Dept. of Electrical & Computer Eng.
Aristotle University of Thessaloniki
GREECE

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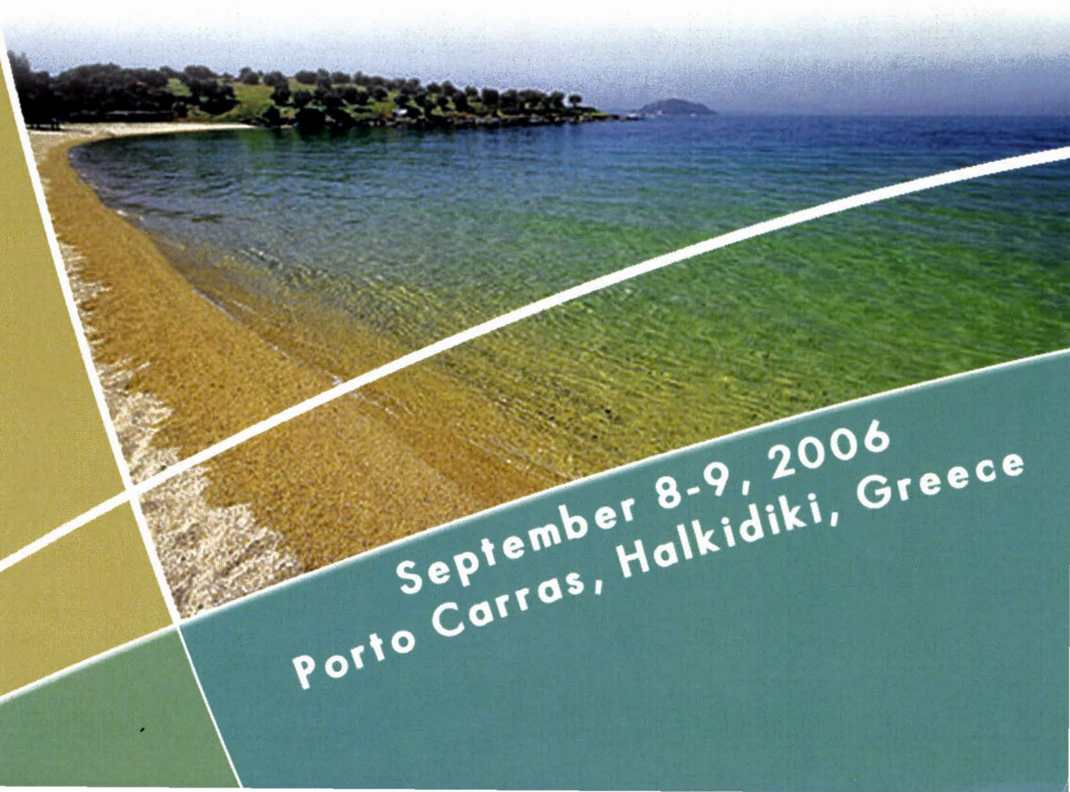
ILSA 2006, SEPTEMBER 8-9 HALKIDIKI, GREECE
AUTH
International Lung Sounds Association

ILSA '06

31st International Lung Sounds Association Conference



September 8-9, 2006
Porto Carras, Halkidiki, Greece

ILSA '06

31st International Lung Sounds Association Conference

Presented by

The International Lung Sounds Association

PROGRAM & ABSTRACTS

September 8-9, 2006

Porto Carras, Halkidiki, Greece

ORGANIZATION

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University of Kentucky

Lexington, KY, USA

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Prof. Hans Pasterkamp

Dr. Leontios Hadjileontiadis

ILSA '06 Local Organizer:

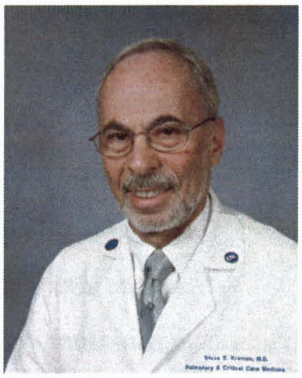
Dr. Leontios Hadjileontiadis

WELCOME MESSAGE

WELCOME to the 31st annual meeting of the International Lung Sounds Association, held for the first time in Greece. Dr. Leontios Hadjileontiadis, our host, has arranged a unique experience for the attendees this year and the program promises to be fertile and compelling. Although we will emphasize sleep acoustics at this meeting, the submitted presentations, as is usual, cover the gamut of respiratory acoustics reflecting the diverse backgrounds and interests of the participants. I look forward to a great meeting and a very enjoyable time for all.

Steve Kraman

Steve S. Kraman, M.D.
President, ILSA



HISTORY OF THE INTERNATIONAL LUNG SOUNDS ASSOCIATION

IN OCTOBER 1976, the First International Conference on Lung Sounds was held in Boston, MA. The objectives of this conference were defined as follows:

> *"Studies on lung sounds have been reported with increasing frequency in recent years. This conference is convened to provide an opportunity for exchange of ideas and experience among those who have an active interest in the subject. Clinicians, physiologists, engineers and perceptual psychologists can each contribute towards a better understanding of what lung sounds mean. They will have a better chance of doing so after taking together."*

> *"We hope that comparisons of methods of recording, analyzing and describing lung sounds will reduce ambiguity. We hope that discussions about work in progress may prevent unnecessary duplication of effort. We hope that investigators will save time and avoid some mistakes by learning what others have done."*

Enthusiasm generated by this conference has continued, and annual meetings have been held since. These annual conferences have typically occurred over a period of two to three days, two days being devoted to presentation of papers with discussion, and a half day being devoted to a workshop. Attendance at the conferences has averaged about 60. This is the 31st annual meeting.

Co-founders: *Robert G. Loudon*, MD and *Raymond L. H. Murphy, Jr.*, MD

LIST OF ILSA CONFERENCES

No	Date	Place	Local Organizer(s)
1.	October 1976	Boston, MA	Raymond L. H. Murphy, Jr.
2.	September 1977	Cincinnati, OH	Robert Loudon
3.	September 1978	New Orleans, LA	William Waring
4.	September 1979	Chicago, IL	David Cugell
5.	September 1980	London, England	Leslie Capel & Paul Forgacs
6.	October 1981	Boston, MA	Raymond L. H. Murphy, Jr.
7.	October 1982	Martinez, CA	Peter Krumpe
8.	September 1983	Baltimore, MD	Wilmot Ball
9.	September 1984	Cincinnati, OH	Robert Loudon
10.	September 1985	Tokyo, Japan	Riichiro Mikami
11.	September 1986	Lexington, KY	Steve S. Kraman
12.	September 1987	Paris, France	Gerard Charbonneau
13.	September 1988	Chicago, IL	David Cugell
14.	September 1989	Winnipeg, Canada	Hans Pasterkamp
15.	October 1990	New Orleans, LA	David Rice
16.	September 1991	Veruno, Italy	Filiberto Dalmasso
17.	August 1992	Helsinki, Finland	Anssi Sovijärvi
18.	August 1993	Alberta, Canada	Raphael Beck
19.	September 1994	Haifa, Israel	Noam Gavriely
20.	October 1995	Long Beach, CA	Christopher Druzgalski
21.	September 1996	Chester, England	John Earis
22.	October 1997	Tokyo, Japan	Masahi Mori
23.	October 1998	Boston, MA	Sadamu Ishikawa
24.	October 1999	Marburg, Germany	Peter von Wichert
25.	September 2000	Chicago, IL	David Cugell
26.	September 2001	Berlin, Germany	Hans Pasterkamp
27.	September 2002	Helsinki, Stockholm	Anssi Sovijärvi
28.	September 2003	Cancun, Mexico	Sonia Charleston, Ramón Gonzales Camarena & Tomás Aljama Corrales
29.	September 2004	Glasgow, Scotland	Ken Anderson & John Earis
30.	September 2005	Boston/Cambridge, MA	Raymond L. H. Murphy, Jr.
31.	September 2006	Halkidiki, Greece	Leontios Hadjileontiadis

ILSA 'O6 CONFERENCE INFORMATION

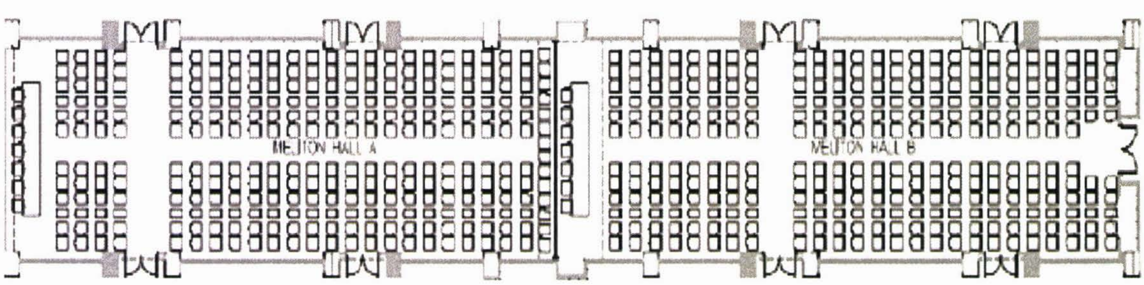
Conference Venue

Porto Carras Grand Resort Meliton/Sithonia

Halkidiki, Greece

Conference Hall

Meliton Hall A-B, First Floor Area (324 m^2)



Registration/Certificate of Attendance/Abstracts CD-ROM

REGISTRATION will be held in front of the Meliton Hall A-B (Meliton first floor area), on *Friday morning (September 8, 2006) between 9:00-10:00 am.* Participants, duly registered will receive a certificate of attendance. In addition, attached to the abstract book, an Abstracts CD-ROM will be provided, including the abstracts of the conference, equipped with search capabilities (author, title, keyword, session, etc) and general information about the ILSA'06 conference.

Posters/Student-Young Researcher Awards

POSTERS will be on display on *September 8th, 2006 in the Meliton Hall A-B after 1:00 PM*. The poster discussion will begin at *3:00 pm*. Four student/young researcher awards of US$250 each will be awarded according to the scientific merit of the submitted works. Judging forms will be provided to all participants and the results will be announced by Prof. Steve Kraman, *President, ILSA*, just before the closing remarks of the conference (*September 9th, 2006, 3:30 PM*).

Acknowledgements

THE ORGANIZERS would like to express their gratitude to the *Department of Electrical & Computer Engineering, its Division of Telecommunications and its Laboratory of Telecommunications, Aristotle University of Thessaloniki, Greece*, along with the *Greek Mobile Telecommunications Company COSMOTE S.A.*, for their kind support in the realization of the ILSA'06 conference. Special thanks go to the Vice-Rector of the Aristotle University of Thessaloniki, Greece, *Prof. Stavros Panas*, for his kind support and encouragement; *Ms. Styliani Taplidou*, Electrical & Computer Engineering-PhD student, for the editing and formatting of the abstracts; *Ms. Vassiliki Kosmidou*, Electrical & Computer Engineering-PhD student, for the realization of the proceedings CD-ROM; *Mr. Ilias Kitsas*, Electrical & Computer Engineering-PhD student, for the artistic realization of the conference material; *Mr. Konstantinos Panoulas*, Electrical & Computer Engineering-PhD student, for his technical support with regard to network issues; and *Mrs. Niki Bai*, director of the TOP EVENTS, for her collaboration in the organization of the conference.

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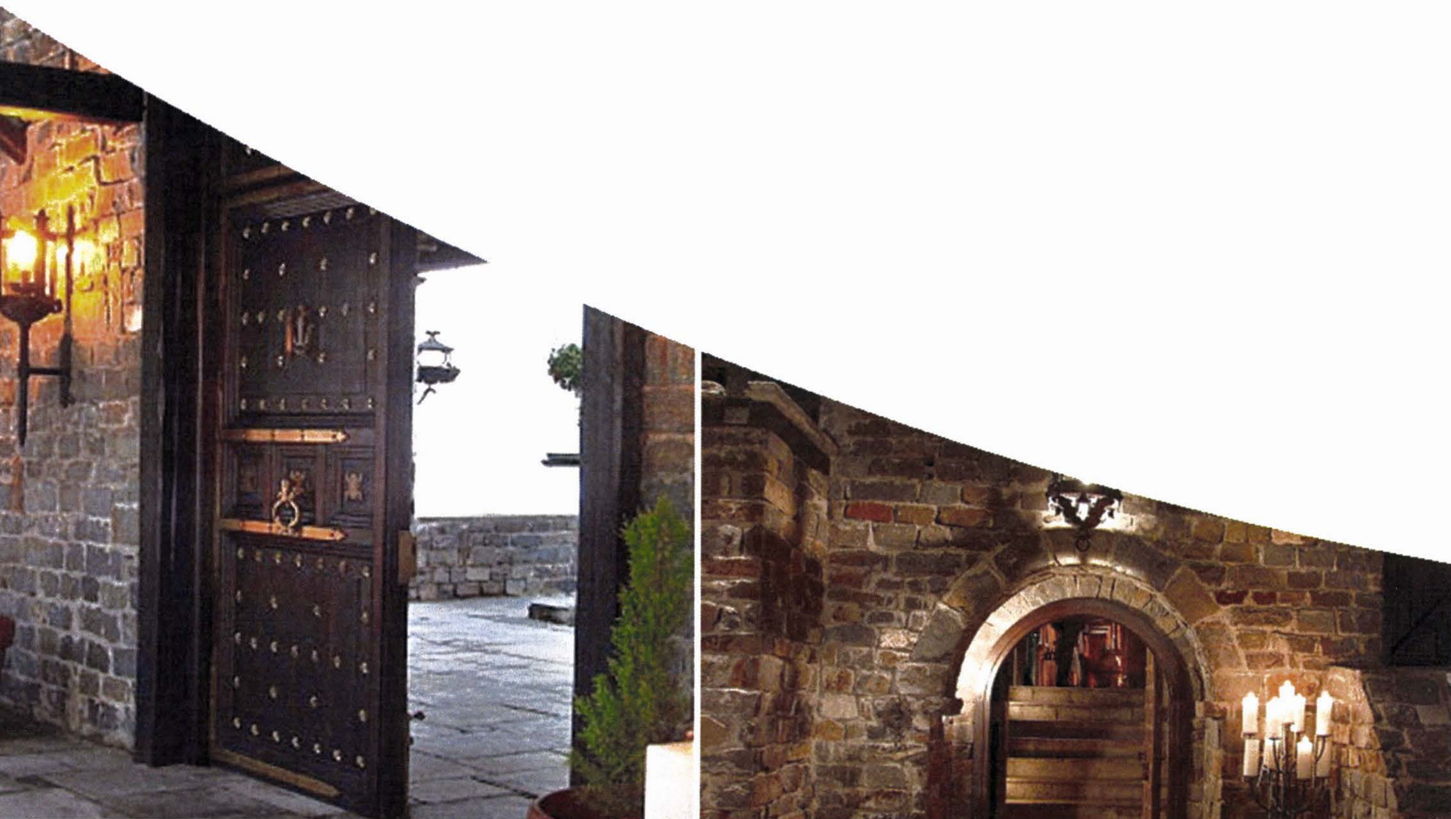
SCIENTIFIC PROGRAM
&
ABSTRACTS



paper.

