band pass of 100 to 2000 Hz. An upper cut-off frequency of 2000 Hz has been selected, as above this no significant useful data were observed in the breath sound signal.

C. Evaluation

In this study we have carried out our experimentation on the similar lines of a spirometric test. Spirometric test procedure starts with normal breathing followed by forceful exhalation to the fullest capacity of lung and ends with immediate inhalation. Figure 3 shows the standard spirometric graphs obtained from the spirometric test as mentioned in American thoracic society (ATS) standards [18].

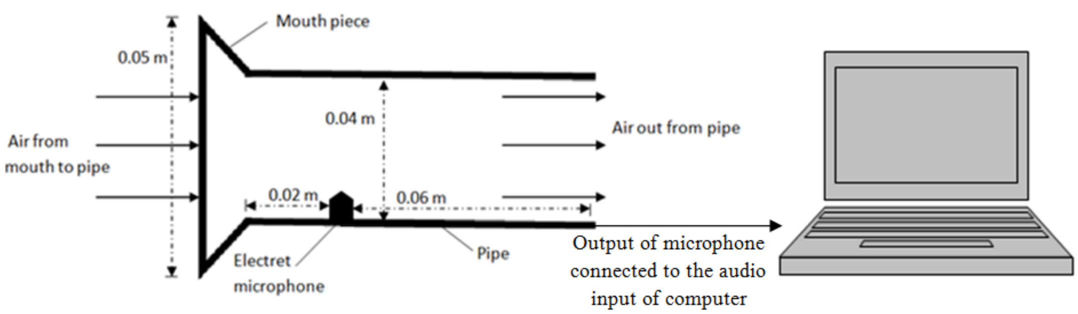

Fig. 2 Recording setup

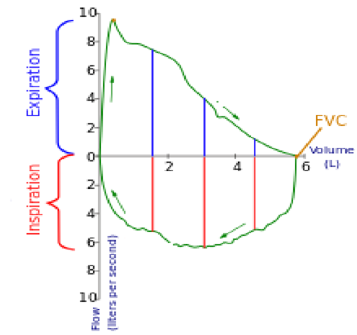

Fig. 3 (a) Flow rate-volume graph

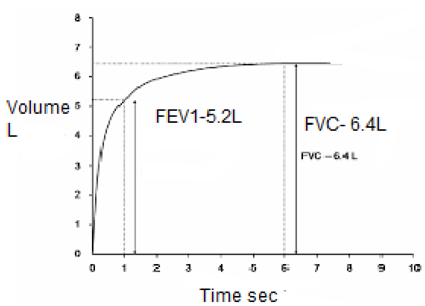

Fig. 3 (b) Lung volume-time graph

Where,
FVC - Forced vital capacity (spirometry test value used in the assessment of chronic obstructive pulmonary disease).
FEV1 - Forced expiratory volume in first second (an important measure of the pulmonary function).
It is observed from figure 3(a) & 3(b) that flow rate and volume reaches to the maximum value during the first few seconds of exhalation depending upon individual’s lung capacity. Max. Forceful exhalation (FEV1) occurs during the first second of the spirometric test and is an important parameter from the diagnosis point of view. Hence, for the investigation, inspiration and expiration data of the first second has been extracted from the individual recordings. About 4000 samples of data points have been taken from the individual’s expiration and inspiration data. The extracted data is then analysed using MATLAB R2012 (The Math-Works, Inc., Natick, MA). Variation of exhaled air force and in turn sound according to anthropometric parameters (height, weight, age) and gender of human beings has been carried out.
The data has been evaluated using the technique of Fast Fourier Transformation (henceforth FFT). Using Fourier Transformation on a signal yields the major frequency representation of the signal. Mathematically the Continuous Fourier Transformation is described as:

$$F(f) = \int_{-\infty}^{\infty} f(t)\, e^{-j2\pi ft}\, dt \qquad ......(1)$$

In Equation (1), f (t) is the input signal and F (f) is FFT of f (t). In spirometric signal analysis, this input signal is usually a time domain representation of the signal: amplitude of the sound as a function of time. A microphone recording of a spirometric signal is a time domain representation [19]. From the FFT plot (Figure 4) peak frequency and significant frequency range (amplitude > 0.001) has been calculated.

