UNIVERSITÀ DEGLI STUDI DI MILANO

SCUOLA DI DOTTORATO
Sanità e Produzioni Animali: Scienza, Tecnologia e Biotecnologia

DIPARTIMENTO
Scienze Veterinarie per la Salute, la Produzione Animale e la Sicurezza Alimentare

CORSO DI DOTTORATO
Produzioni animali XXVI ciclo

TESI DI DOTTORATO DI RICERCA

THE USE OF IMAGE LABELLING TO IDENTIFY PIG BEHAVIOURS FOR THE DEVELOPMENT OF A REAL-TIME MONITORING AND CONTROL TOOL

AGR 10

NOME DEL DOTTORANDO
ISMAYILOVA GUNEL

TUTOR
GUARINO MARCELLA

COORDINATORE DEL DOTTORATO
PROF. GUSTAVO GANDINI

A.A.

2012/2013

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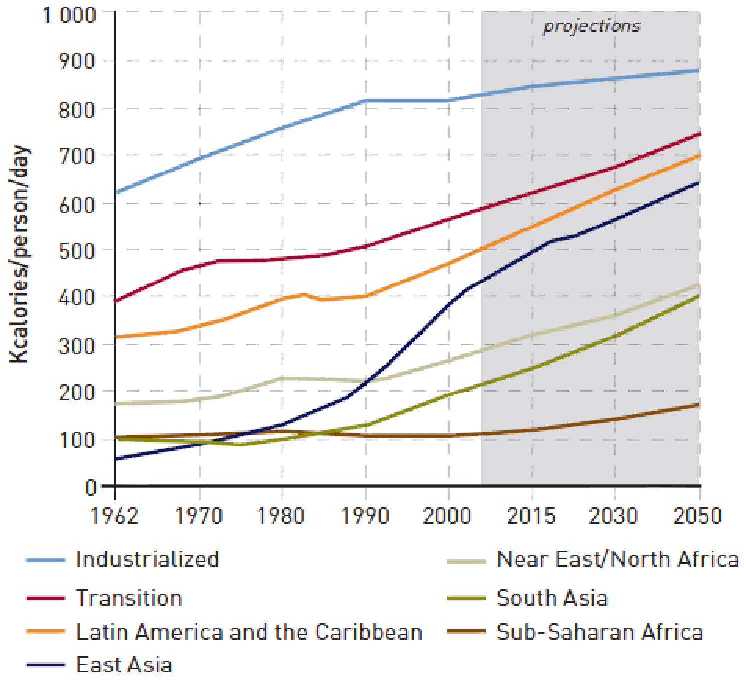
CHAPTER 1

General Introduction

Introduction

1.1 Current situation of the livestock production

The livestock production, along with food and agriculture in general, is continuously undergoing major change over the recent decades. The factors such as word population growth, urbanisation, growing economies, and shift in dietary preferences have contributed to the increasing demand for animal products. This can be seen in Figure 1 where a clear increase of the consumption of foods of animal origin per capita worldwide is reported (Steinfeld et al, 2006a). Global production of meat is projected to more than double from 229 million tonnes in 1999/01 to 465 million tonnes in 2050, and that of milk to grow from 580 to 1 043 million tonnes (Steinfeld et al, 2006a).



Note: For past, three-year averages centered on the indicated year. Livestock products include meats, eggs, milk and dairy products (excluding butter). Source:FAO (2006)

FIGURE 1: *Past and projected food consumption of livestock products*

Most of production growth is taking place in developing countries (Steinfeld et al, 2006b), which are projected to account for about 78% of the increased meat production between 2011 and 2020 (OECD-FAO, 2011). To this demand in production growth the livestock sector responds with further intensification, leading to significant increase of the worldwide number of livestock. Consequently, big farms with large number of animals have largely overtaken small-scale family based activities. This transformation, however, brought a number of related problems such as negative impact on environment, animal health and welfare (e.g. Blockhuis et al., 2010; Botreau et al., 2009; Sorensen and Fraser, 2010). The adverse consequences of livestock sector industrialisation have raised serious public concerns and a lot of efforts are overtaken to solve this problems. As FAO stated (Steinfeld et al, 2006a), that the livestock sector have to live up to the challenge of finding suitable technical solutions for more environmentally sustainable resource use in animal agriculture; multisector and multiobjective decision-making is required.

1.2 The challenge for the modern farmer

Industrialisation of livestock sector and demand of higher animal production have brought to the modern farmers not only the necessity to increase the number of animals per farm but also the challenge to fulfil numerous requirements to make their business sustainable. The profitability of the farm rests the main objective of the farmer, but at the same time he has to meet increasingly stringent regulations on food safety and quality, control of zoonotic disease transmission, animal welfare and health, reduction of the use of medical treatments, and an acceptable environmental impact of livestock production (Berckmans, 2003; 2004; Frost et al., 2003). Furthermore, customers are becoming more sophisticated and now requiring high quality and safe products, animal welfare and environmentally friendly but at an acceptable price (Frost et al., 1997). Though, the farmer nowadays is compelled to balance between society’s view on what constitutes acceptable livestock production against the need to produce animals cheaply and efficiently (Frost et al., 2003). Since livestock systems are sets of complex interconnected processes, it is difficult to find this balance as potentially competing demands are to be satisfied (Frost et al., 1997). Moreover, the farmers are facing diminishing supply of skilled stockman, while confronted with increasing pressure to take care for a large number of animals in order to have economically viable farm (Schofield et al., 2002).

This current situation suggests that the farmers need a support and effective solutions. One of the emphases of researchers and commercial developers should be on development of engineering technology solutions to monitor livestock farming with management decisions left to the farmer. The ever-lower costs of technology should be harnessed to satisfy the demand for information about animal-based products and farming methods, thereby meeting a current need in support to farmer in working according to society demands but at the same time reducing a workload without loss of efficiency and within economic and ecologic sustainability.

1.3 Precision Livestock Farming (PLF): Technology to support monitoring of animals on farm

1.3.1 Introduction to PLF

Precision Livestock Farming (PLF) is defined as management of livestock farming by automatic real-time monitoring/controlling of production/reproduction, health and welfare of livestock and environmental impact (Berckmans, 2013). The main purpose of Precision Livestock Farming (PLF) is to improve the efficiency of production, while increasing animal and human welfare, via applying advanced information and communication technologies, targeted resource use and precise control of the production process (Cumby and Phillips, 2001; Wathes et al., 2008; Banhazi et al., 2012).

PLF consists of measuring variables on the animals or in their environment, modelling these data to select information, and then using these models in real time for monitoring and control purposes.

The basic scheme of PLF system presented in Figure 2 relies on four essential elements (Wathes, 2010):

1. Continuous sensing of the process (animal) responses with a continuous exchange of information with the process controller;

2. Compact, mathematical model, which predicts the dynamic responses of each process output to variation of the inputs and can be – and is best – estimated online in real time;

3. Target value and/or trajectory for each process output, e.g. a behavioural pattern, pollutant emission or growth rate;

4. Actuators and a model-based predictive controller for the process inputs.

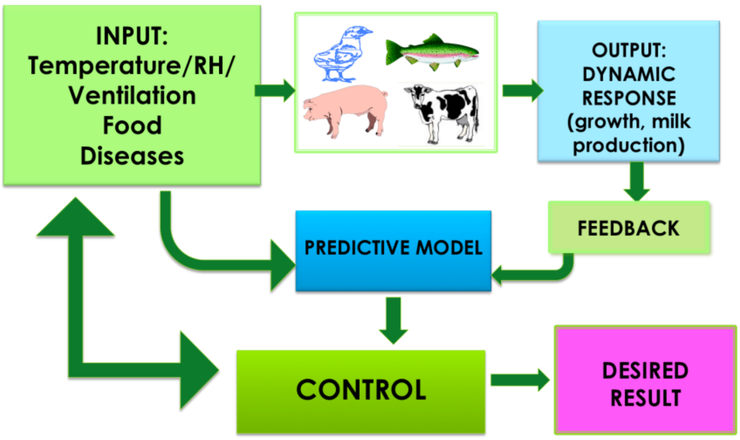


***FIGURE 2**: Schematic representation of the application of PLF to intensive livestock systems*

1.3.2 PLF for Automatic monitoring of animals

Being completely responsible for all confined animals under control and all aspects of their husbandry, farmers, however, have less time in their disposal to give individual attention to each animal. This responsibility for each individual animal is not only moral obligation or social pressure, it is also in the farmer’s commercial interest. Good care is the key for increased productivity, health and welfare of the animals and thus for profitable and sustainable business. In this regard, PLF offers high opportunities for the monitoring of animals and, thus, supports farmers to provide better care. The main concept of PLF is to consider the animal as the most crucial element in the biological production process (Berckmans, 2004). Each single animal in the farm production process is a complex, individually different dynamic and time-variant organism. The best way to monitor complex and continuously changing animal responses is through continuous automated and real time measurements. After gathering the information in the control system, the crucial part of efficient control is the prediction of how the animal will respond to different farming conditions. The system outputs can then be used as "early warning systems" that improve the management of animal needs at any time. The overall goal is to achieve a complete and continuous assessment of the state of livestock and their environment in terms of health, welfare, performance and environmental related issues.

1.4 PLF: Technologies

To develop new products for bioprocesses, the combination of biological knowledge with expertise in technology should be fastened. Technology is becoming increasingly cheaper and smaller, consuming less energy and improving the possibilities for monitoring various biological processes. Recent technological developments create the possibilities today to measure, model, monitor and control livestock production processes in real-time (Berckmans and Guarino, 2004, 2008). New technology can contribute to this task, even with large flocks or herds, thanks to the evolution in sensors and sensing techniques, (Frost et al., 1997; Berckmans, 2003). From the vast selection of the existing sensors and sensing techniques used in research, three have received particular attention: vision, sound technologies and sensors attached to the body.

1.4.1. Vision technology

Vision techniques include the use of video cameras in combination with visual image analysis (VIA) techniques (Shofield et al., 1999). The use of video cameras has the following advantages (Bloemen et al., 1997, Cangar et al., 2008): cameras used are relatively cheap; it is non-invasive, thus the animals are not disturbed by the measurements. In addition, it facilitates the collection of more frequent data over longer time periods and no huge data storage is required. This system allows for measurement of the plan-view area of indoor housed animals, by video camera mounted overhead. These cameras are inexpensive compared with computer hardware and software costs, easy to install, calibrate and maintain. A number of cameras can share one computer. However, VIA techniques have also certain limitations in practical conditions. In commercial livestock houses, image analysis for behaviour recognition becomes more complicated. Lighting, camera characteristics, background and test subject's traits all influence the ability of the system to recognize the subject and record its movement accurately (Hoy et al., 1996, Cangar et al., 2008).

Vision techniques have proven to have great potential to be used for behaviour analysis of different animals (De Wet et al., 2003, Leroy et al., 2004). Leroy et al. (2006) quantified the behaviour of a single laying hen by using a fully automatic on-line image-processing technique, while Pereira et al. (2004) used video cameras to perform a qualitative analysis of broiler breeder behaviour. Tillett et al. (1997) and Lind et al. (2005) used image processing technique to track the pig's movements. Dawkins et al. (2009) showed that the optical flow patterns of broiler flock movements captured by image analysis provided valuable estimation of broiler welfare. Moreover, image analysis techniques allowed to estimate the size, shape and weight of farm animals; (White et al., 2004; De Wet et al., 2003; Chedad et al., 2003) and to monitor water intake (Kashiha et al., 2013c). Two-dimensional (2D) computer vision approaches was widely used to detect lameness in cows focused on the measurement of different gait, posture variables (Poursaberi et al. 2010, Pluk et al., 2010, 2012) and the body movement pattern (Poursaberi et al., 2011; Viazzi et al., 2013).

1.4.2 Sound technology

Similarly to described above vision techniques, application of sound for the automatic monitoring of animals on farms has the advantages of being inexpensive, non-hazardous, non-invasive, without direct contact with the animals, while a limited number of microphones can measure groups of animals in big spaces.

Sound techniques are based on bio-acoustics- the scientific study of sounds produced by biological organisms (Fletcher, 2004). Vocalisation is an expression of a distinctive inner state of an animal and has partly evolved as communication signal to indicate some type of “need”. Hence, it is reasonable to regard vocalisation as one of the indicators of an animal’s state. The different animal vocalisations are varying in their intensity, frequency, duration and other parameters and could be recognised automatically using their specific characteristics. The recognition of sounds produced by animals could be used for the monitoring of animal’s conditions, animal health status and welfare (Van Hirtum and Berckmans, 2004, Moura et al., 2008). Various approaches have been presented that identify characteristics of coughing in animals (Moreaux et al., 1999, Van Hirtum and Berckmans, 2001a) and automatically identify cough sound from field recording (Van Hirtum and Berckmans, 2001b). The research on cough analysis by Van Hirtum and Berckmans (2004) has suggested that recognition of cough sounds can be used as a biomarker for aerial pollutants, using spectral distances as a classification criterion. The sick cough recognition and localisation was studied in order to visualise the spread of respiratory disease in pigs compartments in order to monitor pigs health status (Exadaktylos et al., 2008, Ferrari et al., 2008, Silva et al., 2008).

Real time monitoring using vocalisation analysis allowed the detection of piglet stress exposure in the work of Moura et al. (2008). Also for chickens, sound analysis has been successfully used to monitor their status. Zimmerman et al. (2000), for example, used sound technology to quantify vocal expressions of feeding motivation and frustration in the domestic laying hen. In incubation processes sound technology can be used to detect different incubation stages (Exadaktylos et al., 2011).

1.4.3 Sensors

The main advantage of sensors is that the behavioural and performance related data of every individual animal can be recorded in real time simultaneously, continuously and on-line. However, the use of the sensors attached to animals has also a number of disadvantages: they should be attached to every animal, which affects the cost for their on-farm application in the farms with high number of animals; can be invasive and alter the behaviour; can be lost or destroyed by the animal.

For individual animals like cows a number of sensors on the body are commercially available for use at farm level. For example, accelerometer-based IceQube sensor, measuring three-dimensional motion, with continuous monitoring through data capture many times a second. By positioning this sensor on one of the cow's hind legs, lying patterns and locomotion can then be analysed and a daily mobility value is created. Other two devices were mentioned for measuring 'lying down' behaviour: IceTag3D (IceRobotics) and biomotional analysis (FBI Science). The first can measure the total lying down time, and could potentially also measure the time it takes for the cows to lie down. The second technique, biomotional analysis, could be used to record movement patterns of the body of a single animal, and hence give information about the ease with which animals lie down. Other sensors available today include pedometers for monitoring oestrus behaviour in dairy cows (Brehme et al., 2004). Automatic weighing systems for broilers, laying hens and turkeys have been used for a number of years to estimate the average weight of a flock (Aerts et al., 2003c; Vranken et al., 2004). Telemetry sensors for measuring heart rate, body temperature and activity have been developed (Mitchell et al., 2004). Sensors for quantifying milk conductivity and yield of individual cows are available and may be used to optimise production and provide early detection of poor welfare in individuals (Kohler and Kaufmann, 2003).

1.5 Development of automatic monitoring tools

1.5.1 Selection of target variables, technology and gold standard

The four most important areas covered by PLF-systems to improve sustainability of the farm are animal welfare, health, environmental load, and production. The basic PLF methods involve continuously measuring animal responses (bio-signals), reflecting the change of their welfare, health status or environment. These bio-signals are detected by the PLF algorithm and translated into real-time monitoring information reported to the farmer. The process of the successful algorithm development, schematically presented in Figure 3, involves a number of steps necessary to perform.