FRIDAY, SEPTEMBER 8th, 2006

9:00 AM **Registration**

10:00 AM **Welcome and opening remarks**

SESSION I: Airflow, Asthma, Wheeze

Session Chair: Leontios Hadjileontiadis

10:15 AM *Posture effects on the relation of airflow and lung sounds*
J. A. Fiz, J. Gnitecki, S. S. Kraman, G. R. Wodicka, and H. Pasterkamp

10:30 AM *Relationship between flow-volume curve and expiratory wheeze in bronchial asthma*
H. Kiyokawa, S. Takafuji, and M. Yonemaru

10:45 AM *Presentation of a sample test case on the self-excited oscillations in collapsible tube flows*
M. Ö. Çarpinlioğlu and V. Oruç

11:00 AM *Vesicular and broncho-vesicular breath sound and airway inflammation in asthma*
Y. Nagasaka, S. Yasuda, Y. Ieda, T. Sugiura, T. Shimoda, and C. Habukawa

11:15 AM *On analyzing the harmonic content of wheezes using wavelet bicoherence*
S. A. Taplidou and L. J. Hadjileontiadis

11:30 AM **Coffee break**

SESSION II: COPD, Cough, Crackles

Session Chair: Zahra Moussavi

11:45 AM *Monitoring lung sounds of COPD-patients*
M. Silva, S. Van Neck, T. Lauwerier, J.-M. Aerts, M. Decramer, and D. Berckmans

12:00 AM *A development of a new cough monitoring system using wireless accelerometer*
A. Murata and S. Kudoh

12:15 PM *Crackles in Asbestosis*
R. Murphy

12:30 PM *Background Signal Elimination for Crackle Analysis*
M. Yeginer and Y. P. Kahya

12:45 PM *Analysis of simulated crackle sounds by empirical mode decomposition*
S. Charleston-Villalobos, R. González-Camarena, G. Chi-Lem, and T. Aljama-Corrales

1:00 PM **Lunch**

SESSION III: Poster Session
Session Chairs: Noam Gavriely and Sonia Charleston-Villalobos

2:30 PM **Poster Viewing**

Poster Discussions

3:00 PM *Automated Lung Sound Analysis in Patients with Chronic Obstructive Lung Disease*
R. Murphy, A. Vyshedskiy, R. Paciej, A. Wong-Tse, and D. Bana

3:10 PM *Wheeze analysis using the Hilbert-Huang transform*
S. A. Taplidou and L. J. Hadjileontiadis

3:20 PM *Effect of anti-inflammatory treatment on breath sound and airway inflammation in asthma*
Y. Nagasaka, S. Yasuda, Y. Ieda, T. Sugiura, T. Shimoda, and C. Habukawa

3:30 PM *Increased lung sound intensity after salbutamol inhalation indicates significant bronchodilation*
J. A. Fiz, J. Pang, J. Gnitecki, and H. Pasterkamp

3:40 PM *Estimation of Inspired Volume Prior To Coughing From Sound*
K. McGuiness, A. Kelsall, A. Woodcock, and J. A. Smith

3:50 PM **Poster summary by the Session Chairs**

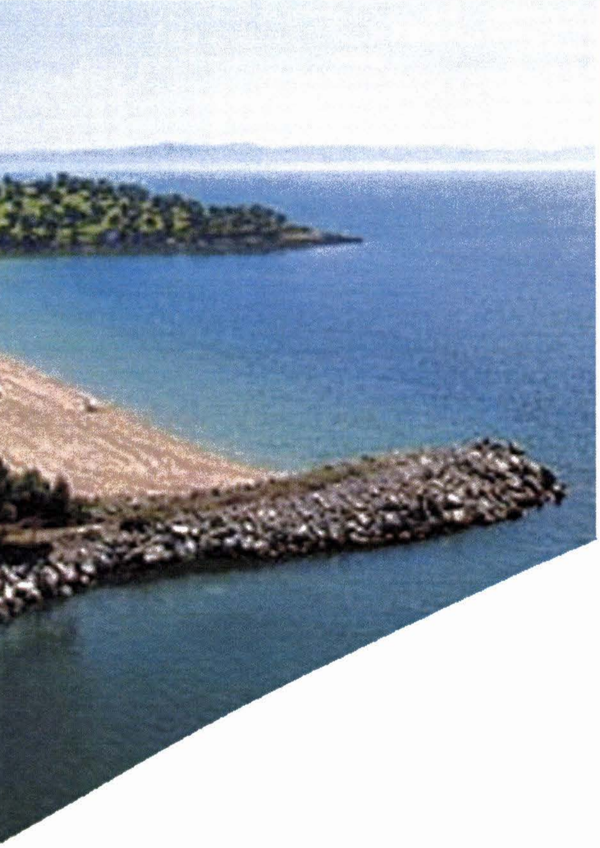
3:55 PM **Coffee break**

4:15 PM **Business Meeting**

SATURDAY, SEPTEMBER 9th, 2006

	SESSION IV: Sleep Acoustics Symposium Session Chairs: Hans Pasterkamp and Ray Murphy
9:30 AM	*Acoustic analysis methods applied to sleep research* T. Penzel, V. Gross, C. Reinke, and U. Koehler
9:45 AM	*Apnea Detection by Acoustical Means* A. Yadollahi and Z. Moussavi
10:00 AM	*Clinical use of nocturnal long-term recording of breath sounds* U. Koehler, C. Reinke, V. Gross, and T. Penzel
10:15 AM	*Nocturnal long -term recording of snoring in patients undergoing polysomnography* D. Matsiki, X. Deligianni, E. Vlachogianni-Daskalopoulou, and L. J. Hadjileontiadis
10:30 AM	**Coffee break**
10:45 AM	*Nocturnal long term recording of respiratory sounds (LTR-RS) in patients with gastroesophageal reflux in combination with 24-h pH testing* S. Koch, D. Vasilescu, R. Koch, B. Bort, C. Reinke, V. Gross, and U. Koehler
11:00 AM	*Nocturnal long term recording of respiratory sounds (LTR-RS) in patients with rhinosinusitis* B. Bort, R. Koch, S. Koch, D. Vasilescu, C. Reinke, V. Gross, and U. Koehler
11:15 AM	*CPAP treatment on cognitive Performance of Aviators with Obstructive Sleep Apnoea Syndrome* C. Kourtidou-Papadeli, E. Daskalopoulou, C. Papadelis, P. Angelidis, M. Psymarnou, and E. Perantoni
11:30 AM	*Pilot monitoring to prevent the sleep apnea syndrome and maximize performance* C. Kourtidou-Papadeli, M. Psymarnou, P. Angelidis, and S. Spyrou
11:45 AM	**Coffee break**
12:00 AM	**Panel Discussion on Sleep Acoustics** Discussion Leaders: Steve Kraman, Hans Pasterkamp, Ray Murphy and Thomas Penzel

12:45 PM	**Group Photo**
1:00 PM	**Lunch**
	SESSION V: Swallowing, bowel, heart sounds Session Chair: Shoji Kudoh
2:30 PM	*Automated Extraction of Swallowing Sounds Using a Wavelet-Based Filter* Z. Moussavi and M. Aboofazeli
2:45 PM	*Contamination of the acoustic response of the gastrointestinal tract by lung sounds* J. A. Hession and B. A. O. McCormack
3:00 PM	*Acoustic cardio-pulmonary interactions* N. Gavriely, G. Amit, K. Shukha, and N. Interator
3:15 PM	**Student/Young Researcher Award Voting Reports**
3:20 PM	**Coffee break**
3:30 PM	**Award Announcement/Closing Comments** Steve Kraman, *President, ILSA*



SESSION I: Airflow, Asthma, Wheeze

Session Chair: Leontios Hadjileontiadis

POSTURE EFFECTS ON THE RELATION OF AIRFLOW AND LUNG SOUNDS

J. A. Fiz[1*], J. Gnitecki[1**], S. S. Kraman[2], G. R. Wodicka[3], and H. Pasterkamp[1]
[1]*Manitoba Institute of Child Health (Biology of Breathing Group), Winnipeg, Canada*
[2]*University of Kentucky, Lexington, KY, USA*
[3]*Purdue University, West Lafayette, IN, USA*

THE RELATION of lung sound intensity (LSI) to pulmonary ventilation has long been of interest to researchers in respiratory acoustics. Several studies have addressed the changes in LSI that occur with changes in posture, incl. head-down and lateral decubitus positions. The prone position has been widely studied with regard to improving ventilation and gas exchange in critically ill patients but to our knowledge the effect of "proning" on LSI has not been investigated. We therefore recorded lung sounds from six healthy male non-smoking volunteers, age 16-32 y. Spirometry confirmed their normal lung function (FVC 103 ± 13%, $FEV_{1.0}$ 102 ± 15% predicted; mean ± SD). Airflow at the mouth was measured with a pneumotachograph. Two contact sensors were attached over corresponding sites of the posterior lower or anterior upper lungs. Recordings were made for at least 50 sec in the sitting, prone, supine and lateral decubitus positions. Power spectral analysis provided inspiratory LSI estimates for two ranges of airflow and frequencies. Background sound intensity was established from 5 sec of breath hold. Expiratory LSI was barely above background and was not considered in the further analysis. We found asymmetries of inspiratory LSI as previously reported, i.e. greater LSI over the left posterior lower lung, also in the prone position but there was no significant change in the relation of LSI and airflow when prone (see Fig.1). In the lateral decubitus positions, LSI at the uppermost lung posteriorly was lower compared with the dependent lung, particularly at higher frequencies. Anteriorly, this was significant only at low frequencies in the left decubitus position. No significant asymmetry of LSI and no difference compared to sitting was found in the supine position. These observations agree with physiologic principles of pulmonary ventilation in the different body positions. No effect of "proning" was found in our healthy subjects but it is conceivable that improved ventilation in critically ill patients may be reflected by increased LSI in the prone position.

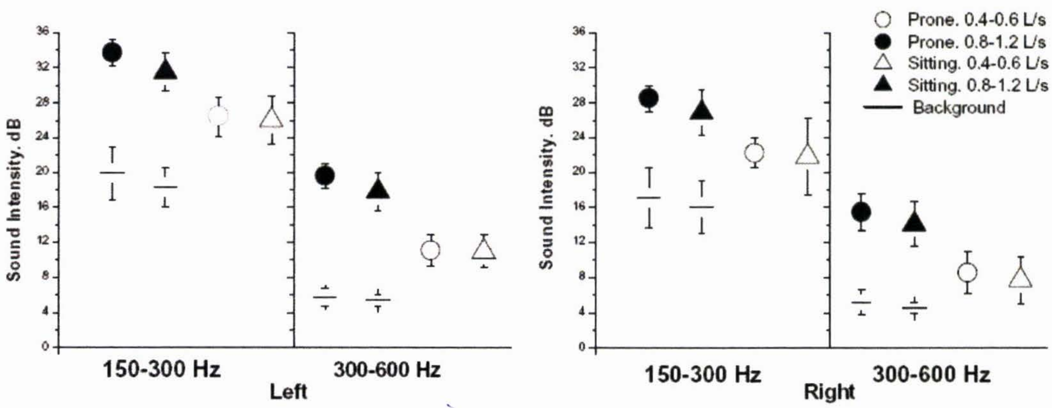


Fig. 1. Posture effect on inspiratory LSI over both posterior lower lungs.

* Dr. Fiz was a Visiting Scholar, supported by Children's Hospital Foundation of Manitoba.
** Ms. Gnitecki is supported by a scholarship from NSERC.

