Automatic Wheeze Detection and Lung Function Evaluation
A Preliminary Study

Ana Oliveira[1], Cátia Pinho[1,2], João Dinis[1,2], Daniela Oliveira[1] and Alda Marques[1]
[1]*School of Health Sciences, University of Aveiro (ESSUA), Campus Universitário de Santiago, Aveiro, Portugal*
[2]*Institute of Electronics and Telematics Engineering of Aveiro (IEETA), University of Aveiro, Campus Universitário de Santiago, Aveiro, Portugal*

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Abstract: The automatic detection of wheeze offers the potential for diagnosing and monitoring respiratory diseases, e.g., lower respiratory tract infection (LRTI). By determining the relationship between wheeze detection and other lung function data, it is possible to develop a more sensitive tool for detecting respiratory conditions. This pilot study aimed to: i) explore the robustness of a time frequency wheeze detector (TF-WD) and ii) describe the correlation between wheezing and spirometry parameters. Lung sounds and spirometry parameters were acquired from six outpatients with LRTI (five with right lung infection). Number, fundamental frequency and duration of wheezes were obtained through a TF-WD algorithm. The performance of the TF-WD algorithm was evaluated by comparing its findings in 40 files with those annotated by two experts. Results suggest that the TF-WD algorithm is an efficient and robust method for computerised wheeze detection in LRTI (SE=72.5%; SP=99.2%). Furthermore, significant correlations were found between the percentage predicted of forced expiratory volume in 1 second and forced vital capacity (FEV_1pp and FVCpp) and wheeze duration at lateral (rs=-0.9, p=0.03) and posterior (rs=-0.9, p=0.01) right regions respectively. These results support the use of pulmonary auscultation and spirometry to detect areas of obstruction in LRTI.

1 INTRODUCTION

Lower respiratory tract infection (LRTI) are among the most common infectious diseases, with an annual incidence of approximately 429 million cases worldwide (World Health Organization, 2008).

Currently, health professionals use respiratory function tests, such as spirometry and standard pulmonary auscultation to diagnose and monitor patients with these respiratory conditions (Marques et al., 2006). However, standard auscultation has been reported as a subjective process (Sovijärvi et al., 2000) and therefore, many research efforts are being conducted to automatically detect, quantify and characterise respiratory sounds (Dinis et al., 2012).

Wheezes have been the most common type of ALS investigated for diagnostic purposes, using the stethoscope (Earis and Cheetham, 2000). They are clinically defined as musical sounds characterised by their location, intensity, pitch (frequencies above 100Hz) and duration (longer than 100 ms) (Sovijärvi et al., 2000). These respiratory sounds can be classified as monophonic or polyphonic, and are mainly associated with diseases that structurally involve the narrowing of airway calibre such as bronchospasm or airway obstruction (Meslier et al., 1995). Their presence have proved to have a significant contribution in the diagnosis and monitoring of LRTI (Paciej et al., 2004). Taplidou and Hadjileontiadis (2007) wheeze detection algorithm has been shown to be reliable and valid for cystic fibrosis (Oliveira et al., 2011), however it requires further validation for different respiratory diseases.

It has been suggested that the combination of spirometry with computer aided lung sound analysis increases the sensitivity for detecting early signs of respiratory diseases (Marques et al., 2009), however this fact needs to be investigated.

This preliminary study aimed to explore the robustness of a TF-WD algorithm and describe the correlation between wheezing and spirometry parameters in patients with LRTI.

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2 METHODS

2.1 Participants

Participants were eligible for the study if they presented at the emergency department of the Hospital Infante D. Pedro, (Aveiro, Portugal) with cough and at least one of the following symptoms: sputum, dyspnoea, wheezes or chest pain, according to the guidelines for the diagnosis of LRTI (Woodhead et al., 2011) and were ≥18 years old. Ethical approval was obtained from the Ethics Committee of Hospital Infante D. Pedro. All participants gave written informed consent prior to any data collection.

2.2 Data Collection

Data were collected by two researchers in a clinical setting within 24 hours of hospital presentation. Socio-demographics and anthropometric data were collected first. Then, respiratory sound recordings for short-term acquisitions were performed according to the Computerized Respiratory Sound Analysis (CORSA) guidelines (Rossi et al., 2000), i.e., participants were in a seated-upright position and lung sound data was collected with a digital stethoscope (Thinklabs® Rhythm: ds32a, Colorado, US) in seven chest locations (trachea, left and right: anterior, lateral and posterior). Respiratory sounds were recorded three times for each location with 25 seconds duration each to assure that 7-10 respiratory cycles were recorded (Rossi et al., 2000). Finally, forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC) and peak expiratory flow (PEF) were acquired with the spirometer MicroLab Micro Medical 36-ML3500-MK8, UK, following the European Respiratory Society guidelines (Miller, 2005).

