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Breath Analysis of Respiratory Flow using Tracheal Sounds

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Abstract—**While lung sounds intensity is significantly different during inspiratory and expiratory phases, such difference is not audible between the two respiratory phases when listening to tracheal breath sounds. In this study we investigated whether any difference exists between the average power and log-variance of the band-pass filtered tracheal breath sound between the respiratory phases. We used data from 9 healthy subjects without any pulmonary diseases at 4 different flow rates (low, medium, high and very high) and compared the two features at six different frequency ranges from 70 to 1200Hz. The most pronounced differences between the two respiratory phases were found in the 300-450Hz and 800-1000Hz for the average power and log-variance, respectively.**

Keywords – Breath sounds, respiratory phases, average power, log-variance.

I. Introduction

Respiratory flow can be measured either directly, i.e. using spirometry devices such as pneumotachographs or nasal cannulas or indirectly by the means of monitoring chest or abdominal movement [1]. Due to difficulty of applying these devices to young children or patients with neurological impairments as well as the inaccuracy of some of the flow measurement techniques and instruments that are easier to be applied [2-4], airflow estimation by acoustical means using tracheal breath sounds has received considerable attention in recent years.

Several researchers have investigated the relationship between respiratory flow and breathing sounds, and proposed a few flow estimation methods [5-8]. However, all of those methods require both lung and tracheal sounds in order to determine respiratory phases, i.e. inspiration/expiration. We aimed to investigate whether it would be possible to detect respiratory phases using only tracheal breath sounds.

The most commonly used feature of tracheal breath sound is the average power (P_{ave}) of the sound over different frequency bands [7-9]. Another feature, much similar in concept to P_{ave}, is the log-variance of the sound signal [8]. The change in both these features with respect to different respiratory phases has not been studied.

It is commonly believed that tracheal expiratory sounds are louder than inspiratory sounds. In this study we investigated the pattern of changes in P_{ave} and log-variance of tracheal breath sounds in each of the respiratory phases at different flow rates. In particular, we were interested to investigate whether these changes are significant between the two respiratory phases.

Along with ambient noise, heart sounds (HS) is another inevitable source of interference affecting respiratory sounds. The majority of cardiovascular sound energy is in the frequency range of approximately 20-200 Hz [9] that has predominant effects in shallow and low flow rates. Hence, we also investigated whether HS cancellation affects the sound pattern between the two respiratory phases.

II. Method

A. Data

Tracheal breath sounds and the airflow signal from 9 healthy non-smoker subjects (4 males, age 33.8±19.5 years) with no history of major respiratory diseases were used in this study.

The tracheal breath sound was recorded using a Siemens accelerometer (EMT25C) placed over the suprasternal notch of the subject using a double-sided adhesive ring tape. The subjects wore a neck brace to ensure minimal movement of the neck and to standardize the position of the neck of the subjects. The breath sound signals were amplified and band-pass filtered (50-2500 Hz) prior to digitization.

Respiratory flow was measured by a pneumotachograph (Fleich No.3) connected to a pressure transducer (Validyne, Northridge, CA) with a mouthpiece tube.

The signals were digitized simultaneously at a sampling rate of 10240Hz. The flow signal was later down-sampled to320Hz.

B. Procedure

Each subject was asked to be in upright sitting position and to hold the mouthpiece pneumotachograph to his/her mouth with one hand. While wearing a nose clip, the subject was then instructed to wrap their lips around the mouthpiece to eliminate any air escaping from the tube, and to breathe through their mouths. While watching their flow rates on the oscilloscope screen, the subject was given visual instructions to breathe at four different flow rates: 0.2-0.5L/s (low), 0.5-0.8L/s (medium), 0.8-1.2L/s (high) and >1.2L/s (very high) with approximately 3-5 breaths in each flow rate successively followed by five seconds of breath-hold . The entire trial was approximately 1-2 minutes.