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RELATIONSHIP BETWEEN FLOW-VOLUME CURVE AND EXPIRATORY WHEEZE IN BRONCHIAL ASTHMA

H. Kiyokawa[1], S. Takafuji[1], and M. Yonemaru[2]
[1]*International University of Health and Welfare Atami Hospital, Dept. of Respirology*
[2]*Isehara Kyodo Hospital, Dept. of Internal Medicine*

PURPOSE: Airway narrowing measured by pulmonary function test reflects severity of bronchial asthma (BA). Because wheeze is also associated with airway narrowing of BA, we hypothesized the expiratory lung volume before wheeze onset during the slow vital capacity maneuver (volume to rale: VtoR) can be a quantitative measurement of airflow obstruction. In our last report, we found the VtoR correlated with $FEV_{1.0}$, PEF and $FEV_{1.0}\%$. In this study, we investigated the relationship between VtoR and flow-volume curve (F-V curve).

METHODS: During slow vital capacity maneuver, breath sounds were recorded with a microphone at the mouthpiece of pneumotachometer and were stored to the personal computer. We measured the time between start of expiration and onset of wheeze (t) on the sonogram and then VtoR was determined with using above t and time-volume curve. We calculated the correlation between VtoR and V75, V50, V25 determined from F-V curve. This study is approved by ethical committee.

SUBJECTS: Adult non-smoker BA patients without known recent respiratory tract infection were informed and enrolled to this study. From 23 subjects, we have obtained 70 sets of recordings. Among those, expiratory wheeze was detected 63 recordings from 20 subjects and those were proceeded to analysis for VtoR.

RESULTS: In comparison with F-V curve, correlation between VtoR and V75, V50 and V25 were 0.782, 0.712 and 0.582 respectively.

DISCUSSION: Wheeze is generated mostly at large to middle-sized bronchus because significant airflow is required to generate airway wall vibration. Since VtoR directly depends on wheeze, we considered that above result has consistency. While, less correlation with V25 seen in the lower lung volume partially results from the instability of airflow by increased airway resistance. We considered that VtoR presents airflow obstruction quantitatively.

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PRESENTATION OF A SAMPLE TEST CASE ON THE SELF-EXCITED OSCILLATIONS IN COLLAPSIBLE TUBE FLOWS

M. Ö. Çarpinlioğlu[1] and V. Oruç[2]

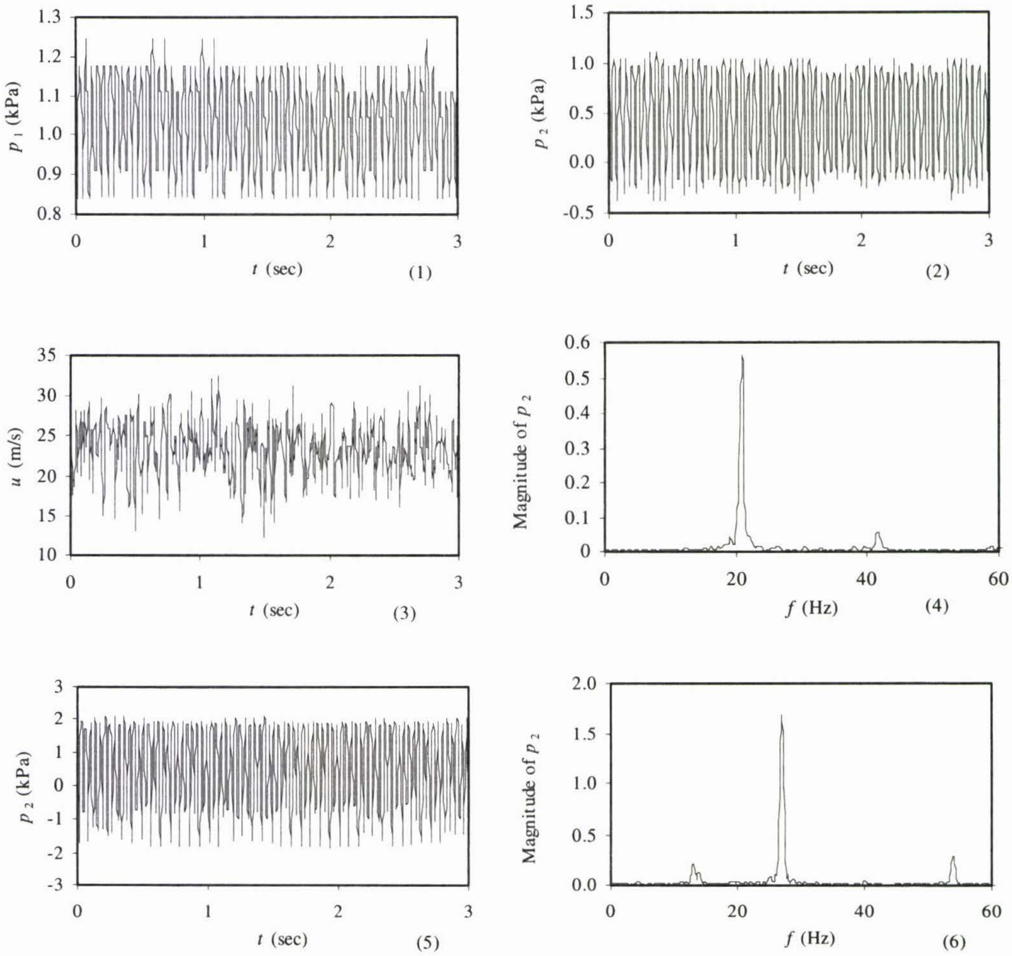
[1]*Department of Mechanical Engineering, University of Gaziantep 27310 Gaziantep-Turkey*
[2]*Department of Mechanical Engineering, University of Dicle 21280 Diyarbakir-Turkey*

A SYSTEMATIC experimental investigation was conducted to determine the onset of collapse for flow of air through a variety of elastic tubes of different geometrical and material characteristics under the action of external pressure, p_e applied to the walls of the tubes uniformly. In some of the cases with greater magnitudes of p_e than internal pressure, p_i tubes were collapsed and self-excited oscillations were formed downstream of the collapse position. However it was observed that there were some cases for which collapse was not associated with the generation of oscillations depending on the applied experimental constraints [1].

The experimental data through a silicone rubber test tube of 25.4 mm inside diameter, length to inside diameter ratio of 7.5 and thickness of 1 mm are presented briefly herein. The tube was placed without a longitudinal strain in an air-tight chamber known as "Starling resistor". The upstream and downstream pressures of the tube which are p_1 and p_2 respectively were measured by means of pressure transducers and cross-sectional velocity distribution downstream of the tube, $u=u(r)$ was measured by means of a hot wire anemometer. The frequency of the oscillations was determined using the Fast Fourier Transform (FFT) analysis of the signals of measurement devices. A sample test case with the generation of self-excited oscillations downstream of the collapse position is referred for an air flow rate of 0.01 m^3/s. The variation of p_1, p_2 and calculated oscillating velocity u based on $u=u(r)$ with time t corresponding to p_e = 2 kPa at which just oscillations started are shown in Fig. 1 to Fig. 3. The flow is highly unsteady due to the presence of oscillations sensed by the magnitudes of referred parameters as p_1 varying between 1.2 kPa and 0.85 kPa ; p_2 varying between 1 kPa and –0.4 kPa ; u varying between 30 m/s and 15 m/s . The frequency f of the oscillations is determined from FFT of the p_2 signal and FFT of the u signal separately. The separately determined frequency magnitudes confirm each other. For the discussed case f is 20.8 Hz as can be seen from FFT of the p_2 signal in Fig. 4. Increase in p_e at the same air flow rate: 0.01 m^3/s results a different flow behaviour simply. At p_e = 3.28 kPa , the variation of p_2 with t is shown in Fig. 5. It is seen that p_2 is approximately varying between –2 kPa and 2 kPa with an increase in the magnitude of f sensed in the FFT of p_2 shown in Fig. 6. As well as the change in the variation of p_2, the magnitude of f has a varying value of 26.94 Hz.

The experimental investigation is still in progress particularly focusing on the dynamics of self-excited oscillations to have a link with flow of air in airways.

[Figs. in next page]



Figs. 1-6. (1)-(3): p_1, p_2 and calculated oscillating velocity u with time t; (4): FFT of the p_2 signal; (5): The variation of p_2 with time t; (6): FFT of p_2.

REFERENCE:

[1] M. Ö. Ç. and V. Oruç, "A Correlation Study for the Determination of the Onset of Collapse in Elastic Tube Flows," *Journal of Biomechanics*, In process (2006).

VESICULAR AND BRONCHO-VESICULAR BREATH SOUND AND AIRWAY INFLAMMATION IN ASTHMA

Y. Nagasaka[1], S. Yasuda[1], Y. Ieda[1], T. Sugiura[1], T. Shimoda[2], and C. Habukawa[3]
[1]*Department of Pulmonary Medicine at Kinki University Sakai Hospital*
[2]*National Fukuoka Medical Center*
[3]*National Minami Wakayama Medical Center*

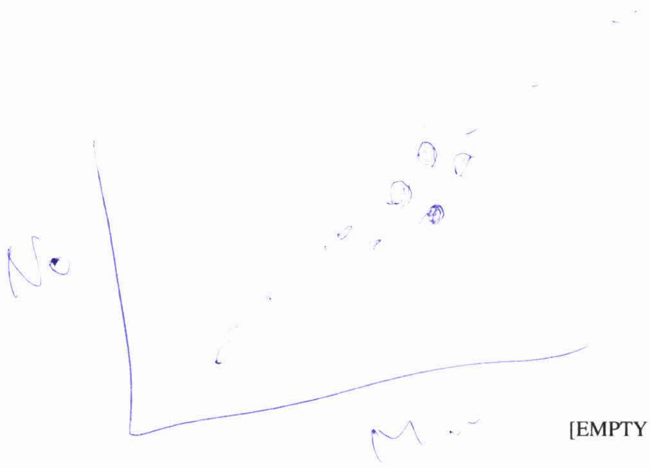
WE STUDIED if breath sounds in patients with rather stable bronchial asthma who have no acute asthmatic symptoms reflect their lung function or the degree of their airway inflammation. Forty-nine cases of mild to moderate (Step2 & 3) asthma were examined. We analyzed the breath sound by a sound spectrometer (KENZMEDICO Model SSAS-2000) followed by lung function tests and examination of markers of airway inflammation, i.e., exhaled nitric oxide (eNO) levels, inflammatory cells in induced sputum.

We distinguished the breath sound into vesicular (VS, n=28) and broncho-vesicular (BS, n=36) by auditory impression, i.e., by listening the tone of recorded expiratory and inspiratory breath sound.

The recorded breath sound was also analyzed by a sound spectrometer and we determined the highest pitch of expiratory and inspiratory breath sound. According to our preliminary study, we found we can dictate the sound intensity of louder than -50 dB. We determined the highest pitch of inspiratory (HIS) and expiratory (HES) breath sound as the audible sound which has intensity of higher than -50 dB, lasting for more than 0.2 sec. and recorded in more than three breath cycles.

In VS, HIS was 399±128.1 Hz, HES was 235±49.2 Hz. In BS, HIS was 571±157.4 Hz, HES was 378±79.5 Hz. There was no significant difference of pulmonary functions including %FVC, FEV1%, FEF25 and FEF 50, between the conditions when VS and BS were recorded. However, eNO (33.2±21.6 vs 65.7±66.9 ppb, $p<0.016$) and % of eosinophils in induced sputum (5.4±7.2 vs 13.8±19.7%, $p<0.034$) was higher in condition with VS than in condition with BS.

We conclude that we are listening vesicular breath sound as high as about 400 Hz in inspiration and about 240 Hz in expiration. In broncho-vesicular breath sound, we are listening as high as 570 Hz in inspiration and 380 Hz in expiration. The differences of the character of the audible breath sound reflected the degree of their airway inflammation in asthmatic patients who have no acute asthmatic symptoms. Thus, when we are listening bronco-vesicular breath sound in stable asthmatic patients, their asthma appears to be under treated.



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ON ANALYZING THE HARMONIC CONTENT OF WHEEZES USING WAVELET BICOHERENCE

S. A. Taplidou and L. J. Hadjileontiadis

Dept. of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece (http://psyche.ee.auth.gr)

WHEEZES are abnormal breath sounds, which are observed in patients with certain obstructive pulmonary diseases. The aim of the current study was the analysis of the nonlinear characteristics of asthmatic wheezes, as they are revealed in the quadrature phase coupling of wheeze harmonics evolving over time.

To this end, higher-order spectra were combined with continuous wavelet transform, which offers a time-scale representation of the signal, hence, reserving time information, assisting the identification of nonlinearities of the localized features (i.e., wheezes) within the signal. For the analysis of wheezes, wavelet bispectrum, wavelet bicoherence, summed wavelet bicoherence and evolutionary wavelet bicoherence were used. The analysis was applied to breath sounds signals from patients with asthma, exhibiting either monophonic or polyphonic wheezes during the breathing cycle.