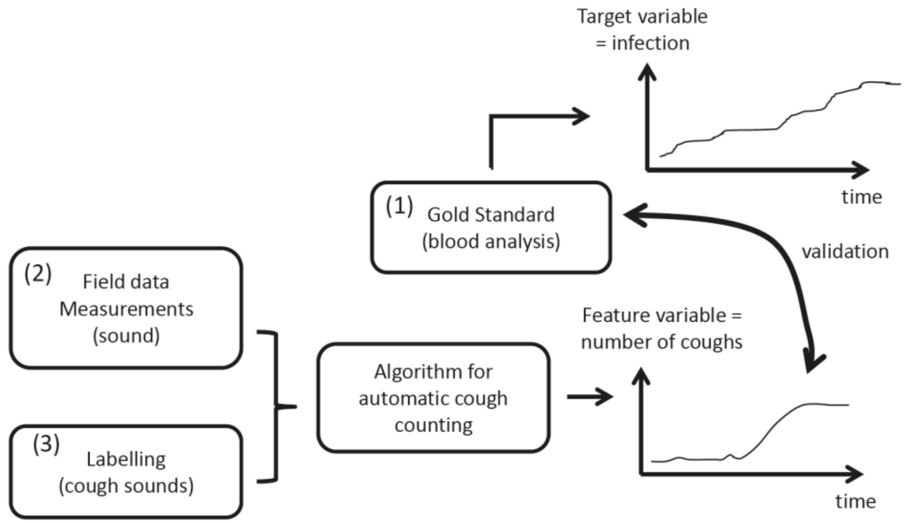


***FIGURE 3:** Process of algorithm development: a schematic overview*

Source: Berckmans, 2013

The most important step is selection of the right target variable, having an important implication on farm performance status. This target variable directly relates to the final objective of the algorithm (Berckmans, 2013). For example, one of the important target variables for the monitoring of the pigs health status on the farm is the infection status. Welfare of the animals on the farms could be monitored by the incidence of abnormal behaviours on the farm. In this case, the target variable could be, for example, the incidence of tail biting or aggression. The next step is the definition of the bio-signals which could give necessary information about the selected target variable. For example, in case of respiratory disease the cough could be taken as characterising bio-signal, while for aggression it could be the fight. When the target bio-signal is defined the most suitable sensing technique should be selected. Among already existing automatic systems the most used for the detection of behavioural response is the use of visual technology (cameras), for vocalisations-sound technology (microphones), while for physiological condition-sensors on the body. However, in some cases for the achievement of some target variables the multiple bio-signals of different origin should be detected, then the combination of different techniques is required. The next step is definition of a reliable gold standard, to be used on the final stage of the algorithm development as the reference to test and validate the performance of PLF techniques. A gold standard can be defined as a state-of-the-art scientific measurement or method which enables us to draw a conclusion relating to the final objective of the algorithm or the status of the target variable (Berckmans, 2013). A gold standard might be blood analysis in case of infection status, or visual scoring by experts in case of abnormal behaviours (e.g. following Welfare Quality® assessment protocol).

1.5.2 Labelling procedure

When the bio-signals are collected through field measurements the next step is so-called labelling procedure carried out by the specialist. Labelling could be defined as detailed audio-visual analyses to understand all variations in measured field data to be used for algorithm development calculating the feature variable (Berckmans, 2013). The feature variable is the variable calculated from the field measurements of bio-signals which are captured by sensor signals, image or sound information (Berckmans, 2013). For example, for the algorithm detecting aggression level in pig compartment a number of fights could be the feature variable, while for the respiratory infection- the number of coughs. A human observer carries out off-line manual marking of feature variables from video or audio registrations to create a reference point for the algorithm. The accurate and detailed labelling plays crucial part in the process of development of successful monitoring algorithm able to detect the feature variable, which is actually a bio-signal produced by the animal much more complex than any artificial system (Berckmans, 2004). An algorithm never can be more accurate than the accuracy of the labelling of the data that was used for its calibration and testing (Leroy, 2008). In sound analysis for example it is shown how difficult is the audio-visual “manual” labelling of individual pig coughs in a field situation (Aerts et al., 2005). The quality of the labelling strictly depends on the experience and knowledge of the labeller. This procedure is very-labour intensive, time-consuming and requires close attention. For example, manual labelling of 48 hour video involving marking start and stop points for only 7 feature variables can easily take a few man-months (Berckmans, 2013). For facilitation of the procedure and reduce the workload labellers use supporting tools such as **Adobe Audition®** for sound labelling and **Labelling Tool** for image labelling.

Labelling tool is an easy but powerful instrument developed by KU-Leuven M3-BIORES research team. The labelling tool was developed in MATLAB© 2010b. The output of the program can be used for statistical analysis and for developing a behavioural model - for example, a model able to detect pigs’ aggression. The User Interface was designed as simple as possible, with an immediate usage for the end user. The tool is also highly configurable and customizable in order to be reused for different experiments. A configuration file stores all the parameters of the program, such as the list of behaviours to be labelled.

The Labelling Tool consists of two modules: Initialization and Labelling Tool interfaces . The first module (Figure 4) is necessary to configure and to initialize the videos. In this step the image needs to be calibrated in order to define how many square centimetres in the pen correspond to a pixel: the linear factor that measures the distance in the video pixels is calculated by knowing the dimension of a specific object or the dimension of the pen itself. In this phase it is also possible to define zones of interest inside the video. By creating multiple zones it is possible to relate the labelled variables to a specific zone of the pen.

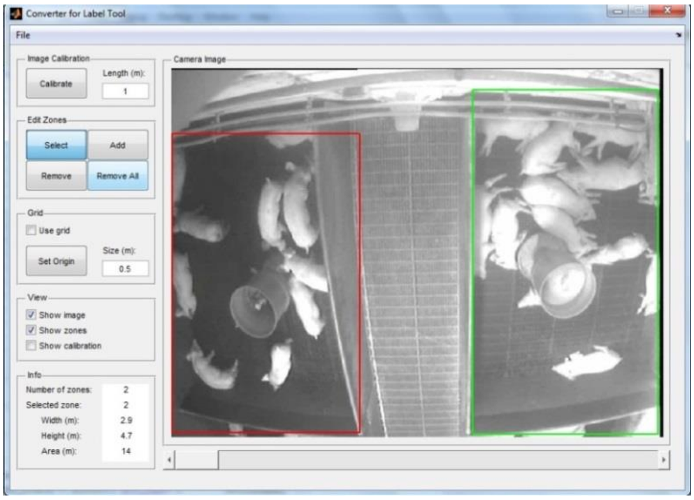


FIGURE 4: Initialization of the video and definition of zones of interest on the image

The Labelling Tool interface (Figure 5) displays the occupational (Figure 5a) and activity (Figure 5b) indexes measured from the video for each zone in order to speed up the manual labelling process.

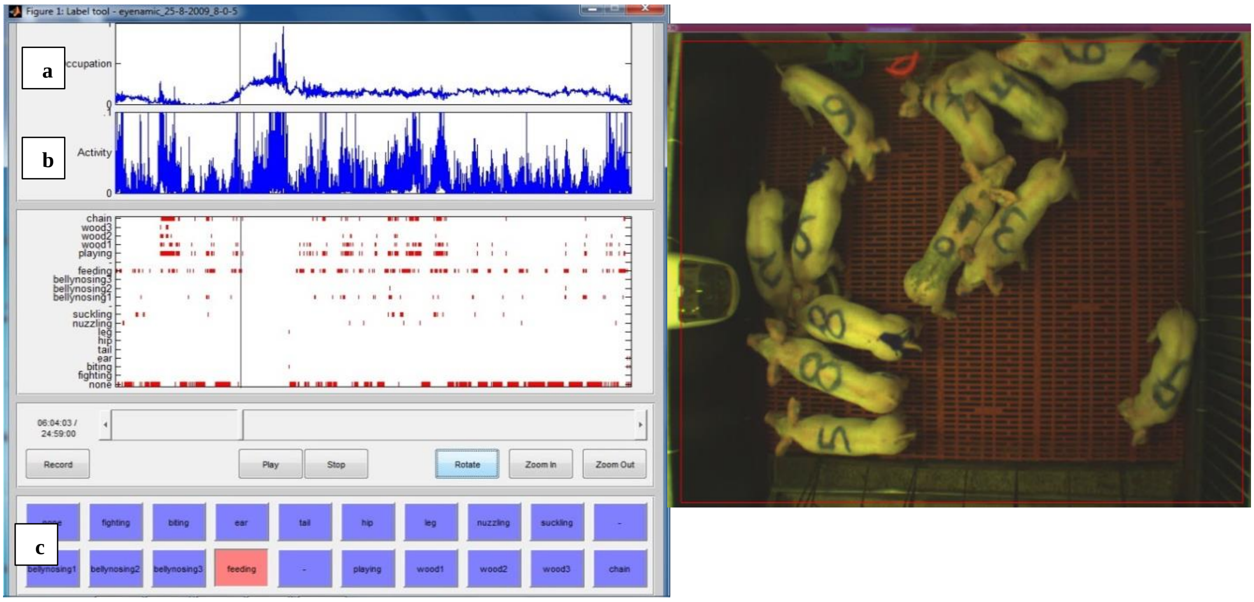


***FIGURE 5:** Screenshot of Labelling Tool. a) Occupation index. b) Activity index. c) Customisable buttons*

The normalized *activity index* is a measurement that quantifies the activity of animals in practical field conditions (Leroy et al., 2006). The idea behind is that the change in intensity of the pixels in consecutive frames provides a good estimation of the activity of the animals. This information can be used for skipping part of the videos. In fact, if the activity is close to zero, the animals are not moving in the particular zone and therefore the experts can leave out these intervals. Since pigs spend a lot of their time in complete inactivity, the time needed for labelling could be drastically reduced.

The occupational index is a measurement that calculates the fraction of the area occupied by the animals (Leroy et al., 2006). In the images, the pixels representing the pigs have a different intensity than the one of the background. By applying a threshold value to the intensity, it is calculated whether each pixel is considered foreground (pigs) or background. The occupational index can also support the manual labelling process because an index value of zero means that no pigs are present in the zone and that it is therefore not necessary to look at these parts of the recordings.

The software interface is customisable, so the labeller can name the buttons identifying the chosen behaviour. (Figure 5c).

With this tool the labeller can easily classify behaviours during the manual sliding of the video, and when a specific behaviour, or multiple behaviours, is/are observed in the image the matching button/buttons is/are selected. Data collected in this way can be exported, in order to create a data set containing all the information useful for the development of an algorithm for the automatic detection of behaviours (starting/end time, duration, description of the behaviours and the identification of animals).

The sound labelling is supported by audio editing software like **Adobe Audition®**. This kind of software provides a visual representation of sound waves, displaying waveforms for the evaluation of audio amplitude or the spectrum of the sound, which reveals audio frequency (Figure 6).

***FIGURE 6:** Screenshot of Adobe® Audition®. Waveform (a) and spectral display (b) of an audio file.*

The waveform display (Figure 6a) shows a waveform as a series of positive and negative peaks. The x-axis (horizontal ruler) measures time and the y-axis (vertical ruler) measures the amplitude that is the loudness of the audio signal (Adobe® Systems Incorporated, 2003).

The spectral display (Figure 6b) shows a waveform by its frequency components, where the x-axis (horizontal ruler) measures time and the y-axis (vertical ruler) measures frequency. This view allows the analysis of audio data in which frequencies are most prevalent. Colours range from dark blue, indicating low-amplitude frequencies, to bright yellow, indicating high-amplitude frequencies (Adobe® Systems Incorporated, 2003).

During the listening of the audio files it is possible to zoom in and out in the two domains (frequency and amplitude) in order to visualize clearly the energy envelope of each sound.

When a sound of interest (e.g.: a cough, a sneeze or a vocalization, etc.) is detected, the labeller can mark it and can insert a label describing the sound (Figure 7). For each sound, the start, the end and the duration is automatically recorded.

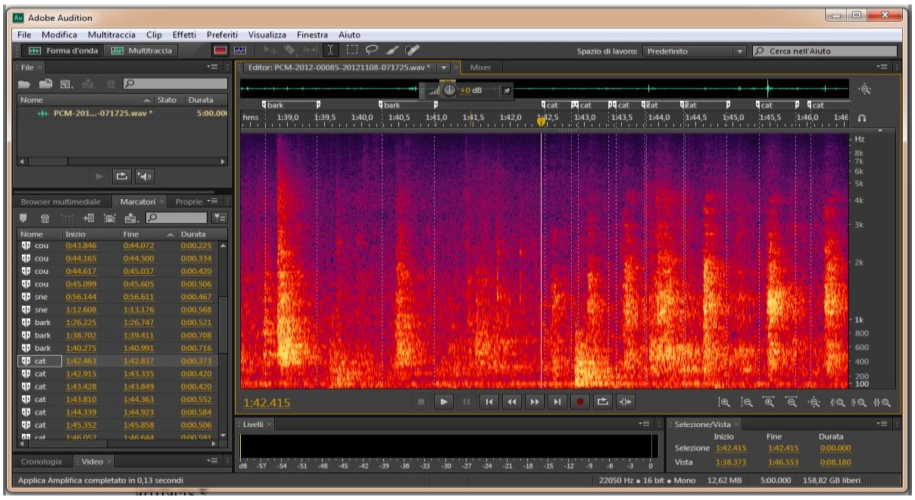


FIGURE 7: *Screenshot of Adobe Audition®. Spectral display of an audio file with the insertion of labels describing a cough attack (CAT).*

1.5.3 Algorithm development and testing

Only after the manual labelling of the field data is finished, it is possible to analyse and individuate the specific patterns of the animals' activity in order to develop the model that recognises the feature variables (e.g. specific behaviours or coughs). It allows to develop the the first part of the algorithm which calculates the values of the feature variables (Figure 3). The manual labelling data is also essential to validate the robustness of the model by comparing the results of the algorithm with created labelling dataset.

The next step is to develop the second part of the algorithm, namely to compare the feature valuable with the results of the gold standard in order to validate the algorithm. Validation means that the algorithm is tested on independent data that were not used during its development (Berckmans, 2013).

The most important part of development process of the monitoring algorithm is the final testing in real livestock houses which could show the ultimate results in terms of its performance in real time in continuously changing animal-related environment.

1.6 Application of technology to improve and assess animal welfare

1.6.1 The importance of Animal welfare assessment and monitoring

Animal welfare is a pressing public concern and its incorporation into farming practices is supported by the EU. Following new European rural Policy (2007-2013) approved by European Commission (2004), farmers applying ¨Good farming practices¨, which includes animal welfare legislation, receive direct payments. However, there is no European standard to assess animal welfare while bringing the information to consumers (Botreau et al., 2007). European citizens hold farmers primarily responsible for animal welfare. But farmers should be supported by institutional arrangements. There is common agreement that standards for animal welfare assessment and a reliable monitoring system need to be established. The main constraint on the development of an overall welfare assessment is that some welfare aspects are not easily assessed in an objective way, either qualitatively or quantitatively (Müller-Graf et al., 2008; Blokhuis et al., 2008). At present, animal welfare status on-farm is usually inferred from external parameters, such as cage size or feeder space. This approach has serious limitations because the relation between such design parameters and animal welfare is not clear. Current research offers the possibility of assessing the welfare of animals more directly, in terms of their condition, health, performance and behaviour. Despite the advances in research, a key question remains: how to develop and implement animal-based indicators in order to assess animal welfare more appropriately. Animal-based indicators refer to parameters such as body condition, abnormal behaviour, and skin lesions, which are measured on the animal itself. They are presumed to more directly reflect the actual welfare state as intended by legal requirements. The incorporation of animal-based measures such as foot lesions, breast blisters and mortality has played an important role in the relatively recent debates underlying the new Broiler Directive (adopted in May 2007; European Commission, 2005: GAIN report E35108).

Several research projects have been working on the development of animal-based measures and such measures are also considered in various assessment schemes. The outcomes of the Welfare Quality® Project provide the methodology for assessing animal welfare and a standardised way to assign farms a welfare grade from poor to excellent (Blokhuis et al., 2010). The welfare assessment protocols (Welfare Quality®, 2009a,b,c) give the procedures and requirements for the assessment of welfare in cattle, pigs and poultry according to this methodology.

At present most parameters included to the assessment protocols are measured by auditors during farm visits. The practical implementation of this kind of assessment has certain limitations. For example, according to the Welfare Quality® protocol (Welfare Quality®, 2009b) a total of 26 measures should be manually assessed for grower pigs on farms, which takes a lot of time. Moreover, assessment by ethologists is very expensive for practical application and has disadvantages of limited time period of observation. There is also a human factor, as assessment by the auditor is subjective and depends also on the level of his training and actual knowledge. Insufficient training of auditors, for example, who do not allow enough time for animals to completely settle down during tests, and possibility for farmers to affect animal behaviour before the visit by adjusting climate control or providing some enrichment materials such as straw, can affect the outcome of the audit. If the most important measurements could be automated and monitored continuously, this would make an enormous contribution to the assessment of animal welfare.

Automated measuring of animal-based parameters on farm is a new and promising field with a number of potential advantages when compared to on-farm auditing. These include real-time recording, web-based information exchange, more objective measuring of parameters, and the avoidance of biosecurity risks associated with farm visits. Moreover, automated recording may enable the parameters currently not feasible for on-farm assessment, such as heart rate and plasma cortisol (stress hormone) levels, to be incorporated in the welfare assessment scheme. Essentially, automated recording may increase repeatability and feasibility of large scale assessment and ultimately reduce costs and time consumption.

1.6.2 Monitoring of animal behaviours to improve animal welfare and farm management.

From the current scientific point of view, animal welfare (feelings) and animal responses (behaviour and physiology) are part of biological control systems (needs). The animal's behaviour and physiology are functional mechanisms which help the animal to cope with environmental challenge. These coping mechanisms may or may not be successful.

In any environment, the animal receives stimuli which may be regarded as 'input'. These include parameters describing the environment in which the animals are housed and managed, such as space allocation, farmer management and floor type. These parameters are known as environment-based parameters or 'means prescriptions', because they identify resources that are perceived as meeting welfare demands.