Patients received standard medical treatment for LRTI and after three weeks, the time taken to recover from a LRTI (Woodhead et al., 2011), all the pre intervention measurements were repeated.

2.3 Wheeze Detection

Wheezes were detected using the algorithm described by Taplidou and Hadjileontiadis (2007). This algorithm is based on a time-frequency analysis technique: the Short-time Fourier transform (STFT), proposed by Gabor (1946). In the implemented algorithm, the signal was digitally filtered (band pass 60–2100Hz, order-8 Butterworth) and resampled (to $5512s^{-1}$) before the STFT calculation. To remove noise from the signal, a smoothing procedure based on box filtering, also known as mean-filtering, was applied. Peaks higher than a specific magnitude threshold were then selected and classified as wheezes or non-wheezes, according to a set of criteria that includes: local maxima, peak coexistence and continuity in time (Taplidou and Hadjileontiadis, 2007). For each wheeze duration and fundamental frequency were obtained.

2.4 Algorithm Robustness Evaluation

Sounds annotation by respiratory experts is the most common and reliable method to assess the robustness of algorithms to detect ALS (Guntupalli et al., 2008). Nevertheless, annotation is a time–consuming process, being difficult to conduct in a large amount of sound files. To overcome this difficulty, 40 respiratory sound files were randomly selected from a total of 252, through a simple randomisation. Two respiratory physiotherapists, with experience in visual-auditory wheeze recognition, independently annotated the selected sound files in terms of presence, number and duration of wheezes. For the annotation, the Respiratory Sound Annotation Software v1.1 was used (Dinis et al., 2012).

2.5 Statistical Analysis

The robustness evaluation of the algorithm was obtained by comparing its wheeze detection with the assessment of the two expert respiratory physiotherapists. Cohen's kappa coefficient was used to assess the inter-rater agreement between the physiotherapists. The performance of the TF-WD algorithm was calculated through the sensitivity (SE) and specificity (SP) of the algorithm. True positives/negatives and false positives/negatives were counted by comparing each point of the sound file.

The univariate relationships between gender and the participants' individual characteristics were examined by the Mann–Whitney U-test. Differences between calculated parameters in the first (base) and the second acquisition (post) were explored with paired sample t-test or Wilcoxon Signed Ranks test when the data did not follow a normal distribution.

Spearman's correlation coefficient was used to correlate number, duration and fundamental frequency of wheezes with spirometry parameters.

Data were expressed as number, mean and standard deviation (Mean±SD). Analysis was performed using PASW® Statistics 18.0 software (SPSS Inc, Chicago, IL, USA) and Matlab®R2009a (The MathWorks, Inc, Natick, MA, USA). Significance level was set at $p<0.05$.

3 RESULTS

The proportion of agreement between the two physiotherapists was very good (k=0.804). The SE of the automated method was 99.2%, SP was 72.5% and the performance was 84.8%. The total number of wheezes detected by the algorithm was 37 at baseline and 89 at post treatment.

Six participants (three males) diagnosed with LRTI enrolled in this pilot study, five of whom presented the focus of the infection in the right lung. Their characteristics are summarised in table 1. The sample at baseline was generally homogeneous.

Table 1: Sample characterisation.

Variables	Base	Post	p
Patients (n)	6	6	-
Age (years)	44.5 ± 4.5	44.5 ± 11.1	-
Height (m)	1.6 ± 0.0	1.6 ± 0.1	-
Weight (Kg)	79.5 ± 8.1	79.7 ± 8.5	0.92
BMI (Kg/m^2)	29.3 ± 2.6	29.3 ± 2.7	0.92
FEV_1pp	84.0 ± 3.9	101.2 ± 5.0	**0.01***
FVCpp	84.7 ± 5.7	99.3 ± 5.6	0.05
PEFpp	50.7 ± 5.0	78.7 ± 8.9	**0.01***
Nº of wheeze	6.0 ± 0.9	14.8 ± 2.3	**0.03***
Dt of wheeze (s)	0.21 ± 0.0	0.22 ± 0.0	0.63
Fq of wheeze (Hz)	365 ± 37.0	363 ± 29.1	0.92

BMI: body mass index; FEV_1pp: percentage predicted of forced expiratory volume in 1 second; FVCpp: percentage predicted of forced vital capacity; PEFpp: percentage predicted of peak expiratory flow; nº: number; Dt: duration; Fq: frequency. Results are shown in mean ±standard deviation.
*p < 0.05.