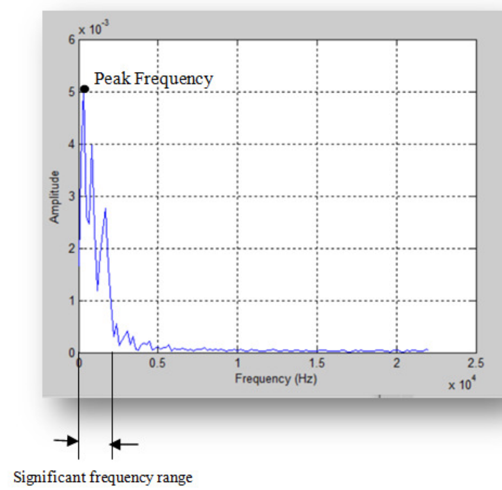

Fig. 4 FFT Plot

The Power Spectral Density (henceforth PSD) which is a measure of a signal's power intensity in the frequency domain is then calculated. The PSD provides a useful way to characterize the amplitude versus frequency content of a random signal. On integrating PSD over a given frequency range computes the average power in the signal over that frequency band. The peaks in this spectrum do not reflect the signal power at a given frequency. The PSD has been calculated using the Welch method, which uses the concept of periodogram estimates. Welch method reduces noise in the estimated power spectra in exchange for reducing the frequency resolution. Due to the noise caused by imperfect and finite data, the noise reduction from Welch's method is often desired. Using the PSD plot for individual signals the maximum PSD (dB/Hz) and the peak frequency at which it occurs has been calculated as shown in Figure 5.

Truncated Fourier transform $\hat{x}_T(\omega)$ integrated over a finite time interval [0.T] (equation 2) is used to calculate the PSD given by $S_{xx}(\omega)$ (equation 3).

$$\hat{x}_T(\omega) = \frac{1}{\sqrt{T}} \int_0^T x(t) e^{-i\omega t}\, dt. \quad \text{.... (2)}$$

$$S_{xx}(\omega) = \lim_{T\to\infty} \mathbf{E}\left[|\hat{x}_T(\omega)|^2 \right]. \quad \text{.... (3)}$$

Where **E** denotes the expected value calculated by equation (4).

$$\mathbf{E}\left[|\hat{x}_T(\omega)|^2\right] = \mathbf{E}\left[\frac{1}{T}\int_0^T x^*(t)e^{i\omega t}\,dt \int_0^T x(t')e^{-i\omega t'}\,dt'\right] = \frac{1}{T}\int_0^T\int_0^T \mathbf{E}\left[x^*(t)x(t')\right] e^{i\omega(t-t')}\,dt\,dt'. \quad \text{... (4)}$$

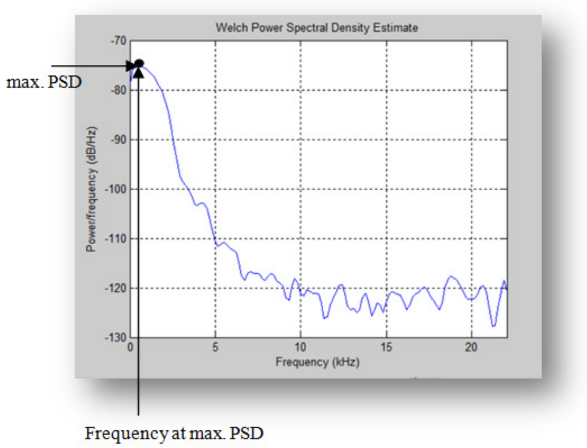

Fig. 5 PSD Estimate Plot

Further, the signal power in dB has been calculated over the given frequency band. From Power plot, maximum signal power and the frequency at which maximum signal power lies has been calculated as shown in Figure 6. Mathematically signal power can be calculated as:

$$P_x = \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{n=+N} |x(n)|^2$$

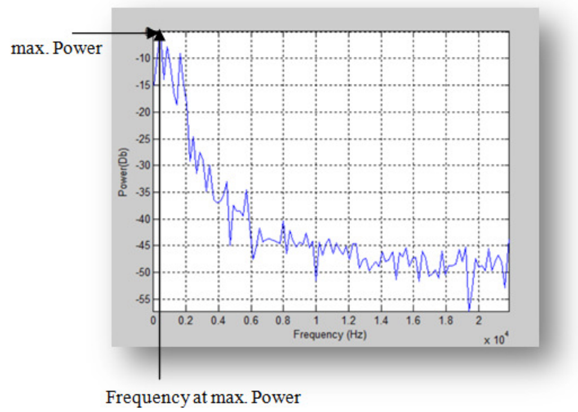

Fig. 6 Power Plot

These parameters are commonly used for the analysis of this kind and hence are included in the study. The values of different parameters have been averaged and standard deviation (SD) has been calculated for individual groups. All these statistical calculations has been made using Excel 2007 (v12.0) developed by Microsoft for Windows.