The animal compares the incoming stimuli with its needs, breeding and its previous life experiences (e.g. through learning and development). In response to stimuli from the environment, animals may or may not exhibit behavioural and physiological responses: the animal-based 'output' that helps the animal to cope with challenges (Figure 8). These responses indicate the level of welfare and the extent to which an animal has succeeded or has failed to cope with challenges (e.g. abnormal behaviours, elevated stress hormones, certain vocalisations).

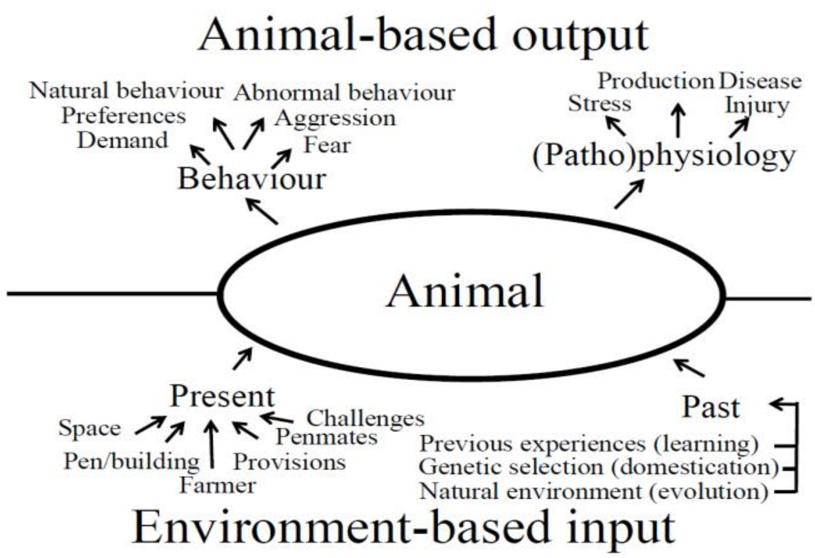


FIGURE 8: *Relations between various kinds of environment-based input and animal-based output.*

Source: European Parliament , Science and Technology Options Assessment (STOA): Animal-based Welfare Monitoring Final Report (2009) IP/A/STOA/FWC2005-28/SC28/40. IP/A/STOA/2007-09 PE 417.479.

The welfare concept has to be translated via behavioural needs into quantifiable behavioural parameters that can be used as inputs to model automated behaviour systems (Mishra et al., 2005). Quantification of the behaviour of animals is essential for monitoring them (Cangar et al., 2008). These monitoring systems could give an alert to the farmer in order to improve the management practices on the farm in order to ensure that a range of specific needs are met by the animals. The incidence of some behaviours (e.g. abnormal behaviours) repeating over time are signalising problems induced by the surrounding environment. For example, repeated coping attempts to inadequate environment, such as barren and restricted conditions without possibility of performance of their natural behaviours could induce abnormal behaviours in confined animals. Abnormal behaviour is behaviour that differs in pattern, frequency, or context from that which is shown by most members of the species in conditions that allow a full range of behaviour (Fraser and Broom, 1990). An abnormal behaviour might help an individual to cope, but it is still an indicator of the poor animal welfare (Broom, 1991). Other abnormal behaviour might be wholly pathological in that it serves no function and is caused by mental or physical disorder. Just some examples of such behaviours are tail and ear biting; cannibalism; bar-biting and sham-chewing (with nothing in their mouth).

The more such behaviours are shown, the poorer is the welfare and more is a necessity for the farmer to intervene with adapted managerial decisions.

Animal responses could be also used for the early warning of the farmer about environmental conditions on his farm which could lead to the health problems, such as temperature conditions inappropriate for the animals. Huddling, resting next to one another, and spreading are the stereotypical postural patterns of group-housed animals when experiencing cold, comfortable, and warm/hot sensation, respectively. Dedicated animal caretakers often use such behavioural patterns to fine-tune the ideal air temperature settings. The specific cough sounds produced by the pigs can be used as a biomarker for aerial pollutants on farm (Van Hirtum and Berckmans,2004).

1.7. Overview of the BioBusiness project

This thesis is based on the research carried out within the Marie Curie BioBusiness project (FP7-PEOPLE-ITN-2009-2014): “Training in research, product development, marketing and sales in biobusiness”. The overall objective of the project is to train biologically educated people such as veterinarians, biologists, physiologists, animal scientists and biomedical scientists to collaborate with technologically-driven people and make them familiar with modern technology. This is achieved by introducing the concepts of Precision Livestock Farming (PLF), a technology that allows the development of management tools for continuous automated monitoring of farm animals to improve their health, welfare and performance. Finally, training in the project covers research, product definition and development, marketing and sales for bio-livestock businesses.

For reaching this aim the BioBusiness project was subdivided in three separate research parts: improved conditions for incubating eggs (subproject A), automatic detection of lameness in cows (subproject B) and an automatic monitoring of pig undesired behaviours (subproject C).

This thesis is a part of the subproject C aimed to develop an automatic monitoring system of pig undesired behaviours. The collaborative research was carried out by four partner institutions: Milano University (UMIL), University of Veterinary Medicine Hanover (TiHo) and Catholic University of Leuven (KULeuven), as scientific partners and the Fancom BV, as industrial partner.

1.7.1 Description of the idea behind

In livestock production, some animal behaviour, such as aggression and cannibalism pose a serious welfare issue and create great problems in livestock farming management, resulting in economic losses. For this reason this behaviours could be defined as undesired behaviours. In pig husbandry, for example, aggressive behaviours (e.g. fighting) or abnormal behaviours (e.g. tail-biting, ear-biting) are undesired behaviours since they cause high stress level: the pigs become more easily subjected to diseases and have lower growth levels. The scratches and wounds due to the fights or cannibalistic behaviours can lead to serious production losses and even the death of the animals. The key idea was to develop an automatic monitoring and control tool of undesired behaviours. This tool is composed of two principal components: control and monitoring. The control component aims to reduce undesired behaviours in livestock by using the intelligence of the animals and their ability to learn. The patent for this approach was submitted. The animals are trained in a fully automatic way by a combination of triggers and rewards. By doing so, attention of the animals is grabbed by the trigger(s) (e.g. sound, light) at the moment that early signs have been observed in order to stop the undesired behaviours in a fully automatic way. If the attention of the livestock is obtained, then the animal can be rewarded (e.g. giving feed). The schematic diagram in Figure 9 shows the idea how to stop undesired behaviours by training the animal in a fully automated way.

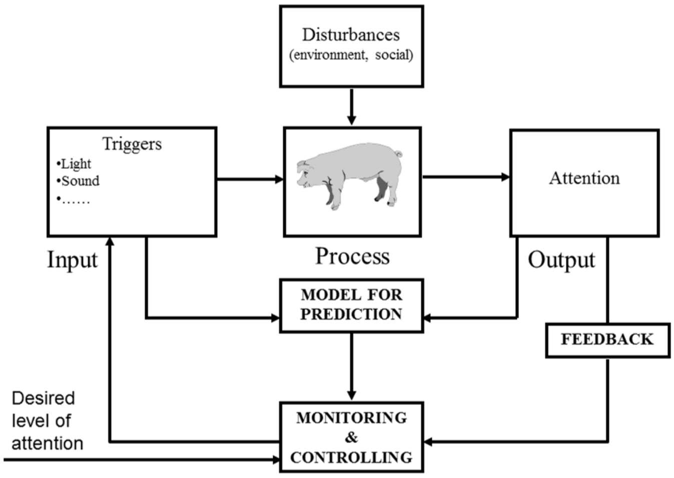


FIGURE 9: *Principle of automatic monitoring and control tool of undesired behaviours*

Source: Patent "Automated monitoring and controlling of undesired livestock behaviour" WO 2013122468 A1

The monitoring component is an automatic monitor which would be able to detect undesired behaviours (e.g. aggressive interaction) automatically by dynamic analysis of the interactions between animals. The animals are monitored continuously by monitoring algorithm using sensors, such as cameras. Cameras are used to extract specific variables used to detect undesired behaviours. When the behaviours are detected the signal is given to the control mechanism. Continuous, real time measurement of aggressive behaviour of pigs should in the first instance allow creating an objective and accurate information system that a farmer can use in order to reduce the aggression on his farm. In the second instance it should give a possibility to automatically lower the aggression level by application of trigger (i.e. sound, smell) and reward combination that will change pig's behaviour in a way that the incidence of target behaviour is reduced.

1.7.2 Objectives of the collaborative research

The overall objective of this research project was to develop an automatic tool to monitor and control aggressive behaviour of pigs, using a control mechanism activated by the mathematical algorithm detecting pig's behaviours from the camera image in real time in fully automatic way.

This overall objective can be broken down to four more specific objectives that would together achieve the overall goal of the project as follows:

i. To understand causes and pattern of execution of aggressive behaviour of weaned pigs, particularly after mixing;
ii. To develop algorithms which can automatically detect such behaviours and which can be automatically recognised via video observations;
iii. To design and test an intervention method by which violent actions among pigs can be stopped or at least reduced;
iv. To achieve a proof of concept for the further development of a product which can be used on commercial farms to mitigate violent aggression among pigs.

The general objective of this thesis was to contribute to the development of the real-time monitoring and control tools through development and implementation of the image labelling technique.

The specific objectives were to:

i. Define and realise manual image labelling as a reference for development of an automatic monitoring tool of pigs behaviours

ii. Define the feature variables to be used for development of an algorithm for an automatic monitoring and control tool of pig behaviours

iii. Build up a labelling database to be used for the development of a prototype for monitor and control of pig aggression

iv. Analyse the effectiveness of the control component of the automatic tool on reduction of aggression after mixing

CHAPTER 2

Image labelling for the development of pig aggression monitoring and control tool

This chapter consists of two published peer reviewed articles and two articles submitted to the peer reviewed journals. The aim of this chapter is to illustrate image labelling input to different stages of aggression and monitoring tool development.

i. Subchapters 2.1 and 2.2 report results from development of the aggression monitoring component of the automatic tool. This part of the study aimed to understand causes and pattern of execution of aggressive behaviours of weaned pigs in order to define the feature variables and to develop an algorithm which can automatically detect such behaviours from video recordings.
ii. Subchapters 2.3 and 2.4 report results from development of the aggression control component of the automatic tool. This part of the study aimed to design and test an intervention method by which aggression behaviours between pigs can be stopped or at least reduced.

2.1 How do pigs behave before starting an aggressive interaction ? – Identification of typical body positions in the early stage of aggression using video labelling techniques.

Gunel Ismayilova[1] ,Maciej Oczak[2] ,Annamaria Costa[1] , Lilia Thays Sonoda[3], Stefano Viazzi[2], Michaela Fels[3], Erik Vranken[2], Jörg Hartung[3], Claudia Bahr[2], Daniel Berckmans[2] , Marcella Guarino[1]

[1] Department of Veterinary and Technological Sciences for Food Safety, Faculty of Veterinary Medicine, Università degli Studi, Milan, Italy

[2] M3-BIORES: Measure, Model & Manage Bioresponses, Katholieke Universiteit Leuven, Leuven, Belgium

[3] Institute for Animal Hygiene, Animal Welfare and Farm Animal Behaviour, University of Veterinary Medicine Hannover, Foundation, Germany

Published in Berliner und Münchener Tierärztliche Wochenschrift 126 (2013), 113–120

Received 3 August 2012; accepted 26.November.2012; published 08 March 2013

Abstract

The aim of this study was to identify, quantify, and describe pre-signs of aggression in pigs and the early stages of aggressive interactions. The experiment was carried out at a commercial farm on a group of 11 male pigs weighing on average 23 kg and kept in a pen of 4m x 2.5m. In total 8 hours were videorecorded during the first 3 days after mixing. As a result, 177 aggressive interactions were identified and labelled to find pre-sign body positions before aggressive interactions, attack positions and aggressive acts performed from these positions. A total of 12 positions were classified as pre-signs (P1-P12) and 7 of them were identified immediately at the start of aggressive interactions (P6-P12). Most common pre-sign positions were P3-pigs approaching and facing each other (24%) and P2-initiator pigs approaching from the lateral side (18%). In 80% of the cases the duration of pre-signs was 1-2 sec. 72% of all aggressive interactions were short (1 to 10 sec). The most frequent attack positions were P12-inverse parallel (39.5%), P7-nose to nose, 90° (19.77%) and P9-nose to head (13.5%). The most frequent aggressive acts from attack positions were head knocking (34.4 %), pressing (34,4%) and biting of different body parts (29.4 %). Head knocking was mostly observed in relation to P7 and P2 positions and biting was common in the P7 position. In conclusion, pigs adopt specific pre-signs and body positions before the escalation of aggressive interactions. This could be used as potential sign to identify a beginning aggression.

Keywords: *pig, aggression, body position, labelling, precision livestock farming*

2.1.1 Introduction

Numerous scientific studies on pigs' behaviour show that under farm conditions pigs tend to maintain the same behavioural characteristics and habits as in nature, including social structures in groups (Frädrich, 1974; Schnebel and Griswold, 1983; Graves, 1984). Under intensive farming, group composition often does not remain stable over a longer period, thus it is much more difficult to establish a fixed social structure. Mixing with unacquainted pigs occurs usually after weaning, at the beginning of the fattening period or in breeding herds with sows leaving to farrow and being reunited after service. This standard practice can result in elevated levels of aggression (Spoolder et al, 2000; Turner et al., 2009). Numerous behavioural studies were carried out in the past with the aim to understand aggressive behaviours in pigs on farms and to describe the fighting mechanisms and the behavioural sequences during the fighting process (Fraser, 1974; Jensen, 1980, 1982, 1994; Jensen and Yngvesson, 1998; McGlone, 1985; Rushen, 1987; Rushen and Pajor, 1987; Rushen, 1988; Turner et al., 2006). These studies reveal that fighting is a gradual developing complex event, often starting with mutual exploring procedures, such as nose to nose interaction, eventually leading to pushing, pressing, head-knocks, jumping on opponent and vigorous biting mostly on the head, ears, and neck (McGlone, 1985; Geverink et al., 1996; Jensen and Yngvesson, 1998; Weary and Fraser, 1999), resulting in numerous skin lesions on the body the longer or more frequent the fight goes on. However, while these studies represent an advance in description of fighting strategies, no particular attention was given to the pre-aggression phase in pigs behaviour in real postmixing conditions. There are few studies of aggressive behaviour in the resident-intruder test. For the resident-intruder test, a resident pig is placed in one half of its home pen, separated from its pen mates. An intruder pig which is often younger or lighter than the resident pig, is then introduced into the area of the resident pig. Attacks and/or attack latency are recorded (Erhard and Mendl, 1997; Erhard et al., 1997; D'Eath and Pickup, 2002). D'Eath and Pickup (2002) showed the existence of certain behaviours and body positions that pigs adopt during the attack latency period. However, the description of the social behaviours before the aggression in a resident-intruder test, designed for evaluation of individual aggressiveness could not reflect the reality of pre-aggression behaviour of the animals in real post-mixing conditions, where pigs are mixed into new, large groups in an unknown environment. Thus further in-depth studies are needed. Reliable early indicators of aggression could help to predict aggressive interactions and may be used for immediate intervention in the right moment in order to avoid or at least reduce the number and intensity of fighting encounters. According to Parratt et al. (2006) minimizing fighting among pigs alleviates stress, improves welfare of the animals and enhances production efficiency. The aim of this study was to identify, quantify, and describe the pre-aggression phase and the early stages of aggressive interactions in video images in order to find reliable early indicators to predict aggression under real post-mixing conditions.

2.1.2 Material and Methods

<u>Animals and housing</u>

The experiment was carried out at a commercial fattening pig farm located in Heusden, the Netherlands. The experimental pigs (Topigs 20 x Pietrain) were previously housed in stable groups of 11 individuals weaned at the age of 4 weeks. They were kept in pens sized 1.5 m by 1.5 m and fed dry feed ad libitum. At the age of 9 weeks they were transported to the experimental facility in a group of two hundred pigs. From this group, 11 non castrated males pigs weighing on average 23 kg (± 1.31) were randomly selected for the test group. The test pen was 4 m by 2.5 m with partially slatted concrete floors and solid walls; and equipped with a central flow ventilation system (Fancom B.V. – F21). The pigs were fed dry feed ad libitum from a feeder with 2 feeding places using a Fancom B.V. – F71 feeding system. Standard colour spray was applied to the backs of the pigs to identify individuals in overhead video recordings.

Experimental installations

The video recordings were performed using a camera (Allied Vision Technologies®, model F080C) with 4.8 mm lens, placed above the pen in central position at a height of 2.3 m, that permitted an overhead image of the whole pen. Colour images were captured with a rate of 25 images per second with a resolution of 1032 x 778 pixels. The videos were stored in a computer for later analysis.

