Automatic Wheeze and Respiratory Phase Detectors to Evaluate Respiratory Physiotherapy in LRTI

A Preliminary Study

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Abstract: Respiratory physiotherapy is a gold standard intervention for chronic respiratory conditions. However, its application in acute respiratory diseases (e.g., LRTI) is not well established. The objective and reliable measurement of adventitious lung sounds (ALS), such as wheezes, has the potential to contribute to respiratory physiotherapy evidence base. This paper reports on the implementation of reliable and published automatic wheeze and respiratory phase detectors to assess wheezing parameters pre/post respiratory physiotherapy treatment in patients with LRTI. Twenty patients with LRTI were randomly allocated to control group, which received standard medication treatment, or experimental group, which received standard medication plus respiratory physiotherapy treatment. Respiratory sounds were recorded in seven chest locations. Wheeze parameters, namely occupation rate, main frequency, duration and type were obtained per respiratory phase. Wheeze occupation rate was statistically significantly reduced in both groups following treatment ($p<0.001$). There was a greater reduction in wheeze occupation rate in the experimental group reaching statistical significance for the inspiratory phase ($p=0.019$). This promising result indicates the potential value of respiratory physiotherapy in LRTI. It also highlights the potential to use acoustic methods to establish respiratory physiotherapy efficacy.

1 INTRODUCTION

Lower respiratory tract infection (LRTI) covers a wide range of diseases from a mild mucosal colonisation or infection, an acute exacerbation of chronic bronchitis/chronic obstructive pulmonary disease (COPD), to an overwhelming parenchymal infection such as community acquired pneumonia (CAP) (Woodhead et al., 2011).

It is estimated that the annual incidence of adult people with LRTIs consulting healthcare providers ranges from 8-124 per 1000 population in Europe (Ward and Ayres, 2000) and more than 5 million cases of CAP occur annually in the United States of America, especially in the winter months (Graham, 2008). Any age group can be affected however, LRTI is more common in those under 5 and above 45 years old (Graham, 2008).

Respiratory physiotherapy has been recognised as an important component in the treatment of respiratory patients. Evidence of benefit has been demonstrated in chronic respiratory conditions (Garrod and Lasserson, 2007). However, there is a need to establish efficacy in acute respiratory diseases (e.g., LRTI).

It is widely accepted that adventitious lung sounds (ALS), namely crackles and wheezes, contain important information about pulmonary dysfunctions (Laennec, 1935). Wheezes have been the most common type of ALS investigated for diagnostic purposes using the stethoscope (Earis and Cheetham, 2000).

Wheezes are pitch-based sounds sustained for longer than 100 ms with frequencies above 100 Hz. It can be classified as monophonic (single frequency) or polyphonic (multiple frequencies) and occur mostly during expiration, however they can also be heard during inspiration in more severe cases (Sovijärvi et al., 2000). This ALS can be heard in several diseases involving narrowing of airway calibre (Meslier et al., 1995). Although COPD and asthma are the main respiratory diseases presenting

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wheezes (Waris et al., 1998), this type of ALS also contributes to the diagnosis and monitoring of LRTI (Woodhead et al., 2011).

According to the European Respiratory Society (ERS) guidelines (Charbonneau et al., 2000), the percentage of the respiratory cycle occupied by wheezes is of special interest - the higher the percentage the more severe the disease is (Sovijärvi et al., 2000). Previous studies have shown an association between the degree of bronchial obstruction and the proportion of the respiratory cycle occupied by wheezing (Baughman and Loudon, 1984). However, additional measurements such as the number of wheezing peaks, their main frequencies, duration, timing in respiratory cycle and location of the recording (chest wall or trachea) can also be relevant and should be calculated if possible (Piirilä et al., 2000). In order to address these parameters an automatic acoustic approach is desirable.

