ANALYSIS OF COUGH SOUNDS FOR DIAGNOSIS OF RESPIRATORY INFECTIONS IN INTENSIVE PIG FARMING

S. Ferrari, M. Silva, M. Guarino, D. Berckmans

ABSTRACT. Respiratory diseases are widespread causes of mortality and loss of productivity in intensive pig farming. Cough is one of the symptoms and a central element in screening and diagnosis of common illnesses caused, for example, by Pasteurella multocida or Actinobacillus pleuropneumoniae (App). The aim of this research is to compare the acoustic features of cough sounds originating from the mentioned infections and non-infectious cough sounds provoked by inhalation of citric acid by means of labeling and sound analysis. The acoustic parameters investigated are peak frequency and duration of the cough signals. The differences resulting from the sound analysis confirm the variability in acoustical parameters according to health status or disease in the animals. In infections, there is a change in the status of the respiratory system; consequently, infectious coughs are different from non-infectious coughs. The duration of single infectious coughs is considerably different among the types of cough analyzed, which are: non-infectious coughs, App coughs, and P. multocida coughs. Frequency analysis of single coughs allows a more general classification between non-infectious and infectious coughs. Acoustics parameters can be used in an algorithm-based alarm system to automatically identify cough sounds and provide farmers an early warning about the health status of their herds.

Keywords. Cough sounds, Infections, Pigs, Sound analysis.

Respiratory pathologies are frequent in pig husbandry, and cough is their principal symptom. Due to their numerosness and incidence on farms, it is crucial to find an objective and non-invasive method to investigate cough sounds, with the aim of understanding the spread and evolution of respiratory diseases. It has been shown that pig vocalization is directly related to pain, and classification of such sounds has been attempted (Marx et al., 2003). It is also common practice by veterinarians to assess cough sounds in pig houses for diagnostic purposes. In this regard, there have been attempts to identify the characteristics of coughing in animals (Van Hirtum and Berckmans, 2002a, 2002b) and automatically identify cough sounds in field recordings (Aerts et al., 2005; Van Hirtum and Berckmans, 2001, 2003a, 2003b).

The analysis in this work considers three databases of coughs collected under field and laboratory conditions. Two databases were recorded from infections by multifactorial respiratory diseases mainly caused by Actinobacillus pleuropneumoniae (App) and Pasteurella multocida, and the third database of coughs was induced under laboratory conditions by inhalation of citric acid.

The two most important primary bacterial agents involved in respiratory disease are considered to be Mycoplasma hyopneumoniae, which causes enzootic pneumonia (Ross, 1992), and App, which causes pleuropneumonia (Sebunya and Saunders, 1983). The most important secondary agent, which becomes involved in respiratory disease only after impairment of the lungs’ defense mechanisms, is considered to be Pasteurella multocida (Ciprian et al., 1988; Pijoan, 1992). App is currently a widespread problem in intensive pig breeding and fattening farming in the EU, Asia, and North America. It can affect pigs at all ages, and the severity of the disease depends on the pig’s immune system, the virulence of the bacillus strain, and the possibility of concomitant infections with viruses and Mycoplasma.

In both the acute and chronic manifestation of these diseases, the animals are affected by cough and dyspnea, hyperthermia in the first phase, lack of appetite, and reduction of weight. The evolution of the disease depends on environmental conditions, population density, and thermal excursions. The change from acute to chronic form may occur months after acute phase clinical recovery. Relapses are frequent. In field conditions, App may interact with other microorganisms like Mycoplasma PRRSV or PCV-2. Sick animals are treated by parenteral antibiotic (Christensen and Bisgaard, 2004).

P. multocida is an opportunistic bacteria that causes pulmonary pasteurellosis and is often associated with and complicates infections from herpesvirus (PRV), arterivirus (PRRSV), and especially M. hyopneumoniae. It is also the cause of progressive atrophic rhinitis (RAP), a significant
and expensive problem in farming worldwide. *P. multocida* type A is often associated with *M. hyopneumoniae* and with high environmental NH₃ contamination. The symptoms vary according to the bacterial strain and immunity status of the pig. The acute phase brings dyspnoea, difficulty in breathing, abdominal hearth beat, dejection, and hyperthermia.

The mortality rate is normally 5% but increases to 40% in association with the latest forms of mycoplasmic pneumonia. The most common chronic manifestation of *Pasteurella* infections affects fattening pigs at the end of the fattening cycle. Cough is the main symptom, as well as abdominal breath and pleurisy adherences. Drop in production due to slow death with progressive decay is typical in this disease.