Frequency analysis of breathe sound signals generated at mouth helps in differentiating between healthy, non smoker, Asthma and smoker subjects. Also this study reveals gender and physical parameter based sound analysis useful for lung diagnosis.

IV. RESULTS AND DISCUSSIONS

The respiratory breathing sound signals of 45 subjects (13 male non smokers; age = 20.63 ± 0.5 yrs [mean ± SD] ; height = 1.71 ± 0.11 m ; BMI = 23.45 ± 2.619 kg/m^2) , (17 female non smokers; age = 20.08 ± 0.51 [mean ± SD] ; height = 1.62 ± 0.46 m ; BMI = 18.72 ± 0.92 kg/m^2) , (10 smokers; age = 20.71 ± 0.48 yrs [mean ± SD] ; height = 1.81 ± 2.75 m ; BMI = 22.30 ± 5.7 kg/m^2) and (5 Mild Asthma Patients ; age = 20.46 ± 0.40 yrs [mean ± SD] ; height = 1.65 ± 0.20 m ; BMI =23.05 ± 0.8 kg/m^2) has been recorded and analysed (Table 1 and 2) .

On the basis of comparisons made in Table 1 & Table 2, the following observations have been made. It is observed from Table 1 that,

The peak frequency of (282.44 Hz) in inspiration signals has been found to be more than that of (220.54 Hz) in expiration signals of healthy male subjects while the peak frequency of (216.47 Hz) in inspiration signals has been found to be less than that of (220.90 Hz) in expiration signals of healthy female subjects and the significant up to (738 Hz - male, 1104 Hz - female) in inspiration signals of healthy subjects has been found to be more (446.27 Hz - male, 495.90 Hz - female) than that of in expiration signals of healthy subjects.

However, no significant difference has been found in the maximum PSD (dB/Hz) in inspiration and expiration signals of healthy subjects, although it has been observed that the PSD is found to be maximum at 172.3 Hz. Some slight increase in maximum Power (0.67 dB) has been noted in expiration signals and major increase in the peak frequency (129.41 Hz) at which the maximum power lies has been noted to be more in inspiration signals of male candidates. Some slight increase in maximum Power (1.935 dB) has been noted in expiration signals and slight increase in the peak frequency (5.94 Hz) at which the maximum power lies has been noted to be more in inspiration signals of female candidates.

Comparison of male and female candidates: A slight increase in peak frequency and significant frequency range has been observed in the expiration signals of female candidates than that of in male candidates. However, no significant differences have been found in the maximum PSD (dB/Hz) in inspiration and expiration signals of male and female subjects. Some minute differences in max. Power (0.74 dB expiration, 0.525 dB inspiration) and the frequency at which max. Power lies in the breathe signals of male (360 Hz inspiration, 230.95 Hz expiration) and female (228.25 Hz inspiration, 222.31 Hz expiration) candidates has been observed which is marked as significant. Insignificant difference has been found in expiration peak frequency signal of male female candidate.

Comparison of smokers and non smoker male subjects: expiration signals- A notable rise (18Hz) in the peak frequency with a major increase in the significant frequency range (608Hz) of smokers has been observed. Differences of -2.54 dB/Hz have been observed in the PSD (dB/Hz). A significant rise in maximum Power (3.24 dB) with a slight increase in the frequency at maximum Power has been observed in smokers. In inspiration signals- A major increase (436 Hz) in peak frequency and significant frequency range (585 Hz) has been observed in smokers. However, no significant (2.67 dB/Hz) changes were observed in max. PSD (dB/Hz) but a huge increase in frequency (590 Hz) at maximum PSD estimate has been noted in smokers. A significant rise in Power (2.22 dB) with a major increase in the frequency at max. Power (366.64 Hz) has been observed in smokers. Due to smoking condition, it is observed that dead space is more in lungs so difference found in various parameters is more.