C. Signal Processing

The recorded tracheal sound signals were high pass filtered with cutoff frequency 70Hz to remove the low frequency noises. The recorded flow signal was used to separate respiratory phases. Although respiratory sounds are largely non-stationary signals, the signal on the upper/lower 20% of the maximum/minimum flow can be considered stationary [9]. Therefore, in each inspiratory/expiratory phase only the portions of tracheal sounds corresponding to the upper/lower 20% of flow signal were investigated.

The power spectrum of the tracheal sound signal was calculated in windows of 50ms (512 samples) with 75% overlap between the successive windows. For each respiratory phase during different flow rates, tracheal sounds' power (in dB) were averaged (P_{ave}) within six predefined frequency ranges: [70-300] Hz, [300-450] Hz, [450-600] Hz, [600-800] Hz, [800-1000] Hz and [1000-1200] Hz. Since the intensities of respiratory sounds are different among different subjects, for each subject the values of P_{ave} were normalized by the maximum value of P_{ave}. The normalized P_{ave} values were then averaged among different subjects for each respiratory phase, and the mean and standard error values were calculated for different flow rates and frequency ranges.

The second investigated feature was the log-variance [8] of the tracheal sound signals. Tracheal sound signals were band pass filtered in the above mentioned frequency ranges. The filtered signals were segmented into windows of 50ms (512 samples) with 75% overlap between the successive windows using a Hanning window. In each window the logarithm of the variance (log-variance) of the signal was calculated. Since HS interfere with tracheal sounds in the frequency ranges below 300Hz [10], the method proposed in [8] was used to remove the effects of HS on the calculated values of log-variance.

For each subject, the values of log-variance in each window were normalized by their maximum value. Then, they were averaged within different frequency ranges at different flow rates.

III. Results and Discussion

Figure 1 shows medium and high flow rate samples of the recorded flow signal along with the spectrogram of the corresponding tracheal sound signal, the normalized log-variance and the normalized P_{ave} over [300-450] Hz. It should be noted that the positive (negative) values of the recorded flow signal are related to the inspiratory (expiratory) phases of the respiration cycle. Investigating the spectrogram of the tracheal sound, it can be seen that the intensity of the tracheal sound increases at higher flow rates. Also, both the normalized log-variance and normalized P_{ave} values follow the changes in the absolute value of the recorded flow signal. While the phase transitions are evident in the spectrogram, normalized log-variance or normalized P_{ave} signals, it is hard to distinguish inspiratory and expiratory phases by either visual or audio means.

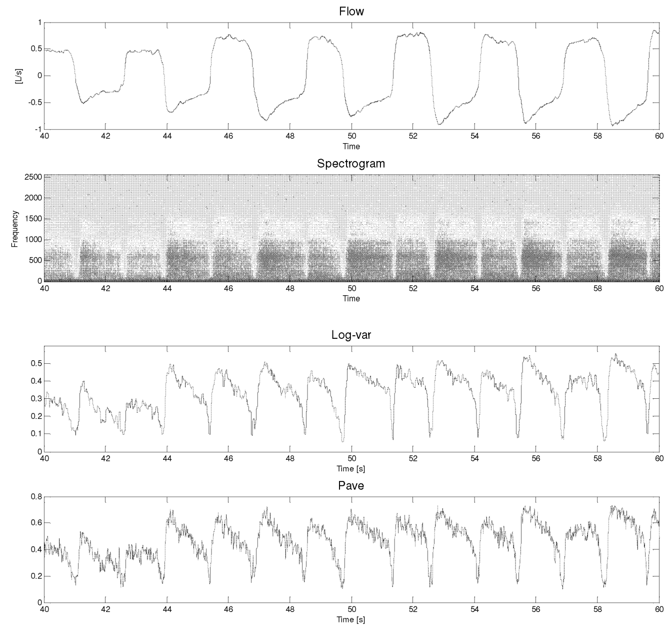
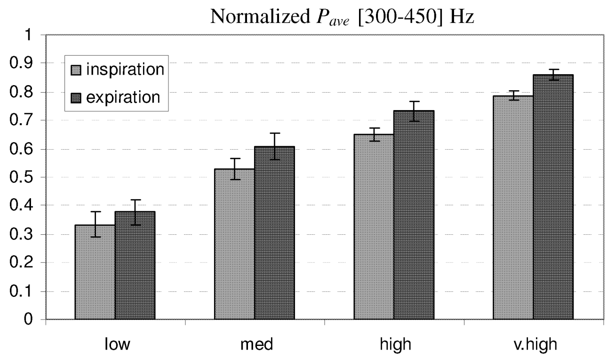
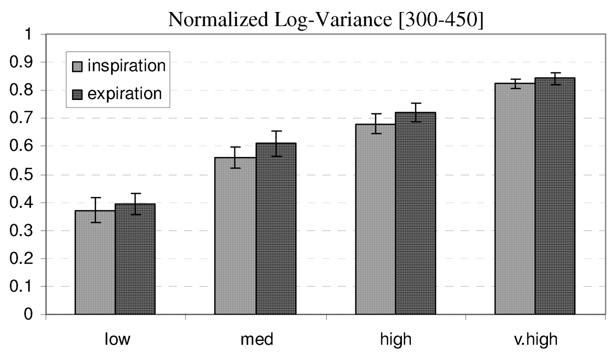


