Original paper

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An evaluation of cough-generated sound and body surface vibration by the MEPIM Vibroacoustic System of Cough Registration (MEPIM VSCR)

Abstract

Background. Cough is one of the most common symptoms in chronic pulmonary disease and cancer but we are still lacking a practical and accurate method for its objective evaluation. The aim of our experiment was to determine a new method of objective cough measurement using the time domain and a spectral analysis of body surface vibration and cough-generated sound.

Methods and Results. Our MEPIM Vibroacoustic System of Cough Registration is based on the simultaneous measuring of body surface vibration and generated sound. An acceleration sensor is fixed to the chest wall of the patient, while a microphone is positioned at a distance of 1 m. The analysis of sound and body surface vibration is carried out by a multianalyzer B&K Pulse. We introduced the FFT analysis of the frequency content of both signals and the measurement of the cross-correlation of sound and vibration signals.

Conclusions. The implementation of spectral analysis techniques may improve our abilities to define cough. Further clinical study should be conducted to answer the question of whether analysis of the frequency band might be useful for defining cough among other events.

Key words: cough, MEPIM Vibroacoustic System of Cough Registration, Fast Fourier Transform, accelerometer, spectral analysis

Introduction

Cough is the main symptom in COPD, asthma and lung cancer. As its subjective reporting is unreliable, several systems for objectively monitoring cough have been developed. However, those based on video or tape-recorder signal registration were only able to operate for a short time [1–11] or appeared to be time-consuming even with the application of sound-activated device recording or methods for removing silence [12–14]. Newer systems register sound either alone, by the use of a portable MP3 player/recorder [15–17], or in combination with a second signal such as movements of the diaphragm or other respiratory muscles detected by an accelerometer, respiratory inductance plethysmography

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[18], or electromyography (EMG) [19–23]. According to the guidelines of the American College of Chest Physicians (ACCP) and the European Respiratory Society (ERS), treatment efficacy for chronic respiratory diseases should be assessed by an objective method of cough monitoring [24, 25]. What is more, the use of ambulatory cough analyzers should not be limited to research but be introduced in clinical practice, especially if symptomatic treatment is the main or only goal. Therefore, the equipment should be portable, lightweight, simple to use and apply, acceptable to the patient and highly reliable. This last requirement considers the differentiation between cough and non-cough sounds and the elimination of extraneous noise [26–30].

Here we are describing the MEPIM Vibroacoustic System of Cough Registration (MEPIM VSCR) based on the simultaneous use of microphone and accelerometer with the implementation of a spectral analysis of the frequency characteristics of both signals.

Description of the measuring system

Device and scheme of the MEPIM VSCR

The analysis of sound and body surface vibration is performed by a multianalyser Brüel&Kjaer type 3560 Pulse with B&K LabShop software, microphone Brüel & Kjaer type 4145, wide range measuring amplifier Brüel&Kjaer type 2610, and an accelerometer Brüel&Kjaer type 4507.

The acceleration sensor is applied to the chest wall on the lower-third part of the sternum and attached by a sticking plaster. The microphone is located at a distance of 1 m from the patient **(Figure 1).**

Methods of cough evaluation

We based the evaluation of cough on an analysis of:

— the amplitude of sound and body surface vibration over time;

— the Fast Fourier Transform (FFT) of vibration and sound frequency;

— the cross-correlation of sound and vibration signals.

Time data recording is implemented for specifying amplitude and time dependencies both for sound and body surface vibration. However, the signal frequency bandwidth is determined by the FFT [31].

In 1882 Jean Baptiste Joseph Fourier discovered that any periodic function could be represented as an infinite sum of periodic complex exponential functions [31]. As the rule was extended to any discrete time function, the so-called Fourier Transform converts a signal expressed in the time domain to one expressed in the frequency domain. The FFT is an efficient algorithm to compute the Fourier Transform, which is widely used in digital signal processing.

Thus FFT provides an understanding of the frequency contents of the signal related to body surface vibration and sound. **Figure 2** presents the differences between laugh and cough, the latter exhibiting a wider frequency band both for sound and vibration.