Several algorithms have been proposed to detect wheeze parameters (Taplidou and Hadjileontiadis, 2007); (Qiu et al., 2005) and respiratory phases (Huq and Moussavi, 2010); (Yildirim et al., 2008). Taplidou and Hadjileontiadis' (2007) algorithm has been reported as the one with the best performance (Oliveira et al., 2011). For respiratory phase detection, Huq and Moussavi's (2010) algorithm is the most recent and overcomes limitations reported by previous studies.

Therefore, this paper reports on the implementation of a reliable and published automatic wheeze and respiratory phase detectors to assess wheezing parameters pre/post respiratory physiotherapy treatment in patients with LRTI.

2 METHODS

A randomised controlled trial was conducted. Ethical approval was obtained from the Ethics Committee of Hospital Infante D. Pedro, Aveiro, Portugal.

2.1 Procedures

Patients were eligible for the study if they presented with cough and at least one of the following symptoms: sputum, dyspnoea, wheezes or chest pain (Woodhead et al., 2011), at the emergency department of the Hospital Infante D. Pedro (Aveiro, Portugal). Twenty participants (10 males) diagnosed with LTRI by the physician, according to the LRTI guidelines (Moher et al., 2010); (Woodhead et al., 2011), were recruited for the study. A simple randomisation (Moher et al., 2010) was use to allocate patients to the control group or experimental group.

The control group was treated with standard medication, i.e. antibiotics, and the experimental group received the same standard medication plus respiratory physiotherapy for acute respiratory conditions. A physiotherapy protocol was carried out three times per week (British Thoracic Society, 2001) for 3 weeks (Woodhead et al., 2011) accomplishing a total of 9 sessions. Each session lasted on average 90±15 minutes (American College of Sports Medicine, 2006). The intervention protocol consisted of: i) breathing retraining techniques to reduce energy costs of breathing and dyspnoea (American College of Sports Medicine, 2006); ii) inspiratory techniques such as incentive spirometry to increase pulmonary expansion (Weiner et al., 1997), prevent atelectasis and aid at sputum clearance (Postiaux, 2004); iii) airway clearance techniques such as the active cycle of breathing to mobilize and clear excess bronchial secretions (Pryor and Prasad, 2008); iv) exercises for thoracic mobility, expansion and flexibility to increase pulmonary volumes; v) aerobic training (walking and cycling) at 60-80% of the patient maximal cardiac frequency to increase tolerance to physical activity and improve the physical fitness of the patient (American Association of Cardiovascular and Pulmonary Rehabilitation, 2006), vi) educational support about the disease and lifestyles to ensure on going effective intervention and to provide the patient with some control over the disease and vii) prescription of home exercises.

All treatment sessions were held in a well-equipped room at University of Aveiro.

2.2 Data Collection

Data were collected by two researchers in a clinical setting within 24 hours of hospital presentation and after 3 weeks of treatment, the time taken to recover from a LRTI (Woodhead et al., 2011).

2.2.1 Demographic, Anthropometric and Lung Function

Demographic and anthropometric data was first collected (height and weight to calculate the body mass index). Lung function evaluation involved the collection of forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) with the spirometer MicroLab Micro Medical 36-ML3500-

MK8, UK, following the ERS guidelines (Miller, 2005).

2.2.2 Respiratory Sounds

Respiratory sound recordings were performed according to the Computerized Respiratory Sound Analysis (CORSA) guidelines for short-term acquisitions, in a clinical room, i.e., participants were in a seated-upright position and lung sound data was collected using seven modified analogue stethoscopes (Classic II S.E., 3M™ Litman®, St. Paul, MN, USA). Each stethoscope was attached to the body using an adhesive tape (Leukosilk®, BSN Medical GmbH, Hamburg, Germany) in seven chest locations, i.e., trachea, left and right anterior, lateral and posterior regions. Respiratory sounds were collected by custom-made microphone and preamplifier circuit (Intelligent Sensing Anywhere®, Coimbra, Portugal) inserted into the main tube of each stethoscope. The resulting analogue signals were further amplified and converted to digital by a multi-channel audio interface (M-Audio® ProFire 2626, Irwindale, CA, USA). The signal was converted with a 24-bit resolution at a sampling rate of 44100 samples per second in each channel and recorded in wave format on a laptop computer. A diagram of the recording setup is shown in figure 1.