In normal practice, antibiotic use is an unreliable remedy because several consolidation lesions do not allow a uniform spread of the active principle. In addition, *Pasteurella* strains are often poli-antibiotic resistant, and an antibiogram is needed before subadministration. Even strategic preventive treatments in the feed or water are often ineffective, and the costs are often larger than the benefits (Pijoan, 1992). Improving farm management gives better results in animal health (e.g., ventilation and air change, temperature control, dust and ammonia control, reduction of animals per barn).

By comparing two types of infectious cough with a non-infectious cough, the aim of this work is to improve the labeling (classification) of recorded coughs by associating acoustic features with specific sounds. In a next step, these features could be used as inputs in an automatic alarm system based on an algorithm that continuously recognizes cough sounds on a farm and provides early warning to the farmer of the animals’ health status. This could moderate the spread of diseases, save costs, and provide information on how to face, in terms of biosecurity, the problem of prevention and spread of respiratory pathologies.

In this work, the term “infectious cough” refers to a cough from a pig with clear signs of a clinical respiratory disease, while a “healthy cough” refers to a cough registered from a pig without repeated clinical evidence. The two types of infectious coughs are used as a model of common pathologies and serve as a reference for describing the common physical characteristics of infectious cough sounds.

**MATERIALS AND METHODS**

**ANIMALS AND PATHOLOGICAL CONFIRMATION**

The pigs used in this study, which were diagnosed with *Pasteurella* (200 animals), derived from a hybrid commercial strain (Landrace × Large White + Danish Duroc boar) and were at the beginning of the fattening period (100 days old and approx. 40 kg lbw). Diagnosis with isolation in pure culture from lung lesions and necroscopic results (the lung area affected was hypertrophic with blank areas from necrotic focuses, fibrinous pleurisy was also present) ensured that the animals were sick with pneumonia due to *P. multocida* type A.

The pigs suffering from *App* infection (250 animals) were three months old and 26 to 35 kg lbw, reaching 90 to 100 kg in 90 days. These pigs belonged to a hybrid line by a cross between Italian Landrace × Large White × Duroc. The *App* biotype1 “serotype 2” was regularly isolated in pure culture from hemorrhagic and necrotic lung lesions (fibrinous pleurisy focuses and fibrinous-hemorrhagic and necrotic bronchopneumonia, the area with pleurisy was reddish and thicker); other pigs in the compartment seroconverted also against *A. pleuropneumoniae*. Concurrent infections were also present.

Previously recorded coughs were used for the database of non-infectious coughs (Moreaux et al., 1999). The researchers induced a cough in healthy animals, free of respiratory diseases, by inhalation of citric acid. The nebulization of citric acid stimulates the cough receptors directly, resulting in coughing. The experiments were conducted with individual healthy animals (for more information on materials and methods and the data acquisition process, see Moreaux et al., 1999).

**SOUND ACQUISITION**

The recordings were collected in two intensive pig farms for 2 to 4 h on different days during two weeks in October and March 2005, the period in which a larger number of infectious coughs occurs. Seven microphones (Monacor ECM 3005, frequency response of 50 to 16,000 Hz) were used for sound acquisition and were connected via preamplifiers (Monacor SPR-6) to an 8-channel analog-to-TDIF (Tascam digital interface) unit (Soundscape SS810-3). The Soundscape unit, which allows simultaneous recording of eight channels, was connected via a TDIF cable to a PCI audio card (Mixer 192). All recordings were sampled at a sample rate of 44.1 kHz with a resolution of 16 bits. All microphones were hung in the pig house at approximately 1.20 m above the ground; their placement in the building is shown in figure 1.

The non-infectious cough sounds were recorded under laboratory conditions (for more information on the installation environment and data acquisition process, see Moreaux et al., 1999). Adobe Audition 1.5 was used for recording and labeling of the cough sounds, Matlab 7.1 was used for signal processing (duration and fundamental frequency), and SAS was used for statistical analysis (GLM procedure).

**ANALYSIS OF THE COLLECTED DATA**

From the recorded sound sessions, we extracted only the cough attacks by offline manual auditive labeling. Digitalization of the sounds allowed the sound recording software (Adobe Audition) to build up spectrograms of the sounds, which was helpful during the first step of labeling since it
helps the operator to discriminate sounds by visual and acoustical means. The spectrograms of the coughs were built using a Hanning windowing function with a 40 ms duration and 20 ms overlap. The signal from the microphone was bandpass filtered (Butterworth 3rd order) between 100 and 10,800 Hz to remove low-frequency noise.