Indicative experimental results from a breath sound signal with two wheezes (Fig. 1) are shown below. From those results, some indicative peaks of the summed squared wavelet bicoherence (Fig. 2(b)) in the analysis of the segment with wheeze are apparent in the area of 200 Hz and 350Hz. Such peaks are absent from summed squared wavelet bicoherence (Fig. 2(a)) corresponding to the breathing segment that does not contain a wheeze. The evolution over time (inspiration-expiration) of the phase coupling between wheeze harmonics can be seen in the evolutionary squared wavelet bicoherence (Fig. 3), where a transition to higher nonlinearly phase-coupled frequency pairs is seen as we move from the inspiratory to the expiratory phase.

Ongoing experiments show the efficiency of the aforementioned approach to successfully capture the nonstationary evolution of the nonlinearities in the harmonic content of wheezes within the breathing cycle.

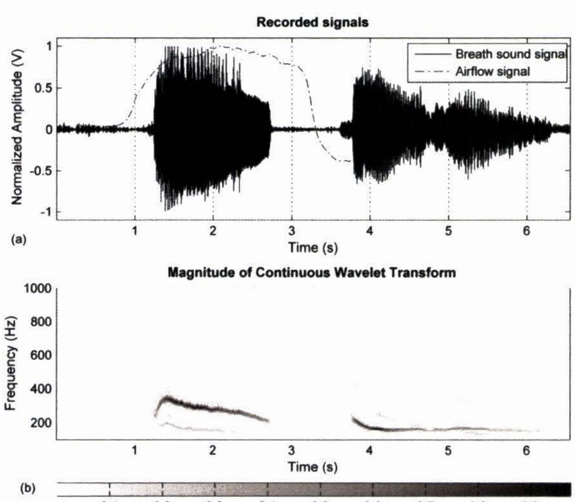
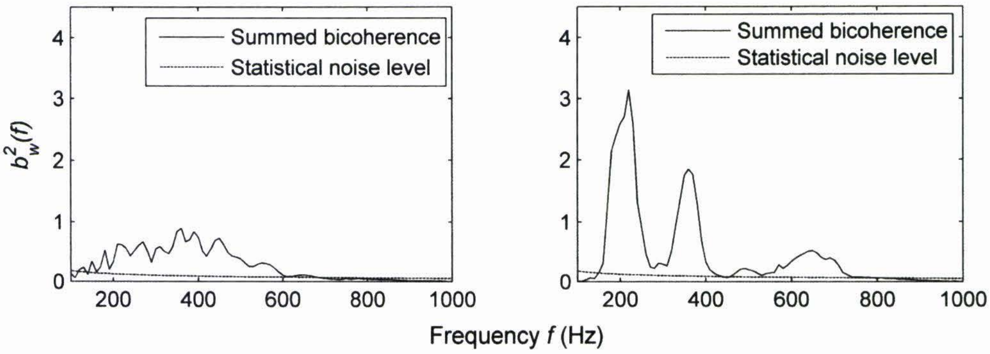


Fig. 1. Experimental results from an asthmatic case. (a) One breathing cycle of a breath sound recording from an asthmatic patient; (b) time-frequency representation of the analyzed signal using the continuous wavelet transform.

[Figs. continue in next page]



(a) (b)

Fig. 2. Summed squared wavelet bicoherence along with statistical noise level (--) of the breath sound signal shown in Fig. 1.are presented for (a) a section without wheeze (2.75-3.75 s); (b) a section with wheeze (3.75-3.75 s).

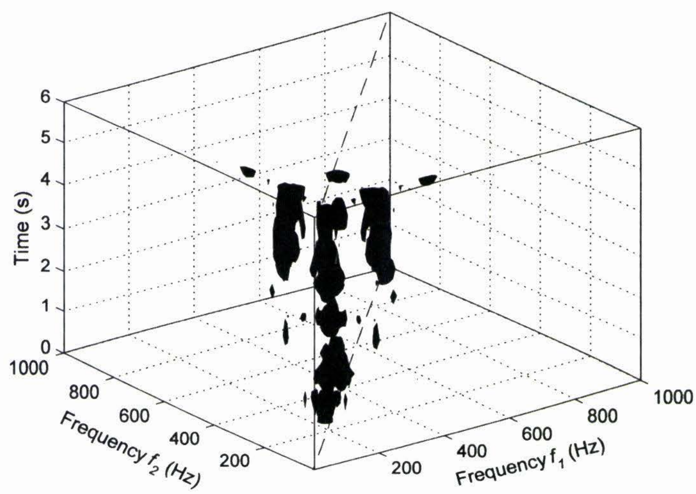
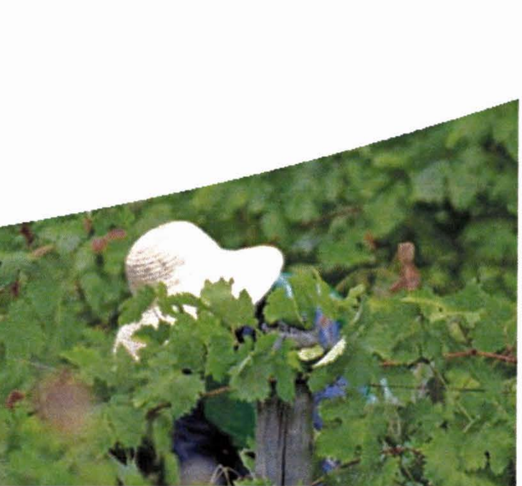


Fig. 3. Evolutionary squared wavelet bicoherence for isosurface $b_w^2(f_1, f_2) = 0.2$.

SESSION II: COPD, Cough, Crackles

Session Chair: Zahra Moussavi



MONITORING LUNG SOUNDS OF COPD-PATIENTS

M. Silva[1], S. Van Neck[1], T. Lauwerier[2], J.-M. Aerts[1], M. Decramer[2], and D. Berckmans[1]

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LUNG sounds analysis is of major importance in diagnostic malfunctions of the respiratory system of COPD-patients. Cough is also an important symptom of COPD. The purpose of this study was to determine how the acoustic properties of cough and lung sounds can help to monitor COPD-patients and if over a timescale of 5 days after being hospitalized information can be gathered about the dynamics of the recorded sounds.

By using an electronic stethoscope, lung and cough sounds of COPD-patients were recorded during 5 days after hospitalization. After recording, automatic algorithms were created to detect adventitious lung sounds and cough characteristics. Wheezes were detected using a pitch determination algorithm with a sensitivity of 0.9 and specificity of 1. Crackles were detected as peaks in the time domain of the respiratory signal with a dynamic threshold. The algorithm had a sensitivity of 1 and a specificity of 0.9. The RMS-value of the second part of the cough was used to classify a cough as productive or dry, which gave a correct classification of 90 % of the coughs. It is also important to state that an individual approach is required for classification of cough sounds, so a comparison of a cough signal to an average cough has much less classification accuracy than when comparing the coughs signals individually, as shown in Fig. 1. The follow-up of the patients showed a standard deviation of 98.75 Hz in case of the cough sounds of the COPD-patient, the follow-up of healthy people revealed a standard deviation of only 23 Hz. During the hospitalisation there were adventitious sounds of every patient, but after a longer recovery only weak breath sound was present. In order to capture more dynamics in the sound signals it is necessary to make recordings over a longer time scale than 5 days. This could lead to techniques for prediction of exacerbations as they have a negative impact on the patient's quality of life and represent at least 50 % of the overall costs associated with the management of the disease. Predicting exacerbations will increase the quality of life of COPD-patients and decrease the economic burden of COPD.

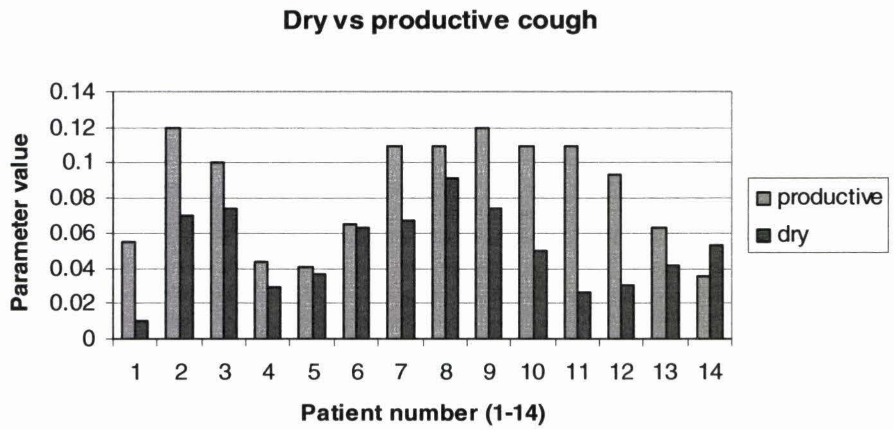

Fig. 1. Discrimination of dry and productive cough is most successful when using an individual defined threshold.

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A DEVELOPMENT OF A NEW COUGH MONITORING SYSTEM USING WIRELESS ACCELEROMETER

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BACKGROUND: Cough is one of the most common symptoms of respiratory disease. Despite its clinical importance, standard methods for objective cough analysis have yet to be established. Therefore we have been developing a non-invasive cough monitoring system. We extracted 6 parameters from recorded cough sounds with IC recorder. And then we classified cough sounds into 6 groups and developed a new objective program of counting coughs. In result, we obtained that the sensitivity was 90.2%, the specificity was 96.5% and the discriminative rate was 93.1%.However we got some problems in our program, that is the outside noise influenced the dropping of discriminative rate (Murata A. Internal Medicine 2006, 45(6), 391-397).

AIM: We thought the discriminative accuracy of cough sounds would improve using the detection of another phenomenon of the thoracic and abdominal movement in addition to the detection of the phenomenon of sounds. Therefore we purposed to evaluate the efficacy of using a wireless accelerometer to count cough sounds instead of microphones.

METHOD: Firstly, we aimed at the movement of the diaphragm and abdominal wall during coughing. And then we contacted a small accelerometer on the upper area of abdominal wall and simultaneously recorded the movement of the abdominal wall on videotape and the signals of an accelerometer contacted abdominal wall during coughing. Next with noise, we recorded cough sounds and measured the signals of an accelerometer contacted on the abdominal wall. And we evaluated the efficacy of the accelerometer for detecting cough sounds.

RESULTS: There was correlation (r=0.77) between the moving average of 2 times integral calculus of signals measured by an accelerometer and the movement of the abdominal wall. Then we thought that an accelerometer was useful for measuring of the movement of the abdominal wall. And in the outside noises, we compared recorded spontaneous cough sounds with measured the signals of an accelerometer contacted on the abdominal wall. As a result, we recognized the cough sounds synchronized with the signals of an accelerometer and then we thought that an accelerometer was useful for detecting cough sounds.

CONCLUSION: We concluded that it was possible to detect cough sounds using the signals of an accelerometer contacted on abdominal wall. We could think that the method of detecting cough sounds using the acceleration signal would be able to supplement the method using the signals of sounds.

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CRACKLES IN ASBESTOSIS

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INTRODUCTION: Occupational exposure to asbestos causes interstitial fibrosis that can be associated with a variety of clinical findings including dyspnea, crackles on auscultation, opacifications on chest x-ray and abnormal pulmonary function.

METHODS: We studied the relationship of crackles to other clinical findings in asbestos exposed shipyard pipecoverers and age matched shipyard workers that did not work directly with asbestos at two points in time 18 years apart.

RESULTS: Crackles were more common in pipecoverers than in the control group on both occasions. Those who had crackles on the initial and follow-up examinations more commonly had roentgenologic opacifications, reduced vital capacities and abnormal diffusing capacities than those without crackles. Crackles were an earlier finding than x-ray changes in both the initial and follow-up exams.

CONCLUSION: This study confirms that crackles are an important manifestation of asbestosis. They can now be detected very efficiently using a multichannel lung sound analyzer, which circumvents observer variability and allows more precise quantification of this phenomenon. This device can be used to monitor exposed workers and to aid in diagnosis of this occupational lung disease.

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BACKGROUND SIGNAL ELIMINATION FOR CRACKLE ANALYSIS

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CRACKLES which are superimposed upon lung sounds especially in pathological conditions are usually distorted with background signal. When parameters to characterize and quantify the morphology of crackles such as initial deflection width or two-cycle duration are extracted, the presence of background signal modulates the waveform of crackles such that the researchers are misguided about the quantifiable crackle parameters. The finer the crackle is, the stronger the effect of the artefact will be. In order to analyze the crackles more accurately, the background signal should be eliminated. The frequency components of crackles which range from 100 Hz to 2 kHz and the frequency spectra of background lung sounds which concentrate between 50 Hz to 200 Hz overlap. Therefore the high-pass filter applied on the signal should be designed by taking the distortion amount of crackle waveform into consideration. If the high-pass filter cut-off frequency is too high, the waveform especially in the case of a coarse crackle will be distorted and the acquired parameters will represent a fine crackle whereas in the case of a low cut-off frequency, background signal will not be eliminated.

METHOD: Signal windows that include at least one crackle are filtered with ascending cut-off frequency values that are dependent on percentiles of the spectral distribution functions (SDF) of the signal windows. A distortion metric is defined and distortion of a crackle is calculated after each filtering. The distortion metric depends on the correlation coefficient between crackle waveforms in the raw signal and in the filtered signal. According to the distortion metric, the optimum cut-off frequency is determined for a crackle. Percentile of SDF that may estimate the optimum cut-off frequency with minimum error is determined by polynomial curve fitting. An example of the background signal elimination is shown in Fig. 1.