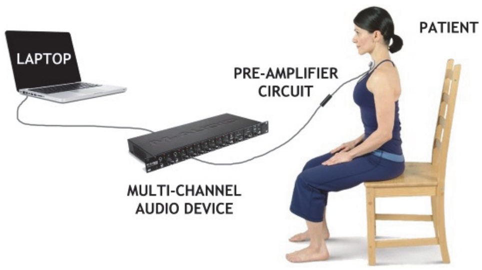

Figure 1: Diagram of the recording setup for one stethoscope.

The average time between the first (pre-treatment) and the second respiratory sound recording session (post treatment) was 22.0±8.8 days for the control group and 22.8±3.1 for the experimental group. Three repetitions per participant (20 seconds each) were performed in each time.

2.3 Automatic Detection Algorithms

Taplidou and Hadjileontiadis (2007) automatic wheeze detector and Huq and Moussavi (2010) automatic respiratory phase detector were implemented, as they have been shown to be reliable (overall performance of 94.6% (2007) with an accuracy of 93.1% (2010)). The combination between these two algorithms allowed the calculation of the wheeze occupation rate in each respiratory phase (i.e., inspiration, expiration) of the recorded signals.

The following sections present a brief description of these algorithms.

2.3.1 Wheeze Detection Algorithm

Wheezes were detected using the algorithm described by Taplidou and Hadjileontiadis (2007). This algorithm is based on the Short-time Fourier transform (STFT), proposed by Gabor (Gabor, 1946), which is a classical method for analysing non-stationary signals. This technique is a Fourier-related transform used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. The Fourier transform of the resulting signal is taken as the window is slid along the time axis, resulting in a two-dimensional representation of the signal, where $x(t)$ is the signal and ω denotes the spectral window.

$$\mathrm{STFT}\{x(t)\} \equiv X(\tau,\omega) = \int_{-\infty}^{+\infty} x(t).\omega(t-\tau)e^{-j\omega t}dt$$

In the implemented algorithm, the signal is digitally filtered (band pass 60-2100Hz, order-8 Butterworth) and resampled (to $5512\mathrm{s}^{-1}$) before the STFT calculation. To remove noise from the STFT signal, a smoothing procedure based on box filtering, also known as mean-filtering, estimates the trend of the frequency content of the windowed signal at each time instant. Peaks higher than a specific magnitude threshold are then selected. These peaks are then classified as wheezes or non-wheezes according to a set of criteria that include local maxima, peak coexistence and continuity in time.

The algorithm allowed the calculation of different parameters, e.g., starting and ending time as well as fundamental frequency of each detected wheeze. It was also possible to classify the wheeze according to its type (monophonic or polyphonic).

2.3.2 Respiratory Phase Detection Algorithm

For the respiratory phase detection, an algorithm using only tracheal sounds was implemented (Huq and Moussavi, 2010). Because of the synchronized multi-channel acquisition, the detected phases and onsets on the tracheal sounds were used to calculate the wheeze occupation rate in the other six places, where the acoustic signal was acquired.

Similarly to the wheeze detector algorithm, the signal was firstly digitally filtered (band pass 150-800Hz, order-10 Butterworth filter) and resampled (to 10240 s^{-1}). The selected filtering band was used to minimise the effect of heart sounds and high frequency noises. In this algorithm, several parameters were collected from the duration, volume and shape of the tracheal breath sound envelope in each phase. For this purpose the logarithmic variance (LV) of the filtered sound signals was calculated. As the LV of the breath sounds resemble a fully rectified flow signal, respiratory onsets (i.e., starting sample of a respiratory phase) can also be detected. Using the majority-vote of parameters between adjacent phases, they can be classified as inspiration or expiration.