The characteristics of the cough sounds were identified in the time and frequency domains of the sound spectrogram. A comparison between non-infectious and infectious cough sounds was made by considering the duration of the signal and the peak frequency (frequency with maximal energy content). The duration of a single cough, the number of coughs, and the time between coughs in a cough attack were considered. The maximal criteria used to recognize sounds were the identification of the sudden increase in amplitude or frequency in the spectrum and the following decrease. The chosen sounds were individually saved in a folder and used for analysis. This is illustrated in figure 2, where the steps of labeling are shown.

Analysis of variance (GLM procedure in SAS) was performed for frequency, duration of single coughs, and duration of cough attacks; more precisely, the significance was calculated with one-way analysis of variance (ANOVA) to compare the means of different groups.

### RESULTS

During the recording sessions, we collected 851 coughs from pigs affected with pasteurellosis and 186 coughs from pigs sick with App (91 and 26 cough attacks, respectively). The average number of coughs in a cough attack was 13 for healthy coughs and 9 and 7 for Pasteurella and App coughs, respectively (table 1). The comparison with the database of non-infectious coughs first investigated the duration of the sounds. The healthy cough sounds were caused by a temporary irritation of the upper respiratory tract. On the other hand, in the case of pasteurellosis, coughs were caused by deep bacterial infection of the lungs, since the infection process starts at the alveolar bronchiol junction, producing exudates. In the case of App, coughs were caused by lung lesions with large red-blue areas in the upper diaphragmatic lobes with an overlying pleurisy. The results, in terms of number of single coughs and cough attacks, mean duration, and standard deviation of the signals, are listed in tables 1 and 2.

The peak frequency range for non-infectious coughs is between 750 and 1800 Hz. For the two lung disorders, the range is between 200 and 1100 Hz (table 4). More specifically, coughs caused by App have lower peak frequency than

---

**Table 1. Number of cough attacks and single coughs in the database.**

<table>
<thead>
<tr>
<th>Type of Cough</th>
<th>No. of Cough Attacks</th>
<th>Total No. of Coughs</th>
<th>No. of Coughs in an Attack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-infectious</td>
<td>11</td>
<td>149</td>
<td>4</td>
</tr>
<tr>
<td><em>P. multocida</em></td>
<td>91</td>
<td>851</td>
<td>5</td>
</tr>
<tr>
<td>App</td>
<td>26</td>
<td>186</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 2. Durations of cough attacks and single cough signals, and standard deviations (SD) of single cough mean durations.**

<table>
<thead>
<tr>
<th>Type of Cough</th>
<th>Mean Duration (s)</th>
<th>Single Cough SD (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-infectious</td>
<td>8.61</td>
<td>0.43</td>
</tr>
<tr>
<td><em>P. multocida</em></td>
<td>6.77</td>
<td>0.67</td>
</tr>
<tr>
<td>App</td>
<td>5.17</td>
<td>0.53</td>
</tr>
</tbody>
</table>

**Table 3. Statistical results of the parameters for the three types of cough.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Single cough duration</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>Cough attack duration</td>
<td>P &lt; 0.05</td>
<td>P = 0.34</td>
<td>P &lt; 0.05</td>
</tr>
<tr>
<td>Frequency</td>
<td>P = 0.07</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

To assess the differences in duration of the three types of single coughs and attacks, analysis of variance (ANOVA) was performed on the collected data using SAS (GLM procedure). The results for the three types of single coughs are presented in table 3, showing highly significant differences in duration. This led us to consider using these signals as a tool to distinguish the origins of cough sounds. Results for the duration of the three types of cough attacks are also shown in table 3. The difference is not significant for all the types (e.g., *P. multocida* vs. non-infectious), so it is not suggested to use this parameter for further analysis.

Analysis of the peak frequency of single coughs showed that lung diseases lower the peak frequency of the cough sound. The peak frequency range for non-infectious coughs is between 750 and 1800 Hz. For the two lung disorders, the range is between 200 and 1100 Hz (table 4). More specifically, coughs caused by App have lower peak frequency than
non-infectious coughs. The peak frequencies of *Pasteurella* coughs are also clearly lower than healthy cough sounds, but less significantly than with *App* (table 4, fig. 3). The results clearly show a decrease in peak frequency of cough sounds with pulmonary diseases.