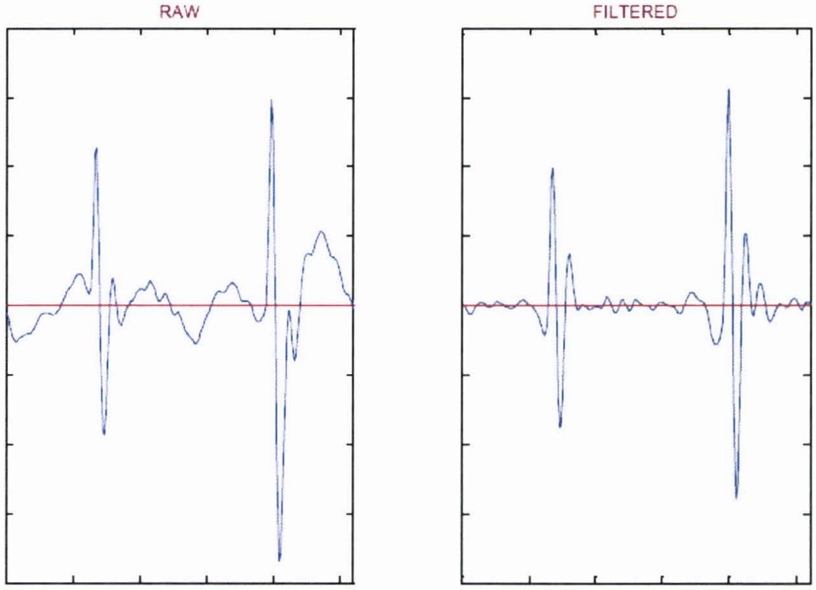

Fig. 1. Example of background signal elimination.

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ANALYSIS OF SIMULATED CRACKLE SOUNDS BY EMPIRICAL MODE DECOMPOSITION

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[2]*Department of Health Science, Universidad Autónoma Metropolitana-Iztapalapa, Mexico City 09340, México*
[3]*Laboratory of Thoracic Acoustic, National Institute of Respiratory Diseases*

FOR ANALYZING fine and coarse crackles sounds, a major problem is their non-stationary behavior. In 1998, Huang et al., proposed the technique of Empirical Mode Decomposition (EMD) for dealing with non-stationary and nonlinear signals. The essence of EMD is to empirically identify the intrinsic oscillatory modes (IMFs) of a signal by its characteristic time scales, from the highest to the lowest oscillation modes. In this work, the ability of EMD to visually discriminate crackles sounds immersed within basic lung sounds was explored. The behavior of IMFs was investigated on basic inspiratory sound containing simulated crackles at known positions and under different SNRs as shown in Fig. 1. The simulated scenarios included three conditions: a) multiple isolated crackles, b) overlapped crackles and, c) combination of both crackles, fine and coarse. In all explored cases, crackles were inserted in the early, middle and late temporal section of basic normal inspiratory sound by a plain sum. For multiple isolated crackle cases, three sets of three crackles with decreasing amplitude were inserted in each section of the inspiratory phase.

The results indicated that oscillatory information of crackles embedded in basic inspiratory "noise" started at IMF2 and were distributed on several IMFs but, depending on the SNR, fine crackles were easier to discriminate from basic respiratory sound than coarse crackles. Overlapped crackles appeared from IMF1; however, individual components were not differentiated. In case of combined time separated, fine and coarse crackles had no effect on the oscillatory information for individual events. Discriminating crackles with low SNRs was a more demanding task, but discrimination was possible at least at 5 dB.

In conclusion, since basic sound distorted the morphology of embedded crackles sounds, conventional crackles criteria for their identification could be of difficult application; therefore, we suggest simulated scenarios to validate techniques for crackle detection. Our results showed that EMD is a promising technique for crackles enhancement, especially for isolated and overlapped fine crackles.

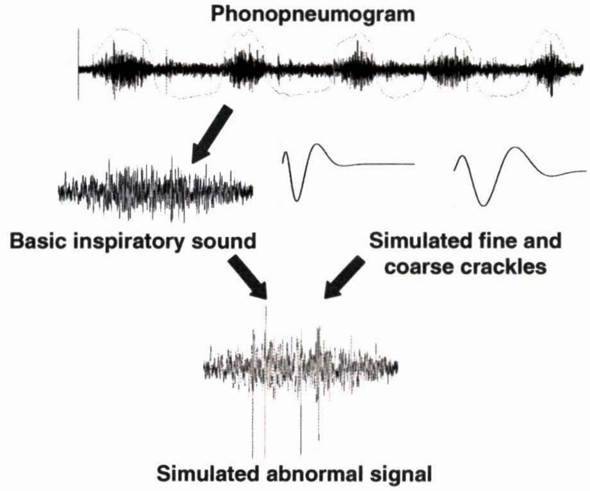

Fig. 1. An example of a basic inspiratory sound containing simulated crackles at known positions and under different SNRs.

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SESSION III: Poster Session

Session Chairs:
Noam Gavriely and Sonia Charleston-Villalobos

AUTOMATED LUNG SOUND ANALYSIS IN PATIENTS WITH CHRONIC OBSTRUCTIVE LUNG DISEASE

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INTRODUCTION: The lung sounds of patients with chronic obstructive lung disease (COPD) have been shown to differ objectively from those of normal subjects using either frequency based or time based analysis, but there is considerable overlap.

PURPOSE: To determine if a rating scale based on both frequency and time based parameters would show more clear differences between patients with COPD as compared to normal subjects than methods based on either frequency or time domain analysis alone.

METHODS: A 16-channel lung sound analyzer was used to collect 20 second samples of sound from patients with COPD (n=128) and normals (n=128) during deeper than normal breathing. Patients were age matched. Seven parameters based on timing, frequency, amplitude, and adventitious sounds analysis were measured. These parameters included: ratio of duration of inspiration to duration of expiration, inspiratory amplitude, the inter-channel inhomogeneity in the timing of the beginning and end of inspiration, ratio of low frequency energy to high frequency energy, crackle rate, wheeze and rhonchi rate. A score was developed based on the findings for each parameter and a total score was calculated for each subject.

RESULTS: The score averaged 6.8±7.1 for normals and 28.0±12.8 for COPD ($p<0.001$). Only 9 COPD patients (7%) had a score below 20. Only 35 normal subjects (27%) had a score above 20. With 20 as a threshold, the score had a sensitivity of 0.93 and specificity of 0.73.

CONCLUSIONS: A score based on timing, frequency, amplitude, and adventitious sounds analysis of lung sounds differed significantly in COPD patients as compared to normals.
This score provided a clearer separation of COPD from normals than did any of the acoustic parameters analyzed separately. While further study is indicated we believe that this technique has the potential of providing a noninvasive tool to aid in diagnosis of COPD.

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WHEEZE ANALYSIS USING THE HILBERT-HUANG TRANSFORM

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(http://psyche.ee.auth.gr)

WHEEZES are abnormal breath sounds, which are observed in patients with certain obstructive pulmonary diseases. The aim of the present study was the time-frequency representation of asthmatic wheezes using the recently introduced Hilbert-Huang transform (HHT) [1].

The implementation of the HHT involves the process of Empirical Mode Decomposition (EMD). The latter analyses the input signal to a series of intrinsic mode functions (IMFs) that satisfy two conditions, i.e., in the whole dataset, the number of extrema and the number of zero crossings must either equal or differ at most by one, and at any point the mean value of the envelope defined by the local maxima and the one defined by the local minima is zero [1]. Having estimated the IMFs, Hilbert transform is applied and the instantaneous frequency is calculated. Then, the amplitude and instantaneous frequency are represented as functions of time in a three-dimensional plot, in which the amplitude is contoured in the frequency-time plane, designating the HHT or Hilbert amplitude spectrum $H(f,t)$. Similarly, the Hilbert energy spectrum can be estimated by squaring the $H(f,t)$. In addition, the instantaneous energy density level, $IE(t)$, can be defined as $IE(t) = \int_f H^2(f,t)df$, which represents the energy fluctuations over time. Moreover, the statistical degree of stationarity, $DSS(f,\Delta\mathrm{T})$, can be defined as $DSS(f,\Delta\mathrm{T}) = \frac{1}{T}\int_0^T \left(1 - \frac{\overline{H(f,t)}}{n(f)}\right)^2 dt$, where T denotes the overall time duration, $n(f) = \frac{1}{T}\int_0^T H(f,t)dt$ corresponds to the mean marginal spectrum and the overline indicates averaging over a definite but shorter time span, $\Delta\mathrm{T}$, than T.

Indicative experimental results of the HHT analysis applied to a section $ws(t)$ of a breath sound signal $s(t)$ containing wheezes (Fig. 1) are shown below. In particular, the first three IMFs are shown in Fig. 1, indicating the initiation of the harmonics with the evolution of the wheeze. Figure 2 (top) illustrates the HHT of $ws(t)$, which shows the variation of the instantaneous frequency over time within two main frequency bands, i.e., 150–200 Hz and 300–400 Hz. Moreover, the estimated $IE(t)$ (Fig. 2–middle) demonstrates fluctuations of the energy during the existence of wheeze. Finally, the estimated $DSS(f)$ (Fig. 2–bottom), for $\Delta\mathrm{T} = 100$ time steps, reveals highly non-stationary frequency bands within the frequency range of ~85 Hz – 375 Hz, especially around 360 Hz (max. value of $DSS(f)$).

These results show potential use of the HHT to clearly identify the non-stationary characteristics of wheezes, taking into account its harmonic content and the energy fluctuation around distinct frequencies. The proposed analysis could be applied in a range of breath sound signals containing wheezes from different pathologies, such as asthma, COPD and pneumonia, in an effort to associate HHT-based characteristics with the diagnostic ones. Ongoing experiments are towards this direction.

[Figs. in next page]

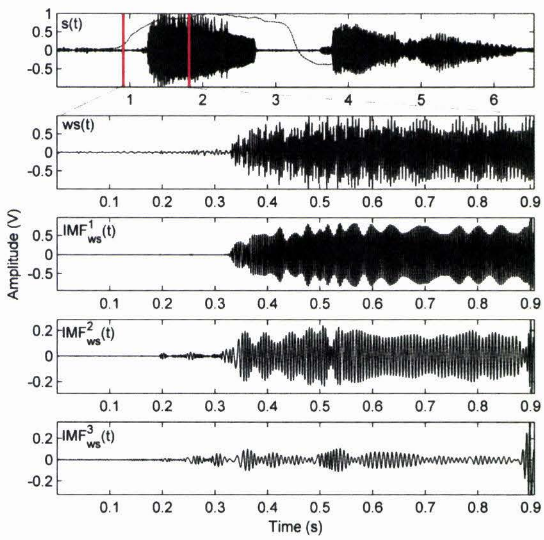

Fig. 1. Experimental results from an asthmatic case. $s(t)$: One breathing cycle of a breath sound recording from an asthmatic patient; $ws(t)$: windowed section of $s(t)$ containing both wheeze and non-wheeze signal; $IMF_{ws}^{i}(t), i = 1,2,3$: the corresponding IMFs.

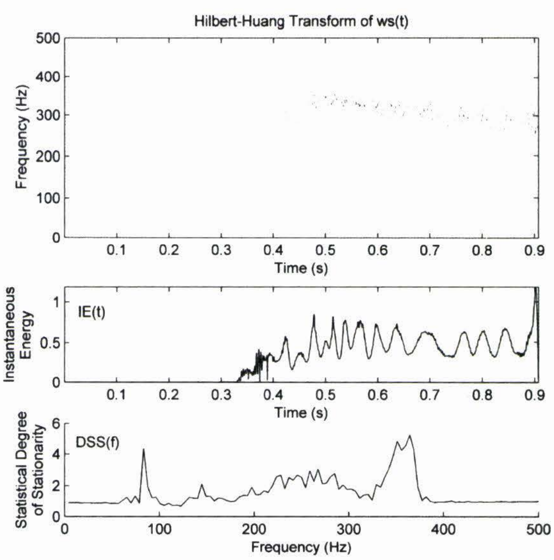

Fig. 2. HHT-based analysis results. HHT of $ws(t)$ (top); $IE(t)$: instantaneous energy density level (middle); $DSS(f, \Delta T)$: degree of statistic stationarity for one-sample overlap and $\Delta T = 100$ time steps (bottom).

REFERENCE:

[1] N. E. Huang, Z. Shen, S. R. Long, M. L. Wu, H. H. Shih, Q. Zheng, N. C. Yen, C. C. Tung, and H. H. Liu, "The empirical mode decomposition and Hilbert spectrum for nonlinear and nonstationary time series analysis," *Proc. R. Soc. Lond. A*, vol. 454, pp. 903-995, 1998.

EFFECT OF ANTI-INFLAMMATORY TREATMENT ON BREATH SOUND AND AIRWAY INFLAMMATION IN ASTHMA

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[2]*National Fukuoka Medical Center*
[3]*National Minami Wakayama Medical Center: Chizu Habukawa*

WE STUDIED if breath sounds in patients with rather stable bronchial asthma reflect their lung function or degree of airway inflammation. Twenty-nine cases of mild to moderate (Step2 & 3) asthma who have been treated with inhaled corticosteroids were examined before and after additional treatment with montelukast (Group M, n-14) or salmeterol (Group S, n=15). We analyzed the breath sound by a sound spectrometer (KENZMEDICO Model SSAS-2000) and determined the highest pitch of inspiratory (HIS) and expiratory (HES) breath sound as described elsewhere. Then we examined lung function tests and markers of airway inflammation, i.e., exhaled nitric oxide (eNO) levels, inflammatory cells in induced sputum.