A non-transparent paper wall was installed between the corridor and the pen in order to prevent any distraction of the pigs by human presence. In this way, a total of 8 hours of video recordings were registered during the first 3 days after mixing (day 1: 2 h, day 2: 3 h, day 3: 3 h).

Video Labelling procedure

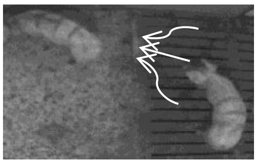
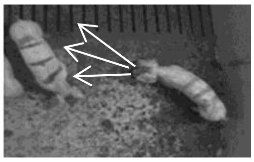
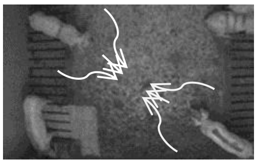
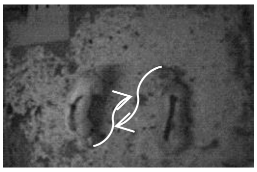
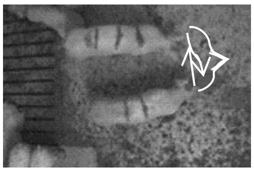
The video recordings were scrutinized for aggressive interactions between the pigs. An aggressive interaction was defined as a close physical contact in which at least one of the interacting pigs performed head knocking, biting, or pressing behaviours. When an aggressive interaction was interrupted or stopped, e.g. by retreat of one or both pigs, this sequence was interpreted as a finished interaction. Any further attack was counted as a new action. Every single interaction was observed to be able to determine the exact starting time and duration of the aggressive interaction and to describe the behaviour and body positions in the early phase of aggression. The body positions which pigs adopt prior the aggressive attacks were considered as pre-signs of aggression.

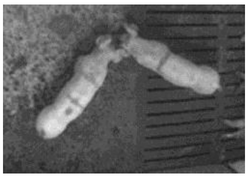
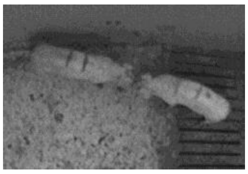
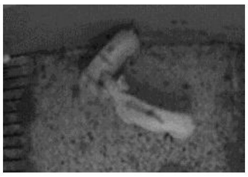
Pre-sign body positions were divided into two categories:

- Distance positions: spatial orientations of the pigs bodies at the moment when the initiator starts an attack from a distance without any contact to the receiver.
- Contact positions: body positions which the two animals adopt at the first contact before the escalation of attack.

In total, 13 body positions of two interacting pigs, were analysed respectively. Of these body positions, five were classified as distance positions and eight as contact positions (Tab. 1).

TABLE 2: *Description of Labelled body positions*

Body Positions	Code	Description
No -contact		
	P1	Starts when initiating pig raises its head to proceed directly to another pig's tail; ends at the first body contact of two pigs at the start of the aggressive interaction.
	P2	Starts when initiating pig raises its head to proceed towards another pig 's body from the lateral side; ends at the first body contact of two pigs at the start of the aggressive interaction.
	P3	Starts when initiating pig or both pigs proceed straightly in direction of each other's head; ends at the first body contact of two pigs at the start of the aggressive interaction.
	P4	Starts when initiating pig or both pigs proceed in parallel but in opposite direction of each other's head ends at the first body contact of two pigs at the start of the aggressive interaction.
	P5	Starts when the pigs move together in parallel facing in the same direction; ends at the first body contact of two pigs at the start of the aggressive interaction.
Contact		
	P6	Pigs stand side-by-side.

	P7	Pigs stand with their noses approaching each other, their bodies forming a 90^{o} angle.
	P8	Pigs stand facing each other straight on.
	P9	The nose of one pig approaches the head, ears or shoulders of another pig.
	P10	The nose of one pig approaches the tail of another pig.
	P11	The nose of one pig approaches any posterior body part of another pig.
	P12	The pigs face each other with their shoulders touching.
	P13	The pig jumps from behind with its front legs on the back or lateral side of another pig.

By examining video images, interactions were categorized into those starting immediately or those with pre-sign positions. The time from the pre-sign body position detection till the beginning of the aggressive interaction was defined as the "attack latency". The contact positions detected at the first body contact of an aggressive interaction were defined as attack positions (Fig. 1).

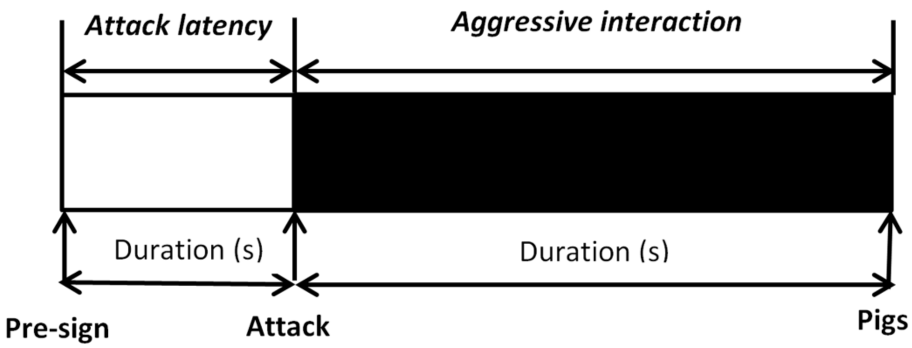


FIGURE 1: *Scheme of the labelling of the aggressive interaction*

The aggressive acts performed by the initiator pig from the attack position were also analysed and described in Table 2.

TABLE 2*: Description of initial behaviours of initiator pigs*

Behaviour	Description
Body biting	Initiator started aggressive interaction by biting (opened its mouth and closed it on any part of the body of another pig, excluding the front part of the body (head, ear, neck)
Head biting	Initiator started aggressive interaction by biting the head region (except ears) of another pig.
Neck biting	Initiator started aggressive interaction by biting the neck zone and shoulders of another pig.
Ear biting	Initiator started aggressive interaction by biting the ear of another pig.
Head knocking	Initiator used a fast side to side or upwards movement of its head to hit any part of the head or body of another pig. The mouth is kept closed (Erhard et al., 1997, Jensen, 1980).
Jump on other	Initiator starts aggressive action by jumping on the responder pig with its forelegs from lateral side or rear.
Push	Initiator starts aggressive action pressing of the shoulder against another pig.

The duration of the aggressive interaction was registered from the moment of attack position detection until separation of the pigs (Fig. 1).

The recorded videos were analysed by one observer using the software “Labelling Tool” (Viazzi et al., 2011) developed in Matlab (R2009a, The MathWorks Inc., MA). The labelling procedure is necessary for the identification of every selected behaviour happening during a certain period of time. Each recorded image is visually checked and manually labelled according to the chosen

variables image by image (25 images per second).When a body position variable was detected by an observer on the video, the appropriate matching button was selected on the Labelling Tool interface and released when finished. In this way the duration of the attack latency and aggressive interaction were calculated. The information of the behaviours labelled were displayed on the panel (Fig. 2). The Labelling Tool allowed to export the data in excel files for statistical analysis.

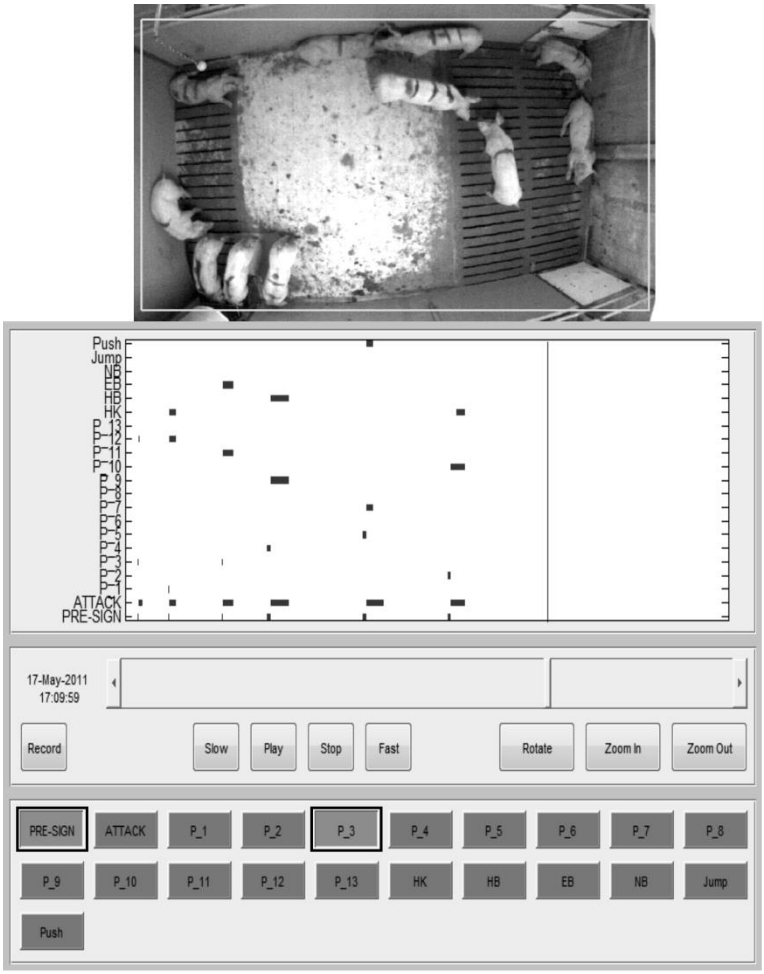


FIGURE 2: *The Labelling Tool interface*

<u>Statistical analysis</u>

Data were processed through the variance analysis (Proc. GLM; SAS, 2008) to estimate the effect of pre-sign positions on duration of attack latency and aggressive interactions.

The statistical analysis was performed using the following model.

yijkl= μ + Ti+ Lk+ eik

y = independent variable of the attack latency or duration of aggressive interactions

μ = overall mean

Ti = effect of i^{th} observation period in hours (i = 1,...8)

Lk= effect of the k^{th} pre-sign positions (k=1, 13)

e_{ik} = random residual

The Frequency procedure (Proc. Freq. SAS, 2008) was applied to obtain the occurrence for each of the body positions and aggressive acts labelled. The duration of aggressive interaction was expressed in classes of 5 sec intervals.

To analyse the transition between the pre-sign position to attack position we computed the transition matrices based on single-order Markov chains, with the scores of pre-sign-positions in the rows and those of attack positions in the columns. What was actually recorded was the order in which the behaviours occurred, regardless of the individuals performing it. After examining the observed frequency transition matrix for large differences between cells, the expected frequency matrix was constructed by calculating the expected frequency for each cell according to the formula (Chatfield and Lemon, 1970):

$$Expected\ frequency = \frac{Row\ total\ x\ Column\ total}{Grand\ total}$$

It was assumed that the transitions between pre-sign positions to attack positions are dependent on one another at some level of probability greater than chance. The expected frequency were calculated and the T-Test on these values was performed to estimate significant differences between expected and real frequencies.

Chi square test (SAS, 2008) was used to calculate the transition frequencies between pre-sign positions and aggressive act of initiator pig at the start of an attack; and to evaluate the relation of the attack positions and the aggressive act.

2.1.3 Results

A total of 177 aggressive interactions were identified from 8 hours of video recordings. The duration of most of registered aggressive interactions (72%) was short, from 1 to 10 sec (Tab. 3).

TABLE 3: *Duration of aggressive interactions*

Duration (sec)	Number of interactions	Percent (%)
1-5	73	41.24
6-10	54	30.51
11-15	15	8.47
16-20	7	3.95
21-25	5	2.82
26-30	6	3.39
31-35	3	1.69
36-40	3	1.69
41-45	1	0.56
46-50	2	1.13
More than 50	8	4.52

The distance pre-sign positions could be noticed before aggressive interactions in 54% of observed aggressive interactions (Tab. 4).

TABLE 4: *Number and percentage (%) of observed positions. The labels are the same as those given in Table 1*

Positions label	Freq. of pre-sign positions	% of pre-sign positions	Freq. of attack positions	% attack positions
No pre-sign position				
P0	50	28.3	-	-
Distance positions				
P1	4	2.3	-	-
P2	32	18.1	-	-
P3	43	24.3	-	-
P4	8	4.5	-	-
P5	9	5.1	-	-
Contact positions				
P6	3	1.7	11	6.2
P7	3	1.7	35	19.8
P8	6	3.4	16	9.0
P9	3	1.7	24	13.6
P10	2	1.1	7	4.0
P11	2	1.1	12	6.8
P12	8	4.5	70	39.6
P13	4	2.3	-	-

The contact pre-sign positions were observed only in 17.5% of the cases. Most common pre-sign positions were P3 (43 pre-signs = 24%), when pigs approached facing each other and P2 (32 pre-signs = 18%), when the attacking pig approached from the lateral side.

Aggressive interactions most commonly began with the animals in inverse parallel position (P12, 39.5% of all bouts), nose-to-nose forming 90° angle (P7, 19.7%) or in perpendicular position with nose approaching to anterior part of the body (P9, 13.5%). The effect of the pre-sign position on duration of attack latency is shown in Table 5.

TABLE 5*: Duration of attack latency (sec) in relation to pre-sign position*

Codes pre-sign position	Duration LSM± SE	Significance***
Distance positions		
P1	0.8±1.0	NS
P2	1.6±0.4	***
P3	1.5±0.3	***
P4	1.5±0.7	*
P5	2.8±0.7	***
Contact positions		
P6	1.0±1.2	NS
P7	1.67±1.2	NS
P8	2.8±0.8	**
P9	2.3±1.2	*
P10	1.5±1.4	NS
P11	0.5±1.4	NS
P12	3.6±0.7	***
P13	13.3±1.0	***

**P≤.05; **P≤.01.; ***P≤.001.*

A significant relation (P ≤ .001) between the pre-sign position and duration of attack latency was found. It was noticed that pigs attack their opponent at high speed. The attack latency of pigs starting from the distance position was short. Within 1-2 sec the attacking pig bridged the distance to the opponent. The longest attack latency was starting from P5. In this case before an aggressive attack pigs were situated in parallel to each other without contact for 2.8 sec (P ≤ .001; Tab. 5). The attack latency from the contact positions in some cases lasted more than 2 sec without breaking body contact, the longest were P12, before starting an attack pigs could stay in this position for 3.62 sec (P ≤ .001), and P13 (13.3 sec; P ≤ .001), which was corresponding to mounting behaviour and was registered only when led to aggressive interaction. The effect of the pre-sign position on duration of aggressive interaction is presented in Table 6.

***TABLE 6**: Effect of pre-sign positions on duration of aggressive interaction (sec)*

Pre-sign position label	Duration LSM± SE	Significance***
P0 No pre-sign	13.8±2.7	***
Distance positions		
P1	12.3±9.4	NS
P2	12.8±3.3	***
P3	9.4±2.9	***
P4	25.8±6.7	***
P5	19.9±6.3	**
Contact positions		
P6	3.0±10.9	NS
P7	16.0±10.9	NS
P8	14.3±7.7	NS
P9	10.0±10.9	NS
P10	6.0±13.3	NS
P11	13.0±13.3	NS
P12	7.8±6.7	NS
P13	4.0±9.4	NS

**P≤.05; **P≤.01.; ***P≤.001.*

Most of the distance pre-sign positions were found to be related to the duration of aggressive interactions, the longest interactions were observed from P5 (19.89 sec; P ≤ .01) and P4 (25.8 sec; P ≤ .001) positions. The complete transition matrix from pre-sign position to attack position for 177 observed interactions is given in Table 7.

TABLE 7: *The transition matrix for the inter-individual interactions. The first value in each cell is the observed number of transitions, the second is the calculated expected value. The pre-sign positions are listed in the rows and the attack positions in the columns. The codes are the same as those given in Table 1.*

Pre-sign positions	Attack positions							
	P6	P7	P8	P9	P10	P11	P12	Row totals
P0 No pre-sign	2 3.1	11 9.9	3 4.5	8 6.8	2 2.0	6 3.4	18 19.8	50
P1	0 0.2	0 0.8	0 0.4	2 0.5	2 0.2	0 0.3	0 1.6	4
P2	0 2.0	9 6.3	4 2.9	7 4.3	1 1.3	4 2.2	7 12.7	32
P3	1 2.7	4 8.5	7 3.9	3 5.8	1 1.7	0 2.9	27 17.0	43
P4	0 0.5	1 1.6	0 0.7	1 1.1	0 0.3	1 0.5	5 3.2	8
P5	3 0.6	3 1.8	0 0.8	0 1.2	0 0.3	0 0.6	3 3.6	9
P6	3 0.2	0 0.6	0 0.3	0 0.5	0 0.1	0 0.2	0 1.2	3
P7	0 0.2	1 0.6	0 0.3	1 0.4	0 0.1	0 0.2	1 1.2	3
P8	0 0.373	2 1.2	1 0.5	1 0.8	0 0.2	0 0.4	2 2.3	6
P9	0 0.2	2 0.6	0 0.3	0 0.4	0 0.1	0 0.2	1 1.2	3
P10	0 0.1	1 0.4	0 0.2	0 0.3	1 0.1	0 0.1	0 0.8	2
P11	0 0.1	0 0.4	0 0.2	1 0.3	0 0.1	1 0.1	0 0.8	2
P12	0 0.4	2 1.6	1 0.7	0 1.1	0 0.3	0 0.5	5 3.2	8
P13	2 0.2	0 0.8	0 0.4	0 0.5	0 0.2	0 0.3	2 1.6	4
Column totals	11	36	16	24	7	12	71	177

Each cell contains 2 values: the observed number of transitions at the top and calculated expected value at the bottom. T test didn't show any significant difference between expected and real transition frequencies. The most frequent attack position

P12 (71 episodes) began in particular without pre-sign (18 transitions) or followed P3 pre-sign position (27 transitions). Real values in this last case are higher than the expected ones, but this difference was not significant.