Lastly, we implemented the measuring of the cross-correlation of sound and vibration signals to exclude the signals from other sources **(Figure 3)**. As the distance between microphone and accelerometer is 1 m and the sound velocity in the air is

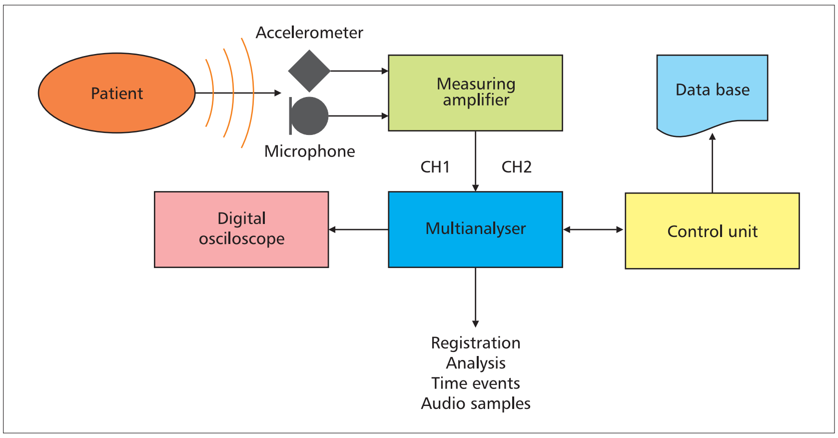

Figure 1. The MEPIM Vibroacoustic System of Cough Registration (MEPIM VSCR). CH1 — the body surface vibration signal channel; CH2 — sound signal channel