In Group M, HIS and HES before and after additional montelukast was 545±183.8 and 421±150.3 Hz for HIS (p=0.015), and 378±167.6 Hz and 294±101.3 Hz for HES (p=0.1). In Group S, HIS and HES before and after additional salmeterol was 535±180.0 and 566±177.6 Hz for HIS (p=0.07), and 354±132.6 Hz and 373±127.2 Hz for HES (p=0.56). In Group M, %FEV1 before and after additional montelukast was 75±22.0 and 80±18.9 % (p=0.04). Blood eosinophils (%) and eNO before and after montelukast was 8±5.0 and 5±3.5 % for blood eosinophils (p=0.005) and 48±36.5 and 33±23.0 ppb for eNO (p=0.02). In Group S, %FEV1 before and after additional montelukast was 76±14.2 and 83±16.5 % (p=0.002). Blood eosinophils (%) and eNO before and after montelukast was 8±5.2 and 7±5.6 % for blood eosinophils (ns) and 42±35.9 and 51±37.1 ppb for eNO (ns). Thus, although there were simultaneous increase of %FEV1 both in Group M and Group S, significant decrease of HIS and decrease of airway inflammatory markers were observed only in Group M.

In this study, there was simultaneous decrease of HIS and airway inflammatory markers, i.e., blood eosinophilia and eNO in Group M. We conclude that breath sound especially highest pitch of inspiratory breath sound reflected the level of airway inflammation in rather stable asthmatic patients who have no acute asthmatic symptoms.

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INCREASED LUNG SOUND INTENSITY AFTER SALBUTAMOL INHALATION INDICATES SIGNIFICANT BRONCHODILATION

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TO STUDY whether increased inspiratory lung sound intensity (LSI) after inhalation of salbutamol relates to increased forced expiratory flows on spirometry, we studied 13 boys and 7 girls, age 11.2 ± 3 y (mean ± S.D.). Because of suspected asthma they had been referred for routine lung function testing, incl. bronchodilator responses. Sound (contact sensor over the left posterior lower lung) and airflow signals (pneumotach) were recorded for at least 60 s before spirometry at baseline and again before spirometry 15 min after inhalation of 200 μg salbutamol. Baseline spirometry showed FVC 108 ± 9.1% predicted, $FEV_{1.0}$ 102 ± 12.4%, and FEF_{50} 93 ± 25.2%. During lung sound recordings, the seated subjects wore a nose clip and were coached to cover a range of air flows to a maximum of 1.5 L/s and finishing with a breath hold of 5 s. Power spectral analysis provided estimates of LSI (in dB) at flow increments of 0.1 L/s in the frequency bands of 150-300 Hz and 300-600 Hz. We found a positive correlation between inspiratory ΔLSI at 300-600 Hz and ΔFEF_{50} (r=0.546, p<0.013) before and after salbutamol. At inspiratory flows above 0.7 L/s, LSI increased (p<0.05) in responders, i.e., in children who had an increase in $FEV_{1.0}$ >10% and/or >20% in FEF50 after salbutamol, but not in non-responders (see Fig.1). After bronchodilator, the difference in accumulated inspiratory LSI at 50 s (ΔLSI50) correlated with $\Delta FEV_{1.0}$ in boys (r=0.79) but not in girls (r=-0.14). The bronchodilator response was significantly greater in boys ($\Delta FEV_{1.0}$ 7.2 ± 3.8% vs. -0.6 ± 3.7%, p<0.05, t-test). Different breathing patterns between boys and girls may also have contributed to this finding. Objective quantification of LSI relative to airflow is more reliable than the subjective interpretation of "air entry" on auscultation. The relation of LSI and air flow as an indicator of changes in human airways warrants further study.

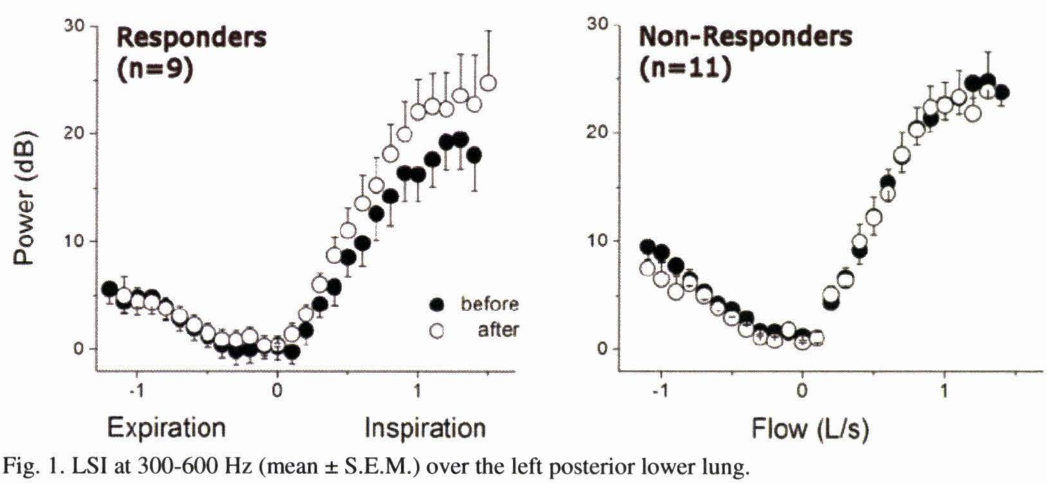

Fig. 1. LSI at 300-600 Hz (mean ± S.E.M.) over the left posterior lower lung.

* Dr. Fiz, Visiting Scholar, and Mr. Pang, Summer Student, were supported by the Children's Hospital Foundation of Manitoba.
** Ms. Gnitecki is supported by a scholarship from NSERC.

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ESTIMATION OF INSPIRED VOLUME PRIOR TO COUGHING FROM SOUND

K. McGuiness, A. Kelsall, A. Woodcock, and J. A. Smith

North West Lung Research Centre, University of Manchester, Manchester, UK

RATIONALE: A cough is a forced expiratory manoeuvre, accompanied by a characteristic sound. The acoustics of cough sounds vary considerably. We hypothesised that the volume of inspiration prior to a cough accounts for some of the variability in acoustics. We predicted that acoustic parameters of voluntary cough sounds would be closely related to the volume from which the cough was generated.

METHODS: We studied 17 healthy volunteers (10 female, 7 male). Each performed three voluntary coughs at nine different lung volumes 10% to 90% of vital capacity (VC) (10% increments); total 27 coughs per subject. Cough sounds were recorded via a contact microphone, placed over the sternum, and saved onto an audio device (sample rate 8 KHz, 16 bit). For each subject's cough signals we determined (1) the peak amplitude of unfiltered sound (dataset U), (2) peak amplitude of high pass filtered sound (dataset F) and (3) area under the curve of the envelope of high pass filtered sound (dataset A). For variables (2) and (3), high pass filtering was repeated over a range of filter frequencies from 1400 Hz to 3600 Hz (step 200 Hz).

Regression analysis was used to determine which of the derived parameters (1-3) most strongly predicted the lung volume from which the coughs were generated.

RESULTS: There was a significant difference between the maximum r2 achieved for dataset A, dataset U and dataset F (p=<0.01). Dataset A (mean = 0.8, SD = 0.092) consistently outperformed dataset U (mean=0.277, SD=0.23) and dataset F (mean=0.48, SD=0.217) in respect of its ability to estimate the inspired volume prior to cough.

CONCLUSIONS: The area under the curve measure provides a consistently better estimation of the volume inspired prior to cough than the other two methods. Optimal high pass filter frequency is highly variable between individuals.

Cough sound detection methodologies which rely on the temporal and spectral patterns of cough sounds perform inadequately. A subject specific methodology which is independent of the spectral and temporal shape of the cough sound but dependant on the volume from which the cough is generated may perform with greater sensitivity than the present cough detection methodologies.

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SESSION IV: Sleep Acoustics Symposium

Session Chairs: Hans Pasterkamp and Ray Murphy

ACOUSTIC ANALYSIS METHODS APPLIED TO SLEEP RESEARCH

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SLEEP covers a third of human life. There are many disorders which have their origin and their expression during sleep. Some disorders, such as sleep apnea, periodic legs movement syndrome, and narcolepsy are specifically bound to sleep. Others such as nocturnal cardiac arrhythmias, nocturnal asthma, and gastroesophageal reflux disease are found during daytime and sleep and show a particularly high expression during sleep.

Acoustic analysis applied to sleep research focuses on snoring and the related breathing disorders being specifically bound to sleep. Beside this nocturnal asthma, and gastric motility are investigated using acoustic analysis methods. The analysis of breathing sounds to detect breathing may be especially useful during sleep since at that period there are less external noises and less disturbance to a regular breathing. This last kind of applications can make use of sleep as a relatively well protected time period with a minimized set of external disturbances in terms of behavior and sounds.

The methods used for acoustic analysis during sleep have to deal with the long term recordings usually lasting for 8 hours. If sufficiently indicative parameters are derived characterizing the underlying patterns then their temporal development over the sleep period can be evaluated. This allows the analysis of a dependency with sleep stages and a development over time as characteristic for chronopharmacology. The methods applied in acoustic analysis as in sleep analysis comprise time domain methods including wavelet analysis, frequency domain methods such as spectral analysis, and statistics based methods. Of these the detrended fluctuation analysis (DFA) appears to give very good results in sleep research. It can be used to distinguish different sleep stages as non-REM and REM sleep. These sleep stages show different statistical properties in the regulation of the heart beat, the respiratory frequency and in other respiratory parameters. The DFA method requires a minimum duration of the recording due to its statistical nature and therefore it has not been applied to short term recording as they were used in most lung sound analysis approaches.

We assume that the methods developed and used in sleep research can provide very valuable new views on long term acoustic recordings. And as many acoustic patterns, healthy and pathological ones, are observed during sleep, these sleep related acoustic phenomena can be subject to any method developed for long term signal analysis. Sleep with its controlled environment and its known physiological states presents a bench mark environment to investigate physiology and pathophysiology related to disorders which have an acoustic expression.

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APNEA DETECTION BY ACOUSTICAL MEANS

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IN THIS paper a new non-invasive method for apnea detection is proposed. Eight healthy subjects participated in this study. They were instructed to breathe very shallow with different periods of breath hold to simulate sleep apnea. Following our previous study in successful use of entropy for flow estimation, in this study the Otsu threshold was used to classify the calculated entropy into two classes of breathing and apnea. The results show that the method is capable of detecting the apnea periods even when the subjects breathe at very shallow flow rates. The overall lag and duration errors between the estimated and actual apnea periods were found to be 0.207 ± 0.062 and 0.289 ± 0.258 s, respectively. The performance of the method for a typical signal is shown in Fig.1, below. The results are encouraging for the use of the proposed method as a fast, easy and promising tool for apnea detection.

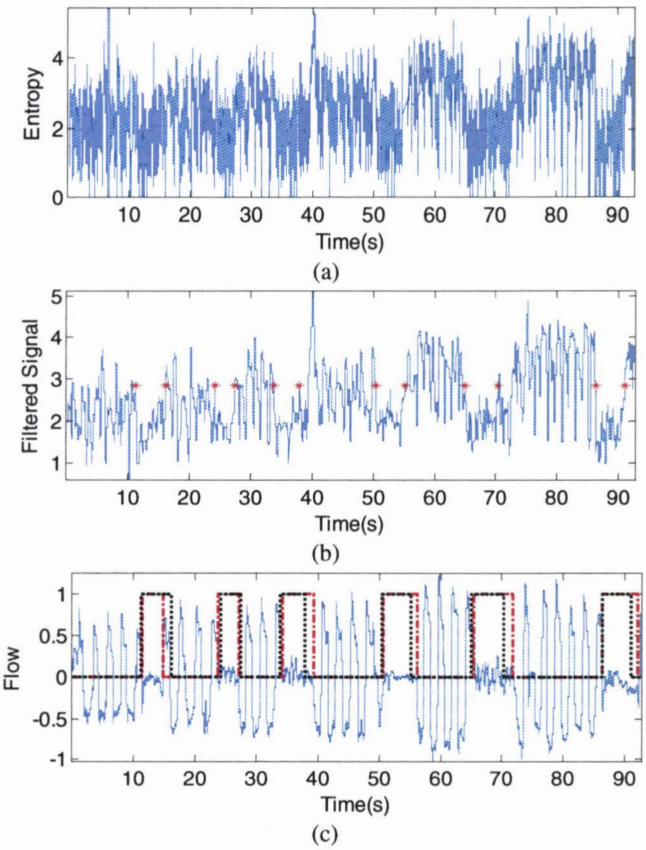

Fig. 1. (a) Tracheal sound entropy, (b) entropy after applying nonlinear median filter (star marks represents the estimated apnea segments) and (c) flow signal (solid line) along with the estimated (dotted line) and real (dashed line) apnea segments for a subject.