Figure 3 shows the relation of aggressive acts to pre-sign positions. Head knocking behaviour was

observed mostly at the start of interactions without pre-sign and those anticipated by P2 pre-sign position. Push was anticipated mostly by P2 and P3 pre-sign positions.

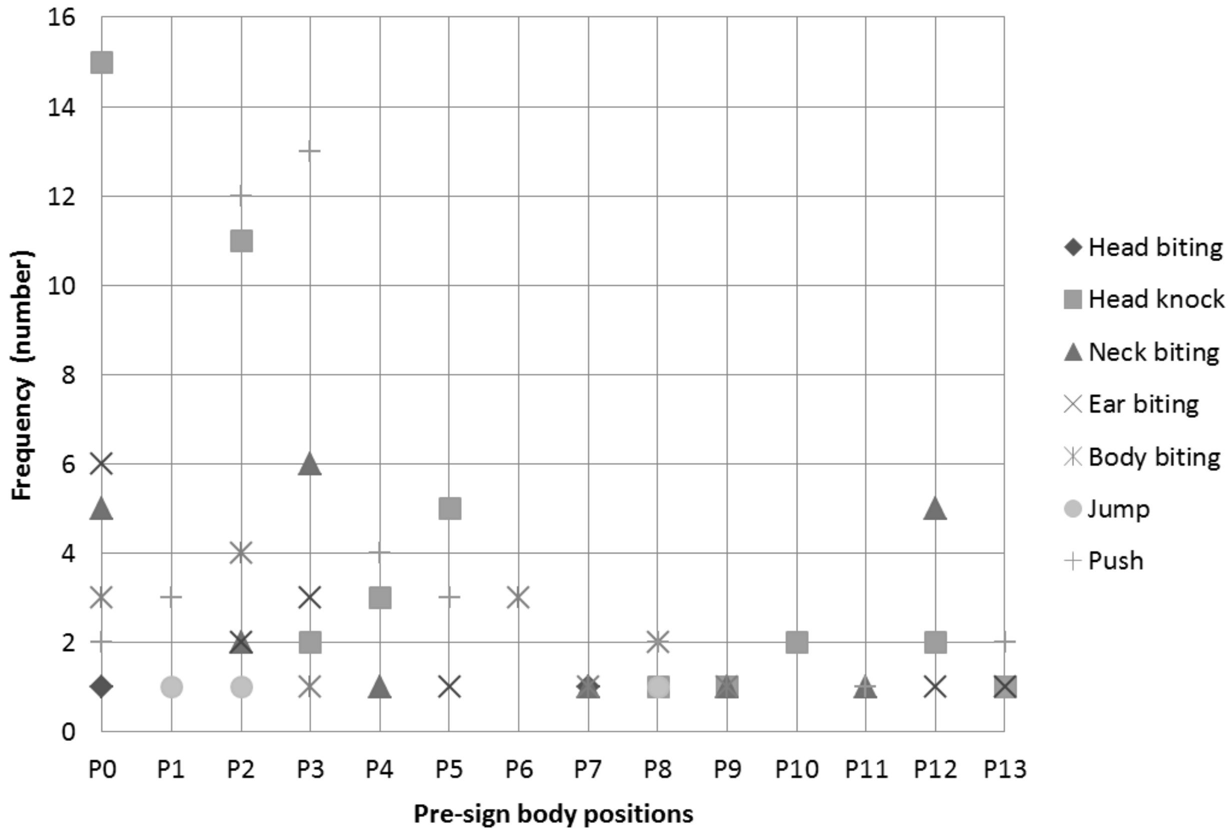


FIGURE 3: *Transition frequencies between pre-sign positions and aggressive act of initiator pig at the start of an attack (The overall Chi-square value indicated a difference (***P≤.001))*

Figure 4 shows the aggressive acts that the initiator pigs performed from the attack positions. In relation to attack body positions, the most frequent aggressive acts were head knocking (34.5%) and push or pressing (34.5%). The most frequent attack positions from which head knocking and push were performed were P12 and P7. The bites were particularly directed to the neck (13%) and ears (8.5%). From P12 positions, pigs started aggressive interactions with biting more frequently than from other positions mostly directed towards the neck (Fig. 4). On occasion, pigs bit other regions of the body when they attacked, particularly flanks or back (6.8%).

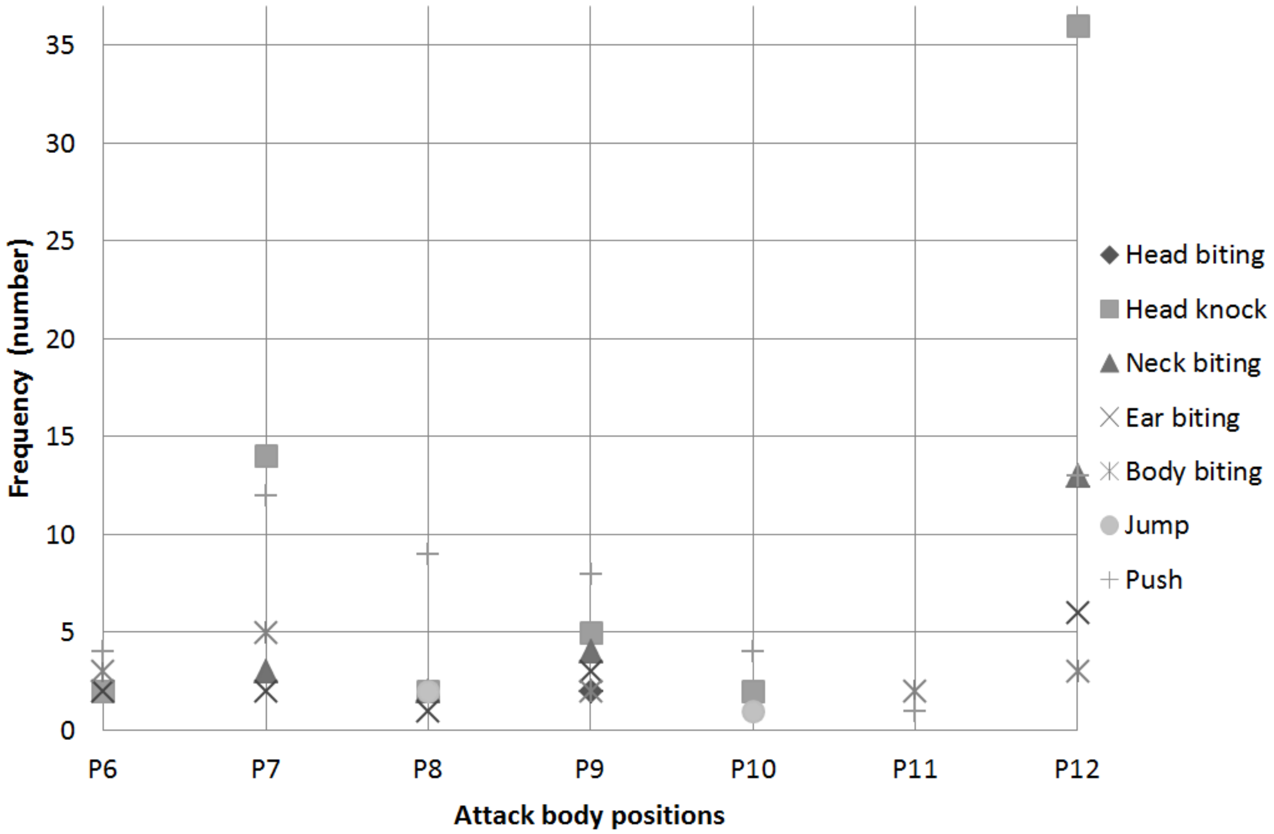


FIGURE 4: *Aggressive acts of initiator pig performed from attack positions (The overall Chi-square value indicated a difference (***P≤ .001))*

2.1.4 Discussion

The aim of this research was the identification of pre-signs of pigs aggressive behaviour in the pre-aggression phase which can possibly be used for an early intervention before the escalation of aggression. The results of video labelling showed that in the most of cases (70% of all aggressive interactions) we could observe pre-signs on video images. 54% of all aggressive acts were started from distance pre-sign positions whereas contact pre-sign positions were observed only in 17.5% of cases. It shows, that in a group of recently mixed pigs under real farming conditions, the initiator mostly had no contact with the receiver shortly prior the attack which is in contrast to the results obtained from the resident-intruder test by other authors (Erhard et al.,1997; D’Eath and Pickup, 2002). This difference could be explained by the fact that in our experiment the pre-signs of all the attacks happened during a certain post-mixing period and not only when the opponents first met. The distance pre-signs could also precede the repeated attacks, when the pigs are already acquainted with each other. In fact, some of contact positions are corresponding to those described by D’Eath and Pickup (2002) as social behaviour positions of pigs during the attack latency period. They characterised them as positions adopted during the performance of recognition and assessment behaviour. In their study, aggressors initiated more head-to-head positions and T-position-head. Our results showed P12 corresponding to their head-to-head position as the most represented among the contact pre-sign positions (5%). The attack latency in those 80% of the cases when a pre-sign position was detected had a duration of 1 to 2 sec. This means that there is a time span of approximately 1 to 2 sec available for any intervention technology in order to stop the aggressive behaviour before injuring fighting starts. In general, the attack latency from the distance pre-sign positions lasted shorter than from contact positions, ranging between 1 (P1 position) to 2.8 sec (P5 position). Among the contact pre-sign positions the longest attack latency started from P12 (3.6 sec) and P13 (13.3 sec) positions. The considerable difference in duration of attack latency from P13 could be explained by the mounting behaviour performed from this position, which lead to the aggressive interaction, thus it was considered as a pre-sign. The most frequent distance positions observed were P3 (24% of all aggressive interactions) when an initiator pig arrived directly facing another pig and P2 (18%) when a pig approached the opponent from the lateral side. It was also found that pre-sign positions which pigs adopt before an attack affected the duration of aggressive interaction. Aggression anticipated by P4 and P5 distance pre-sign positions had longer duration (20–25 sec) than from other positions. By statistically relating each of the pre-sign positions to the attack positions, the effects of each pre-sign on the attacking strategies can be measured. It is very likely that the attack position of each piglet is dependent on its own earlier body orientation. An intra-individual sequence analysis showed that the most frequent sequence for an attack was P3 pre-sign position followed by P12 attack position. To the best of our knowledge, this is the first study which identified early signs of aggressive interactions among pigs in post-mixing conditions. Some authors describe typical fighting positions in pigs when fighting has already begun (e.g. Jensen,1980; McGlone,1985; Rushen and Pajor ,1987; D'Eath and Pickup, 2002). T-position-head was found by Rushen and Pajor (1987) to be the most effective offensive move during fights, allowing a pig to attack with minimal risk of the intruder retaliating. Headto- head position was thought to be more reciprocal, allowing both pigs the chance to attack the head region of the opponent. In fact, in our study, P12 position (head-to-head) was the most frequent attack position (39.55%) which confirms the results (37% of all bouts) of Rushen and Pajor (1987). In the study of D'Eath and Pickup (2002) most attacks occurred from T-position-head (P9 and P7). Our study showed that attack positions P12, P7 and P9 were represented in 72.7% of all interactions. This opens opportunities to focus on these positions for monitoring the onset of this type of aggression. Rushen and Pajor (1987) stated that the motivational significance of special positions adopted during fights reflects simple physical mechanics of delivering bites to particular target areas. Numerous studies of aggressive behaviours showed that ears, neck/shoulders and head are the main target zones for bites during the fights (e.g. McGlone, 1985;

Rushen and Pajor, 1987). Our results agree with these studies, since at the start of the aggressive interactions the bites were directed mostly to the neck and ears. From P12 position pigs started aggressive interaction with biting more frequently than from other positions, mostly the neck was bitten, as this target zone was the most achievable for the bites from this position. However, the most frequent aggressive act was the head knock, mostly from P12 and P7 positions. Our findings are similar to those of Jensen (1982), who found that after nose-to-nose position (it was considered in our study as P7 and P8 positions) head-to-head and head-to-body knocks are the most frequent behaviours at the start of fights.

2.1.5 Conclusions

In 70% of 177 investigated aggressive interactions of young fattening pigs pre-signs of aggression could be detected by the used video labelling technique. Two distance positions (P3 and P2) and three attack positions (P12, P7 and P9) are dominating and could be used for early detection of aggression. In 80% the attack latency had a duration of 1 to 2 sec depending on the pre-sign position. Our results indicate that there is a potential for early intervention before the escalation of aggressive acts among pigs. This intervention as well as the detection of the early signs of aggression could be done automatically. Further research is needed to reach this goal and to develop adequate automatic monitoring and intervention systems which could enhance animal welfare preventing pigs from suffering aggressive attacks and injuries.

2.2 Image features extraction for classification of aggressive interactions among pigs.

S. Viazzi[1], G. Ismayilova[2], M. Oczak[1], L. T. Sonoda[3], M. Fels[3], M. Guarino[2], E. Vranken[1], J. Hartung[3], C. Bahr[1], and D. Berckmans[1]

[1]Division of Measure, Model & Manage Bioresponses (M3-Biores), KU Leuven, Kasteelpark Arenberg 30, 3001 Leuven, Belgium

[2]Department of Veterinary and Technological Sciences for Food Safety, Faculty of Veterinary Medicine, Università degli Studi, Via Celoria 10, 20133 Milan, Italy

[3]University of Veterinary Medicine Hannover, Foundation, Germany, Institute for Animal Hygiene, Animal Welfare and Farm Animal Behaviour, Bünteweg 17p, 30559 Hannover, Germany

Submitted to Computers and Electronics in agriculture (COMPAG) 1 July 2013

Abstract

The aim of this study is to develop a method for continuous automated detection of aggressive behaviour among pigs by means of image processing. In 5 repetitive experiments 24 piglets were mixed in 2 pens after weaning and captured on video for a total of 60 hours. From these video recordings, a dataset containing 150 episodes with and 150 episodes without aggressive interactions was built through manual labelling. The Motion History Image was used to gain information about the pigs' motion and to relate this information to aggressive interactions. Two features were extracted from the segmented region of the Motion History Image: the mean intensity of motion and the occupation index. Based on these two features, the Linear Discriminant Analysis was used to classify aggressive interactions in every episode. Applying leave-one-out cross-validation, the accuracy of the system was 89% with a sensitivity of 88.7% and a specificity of 89.3%.

Keywords: *pig behaviour, monitoring tool, image processing, precision livestock farming*

2.2.1 Introduction

In intensive farming, pigs are kept in a confined environment and express aggressive behaviour on a much higher level (Erhardet al.,1997, Stukenborg et al., 2011) than they do in a natural environment. Reasons for this aggressive behaviour in intensive farming conditions can be found in the limited space allowance (Weng et al., 1998), barren environment (Durrell et al., 1997), low fibre feed diets (Meunier-Salaun et al., 2001) and repeated changes in group composition (Spoolder et al., 2000, Turner et al., 2009). In fact, domesticated pigs are hierarchical animals just like wild pigs (McBride et al., 1965). In intensive farming, the group hierarchy does not always remain stable due to the commercial practice of mixing the animals. This mixing usually occurs after weaning, at the beginning of the fattening period or in sows after service due to management choices. This practice results in intense, aggressive interactions, which occur mainly within the first two days from the new group formation (Keeling and Gonyou, 2001) until the new dominance hierarchy has been established. These encounters can lead to wounds that may cause infections and may even be lethal in extreme cases (McGlone et al., 1980).

Furthermore, aggression leads to economic losses because weaker animals that are dominated by more aggressive animals do not have enough access to food, which results in a decrease of growth rate and increase of weight variability within the pen (Stookey and Gonyou, 1994). Injuries caused by aggressive interactions can also cause a significant loss in value due to the condemnation of carcass parts or downgrade of the carcass to a lower meat quality (Faucitano, 2001). Additionally, stress caused by aggressive behaviour can reduce the fertility of breeding sows (Kongsted, 2004). Aggression among pigs is therefore one of the most important health, welfare and economic problems in intensive farming (Faucitano, 2001, Bracke et al., 2002).