Figure 1. From top to bottom, medium and high flow rate samples of the recorded flow signal, the spectrogram of the corresponding tracheal sound, estimated normalized log-variance and normalized P_{ave} in the frequency range of [300-450] Hz.

Investigating the mean and standard error values of the normalized P_{ave} at different flow rates within the six predefined frequency ranges, it was found that during medium and high flow rates the highest differences between inspiratory and expiratory phases were achieved in the frequency range of the [300-450] Hz (Table 1). Also, this frequency range gives the second highest difference for low and very high flow rates. Therefore, this frequency range was chosen as the optimum range for examining the changes in the average power values respect to respiratory phases.

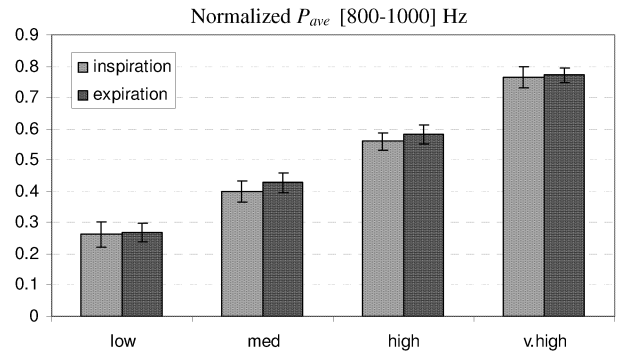


(a)

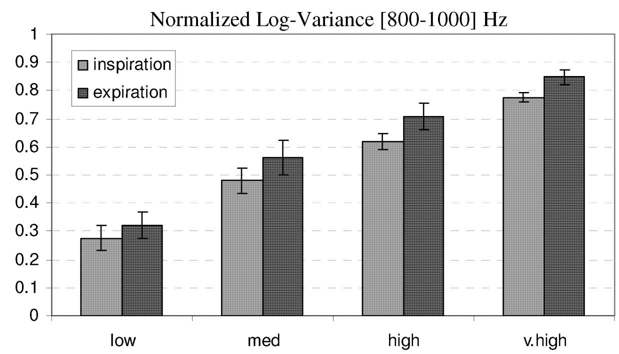


(b)

Figure 2. Comparison of the mean and standard error values of the estimated a) normalized P_{ave} and b) normalized log-variance values in the frequency range of [300-450] Hz for the respiratory phases.



(a)



(b)

Figure 3. Comparison of the mean and standard error values of the estimated a) normalized P_{ave} and b) normalized log-variance values in the frequency range of [800-1000] Hz for the respiratory phases.