2.4 Statistical Analyses

Statistical analysis was conducted using SPSS® 19.0. Differences between parameters in the first (pre-treatment) and the second respiratory sound recording (post treatment) were explored with paired samples T-test. Wheeze occupation rate (R), main frequency (F) and type of wheeze (T) evaluated on both inspiratory and expiratory phase recordings were analysed. R value was established in the range zero to one (where 0 was given when no wheezes were detected and 1 when the respiratory phase was fully occupied). The T was classified as 0 if monophonic or as 1 if polyphonic.

Statistically significant differences between groups (control vs. experimental group) at each parameter assessed on pre and post treatment was explored to evaluate the impact of the respiratory physiotherapy. For this purpose also an independent samples T-test analysis was performed.

Data were expressed as mean and standard deviation (Mean±SD). Significance level was set at $p<0.05$.

3 RESULTS

A total of twenty participants (10 males) diagnosed with LTRI enrolled in this pilot study. Eleven patients (4 males) composed the control group while the experimental group was composed by 9 patients (6 males). The sample is characterised in Table 1.

Paired sample t-test results for pre-post treatment analysis on control and experimental groups are present in Table 2. A statistically significant decrease was observed in both inspiration and expiration wheeze occupation rate in both groups.

Table 1: Sample characterisation.

	Age (yrs)	BMI (kg/m^2)	FVC$_{PP}$ (%)	FEV$_{1\text{-}PP}$ (%)
CG	52.9 ± 18.3	26.1 ± 5.2	75.7 ± 21.6	72.2 ± 29.8
EG	49.9 ± 23.2	23.4 ± 4.6	62.6 ± 25.9	62.2 ± 29.0
T	56.0 ± 13.7	24.9 ± 4.9	69.8 ± 23.9	67.7 ± 28.2

CG – Control group; EG – Experimental group; T- Total; BMI – Body mass index; FVC$_{PP}$ – percentage predicted of forced vital capacity; FEV$_{1PP}$ – percentage predicted of force expiratory volume in 1 second.

The difference in wheeze occupation rate between both studied groups is presented in Table 3.

A superior reduction in occupation rate in both inspiratory and expiratory respiratory phases (figure 2), after physiotherapy treatment was observed, reaching statistical significance for the inspiratory phase ($p=0.019$).

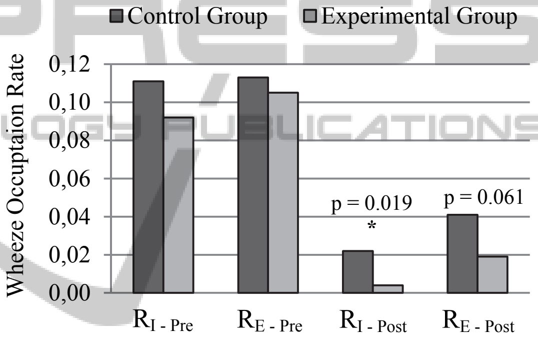

Figure 2: Wheezes occupation rate differences between control and physiotherapy groups. Significance level set to $^{*}p<0.05$.

4 DISCUSSION

The combination between different algorithms contributes to establish objective measures to assess the effect of respiratory physiotherapy in patients with acute respiratory diseases (e.g., LRTI).

The values collected at baseline for FEV1$_{pp}$ (67.7 ± 28.2) and FVC$_{pp}$ (69.8 ± 23.9) were lower than those previously reported for patients with LRTI. Melbye et al. (1994) found that FEV1$_{pp}$ in patients with upper or lower respiratory tract infection was 90% of the predicted value, however various factors could affect this value, such as cough, dyspnoea and smoking habits. Such factors were highly prevalent in the present sample. Furthermore, in the study of Melbye et al. (1994) the spirometry test was performed in the standing position while in the present study patients presented with severe symptoms of pain, cough and dyspnoea and were instructed to perform the test in the sitting position,

Table 2: Paired sample t-test results for pre-post treatment analysis on control and experimental groups.