Since the duration of aggression is strongly related to the skin lesions inflicted on the animals (Turner et al., 2006), this study will only focus on aggressive interactions that last for a certain time and thus have a higher probability of being harmful encounters. Therefore, an aggressive interaction was defined in this study as a close physical contact which lasted at least five seconds and in which at least one of the interacting pigs exhibited head knocking, biting, or pressing behaviour.

So far, different studies have aimed at the development of automated systems for pig production. Examples are systems to detect oestrus by using infrared sensors (Freson et al., 1998), to monitor drinking behaviour (Madsen et al., 2005), or to detect infected cough by sound analysis (Van Hirtum and Berckmans, 2003, Exadaktylos et al., 2008). Other systems assess the thermal comfort (Shao and Xin, 2008) or estimate the live weight (Wu et al., 2004) by means of image processing.

However, no studies have been carried out so far to automatically monitor episodes of aggressive behaviour. Today, the farmer assesses the severity of aggression (i.e. scratches) merely by visual observation.

Hence, the objective of this paper is to develop a method for automatic detection of aggressive interactions among pigs by means of computer vision techniques. The suggested method aims at classifying episodes with and without aggressive interactions by using dynamic local and temporal information of mean intensity and mean occupation of movement. The hypothesis of this study is that aggressive interactions generate both a high level of movement, particularly during intense fights, and a specific pattern of movement such as rotational movement caused by trusting and parrying in fights.

2.2.2 Materials and methods

Animals and housing

Five repetitive experiments were conducted between the 20th of October 2011 and the 25th of August 2012 at the Ruthe experimental farm of the Hannover Institute for Animal Hygiene (TiHo). In each of the experiments, a total of 24 piglets of the German National Breeding Programme (BHZP) were selected from four litters of piglets (N=120). From birth until weaning, the piglets were housed with their littermates in a 2 m x 2.3 m pen with partly slatted floor and equipped with a farrowing crate, heated piglet area and water and dry feed ad libitum. At the age of five weeks, the experimental animals were weaned and mixed together from four different litters. From each of the four litters, six piglets weighing at least 10 kg were randomly selected for the experiment and mixed into two pens (N=24). The pens had a dimension of 2 m x 1.8 m and were equipped with slatted floor and solid pen walls. The piglets had ad libitum access to dry feed and water and the animal feeding place ratio was 1.5:1.

The experimental phase started after mixing and lasted 2 days when it was assumed a new hierarchy among the animals was established (Keeling and Gonyou, 2001).

Video recording

Video recordings of this mixing phase provided a dataset that was used to classify aggressive interactions among piglets.

Video were captured for the first 3 hours (09h00 to 12h00) after the groups were established and then for 3 hours at approximately 24 h post-grouping. The idea behind was that during the first 3 hours after mixing the pigs have the most severe fights (Erhard et al., 1997, Spoolder et al., 2000). A relatively short time was needed because of the time consuming labelling procedure since the videos are observed image by image (20 images per sec) to detect all aggressive acts.

A total of 60 hours (3 hours per day) of videos were recorded by two cameras placed 2.0 m central above each pen in order to have a top view perspective. The first camera was a Guppy F-080C camera (Allied Vision Technologies, Germany). The camera used a SV-03514 3.5 mm lens (VS Technology, Tokyo, Japan). It recorded at a resolution of 1032 × 778 pixels. The second camera was a Guppy GC1350 camera (Allied Vision Technologies, Germany). The camera used a Pentax 4.8 mm lens (Pentax Corporation, Tokyo, Japan). It recorded at a resolution of 1360 × 1024 pixels. Both cameras were connected to a computer with LabVIEW (8.6, National Instrument, TX) that recorded synchronised videos in MJPEG. The computer's processor was Intel(R) Core(TM) 2 Quad CPU Q9300 @ 2.50GHz with 6 GB of physical memory. The operating system was Microsoft Windows 7 Ultimate.

Data labelling

From the 60 hours of recorded videos, a total of 378 episodes of interactions (228 aggressive + 150 not aggressive interactions) were identified and manually labelled by an expert observer who used the software "Labelling Tool" (Viazzi et al., 2011) developed in Matlab (R2009a, The MathWorks Inc., MA).

When an aggressive interaction stopped, for example due to the retreat of one or both pigs, this sequence was interpreted as finished and any further interaction was considered a new episode. The starting and ending time of every interaction was therefore determined and used as a reference for the classifier.

The labelling procedure is necessary in supervised learning in order to infer an unknown probabilistic function $P(x, t)$ between inputs $x \in$ X and labels $t \in$ L. This function is called *classifier* when the output is discrete. The *classifier* can only be inferred from labelled data $\{(x_i, t_i) \mid i = 1, . . . , n\}$, where x_i, t_i are drawn independently from $P(x, t)$.

Dataset

In order to evaluate the algorithm, a dataset of 150 episodes with and 150 episodes without aggressive interactions was built (Table 1).

The 150 episodes with aggressive interactions were randomly selected from the 228 episodes manually labelled by the expert.

The 150 episodes without aggressive interactions were built in two steps: 100 episodes without aggressive interactions were randomly selected, while 50 episodes were manually selected by the expert from 11 episodes with low group activity (up to 50% of pig moving, up to 50% of pigs resting), 25 episodes with medium group activity (50-80% of pigs moving) and 14 episodes with high group activity (80-100% of pigs moving). These manually selected data were used as a validation of the algorithm in order to prevent that the randomly selected data without aggressive interaction were generated from instances without any activity (i.e. during sleeping).

TABLE 1: *Dataset used for classifying aggressive interactions. The dataset consisted of 150 episodes with aggressive interactions (randomly selected) and 150 episodes without aggressive interactions (100 randomly selected and 50 manually selected between episode with low, medium and high group activity). In the table is reported the minimum, maximum, mean and standard deviation of the duration of each category of episodes.*

Class	N	Minimum Duration (s)	Maximum Duration (s)	Mean Duration (s)	Std. Deviation Duration (s)
Aggression	150	5	190	17.6	23.2
No aggression (LA)[a]	11	17	35	25.9	5.6
No aggression (MA)[b]	25	8	69	30.0	14.4
No aggression (HA)[c]	14	9	69	25.8	15.8
No aggression	100	5	85	26.2	16.3

a. LA: Low Activity (up to 50% of pig moving, up to 50% of pigs resting).
b. MA: Medium Activity (50-80% of pigs moving).
c. HA: High Activity (80-100% of pigs moving).

Algorithm :Motion History Image

The Motion History Image (MHI) is a static image that represents how motion is moving by describing the pixel intensity as a function of the motion history at that point (Bobick and Davis, 1996). The result is a scalar-valued image (Figure 1) where brighter values correspond to more recent motion. To generate the MHI for movement, the successive image differences I were weighted and layered. A threshold τ (τ = 1 second / 20 frames) was used to set the time window of the duration for which the motion information was kept:

$$\text{MHI}(x,y) = \begin{cases} \text{frame} & \text{if } I(x,y) \neq 0 \\ 0 & \text{if } I(x,y) = 0 \text{ and } \text{MHI}(x,y) < (\text{frame} - \tau) \\ \text{MHI}(x,y) & \text{otherwise} \end{cases}$$

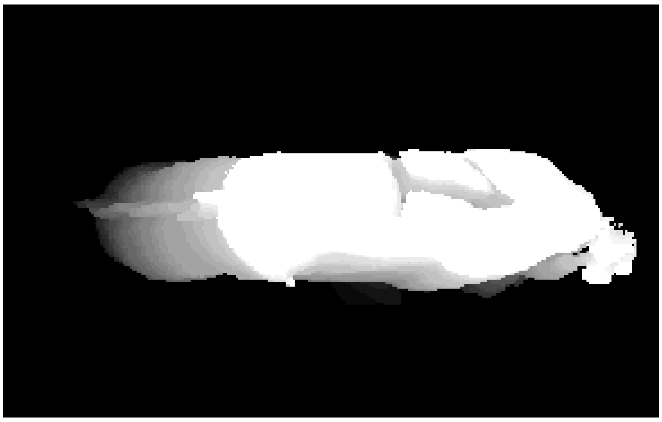


FIGURE 1: *Motion History Image of a pig moving from left to right*

For this study, the MHI was implemented in Matlab (R2010a, The MathWorks Inc., MA). The values of the MHI were rescaled between 0 and 255 pixels in order to obtain a grey scale image. This grey scale image was segmented in order to extract local regions of motion (Figure 2). Since the aggressive interactions happened between at least two pigs and since the mean pixel size of one pig is 20000 pixels, the segmented zones of movement smaller than 24000 pixels were filtered out and excluded from further analysis.

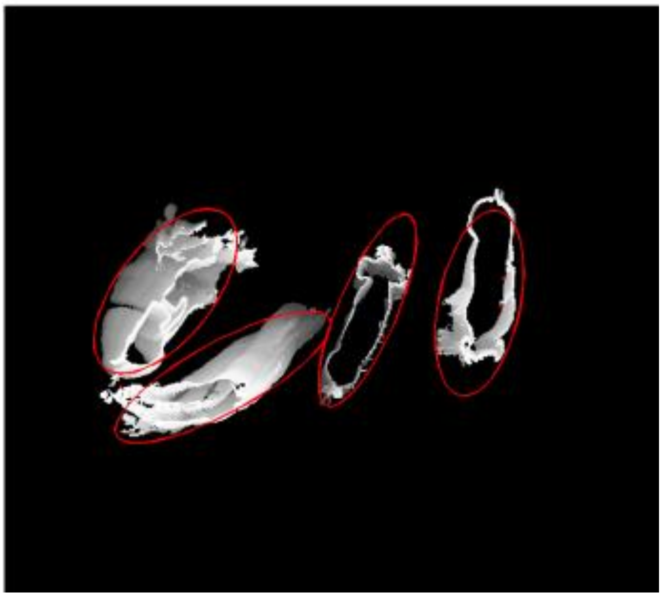


FIGURE 2: *Segmented zones of pig movement from the Motion History Image*

Parameters extraction

Describing the temporal and spatial motion through the MHI and detecting local regions of movement was an important step to understand image data, but it could not classify whether there were aggressive interactions or not. Another step is therefore to generate a numeric feature vector that characterised the properties of the movement. Two different features were extracted from the segmented regions and their means were used for the evaluation of each episode.

Feature1, the mean intensity, is a scalar specifying the mean of all the intensity values in the region. This feature represents how strong and intense the motion in the image is.

Feature2, the occupation index, is a scalar representing the distribution of movement inside the regions and is calculated by the ratio of pixels unequal to zero in the region and the total number of pixels in the region. This feature thus gives distribution information about the movement.

Linear Discriminant Analysis

Linear Discriminant Analysis (LDA) is a method to find a linear combination of features that separates two or more classes. A discriminant function *L* is defined as a linear combination of independent variables, where w_i are the discriminant coefficients, x_i the discriminant variables (in this study x_1 is feature1 and x_2 is feature2) and k a constant.

$$L = k + \sum_{i=1}^{n} w_i x_i$$

In LDA, the discriminant coefficients w_i maximise the distance between the means of the dependent variables. In a binary classification, only one discriminant function is needed to classify whether the episode belongs to one class (L>0) or the other (L<=0).

In this study, the LDA was used to classify if there were aggressive interactions in the video episodes, using *feature1* and *feature2* extracted from image processing.

Data analysis

SPSS (20, IBM, NY) was used for the LDA to classify aggressive and not aggressive interactions.

The first step consisted in the calculation of the discriminant coefficient of the LDA function based on the features extracted from the MHI.

Afterwards the confusion matrix was calculated. The confusion matrix is a matrix in which the rows are the classes defined by the expert and the columns are the predicted classes. From this matrix, statistical measures of performance such as sensitivity, specificity and accuracy were retrieved.

Sensitivity measures the proportion of actual positive values which are correctly classified. Specificity measures the proportion of negative values which are correctly classified. Accuracy measures the proportion of the total instance correctly classified.

In order to have more reliable results of the classifier, the data were also cross-validated by using the leave-one-out method. The leave-one-out method uses a single observation from the original sample as validation data and applies the remaining observations as training data. This method is repeated until each observation in the sample has been used once as validation data. 32 of the 300 episodes did not present a feature value because either no motion or too little motion was present and the episode was therefore filtered out. In order to take these values into account during the final performance measurement of the classifier, the final step consisted in adding the true negative (cases that were filtered out and showed no aggressive interaction), the false negative (cases that were filtered out but showed aggressive interaction) and in finally recalculating the confusion matrix for both cross-validated and not cross-validated data.

2.2.3 Results

The episodes that did not provide any feature information because they were filtered out due to no or only little movement in the MHI nevertheless contributed to the final result of the classifier. Table 2 shows that 2 episodes with aggressive interaction were filtered out and therefore counted as false negative, while 30 episodes without aggressive interactions were filtered out and therefore counted as true negative.

On the remaining 268 out of 300 episodes, a discriminant analysis was conducted to classify whether there were aggressive interactions or not in a video episode. Predictor variables were the two features extracted from the MHI, namely, the mean intensity (*feature1*) and the occupation index (*feature2*).

TABLE 2: *Episodes filtered out and excluded from further analysis. These episodes were taken into account during the evaluation of the classifier's general performance as 2 false negative and 30 true negative.*

Class	Type	Number	Filtered	False Negative	True Negative
Aggression	Randomly generated	150	2	2	0
No aggression	Manually selected (LA)[a]	11	8	0	8
No aggression	Manually selected (MA)[b]	25	1	0	1
No aggression	Manually selected (HA)[c]	14	1	0	1
No aggression	Randomly generated	100	20	0	20

a. LA: Low Activity (up to 50% of pig moving, up to 50% of pigs resting).
b. MA: Medium Activity (50-80% of pigs moving).
c. HA: High Activity (80-100% of pigs moving).

Table 3 illustrates the mean differences and standard deviation between the two features in the two different classes.

TABLE 3: *Descriptive statistical information of the two features used to classify aggressive interactions.*

Class	Feature	Mean	Std. Deviation	Number
No Aggression	Feature1	0.6559	0.11321	120
	Feature2	0.4167	0.13273	120
Aggression	Feature1	0.7577	0.09691	148
	Feature2	0.7032	0.11214	148
Total	Feature1	0.7121	0.11600	268
	Feature2	0.5749	0.18746	268

From the discriminant coefficients, the discriminant function was calculated (Table 4):

$$L = 2.59 * feature1 + 7.603 * feature2 - 6.215$$

TABLE 4: *Discriminant coefficient obtained by using the Linear Discriminant Analysis.*

Variable	Discriminant coefficient
Feature1	2.590
Feature2	7.603
(Constant)	-6.215

In Figure 3 and Figure 4, the scatter plots show the two clusters of episodes with and without aggressive interactions and the calculated LDA boundary.