### DISCUSSION

The possibility to make a distinction between pathological and healthy cough sounds by physical sound features has been shown in this study. Previous literature has focused on this distinction, but specifically in humans. However, Van Hirtum and Berckmans published several works on pig coughs, from the assessment of the cough towards vocalization (Van Hirtum and Berckmans, 2002a), through the automated recognition of spontaneous versus voluntary cough (Van Hirtum and Berckmans, 2002b), to the recognition of cough sound using an algorithm for recognition under laboratory conditions (Van Hirtum and Berckmans, 2003b). Nevertheless, literature on the acoustic features of different respiratory diseases is still unknown. The study of pig coughs has improved characterization of the features of coughs caused by specific agents, in terms of their acoustical parameters. This implies that it is useful to improve cough sound labeling, as it is able to show significant differences between coughs arising from infected and healthy animals.

In our results, infectious coughs showed significantly lower peak frequencies than non-infectious coughs (200 to 1100 Hz for infectious; 750 to 1800 Hz for non-infectious). Korpáš et al. (1996) stated that frequencies of 300 to 500 Hz are the most expressive of healthy human coughs, whereas for cough sounds of bronchitis, the band between 500 and 1200 Hz is most expressive. Sound differences between human and pig coughs can be explained by differences in the amount of air pushed through the respiratory airways or by the dimensions and characteristics of the system itself. For this reason, comparisons of frequencies between the results of the current study and the results of the previously mentioned study (Korpáš et al., 1996) are difficult to make. On the other hand, Van Hirtum and Berckmans (2003b) and Ferrari et al. (2007) showed that the fundamental frequency of coughs from healthy pigs under laboratory conditions is higher than that of coughs from sick pigs.

When considering the duration of a single cough, it can be seen that there is a significant difference between the two groups of cough sounds, i.e., a mean duration of 0.53 to 0.67 s for *App* and *Pasteurella* coughs, while 0.43 s was observed for non-infectious coughs. This trend was also observed by other researchers, who concluded that the duration of infectious coughs is longer compared to non-infectious coughs due to airway obstruction by infection and inflammation for both humans and pigs (Korpáš et al., 1996; Van Hirtum, 2002b). Little information is available in the literature concerning the duration of a single cough or a cough attack. Further analysis should be done to clarify these findings. Although a connection between the time and frequency domain characteristics and the physical parameters of pig vocalizations is not yet known, the present results indicate that such a connection exists and remains to be determined.

By understanding the effect on cough sounds of inflammation of the respiratory airway and structural changes of the cell walls, information can be extracted about the status of the animals. For both laboratory conditions and field situations, this could lead to an interesting acoustic monitoring system. The acoustic features that characterize a sick cough can be used as inputs for an on-line cough counter algorithm. Sound analysis in field conditions provides additional, useful, non-invasive objective and quantitative information about the status of the respiratory system and is a candidate method for an automatic on-line health monitoring tool.

It is suggested that the present application be integrated into an automatic detection system to be used in field conditions. A first step to prove the system is offline automatic classification, which is necessary to understand what kind of acoustic parameters are to be investigated to discriminate types of cough sounds. Further research in characterizing more pathological cough sounds has still also to be done.

Modern swine production is searching for a variety of tools to ensure the health, welfare, and productivity of pigs. Considering the instability of the use of antibiotics (e.g., antibiostatic resistance, antibiotic effectiveness), sound analysis looks promising as a new tool in disease prevention.

### REFERENCES


Ferrari, S., M. Silva, J. M. Aerts, M. Guarino, and D. Berckmans. 2007. Characterisation of cough sound to monitor *Pasteurella*

---

**Table 4. Peak frequency among the three types of single coughs.**

<table>
<thead>
<tr>
<th>Type of Cough</th>
<th>Mean Frequency (Hz)</th>
<th>Frequency SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-infectious</td>
<td>1487</td>
<td>608</td>
</tr>
<tr>
<td><em>P. multocida</em></td>
<td>777</td>
<td>541</td>
</tr>
<tr>
<td><em>App</em></td>
<td>624</td>
<td>422</td>
</tr>
</tbody>
</table>

**Figure 3. Bar plot of peak frequency of the three types of cough.** The representation shows the values obtained from the frequency analysis; vertical lines indicate the standard deviations for each type. Non-infectious coughs show higher peak frequency compared to coughs originating from infected animals, where we obtained lower means. The upper bars indicate the significance among the groups.