Figure 2 depicts the mean and standard error values of the normalized P_{ave} and log-variance in the frequency range of [300-450] Hz for the two respiratory phases at different flow rates. The results show the average values of both features are consistently higher during expiration phase. Also, the difference between the average values of the normalized P_{ave} is slightly increasing as the flow rate increases; however, this relationship does not exist for the normalized log-variance values. Furthermore, in this frequency range, the normalized P_{ave} gives higher difference between the inspiration and expiration phases at all flow rates than that the normalized log-variance does. Thus, in this frequency range the normalized P_{ave} can be chosen as a better discriminator between the respiratory phases.

The mean and standard error values of the normalized log-variance within the six predefined frequency ranges for different flow rates show the highest differences between the phases in the frequency range of the [800-1000] Hz at medium, high and very high flow rates (Table 1). In addition, this frequency range gives the second highest difference in the low flow rate. Therefore, this frequency range was chosen as the optimum range for examining changes in log-variance values during inspiration and expirations phases.

Figure 3 shows the mean and standard error values of the normalized P_{ave} and log-variance in the frequency range of [800-1000] Hz for different respiratory phases at different flow rates. Again, the average values of both features are consistently higher during expiration phase. Also, the difference between the average values of the normalized log-variance increases slightly as the flow rate increases. Also, in this frequency range, the normalized log-variance gives higher difference between the respiratory phases at all flow rates than the normalized P_{ave}. Thus, in this frequency range the normalized log-variance can be chosen as a better discriminator between the two respiratory phases.

Since HS may change the results at low frequency ranges, we also investigated whether the HS removal improves the results. Figure 4 shows a typical log-variance signal along with its corresponding flow signal before and after HS removal in the [70-300] Hz range. However, HS removal did not change the results significantly; it only decreased the standard error consistently (Fig. 5) especially at low and medium flow rate as expected.

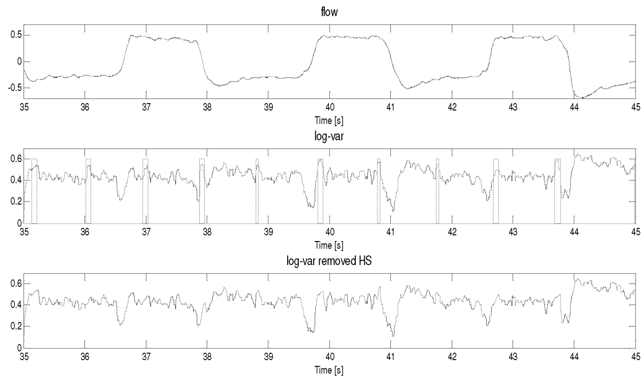
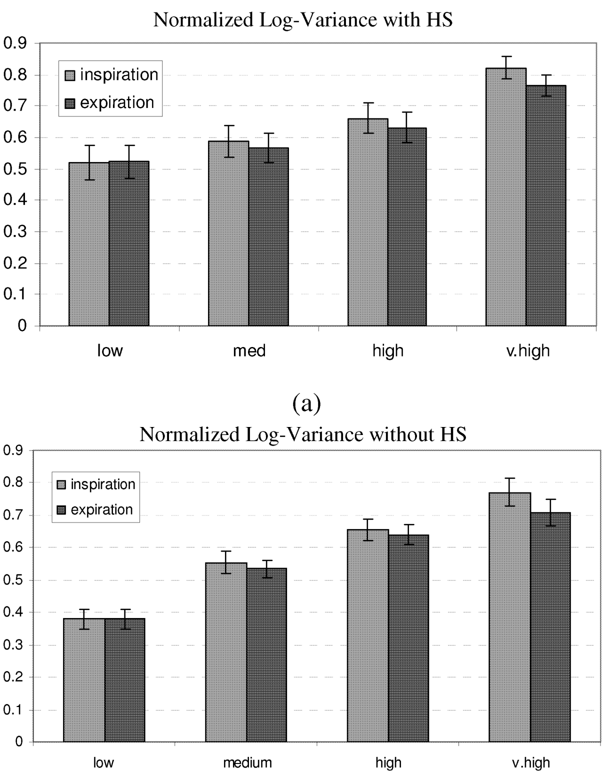


Figure 4. From top to bottom, medium flow rate samples of a typical recorded flow signal, normalized log-variance with identified HS locations and normalized log-variance after HS removal in the frequency range of [70-300] Hz.