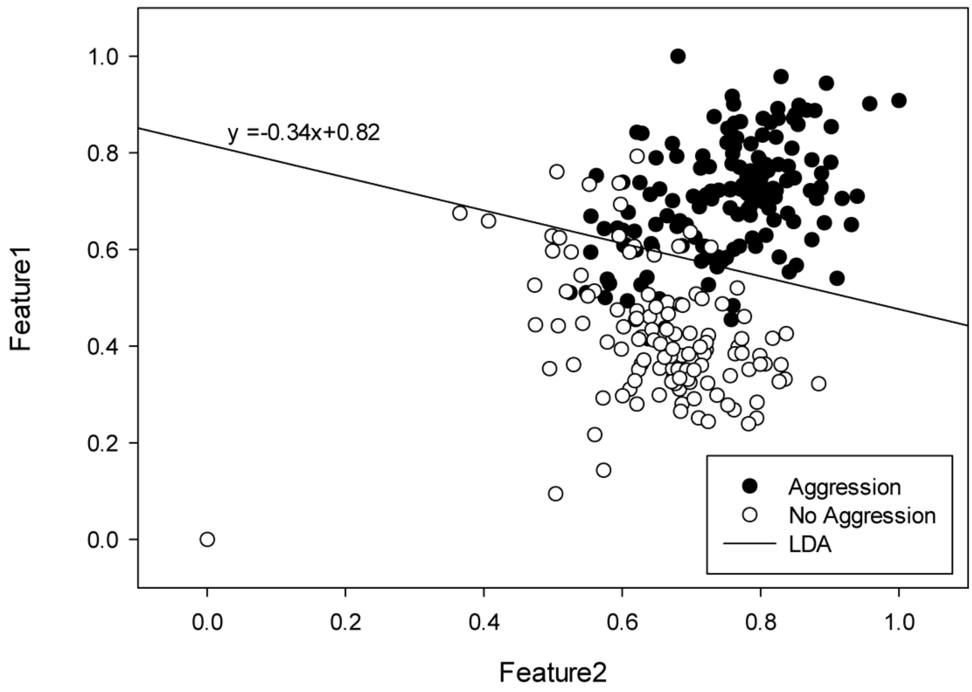


FIGURE 3: *Scatter plot depicting the association between the two features extracted from the MHI for both the classes aggression and no aggression. The line is the calculated LDA boundary representing the separation between the two clusters of data.*

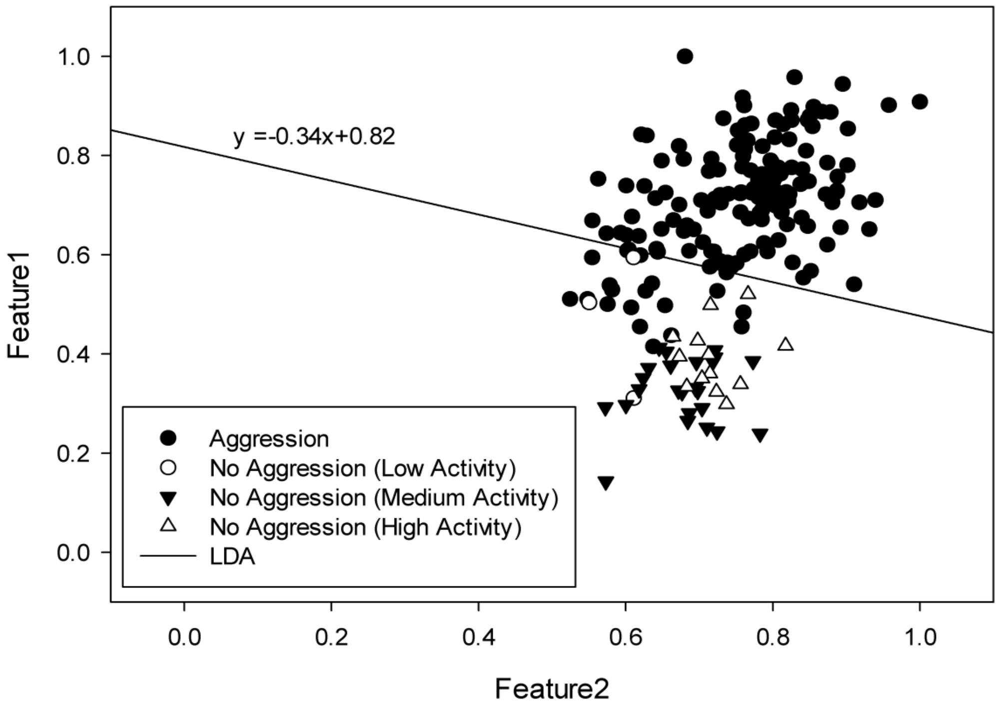


FIGURE 4: *Scatter plot depicting the association between the two features extracted from the MHI for both the classes aggression and no aggression manually selected between episodes with low, medium and high group activity. The line is the calculated LDA boundary representing the separation between the two clusters of data*

Table 5 illustrates the results of the LDA classifier, using leave-one-out cross-validation. As can be seen from the confusion matrix, 133 episodes with aggressive interactions and 108 episodes without aggressive interactions were correctly classified. These results indicate an accuracy of 88.4%, a sensitivity of 89.9% and a specificity of 86.7%.

TABLE 5: *Confusion matrix of the Linear Discriminant Classifier for both the original and the leave-one-out cross-validation dataset, without the episodes that were filtered out.*

		Class	Predicted Group No Aggression	Predicted Group Aggression	Total
Original[a]	Count	No Aggression	108	12	120
		Aggression	15	133	148
	%	No Aggression	90.0	10.0	100.0
		Aggression	10.1	89.9	100.0
Cross-validated[b]	Count	No Aggression	104	16	120
		Aggression	15	133	148
	%	No Aggression	86.7	13.3	100.0
		Aggression	10.1	89.9	100.0

a. 89.9% of original grouped cases correctly classified.
b. 88.4% of cross-validated grouped cases correctly classified.

When the results of episodes filtered out as true and false negative were added, the accuracy becomes 89%, the sensitivity 88.7% and the specificity 89.3% (Table 6).

TABLE 6: *Confusion matrix of the Linear Discriminant Classifier for both the original and the leave-one-out cross-validation dataset, including the episodes that were filtered out*

		Class	Predicted Group No Aggression	Predicted Group Aggression	Total
Original[a]	Count	No Aggression	138	12	150
		Aggression	17	133	150
	%	No Aggression	92.0	8.0	100.0
		Aggression	10.3	88.7	100.0
Cross-validated[b]	Count	No Aggression	104	16	120
		Aggression	15	133	148
	%	No Aggression	89.3	10.7	100.0
		Aggression	11.3	88.7	100.0

a. 90.3% of original grouped cases correctly classified.
b. 89.0% of cross-validated grouped cases correctly classified.

2.2.4 Discussion

This study has shown that local temporal and spatial information about dynamic regions segmented from Motion History Image can be used to extract different features related to aggressive behaviour among pigs. Both extracted features were used for classification: however, the occupation index provided more information about the data variance and therefore had a higher weight (7.603) in the discriminant function compared to the mean intensity (2.59). This can be explained by the fact that intense motion does not necessarily result from aggressive behaviour, but might as well be caused by other behaviour such as chasing or playing. In order to improve the results and to reduce the false positives, little motion or motion involving only one pig were excluded from this analysis.

However, it was not possible to detect all aggressive episodes. The filter directly excluded two aggressive interaction episodes because they involved low movement, although these interactions still included bites. Moreover, it was not possible to detect tail and ear biting as part of aggressive behaviour, but only fighting behaviour. Further studies on the motion gradients can improve the detection of aggressive behaviour by including tail and ear biting behaviour. In fact, the way pigs move provides more information about their behaviour than the intensity of their movement alone. Therefore, patterns of motion rather than the intensity of motion should be further exploited in future studies in order to discriminate between behaviours among pigs.

So far, no studies have been carried out to automatically monitor episodes of aggressive behaviour. However, image processing has been used to calculate information about the pigs' activity by means of the activity index in the study of Costa et al. (2009). Compared to this study, however, in which the activity information was extracted from an entire pen or from fixed zones within a pen, the use of MHI could provide both spatial and temporal information that was calculated automatically from the motion of the animals and was thus not bound to predefined zones. The most crucial disadvantage of using the activity and occupation index as in

Costa et al. (2009) is the fact that movements caused by different kinds of behaviour were summed up and could not be differentiated when occurring within the same zone over time. The activity and occupation index could provide temporal, yet no spatial information. By using MHI, however, no fixed zones needed to be defined. Instead, zones were calculated dynamically, by using the segmented regions of motion, and were then analysed separately. Therefore, the method exploited in this study provided more valuable information to detect aggressive interactions among pigs.

Nevertheless, the classifier in this study was only verified on a single dataset. Future studies should validate the classifier in different environmental conditions and in different processing stages.

According to the Welfare Quality® protocol, the farmers should check the health and welfare status of their animals by assessing injuries in the pen that indicate occurrences of aggression (Dalmau et al., 2009). As this procedure is time consuming and labour intensive, an automatic aggression monitoring system would be beneficial to both farmer and animal.

A monitoring tool that can continuously and automatically detect aggressive behaviour and consequently monitor the level of aggression in each pen is a valuable tool and can be used by the farmer to increase the animals' health and welfare and to decrease the economic losses. With accurate information about the aggression level in each pen, the farmer can intervene more quickly by separating aggressive animals or by introducing environmental enrichment material in order to reduce the aggression level (Schaefer et al., 1990). It may be argued that aggression levels often return to the same level after a certain period of time due to habituation (Bracke et al., 2006). However, by continuous automated monitoring the level of aggression, the environmental enrichment could be changed in order to prevent the effect of habituation whenever the aggression exceeds a certain level. As a result, growth rates and uniformity of pigs as well as fertility of breeding sows could be improved.

2.2.5 Conclusion

In this research, a method based on Motion History Image was used to calculate dynamic, local, temporal and spatial information about the mean activity and occupation index in order to detect aggressive interactions among pigs. The results revealed a classification accuracy of 89%, a sensitivity of 88.7% and a specificity of 89.3% and proved that the two motion features can be successfully used in order to discriminate between aggressive and not aggressive interaction. This might be a first and very important step towards the development of a fully automated system that can detect aggressive interactions among pigs by analysing motion features over time. Furthermore, the approach does not involve high costs and does not interfere with or manipulate the animals. Consequently, this approach analysis offers promising possibilities to continuously monitor pigs in a fully automated way.

2.3 Acoustic-reward learning as a method to reduce the incidence of aggressive and abnormal behaviours among newly mixed piglets

G. Ismayilova[a], L. Sonoda[b], M. Fels[b], R. Rizzi[a], M. Oczak[c], S. Viazzi[c], E. Vranken[c], J. Hartung[b], D. Berckmans[c] , M. Guarino[a]

[a] Department of Health, Animal Science and Food Safety, Faculty of Veterinary Medicine Università degli Studi di Milano, via Celoria 10, 20133, Milan, Italy,

[b]University of Veterinary Medicine Hannover Foundation, Bünteweg 17 P, D-30559, Hannover, Germany.

[c]Katholieke Universiteit Leuven, Kasteelpark Arenberg 30, 3001, Leuven, Belgium.

[d]Corresponding author. Email: ismayilova.gunel@unimi.it

Published in online in Journal of Animal Production Science

DOI: http://dx.doi.org/10.1071/AN13202

Received 21 May 2013; accepted 17 September 2013, published online 6 November 2013

Abstract

The aim of the study was to test whether aggressive actions among piglets could be redirected by an automatically generated sound signal followed by a sweet food reward. Per round, four litters of 25-day-old piglets (BHZP breed) were trained 5 times per day over 8 days to expect a sweet feed reward from a dog feeder after hearing a specific sound. In total 144 piglets in 14 entire litters were trained in five trials. At the end of the training 71% of the piglets were around the feeder 5 s after the feeder sound. After the training period, the piglets were weaned and mixed in two pens, 12 piglets per pen. During 2 days (3 h/day) after mixing two observers (one per pen) hidden behind a wooden wall activated the feeder when aggressive or abnormal behaviour started. A total of 616 aggressive events and 31 incidences of abnormal behaviour (ear biting) were used for the analysis. The logistic regression showed that the type of behaviour had a significant effect on the piglets' response to the feeder sound ($P < 0.001$). The results showed the possibility of interruption of the aggressive behaviours such as head thrust [odds ratio (OR) = 0.43], jump on other (OR = 0.56) or attack with bite (OR = 0.61). Ear biting was very unlikely to continue (OR = 0.55). The risk of continuing elevated aggression level behaviours was doubled in the event of chasing (OR = 2.16) and the risk that fight would continue after the feeder sound was released was 7 times higher (OR = 7.89). Categorical analysis showed a significant effect (<0.001) of the time intervals $t \leq 1$ s and $1 \text{ s} < t \leq 3$ s on interruption of aggression by the feeder sound release. The piglets' response to the feeder sound differed significantly between the experimental days ($P < 0.001$). On the second day of mixing, the feeder sound interrupted 74.9% of aggressive events, compared with 33.7% on the first day. The results suggest that acoustic-reward treatment can distract pigs from performing certain aggressive behaviours and ear biting in piglets when properly applied in time.

Keywords: *sound, reward, learning, aggression, abnormal behaviours, mixing*

2.3.1 Introduction

Elevated forms of aggression are one of the biggest problems of modern pig husbandry, mostly associated with the standard practice of mixing of unfamiliar pigs (Erhard et al. 1997; Spoolder et al. 2000; Stukenborg et al. 2011). Scientists reported other reasons for increased aggression among pigs such as: limited space allowance (Weng et al. 1998), feeding systems promoting competition (Marchant-Forde 2010), barren environment (Durrell et al. 1997) or low fibre feed composition (Meunier-Salaun et al. 2001). Although much of this aggression might be viewed as a harmless trial of strength (Huntingford and Turner 1987) there can nonetheless be serious consequences including impaired growth, stress, wounds, poor meat quality and reduced animal welfare. Therefore, there is a need to control or limit aggressive actions among pigs. Various methods have been tested in the past for their potential to reduce violent aggression in pig groups, including tranquillising drugs that effectively reduced aggression among grouped pigs. However, a high frequency of the aggressive interactions at the end of the drug effect could not be avoided (Pascoe 1986; Csermely and Wood-Gush 1990; Tan and Shackleton 1990). Lowering the light intensity is reported by farmers as an effective to reduce aggression after mixing; however, this method is not effective in reducing the total frequency of fighting (Christison 1996). The provision of barriers to hide behind was not useful to reduce neither the frequency nor the intensity of aggressive interactions (Olesen et al. 1996; Spoolder et al. 2000). However, there is some evidence that enrichment of the environment can have a major inhibiting influence on fighting (Schaefer et al. 1990; Simonsen 1990; Petersen et al. 1995).

One of the most serious animal welfare problems in intensive farming of fattening pigs are tail and ear biting. These abnormal behaviours are assumed to be of multifactorial origin and seem to result from the interaction of various factors, such as: stocking density, floor design, feed composition and lacking of enrichment in pens as well as from breed type and gender (Schrøder-Petersen and Simonsen 2001; Moinard et al. 2003; EFSA 2007). The most common method to prevent tail biting is tail docking. However, this is only allowed under veterinary prescription (European Commission 2001) as a special temporary allowance. Environmental enrichment was also found to reduce the incidence of abnormal behaviours (Beattie et al. 1995, 1996, 2000). However, enrichment objects lose their novelty over time, which in turn leads to a loss of interest by the animal (Van de Weerd et al. 2003, 2006).

In recent years, cognitive abilities of animals have been widely tested (Broom 2010), showing that pigs can successfully learn to cope with difficult experimental tasks (e.g. Sneddon et al. 2000; Moustgaard et al. 2004; Held et al. 2005; Jansen et al. 2009). The term cognitive enrichment was used by Puppe et al. (2007) for an acoustic-reward device, previously described by Ernst et al. (2005). This device was used to train the pigs to approach an electronic feeder for a feed reward after hearing a sound at randomised times each day. For the training, classical (Pavlovian) conditioning was used to create an association between the feed reward and the sound. The animals were taught by operant conditioning to recognise an individual sound and discriminate the sound from other sounds. These experiments showed that sound and feed are effective stimuli for the instrumental learning in pigs, and that the pigs can clearly, selectively and successfully associate between the sound and the feed reward.

Thus, our idea was to use the acoustic-reward learning based on classical conditioning techniques as an approach to reduce the incidence of aggressive and abnormal behaviours in pigs reared in intensive conditions. For this purpose we used a prototype of a food-rewarding device for cognitive enrichment, represented by an electronic dog feeder. The piglets learned to approach the feeder, which released feed after hearing the sound signal. The main objective was to test the effectiveness of trained sound signals on redirecting pigs' attention from aggressive and abnormal behaviours.

2.3.2 Material and methods

Experimental design

The enrichment tool consisted of a commercially available electronic dog feeder (Manners Minder Treat and Train, Sommerville, CT, USA) filled with chocolate candies. The feeder emitted a sound signal immediately before food delivery, and was activated via remote control (Fig. 1).

FIGURE 1: *Pigs gather under the electronic dog feeder after sound and food release*

The study was conducted at the research farm Ruthe of the University of Veterinary Medicine Hannover, Foundation, Germany.

An experimental trial (in total five repeats) consisted of two consecutive phases. Phase 1 (training phase), lasted 8 days and aimed to teach the piglets to recognise the association between the sound and the feed reward representing a classical conditioning paradigm (Angermeier 1994).

In total 144 piglets from 14 entire litters of the German National Breeding Program (BHZP) were used for Phase 1. Per trial, four litters of 25-day-old piglets with average weight of 7 kg (±1) were trained. The piglets were raised from birth until weaning with their litter mates and dam in a conventional farrowing pen (2.30 by 2.00 m) with partly slatted floor, equipped with farrowing crate, heated piglet area and provided with water and dry feed ad libitum. At the beginning of the experiment all piglets were weighed using a platform balance (model DE 150 K2 DC, Kern & Sohn GmbH, Germany) and individually marked on their back with standard colour stock marker (Porcimark, Kruuse, Denmark).

Two electronic feeders were positioned on opposite lateral walls of the selected pens at a height of 0.6 m above the pen floor and activated by an observer from outside of the room in order to not distract the piglets by human presence. The sound was played by the feeder and 2 s later the candies were dispensed. During the training period (from 1000 to 1100 hours) the electronic feeders were activated every 10 min, thus 5 times per day.

Phase 2 (mixing phase) lasted 2 days and aimed to test the response of animals to the electronic feeder sound during the performance of aggressive and abnormal behaviours. In total, 120 piglets were used for this phase. At the age of 35 days piglets were weaned. One day before weaning, all piglets were individually marked again. Per trial, two groups of 12 piglets evenly distributed according to weight (average 9 kg ± 1) and sex were formed from four trained litters. Piglets were transferred to the weaning room and mixed in two pens (2 by 1.8 m) with fully slatted floor and solid pen walls. The piglets had ad libitum access to dry feed and water and the animal to feeding place ratio was 1.5 : 1.