The lung function evaluation showed no differences between genders and all participants presented a statistically significant increase in FEV_1pp (p=0.01), PEFpp (p=0.01) and in the number of wheezes (p=0.03), from the baseline to post treatment (table 1).

Table 2: Correlation between the duration of wheeze and lung function parameters at post treatment.

Wheeze	FEV_1pp		FVCpp		PEFpp	
Duration	rs	p*	rs	p*	rs	p*
Tc	0.1	0.87	0.5	0.32	-0.8	0.06
Ar	0.8	0.14	0.6	0.29	0.1	0.94
Al	0.6	0.28	0.2	0.74	0.2	0.74
Lr	-0.9	**0.04***	-0.5	0.39	0.1	0.94
Ll	0.2	0.75	-0.1	0.87	-0.5	0.40
Pr	-0.6	0.2	-0.9	**0.02***	0.8	0.07
Pl	0.0	1	0.3	0.62	0.2	0.75

Tc: trachea; Ar: anterior right; Al: anterior left; Lr: lateral right ; Ll: lateral left; Pr: posterior right; Pl: posterior left; rs: correlation coefficient.
* p < 0.05.

The results obtained from the wheeze evaluation (number, duration and fundamental frequency) of the 252 sound files were not significant correlated with spirometry parameters (FEV_1pp, FVCpp and PEFpp) at the baseline assessment. However, significant correlations were found post treatment between FEV_1pp and wheeze duration at lateral right region (r_s=-0.9, p=0.04), and between FVCpp and wheeze duration at posterior right region (r_s=-0.9, p=0.01) (table 2).

4 DISCUSSION

This preliminary study demonstrates the robustness of the proposed TF-WD algorithm for computerised wheeze detection in LRTI. Since wheezing are often present in patients with LRTI (Woodhead et al., 2011), this technique can constitute a valuable and practical non-invasive tool for diagnosing and monitoring patients with this respiratory conditions. The overall results of the algorithm (SE=72.5%; SP=99.2%) showed similar performance in the sensitivity and specificity of the wheeze detection compared to previous studies (Taplidou and Hadjileontiadis, 2007); (Oliveira et al., 2011).

A reduced number of wheezes were observed at baseline, probably due to the presence of air or fluid in/or around the lung, causing a decrease in number of breath sounds (Lieberman et al., 2002). This reduced number of wheezing may have contributed to the absence of baseline correlations. Furthermore, a significant increase of wheezing post treatment was observed (p=0.03).

Significant and strong negative correlations were found in the post treatment assessment between: i) FEV_1pp and duration of wheeze at lateral right region, and ii) FVCpp and duration of wheeze at posterior right region. These results suggest that by combining lung sounds with spirometry it may be possible to predict and assess the location of the obstruction with more accuracy.

Oud et al. (2000) found that 60-90% of lung sound data can classify FEV_1-values by using computed spectral sound data. Leuppi et al. (2006), in a study conducted in the emergency setting, reported that airways obstruction may often be overestimated by auscultation and when combining auscultation with spirometry the accuracy of the diagnosis could be increased by approximately 8%.

Additionally to previous research, our study proposes a further analysis of wheezes and lung function data, with the evaluation of more than one location of auscultation and its correlation with spirometry. This correlation gave relevant information to detect respiratory obstructed areas.

As verified only the right areas of the lung had correlation with the wheezes parameters, which can be explained by the fact of the majority of participants enrolled (n=5) presented with right lung infection. Nevertheless, the small sample size (6 participants with LRTI), limits and decrease the statistical power and may have polarised the results.

Currently, there is a lack of published data assessing the correlation between wheeze and spirometry parameters and therefore, it is believed that these findings provide a significant contribution for research and clinical practice.

5 CONCLUSIONS

This study suggests that the TF-WD algorithm is a robust method for computerised wheeze detection in patients with LRTI. Furthermore, the use of computerised auscultation and spirometry as outcome measures to detect the area of obstruction in patients with this respiratory condition is also supported.

However, further studies with larger samples are needed to fully confirm the presented results.

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