Comparison of healthy male candidates and candidates with mild asthma patients: In expiration signals- A slight increase in peak frequency (5.72 Hz) and a large increase in significant frequency range (266.43 Hz) have been noted in case of candidates with allergic asthma. However very minute decrease in maximum PSD (0.6 dB/Hz) estimate with mild asthma patients has been observed and marked as insignificant. A minute decrease in Power (1.13 dB) and some notable increase (44.16 Hz) in the frequency at which maximum power lies have been observed. In inspiration signals- A significant decrease (55.04 Hz) in peak frequency and a large increase in significant frequency range (583 Hz) have been noted in case of candidates with mild asthma patients. However very minute increase in maximum PSD (-2.65 dB/Hz) estimate in allergic asthma subjects has been observed. A minute increase in Power (2.58dB) and some notable decrease (132.97 Hz) in the frequency at which maximum power lies have been observed.

A new approach of exhaled air sound signal analysis using microphone is presented here. The sound frequency analysis, the peak frequency and the significant frequency range in the FFT plot, maximum Power and the frequency at which it occurs, maximum PSD and the frequency at which it lies, is of its own kind.

In pathological processes, changes in breathing sounds have long been known and studied [7]. The inspiration phase has been found to be quite louder in normal breathing respiration sounds which are also in consistent to the findings in [1]. Also it is observed that the peak frequency depends on the cut-off frequency of the high pass filter, shows only minimal variations in different subjects for the described experimental conditions. The parameters used for the analysis of signals are not ideal and are still to be tested.

However, normal lung sounds show large interpersonal variations [7]. Also it has to be taken into account that both a same day variability and a between day variability exists in lung sounds [21]

It has been found a slight displacement of the frequency pattern to the higher values in female candidates than that in male candidates.

TABLE 1

COMPARISON of PARAMETERS CALCULATED for HEALTHY and NON-SMOKER SUBJECTS for EXPIRATION and INSPIRATION

		Healthy and non-smoker			
		Expiration		Inspiration	
		Male	Female	Male	Female
		(n=13)	(n=17)	(n=13)	(n=17)
	Peak Frequency (Hz)	220.54 ± 58.3	220.90 ± 69.53	282.44 ± 65.94	216.47 ± 79.01
	Significant Frequency Range(Hz)	446.27 ± 70.05	495.90 ± 89.37	738 ± 61.79	1104 ± 571.43
PSD estimate	Peak Frequency (Hz)	172.3	172.3	172.3	172.3
	Max. PSD (Db/Hz)	-69.62 ± 3.26	-69.02 ± 4.84	-68.96 ± 4.86	-71.11 ± 2.88
Power estimate	Peak Frequency (Hz)	230.95 ± 71.30	222.31 ± 70.42	360.36 ± 157.49	228.25 ± 72.40
	Max. Power (Db)	18.81 ± 3.72	19.55 ± 4.15	18.14 ± 3.31	17.615 ± 4.255

n = no. of subjects; n.s. = not significant; PSD=Power spectral density; db = decibels; Hz = Hertz

TABLE 2

COMPARISON of PARAMETERS CALCULATED for SMOKERS and ASTHMA PATIENT SUBJECTS for INSPIRATION and EXPIRATION

		Expiration		Inspiration	
		Smoker	Asthma Patient	Smoker	Asthma Patient
		(n=10)	(n=5)	(n=10)	(n=5)
	Peak Frequency (Hz)	238 ± 57.60	226.26 ± 56.32	718.85 ± 134.67	227.40 ± 32.00
	Significant Frequency Range(Hz)	1054.11 ± 248.09	712.70 ± 135.73	1323.14 ± 272.13	1321.60 ± 525.64
PSD estimate	Peak Frequency (Hz)	172.3	172.3	762.94 ± 278.83	172.3
	Max. PSD (Db/Hz)	-67.08 ± 4.07	-69.02 ± 4.96	-71.63 ± 6.51	-66.307 ± 4.96
Power estimate	Peak Frequency (Hz)	225.10 ± 61.89	275.11 ± 115.64	727.40 ± 141.72	227.39 ± 84.84
	Max. Power (Db)	22.05 ± 5.91	17.68 ± 4.57	20.36 ± 8.65	20.72 ± 4.10

n = no. of subjects; n.s. = not significant; PSD =Power spectral density; db = decibels; Hz = Hertz

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