	Control Group				Experimental Group			
	Pre	*Post*	*p*	*t*	*Pre*	*Post*	*p*	*t*
R_I (%)	0.111 ± 0.148	0.022 ± 0.062	*< 0.001*	5.462	0.092 ± 0.141	0.004 ± 0.019	*< 0.001*	4.777
R_E (%)	0.113 ± 0.132	0.041 ± 0.077	*< 0.001*	4.392	0.105 ± 0.153	0.019 ± 0.054	*< 0.001*	4.402
F_I (Hz)	241.3 ± 60.1	415.5 ± 201.1	0.195	-1.554	360.3 ± 221.1	1402 ± 1531	0.555	-0.841
F_E (Hz)	221.2 ± 85.6	396.8 ± 208.1	0.243	-1.368	423.2 ± 168.6	432.8 ± 269.1	0.915	-0.111
T_I (%)	0.050 ± 0.111	0.032 ± 0.074	0.374	1.000	0.083 ± 0.117	0.000 ± 0.000	0.500	1.000
T_E (%)	0.107 ± 0.220	0.106 ± 0.301	0.999	0.001	0.238 ± 0.224	0.142 ± 0.377	0.652	0.475

R - wheeze occupation rate; F - main frequency; T - type of wheeze. Subscript I and E stand for inspiration and expiration, respectively. Significance level set to $p<0.05$.

which could also have affected the test performance.

Table 3: Paired sample t-test results for the two groups.

	CG	EG	p	t
$R_{I\text{ - Pre}}$	0.111 ± 0.148	0.092 ± 0.141	0.455	0.618
$R_{E\text{ - Pre}}$	0.113 ± 0.132	0.105 ± 0.153	0.749	0.282
$R_{I\text{ - Post}}$	0.022 ± 0.062	0.004 ± 0.019	*0.019*	2.762
$R_{E\text{ - Post}}$	0.041 ± 0.077	0.019 ± 0.054	0.061	1.907

CG - Control group; EG - experimental group; R - wheeze occupation rate; Subscript I and E stand for inspiration and expiration, respectively. Significance level set to $p<0.05$.

There were no significant differences in inspiratory and expiratory wheezes occupation rates pre-treatment. This shows that both studied groups were similar in terms of wheezes parameters at baseline assessment.

The results of pre/post treatment analysis (table 2) showed significant statistical decrease in both inspiratory and expiratory wheeze occupation rate for control and experimental groups. This was an expected outcome, because both groups received, at least, standard medication treatment i.e., antibiotics. The experimental group, which received respiratory physiotherapy, presented a significantly lower inspiratory wheeze occupation rate ($p=0.019$) and a pattern of decreased expiratory wheeze occupation rate ($p=0.061$). As previously stated by Sovijärvi et al., (2000), more severe cases of respiratory infection can also present wheezes in the inspiratory phase. The sharp decrease on inspiratory wheeze occupation rate seems to suggest that the respiratory physiotherapy plays an important role on patients with more severe conditions. Another result that supports this theory is the non-existence of inspiratory polyphonic wheezes post-treatment in the experimental group, and, although not statistically significant, a sharp decrease in the expiratory polyphonic wheezes.

5 CONCLUSIONS

This study suggests that by combining respiratory physiotherapy with the standard medical therapy more effective results in the reduction of respiratory wheeze can be achieved in patients with LRTI. Furthermore, the use of wheeze and respiratory phase detectors appears to be a responsive measure to evaluate the efficacy of treatments in LRTI. Further research to assess responsiveness with a larger sample is nevertheless needed.

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