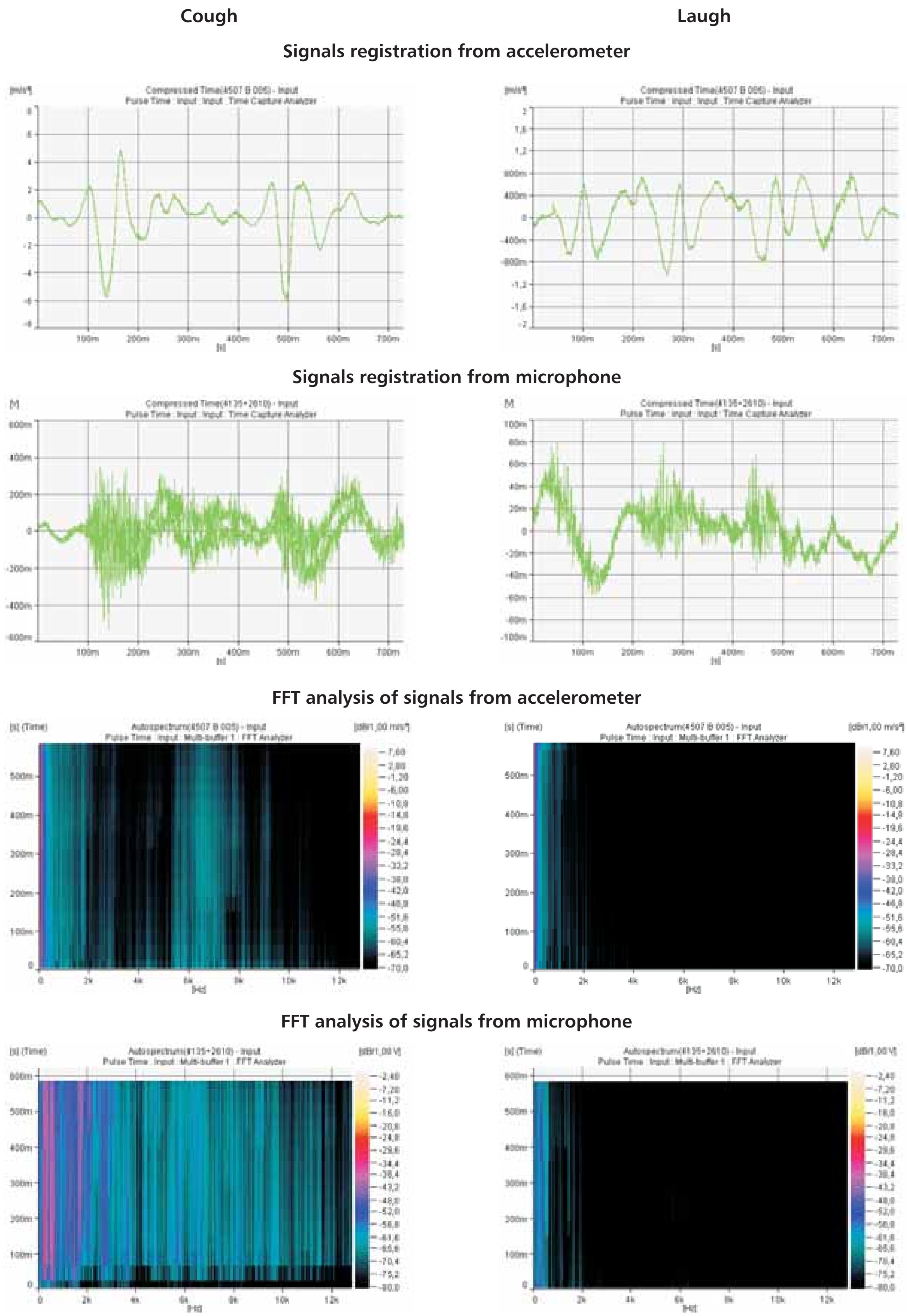

Figure 2. The registration and analysis of cough- and laugh-related sound and body surface vibration as the amplitude in real time and Fast Fourier Transform

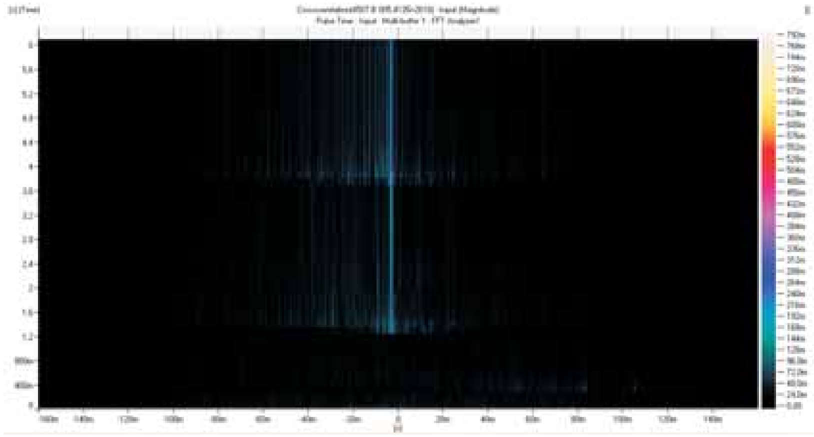

Figure 3. The measurement of the cross-correlation of sound and vibration signals

340 m/s, we assumed the time difference between signals from microphone and accelerometer to be equal to 3 ms. This demonstrated unequivocally that the incident under consideration came from the patient examined. Allowing for differences in the sensors' performance and their characteristics, the cross-correlation coefficient of examined incidents attained 0.4 ÷ 0.5 maximum.

Discussion

According to the ERS definition, cough should be described as a forced expulsive manoeuvre or manoeuvres against a closed glottis that are associated with a characteristic sound or sounds (25). The sound results from rapid changes in airflow generated by the contraction of muscles in the chest wall, abdomen, diaphragm and larynx. To improve cough identification we created the MEPIM Vibroacoustic System of Cough Registration (MEPIM VSCR) based on the sound acoustic and body surface acceleration vibratory properties of cough. We tried to solve two common problems in the field of objective cough detection: firstly, how to exclude signals originating from other sources and eliminate extraneous noise; secondly, how to distinguish a cough from other signals originating from the same patient. We overcame the first barrier by the implementation of measuring the cross-correlation of sound and vibration signals, and the second by introducing the FFT analysis of the frequency content of both signals. The FFT is used extensively in a wide range of digital signal processing applications, including spectrum analysis, high-speed convulsion, filter banks, signal detection and estimation, system identification, audio compression, and spectral modelling sound synthesis. FFT analyzers are, therefore, incorporated in the assessment of the acoustics of musical instruments [32], solid drug dispersion in pharmacy [33], or nucleotide sequence searches in molecular biology [34]. Recently, the FFT has begun to be widely applied to clinical medicine, especially in cardiology for the QRS complex of surface ECGs [35], or cardiac sound analysis [36, 37], and to radiology, especially in magnetic resonance imaging [38, 39]. Vrabec et al. [40], Olia et al. [41] and Korpas et al. [42] also utilized FFT to estimate the cough-related sounds spectrum. As far as we can ascertain, we are the first team to have introduced the FFT analysis of concomitant sound and body surface vibration to determine the frequency component of both signals generated by cough. In future clinical studies, we will challenge the idea that analysis of the frequency band will improve the specificity of cough determination. We believe our MEPIM Vibroacoustic System of Cough Registration (MEPIM VSCR) is an important step towards the introduction of an appropriate device into everyday clinical practice.

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