(a)

(b)

Figure 5. Comparison of the mean and standard error values of the normalized log-variance values (a) with and (b) without HS in the frequency range of [70-300] Hz for the respiratory phases.

Table I presents the summary of the results showing the difference in normalized amplitudes of inspiration and expiration at different flow rates for the average power and log-variance of the band-pass filtered tracheal sounds at different frequency ranges. Overall, the results indicate that both of these features display a relative difference between the phases with log-variance showing slightly more distinction than the average power. Average power demonstrated better results in the 300-450 Hz frequency range and log-variance in the 800-1000 Hz range, however, none were statistically significant.

IV. Conclusion

This study sought to determine the effectiveness of average power and log-variance in distinguishing the respiratory phases at different flow rates. It was found that the P_{ave} and log-variance show the most pronounced differences between the respiratory phases in frequency ranges [300-450] Hz and [800-1000] Hz, respectively; however, none of the differences were statistically significant.

Previous studies of acoustical flow hypothesized that the average power extracted from tracheal sound would be higher for expiration when compared to inspiration. The findings presented in this paper confirm that hypothesis for all but low frequency ranges. For 70-300 Hz, this relationship was inverted for medium, high and very high flow rates (Fig. 5).

The HS removal technique [8] was also applied to log-variance at a frequency range with the most interference with respiratory sounds. Although it lowered the standard error, not much improvement in the mean difference was observed. Therefore, for the purposes of finding a feature showing a significant difference between the respiratory phases, removing HS has little contribution.

The results from both P_{ave} and Log-variance seem to concur as they both essentially measure the variance of the signal. However, since the log-variance feature shows better results at low frequency range, it may be considered as the preferred feature for respiratory phase detection.

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TABLE I: NORMALIZED AMPLITUDE DIFFERENCES (MEAN ± SE) BETWEEN PHASES OF FEATURES FOR DIFFERENT FREQUENCY RANGES

	LOW FLOW		MEDIUM FLOW		HIGH FLOW		VERY HIGH FLOW	
Frequency	Pave	Log-Var	Pave	Log-Var	Pave	Log-Var	Pave	Log-Var
70 - 300	0.033 ± 0.009	0.017 ± 0.004	0.034 ± 0.010	0.033 ± 0.011	0.052 ± 0.012	0.051 ± 0.016	0.072 ± 0.032	0.062 ± 0.028
300 - 450	0.066 ± 0.016	0.056 ± 0.013	0.079 ± 0.016	0.064 ± 0.013	0.083 ± 0.016	0.044 ± 0.013	0.101 ± 0.013	0.048 ± 0.012
450 - 600	0.083 ± 0.031	0.060 ± 0.016	0.057 ± 0.013	0.076 ± 0.017	0.067 ± 0.012	0.075 ± 0.016	0.072 ± 0.010	0.079 ± 0.016
600 - 800	0.054 ± 0.025	0.070 ± 0.017	0.039 ± 0.013	0.083 ± 0.017	0.055 ± 0.019	0.090 ± 0.015	0.088 ± 0.025	0.095 ± 0.018
800 - 1000	0.055 ± 0.026	0.077 ± 0.023	0.034 ± 0.007	0.087 ± 0.017	0.035 ± 0.012	0.097 ± 0.019	0.083 ± 0.026	0.095 ± 0.014
1000- 1200	0.035 ± 0.018	0.085 ± 0.035	0.039 ± 0.012	0.052 ± 0.014	0.048 ± 0.017	0.074 ± 0.012	0.130 ± 0.049	0.067 ± 0.007