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CLINICAL USE OF NOCTURNAL LONG-TERM RECORDING OF BREATH SOUNDS

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THE APPEARANCE of typical acoustical attendant symptoms in specific diseases of the bronchial system, e.g. asthma, has been well-known for a long time. Since the invention of the stethoscope by Laennec in 1819 the assessment of bioacoustical signs is used by medical doctors as a routine method of the clinical examination.

For the diagnosis of bronchial asthma coughing and wheezing are important symptoms that indicate the existence of obstruction. Previous methods in the lung function diagnosis imply always an active cooperation of the patient that is not possible during sleep. Thus a acoustical monitoring and assessment makes sense for a detection and documentation of wheezing and cough.

In the past the respiratory sound was mostly detected as a result of a time-limited auscultation with the stethoscope or by self information of the patient via questionnaire. Auscultation with a stethoscope has many limitations. It is a subjective process that depends on the individuals own hearing and experience. With a simple stethoscope it is not possible to produce quantitative measurements or to make a permanent record of an examination in documentary form. Over the last 40 years, computerized methods for the recording of respiratory sounds have overcome many limitations of simple auscultation. Due to the technical revolution of recording and data storage techniques, continuous high-quality sound recordings are possible nowadays.

A mobile system allows a non-invasive and cooperation-independent nocturnal monitoring of acoustical symptoms in the domestic environment of the patient, especially at night during which most ailments occur. Furthermore computerized long-term recording of breath sounds can be used for monitoring of medical interventions and in chronopharmacology.

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NOCTURNAL LONG-TERM RECORDING OF SNORING IN PATIENTS UNDERGOING POLYSOMNOGRAPHY

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SNORING is a typical inspiratory sound appearing during sleep, mostly in male patients. Snoring may also occur in conjunction with a disordered sleep pattern and can be associated with a range of symptoms, including Obstructive Sleep Apnoea (OSA) syndrome. OSA is a type of sleep apnoea due to upper airway obstruction, during persistent ventilatory movements and it can result in cessation of breathing. The standard diagnosis of OSA comprises a full nocturnal session in a sleep laboratory. Many efforts have been made towards the development of less expensive testing methods and snoring analysis constitutes one of these methods. The aim of the current study is to explore any possible relationship between snoring analysis using wavelet transform and sleep disordered breathing. Snoring sounds were acquired overnight in a sleep laboratory, together with the polysomnography (PSG) testing, via two microphones. The standard PSG microphone was placed on the neck of the patient and another digital microphone was placed near the mouth. Audition Software was used for the recording of respiratory sounds, which was also used for noise reduction. The signal analysis was performed using MATLAB software. The snoring signal analysis was conducted in the frequency domain, using spectral analysis, and in the time-frequency (scale) domain, using the wavelet transform. The analysis was based on the remarks of a doctor specialized on the PSG results. Results of the current analysis led to the detection of heavy snoring, which is a common OSA symptom. Ongoing work is performed towards further evaluation of the proposed method.

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NOCTURNAL LONG-TERM RECORDING OF RESPIRATORY SOUNDS (LTR-RS) IN PATIENTS WITH GASTROESOPHAGEAL REFLUX IN COMBINATION WITH 24-H PH TESTING

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INTRODUCTION: In the literature a principal correlation between nocturnal gastroesophageal reflux disease (GERD) and nocturnal bronchial obstruction associated with wheezing and cough is discussed. The pathophysiological aspects are caused by acid or leach dependent vagal reflex bronchoconstrictions or microaspirations. Up to now, it was not possible to show an immediate coherence between gastric reflux and bronchial obstruction. The nocturnal long-term recording of respiratory sounds (LTR-RS) allows to determine a correlation between gastroesophageal reflux events and the occurrence of pathological acoustic symptoms over time.

METHODS: The study focuses on patients with suspected GERD. The pH level is measured on these patients for 24-h. Simultaneously we record nocturnal lung sounds. The long term recordings are conducted inpatient or in the domestic environment of the patient.

The respiratory sounds are recorded via three air coupled microphones which are placed over the trachea as well as on the chest of the patient. A fourth microphone records the surrounding sounds. The acoustical data are analysed using the standardised method of computer assisted audio-visual assessment of respiratory sounds (CAVARS). After that a histogram of the acoustic symptoms (wheezing, coughing, snoring) can be generated.

Furthermore a lung function test is performed together with a peak expiratory flow (PEF) measurement shortly before going to bed as well as after waking up.

RESULTS/CONCLUSION: In the patients with GERD that we measured up to now wheezing and coughing was found.

The LTR-RS method highlights that it is possible to show a correlation between reflux episodes and pathological acoustic symptoms over time. The method is independent of patient's cooperation, thus enabling measurements during sleep.

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NOCTURNAL LONG-TERM RECORDING OF RESPIRATORY SOUNDS (LTR-RS) IN PATIENTS WITH RHINOSINUSITIS

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BACKGROUND: Chronic rhinosinusitis involves the secretion of mucus and obstruction of the nasal passages. While patients are asleep in the supine position, mucus is moved from the nasal passage towards the throat. Muco-purulent secretion occurs and causes the patient to feel as if he has a lump in his throat. In addition to this sensation the patient experiences hoarseness of the voice and frequently attempts to clear his throat. This combination of symptoms is called post nasal drip syndrome (PNDS).

Acoustic symptoms can be measured by nocturnal long term recording of respiratory sounds (LTR-RS). These sounds are: the swallowing of mucus, coughing, throat clearing, wheezing and rhonchi. Nowadays it is possible to measure these typical symptoms qualitatively and quantitatively over time. These symptoms are partly those of PNDS. Our portable device also allows the patient's symptoms to be measured at home.

METHODS: The examination included the recording of nocturnal respiratory sounds during sleep and a lung function test. Two microphones are fixed to the patient's back and one to the throat to monitor tracheal sounds. The microphones are connected to an amplifier. Patients carry them in a neck pouch, also containing an external microphone, which is connected to the recording device. Recording occurs throughout the night and can be carried out without patient supervision.

Acoustical data were analysed using the standardised method of computer assisted audio-visual assessment of respiratory sounds (CAVARS).

RESULTS/CONCLUSION: Up to now we measured 12 patients with chronic rhinosinusitis the night before the operation. Assessment of the patients shows what proportion experienced the following symptoms: increased swallowing 9/12 patients (75%), snoring 8/12 patients (67%), wheezing 8/12 patients (67%), rhonchi 4/12 patients (33%) and coughing 2/12 patients (17%). In comparison to patients with rhino-sinusitis mentioned in the literature, coughing was underrepresented in our patients group. In volunteer measurements the pathological combination of PNDS symptoms was not found.

Our results show, that LTR-RS is a very effective method for an objective documentation of the acoustic symptoms of PNDS.

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CPAP TREATMENT ON COGNITIVE PERFORMANCE OF AVIATORS WITH OBSTRUCTIVE SLEEP APNOEA SYNDROME

C. Kourtidou-Papadeli[1], E. Daskalopoulou[2], C. Papadelis[1], P. Angelidis[3], M. Psymarnou[3], and E. Perantoni[1]

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INTRODUCTION: Eighty percent (80%) of aviation-related accidents are caused by human error. The role of sleep disorders in these mishaps is unknown and probably underestimated. Many studies have documented various degrees of problems with memory, learning, and a decrease ability to initiate new mental processes in sleep apnoea patients. The purpose of this study was to determine whether recognition and treatment of sleep disorders might lower the rate of aviation accidents and improve operational effectiveness.

MATERIAL AND METHODS: Forty five (45) patients with OSA participated in the study, mean age 44 ± 10.7, RDI 49.22 ± 21, Apnea-Hypopnea Index 31±15, DI 53.12±6.64, Average SaO_2 % 89.20 ± 6.64, min. SaO_2 % 71.07 ± 23.08, % of sleep time with SaO_2<90% 25.76 ± 23.08, and EPW scale 12.96 ± 2.72. For cognitive performance evaluation, a flight simulator electronic program, a multiattribute task battery (MATB) was used with the main outcome measures tracking error (RMSE), response time and number of correct, incorrect, and missed responses for dials and lights.

The subjects were trained on the task until they achieved an asymptotic level of performance and the last three trials on the task before treatment was compared to the last three trials after treatment with continuous airway positive pressure (CPAP).

RESULTS: Tracking error (RMSE) decreased significantly after CPAP treatment. Data with tracking error were submitted to a repeated measures analysis of variance (ANOVA) with treatment and session as within subject factors. The results (see Table I) showed significant main effects of treatment and session, $F(1, 40) = 105.23$, $p<0.001$ and $F(2, 80) = 27.94$, $p<0.001$ respectively. That is, performance improved after the treatment (13.68) as compared to pre-treatment sessions (22.34). Also, Post-hoc comparisons showed that performance was worse for session 1 (20.73) as compared to sessions 2 (17.23) and 3 (16.07), ps<0.001. However, there were no significant differences between sessions 2 and 3, $p>0.05$, where subjects achieved their asymptotic level.

Table I. Means and standard deviations (within parentheses) as a function of treatment and session.

	Session 1	Session 2	Session 3
Pre-treatment	25.89 (17.12)	21.39 (16.37)	19.74 (17.90)
Post-treatment	15.57 (11.40)	13.06 (9.42)	12.41 (8.30)

CONCLUSION: CPAP treatment could reverse cognitive impairment in untreated sleep apnoea pilots and improve their performance.

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PILOT MONITORING TO PREVENT THE SLEEP APNEA SYNDROME AND MAXIMIZE PERFORMANCE

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[1]*Greek Aerospace Medical Association, Thessaloniki, Greece*
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[3]*2nd Regional Healthcare Authority of Central Macedonia, Thessaloniki, Greece*

DATA: Snoring, sleep apnea, and upper airway constricted breathing are common breathing disorders that occur during sleep. It is estimated that between 4% and 7% of the general population have some form of sleep-related breathing disorder. Snoring is the most well known disorder that occurs during sleep. Sleep apnea is a more serious condition associated with complete blockage of the airway causing the individual to stop breathing. In addition to sleep apneas, there is a form of mild interruption of breathing that may appear obstructive called hypopnea. This is an episode of shallow breathing where the airflow is decreased by 50% or more during sleep, lasts for ten seconds or longer, and may be associated with a fall in the blood oxygen level.

Regardless of the condition the potential for a decrease in blood oxygen level and sleep interruption are the basic problems. Usually the oxygen saturation level is around 95%. With sleep disorders, it is not uncommon for the blood oxygen saturation level to reach 80% or lower. This can lead to a serious problem over an entire night and over a prolonged period of time. In addition, the snoring and apnoea can cause a disruption in one's sleep that results in constant interruption called sleep fragmentation. These constant interruptions result in the failure to achieve a restful night's sleep.

Additionally, cardiovascular and cardiorespiratory conditions may be linked to sleep disorders including elevated blood pressure, irregular heart rate, and over prolonged periods, heart attack and stroke.

MATERIALS AND METHODS: The proposed system AviMobi provides a remote monitoring solution for the sleeping disorders, particularly essential in the case of pilots and drivers, for whom prolonged fatigue may result in severe accidents with significant social implications. Via the proposed system the patient is equipped with a wearable oxymeter with wireless transmission capabilities of the oxygen saturation and heart rate measurements. The system continuously transmits data to the Mobinet application where the data is analysed and alarm signals notify the user and the expert when the patient values drop below normal acceptable levels. The system is designed for stress/ fatigue vigilance and wellness monitoring, with the ultimate aim to maximize user performance and minimize error.

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SESSION V: Swallowing, bowel, heart sounds

Session Chair: Shoji Kudoh

AUTOMATED EXTRACTION OF SWALLOWING SOUNDS USING A WAVELET-BASED FILTER

Z. Moussavi and M. Aboofazeli
Department of Electrical & Computer Engineering, University of Manitoba, Winnipeg, Manitoba, Canada

AN AUTOMATED and objective method for extraction of swallowing sounds in a record of the tracheal breath and swallowing sounds was developed in this study. The proposed method takes advantage of the fact that swallowing sounds have more non-stationarity comparing with breath sounds and have large components in many wavelet scales whereas wavelet transform coefficients of breath sounds in higher wavelet scales are small. Therefore, a wavelet transform based filter was utilized in which a multiresolution decomposition-reconstruction process filters the signal. Swallowing sounds are detected in the filtered signal. The proposed method was applied to the tracheal sound recordings of 15 healthy and 11 dysphagic subjects. The results were validated manually by visual inspection using airflow measurement and spectrogram of the sounds and by auditory means. Figure 1, shows a typical swallowing and breath sound signal along with its corresponding spectrogram and airflow; the vertical bars show the detected swallow boundaries by the proposed method in this signal. The method's accuracy was about 93% with only 3% false negative, which is superior to the results of previous methods. Swallowing sound detection may be employed in a system for automated swallowing assessment and diagnosis of swallowing disorders (dysphagia) by acoustical means.

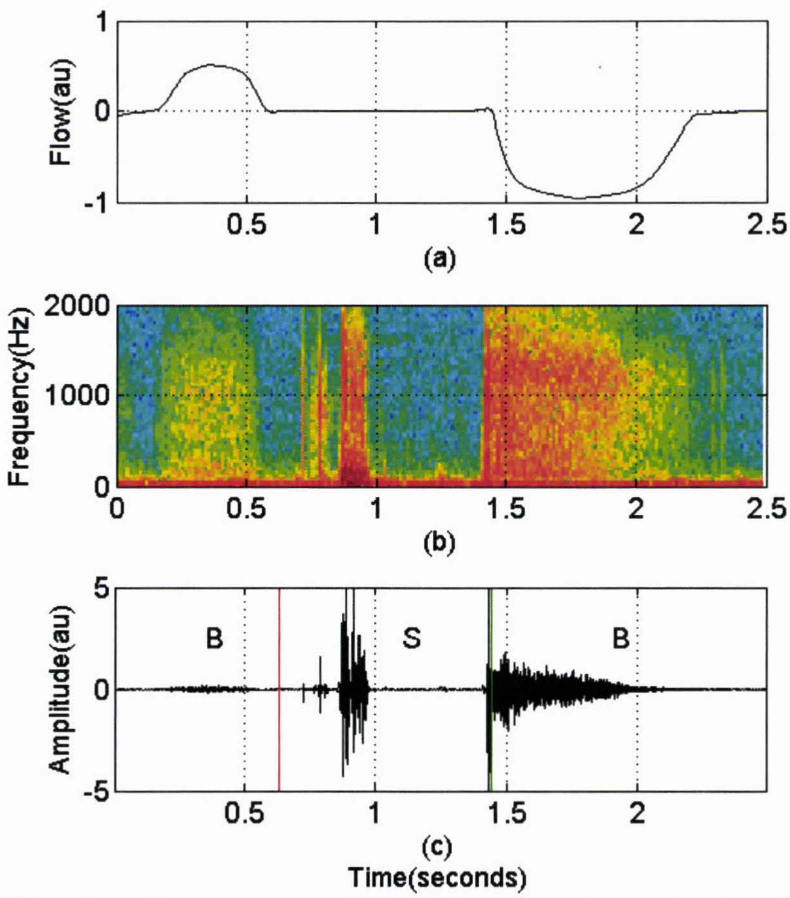

Fig. 1. (a) Airflow signal, (b) spectrogram and (c) tracheal sound waveform as a function of time. Legend: B: Breath Sound, S: Swallowing sound, au: arbitrary units for normalized amplitude, red vertical lines show onset of swallows and green vertical lines show the end of swallowing segments.

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CONTAMINATION OF THE ACOUSTIC RESPONSE OF THE GASTROINTESTINAL TRACT BY LUNG SOUNDS

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INTRODUCTION: It is generally assumed that sounds emitted by the intestine are generated by the content of the bowel passing through the gastrointestinal (GI) tract. Given the complexity of the anatomy of the abdomen, it is difficult to develop an understanding of the relationship between the internal sounds created by bowel content and sounds propagating from the lungs. For example, if a sound is detected in the lower abdominal region, the question could be asked, is that sound a representation of the activity taking place at that precise location in the bowel directly beneath the surface mounted sensor [1], or is it emanating from a source located in the upper chest region?

MATERIALS AND METHODS: Experimental works were carried out to determine the level of cross contamination between lung sounds and gastrointestinal sounds.
The current experiment was designed to identify the separate acoustic signals emitted from the organs in the abdomen and the chest region. The parameters for analysis were set at a frequency spectrum of 7 Hz to 1 kHz.

A quiet and sound proof room was chosen for the measurements. The subject was asked to lie on their back fully stretched out while the data was being recorded. An array of accelerometers (light weight: 3.2 gm sensitivity of 100 mV/g. Endevco Model 256- 10, 100) were placed on the outer surface of the abdomen and chest area.

RESULTS: A comparison of 'low activity' and 'high activity' abdominal and lung sounds over the frequency spectrum was investigated. Typically, low abdominal sound activity occurred below 100 Hz while high abdominal activity occurred between 130 Hz and 280 Hz. Breathing sounds were analysed in a similar fashion using two accelerometers placed over both lungs. The intensity of the vibration created by the normal breathing process appeared to correlate with the response created by the active bowel sound in the low frequency range, below 130 Hz. In the frequency band between 130 Hz and 280 Hz, high abdominal activity displayed amplitudes of 18 dB higher than the lung activity.

DISCUSSION: Results from the experimental work revealed that sounds measured by clinicians on the surface of the abdomen over the GI tract contain a significant portion of lung sounds leading to misdiagnosis particularly in the lower frequency range.

REFERENCE:

[1] J. A. Hession and B. A. O. McCormack, "Modelling the acoustic transmission of biological tissue at low frequencies," *Acoustics Bulletin* 29 (5), pp. 16-20, 2004.

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ACOUSTIC CARDIO-PULMONARY INTERACTIONS

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[2]*Department of Computer Sciences, Tel-Aviv University, Tel-Aviv, Israel*

BACKGROUND: It is well known that breathing affects blood pressure (e.g. "pulsus paradoxus" in asthma) and the splitting of the first (S1) and second (S2) heart sounds. We observed that the amplitude and morphology of S1 and S2 change during the respiratory cycle. We hypothesized that the observed changes are associated with and proportional to the intra-thoracic pressure changes during breathing.

METHODS: Six healthy volunteers breathed freely with open mouth (unloaded, R0) and through four resistive elements (loaded, R1, R2, R3 and R4). Sounds were picked up with PPG sensors with useful frequency range of 2-5000 Hz. The sensors were placed on both parasternal lines and the 4th intercostal space and over the trachea. In addition, the mouth pressure was measured with a calibrated pressure transducer. All data were sampled to the computer for subsequent off-line analysis. Recordings during breath hold were used as control.

RESULTS: The respiratory cycle has a profound effect on the morphology and amplitude of heart sounds. It was found that in normal subjects S2 during the expiratory phase was substantially (up to 4 fold) stronger than at inspiration during loaded respiration (Figure 1). Figure 2 shows the amplitude changes during several respiratory cycles. The effect of intra-thoracic pressure was variable among the subjects.

DISCUSSION: Respiratory-associated intra-thoracic pressure changes affect venous return to the heart, cardiac chamber end diastolic volume, and generated contractile forces. This is reflected in the contraction dynamics and in the acoustic signal that is produced. Noninvasive continuous monitoring of heart sounds may be a possible method for detecting changes in cardio-pulmonary performance in patients.

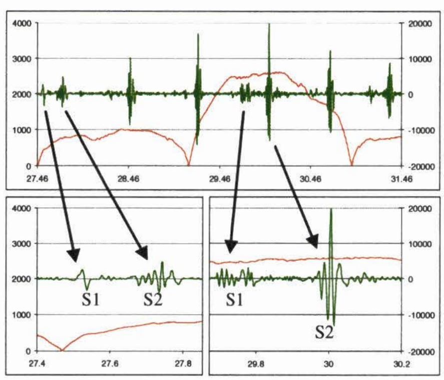

Fig. 1. Heart sounds from left sternal border and rectified mouth pressure (inspiration followed by expiration), top and expanded waveform of two of the heart cycles, bottom. Note the difference in S2 amplitude and the substantial change in appearance (splitting) of S1.

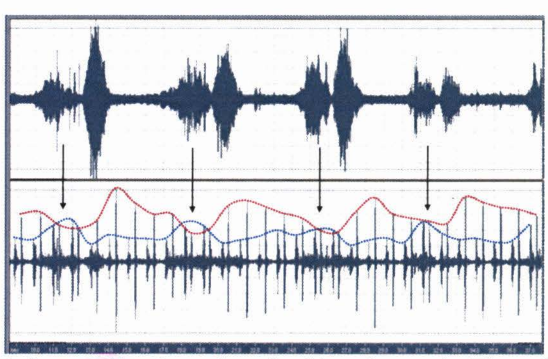

Fig. 2. Heart sounds from left sternal border and tracheal breath sounds. The red line connects S2s and the blue line connects S1s. Note the opposite changes in amplitude of S1 and S2 with the breathing cycle.

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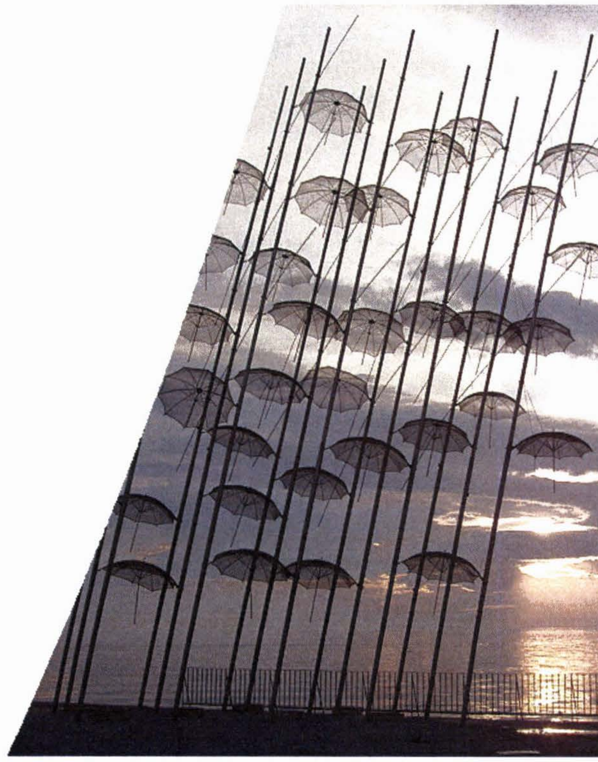
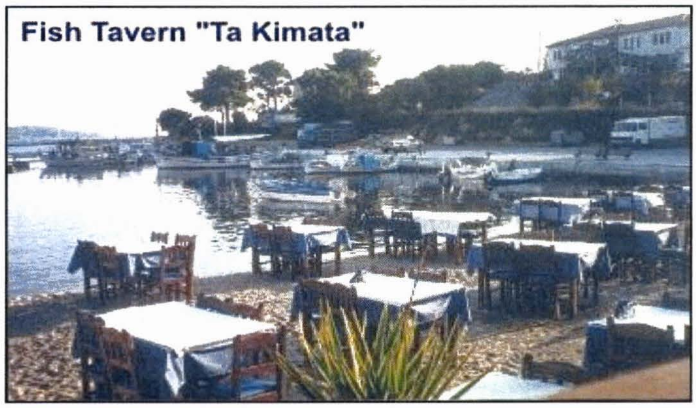
SOCIAL PROGRAM



SOCIAL EVENTS

Thursday, September 7th, 2006, 8:00 pm

Welcome OUZO dinner at the traditional fish tavern in Neos Marmaras 'Τα Κύματα' (The Waves). Transportation by small boat from the Porto Carras Grand Resort Meliton marina (10 mins). This family owned tavern has been operating since 1950 and offers fresh local fish, choice seafood and superior quality.



Friday, September 8th, 2006, 7:30 pm

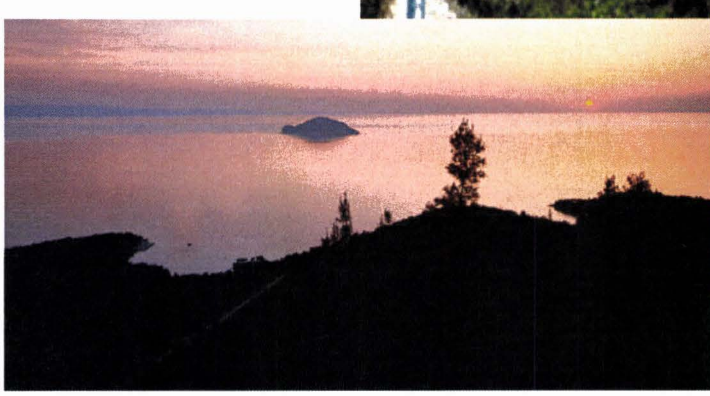
Full moon cruise and dinner on a boat board. Sailing starts from the Porto Carras Grand Resort Meliton marina.

Saturday, September 9th, 2006, 6:00 pm

Conducted tour to the Porto Carras Winery for testing a variety of local wines. Transportation by an internal train from the Porto Carras Grand Resort Sithonia. The winery is one of Greece's most modern wineries and was built amid the rolling vineyards, capable of producing 2,500 tons of white, rose and red wine per year.

Saturday, September 9th, 2006, 7:30 pm

Dinner at the traditional village 'Παρθενών' (Parthenon) (20 mins from the hotel by bus) with a magnificent view of the Halkidiki legs and a beautiful sunset.

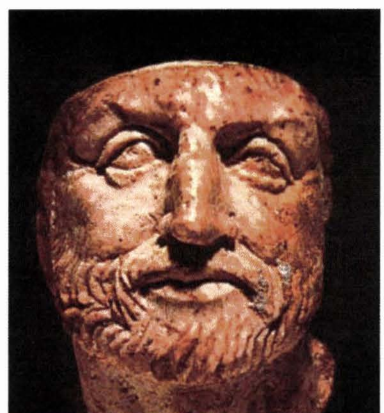


Saturday, September 9th, 2006, 10:00 pm

Porto Carras Casino night! (inside the hotel).

Sunday, September 10th, 2006, morning (optional)

Excursion to Philip's Tomb (Alexander the Grate's father), which will take place after the departure from Porto Carras (10:00 AM). The Tomb is situated in 'Βεργίνα' (Vergina) village, approximately 55 mins from Thessaloniki. Evening events in Thessaloniki will follow the excursion.



Note: Detailed information about the social events will be provided to the participants during the conference.