Direct observations were made for the first 3 h (0900–1200 hours) after the groups were established (Day 1) and then for 3–24 h post-grouping (Day 2). Simultaneous observations were carried out by two observers, one assigned to each experimental pen. The observers were separated from the piglets by a wooden wall in the front of the pens with a small window. The electronic feeders were placed on the lateral walls of the experimental pens at a height of 0.8 m above the pen floor and distantly activated by the observers when the aggressive or abnormal behaviour described in Table 1 was noticed.

In total, the experimental trial lasted for 2 weeks up to the 6th week of age. After the experiment, the pigs were finished following standard fattening production until slaughter weight.

Video recordings

The experimental phases were recorded by two video cameras, Guppy F-080C and Guppy GC1350 (Allied Vision Technologies, Stadtroda, Germany) placed at the height of 2.0 m above the pen floor. Both cameras were connected to a computer with LabVIEW (8.6, National Instrument, Austin, TX, USA) that recorded synchronised videos in MJPEG format with image rate of 20 images per second, resolution of 1032 by 778 pixels for the F080C camera and 1360 by 1024 for the GC1350 and both in colour. The computer's processor was Intel Core 2 Quad CPU Q9300 @ 2.50 GHz with 6 GB of physical memory. The operating system was Microsoft Windows 7 Ultimate.

Data analyses

The video recordings from Phase 1 and 2 were visually analysed by two observers (one per each phase) using the 'Labelling Tool' software (Viazzi et al. 2011) developed in Matlab (R2009a, The MathWorks Inc., Natick, MA, USA). The 'Labelling Tool' permitted the identification of the occurrence and the detailed observation of each behaviour of interest, sliding the video image by image (25 images per second). In total 40 h of video for Phase 1 and 60 h for Phase 2 were analysed.

To evaluate the effectiveness of the training, the daily learning performance was measured by the number of piglets around the electronic feeder for the period from 1 to 5 s after each sound release.

To test the effectiveness of the feeder sound on distraction of animals from the performance of aggressive and abnormal behaviours shown in Table 1 were analysed.

TABLE 1: *Description of piglet behaviour at the moment of feeder sound release.*

Behaviour	Description
Aggressive Behaviour	
Fight	A fight lasts longer than a single aggressive interaction and begins with open-mouthed contact and ends when the pigs lose contact for at least 5 seconds (based on Erhard et al., 1997 and Gonyou et al, 1988). A series of mutual vigorous bites, pushes and head thrusts is carried out by the pigs involved
Chase	Pig is following another pig in quick pursuit, usually biting or trying to bite (Erhard et al., 1997), receiving pig withdraws or escapes
Push rooting disc	Pushing or ramming another pig with his rooting disc without biting, in an event that is not rated as part of a fight
Head thrust	Ramming or pushing another pig with the head, with or without biting, in an event that is not rated as part of a fight (O'Connell and Beattie, 1999)
Lifting other	Pig puts its snout under the body of a pen mate (from behind or the side) and lifts the pig from the floor (after Morrison et al., 2003)
Jump on other	The pig starts an aggressive interaction by jumping with his front feet on another pigs head-neck area (McGlone, 1985)
Abnormal behaviour	
Ear biting	Persistent oral manipulation or biting of the ear of another pig (after Taylor et al., 2010).
Tail Biting	Persistent oral manipulation or biting of the tail of other pig (after Taylor et al., 2010).

When the behaviour was identified by observer, the video was carefully observed image by image. The following parameters were recorded: the start and finish time of each behavioural event; the time of the feeder sound release; the behaviour of the piglets at the moment of feeder sound release (Table 1); the response to the feeder sound during the performance of the behaviour; and the approach time to the feeder.

Statistics

Phase 1

The changes in learning behaviour were analysed by a trialled-measures ANOVA (GLM procedure; SAS 2008) with the trial (five levels) as fixed effect and the training day (8) as fixed and trialled effect. The results are expressed as percentage of piglets around the electronic feeder after the sound exposure.

Phase 2

For the statistical analysis of Phase 2 the parameters described in Table 2 were used.

TABLE 2: *Description of parameters used to evaluate the effect of the feeder sound on piglets performing aggressive and abnormal behaviours*

Parameters	Abbreviation	Description
Behaviour of the piglets at the moment of feeder sound release	BEH	See Table 1
Duration of behavioural event	DUR	Exact duration of behavioural event, calculated as t ime difference between the start of behavioural event (first contact) and its end (pigs separation).
Response of the pig to the feeder sound during the performance of the behaviour	RESP	0=continued behaviour; 1=interrupted behaviour
Time interval between the start of behaviour and the feeder sound release	T_FS	Time interval, calculated as difference between the start of behavioural event and the feeder sound release.
Feeder latency	F_LAT	Latency of pigs response to the feeder sound and interruption of behaviour, calculated as the difference between the time of feeder sound release and the approach time to the feeder.

The Frequency procedure (PROC FREQ, SAS 2008) was used to identify the occurrence of each behaviour, which resulted in the activation of the electronic feeder. Due to the small number of events, push rooting disk, lifting other and tail biting behaviours were excluded from the analysis. A least-squares analysis was carried out with GLM procedure (PROC GLM, SAS 2008) on feeder latency (F_LAT). The model included the fixed effects of trial and pen. The levels of the fixed effects used in the models are described in Table 3.

TABLE 3: *Description of fixed effects used to model duration of behaviours and feeder latency*

Effect	Description	Levels
DAY	Experimental days	Day 1, Day 2
TRIAL	Experimental trial	5
PEN	Pen	Pen 1, Pen 2
BEH	Behaviour	Fight; Attack with bite; Chase; Head trust; Jump on other; Ear biting
RESP	Response to the feeder sound	Interrupted, continued

Logistic regression (PROC CATMOD, SAS 2008) was used to evaluate the effect of behaviour of the piglets at the moment of feeder sound release (BEH) on response to the feeder sound (RESP) (Model 1) and to estimate the significance and the probability of RESP function of time interval between the start of the behavioural event and the sound release (T_FS) (Model 2). In Model 1 odds ratios (OR), 95% confidence intervals (CI) and predicted values of logits were calculated according to the methods proposed by Hosmer and Lemeshow (1989). The OR is a measure of how much more likely (or unlikely) the outcome is among observations with a given risk factor, compared with those without the risk factor (Hosmer and Lemeshow 1989). A 95% CI for an OR implies that the true parameter value lies between the two end points 95% of the time (Kleinbaum et al. 1982). An OR of 1.0 implies that observations with the risk factor are equally as likely to have the outcome as observations without the risk factor. In Model 2, since RESP was a dichotomous categorical variable, logistic regression was used. To estimate the significance and the probability of RESP as the T_FS increases, T_FS was divided in the following intervals:

T1_FS: $t \leq 1$ s;

T2_FS: $1 \text{ s} < t \leq 3$ s;

T3_FS: $3 \text{ s} < t \leq 5$ s;

T4_FS: $5 \text{ s} < t \leq 10$ s; and

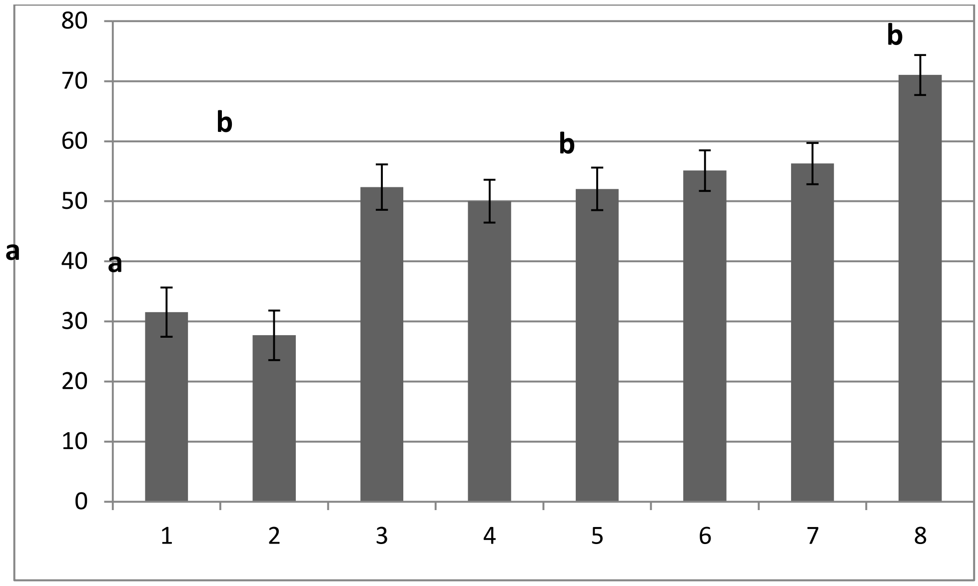
T5_FS: $t > 10$ s.

In order to investigate the association between RESP and DAY, a 2 by 2 contingency table ($\chi 2$ test) was used to assess the difference between observed and expected frequencies of each behaviour.

2.3.3 Results

Phase 1

During Phase 1 of the experiment the animals were trained to approach the electronic feeder after the release of the sound. On the first day 31.6 ± 4.1% of the animals were around the electronic feeder (Fig. 2). On Day 4 the piglets had reached a rate of 50 ± 3.6%. Subsequently, they never fell below that value and reached 71 ± 3.3% at the end of this experimental phase.



(a,b) differ for p>0.05

FIGURE 2: *Learning performance of piglets during the Phase 1 experiment expressed as a mean percentage (LSM± SEM) of the total number of piglets around the feeder 5 s after feeder sound exposure.*

Phase 2

From the whole video database for the five trials a total of 647 behavioural events were used for the analysis. Among the behaviours detected when the feeder was activated the most frequent were chase [n = 189 (29.2%)]; fight [n = 167 (25.8%)] and attack with bite [n = 162 (25%)].

The logistic regression showed that the BEH had a significant effect (P < 0.001) on the piglets' response RESP. The behaviours were included in the model as risk factors for the continuation of the behavioural event after the feeder sound was released (Table 4). The results show the low risk of continuation of the specific aggressive behaviours such as head thrust (OR = 0.43; 95% CI 0.25–0.72), jump on other (0.56; 95% CI 0.26–1.17) or attack with bite (0.61; 95% CI 0.42–0.88) after the feeder sound release. For elevated aggression level behaviours, the risk of continuation doubled in the case of chase (OR = 2.16; 95% CI 1.13–2.2), while the risk that fight would continue after the feeder sound released was 7 times higher (OR = 7.89; 95% CI 5.24–11.89).

TABLE 4: *Risk of continuation: odds ratios and 95 % confidence intervals (C.I.) for the analysed behaviours*

Behaviour	Estimate (β)	Odds ratio	C.I. (OR)
Head trust	-0.85	0.43	0.25-0.72
Ear biting	-0.59	0.55	0.05-5.98
Jump on other	0.58	0.56	0.26-11.17
Attack with bite	-0.49	0.61	0.42-0.88
Chase	0.45	1.57	1.13-2.2
Fight	2.06	7.89	5.24-11.89

Categorical analysis showed a highly significant effect (<0.001) of the time intervals between the start of behavioural event and the feeder sound release T1_FS ($t \leq 1$ s) and T2_FS ($1 \text{ s} < t \leq 3$ s) on interruption of fight by the feeder sound release. During the time interval T1_FS, chase and jump behaviours were effectively stopped (<0.05).

The logistic regression model showed that the probability of fight interruption was indirectly proportional to the time passed from the start of aggression until the feeder sound release (Fig. 3). The feeder sound released within T1_FS had a probability rate of interruption of 0.59, while for T5_FS the probability decreased to 0.53.

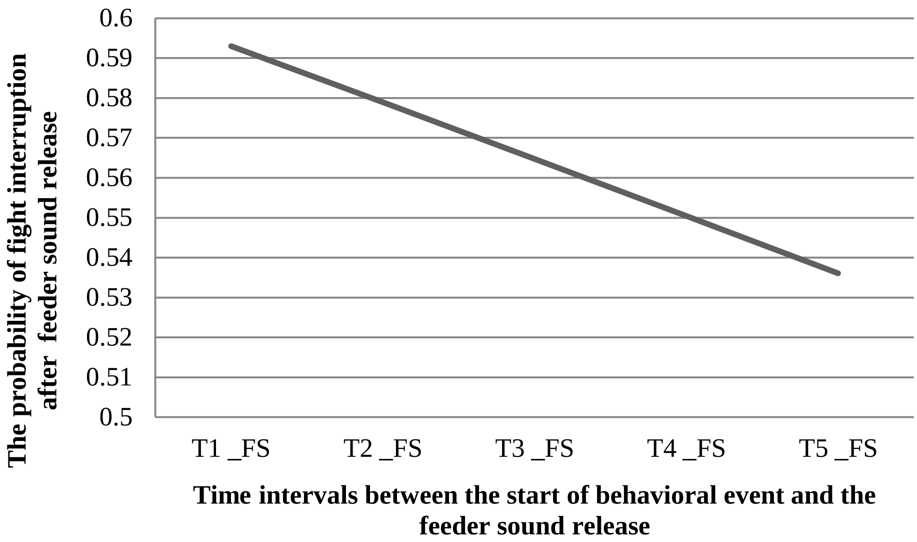


FIGURE 3: *The predicted probability of fight interruption after feeder sound release.*

The response of the piglets to the feeder sound (continued; interrupted) also differed significantly between the experimental days ($\chi 2 = 129.6$, d.f. = 1, $P < 0.001$). On the first day of mixing piglets interrupted only 33.7% (119 of 353) of events, compared with 74.9% (197 of 263) on the second day.

Chi-square analysis revealed a highly significant overall effect of the experimental day (DAY) on the type of BEH ($\chi 2 = 102.2$, d.f = 6, $P < 0.001$). The frequency of the aggressive behaviours was higher during the first day than during the second day (353 versus 263). During the first day a higher proportion of some specific aggressive behaviours occurred than on the second day; such as fights (37 versus 14%) and chase (36 versus 24%), while on the second day piglets performed more attack with bite (36 versus 19%) and head thrust (18 versus 6%). The number of ear biting events did not differ for the 2 days.

Feeder latency

Table 5 shows the mean F_LAT of the piglets, which interrupted their aggressive behaviour. Even though the analysis showed a significant effect of the trial on the

F_LAT (F = 6.46, P > 0.001), the reaction of the pig after the sound release did not delay more than 1 s in all of the experimental trials.

TABLE 5: *The effect of the trial on the latency of response to the feeder sound (in seconds) of the piglets involved in aggressive interaction*

Trial	Feeder Latency LSM±SEM	P-value
1	1.0 ± 0.1	< 0.001
2	0.2 ± 0.1	0.03
3	0.6 ± 0.1	< 0.001
4	0.4 ± 0.2	0.05
5	1.0 ± 0.2	< 0.001

*

2.3.4 Discussion

The aim of the first phase of our experiments was to train piglets to associate the sound of the feeder with the release of the sweet feed through classical conditioning. Classical conditioning paradigm describes how neutral stimuli become conditioned through association, thus gaining the ability to elicit specific behaviours (Lehner 1996). In Pavlov's classic experiment with dogs, the neutral signal was the sound of a tone and the naturally occurring reflex was salivation in expectation of food (Pavlov 1927). In our case, we wanted to condition the piglets to rush immediately to the feeder when the feeder sound occurred. Our data of the performance in the training phase show that the piglets quickly recognise the electronic feeder as a source of an attractive feed. At the third day the number of respondents doubled and remained on a high level during the consecutive days. Both our results and those of Ernst et al. (2006) indicate that in pigs, a functional association between sound and food can be made quickly (3–4 days of training). The increase at the 8th day up to 71% cannot be sufficiently explained. Approximately 30% of the piglets did not approach the feeder after the sound. These piglets may have been afraid of novel stimuli (Andersen et al. 2000), did not learn the association between sound and food reward or may have avoided the feeder when it was occupied by pen mates. From earlier research directed at isolating the important stimuli variables that influence learning (e.g. Martin 1968, 1971; Richardson 1971) it is apparent that, as it is the case in classical conditioning, the presence of a stimulus does not assure that it will enter into a functional association with the response term with which it is nominally paired. A certain behaviour results when an effective stimulus is received or generated by the animal (Lehner 1996). When one behaviour occurs, an ongoing behaviour may be inhibited, if both behaviours cannot be performed at the same time. For example sleeping is inhibited when an animal is ingesting food. It is obvious that for the inhibition of an ongoing behaviour the new stimulus should be stronger than the current one. In pigs, as in most other animals, food acquisition is highly motivating (McLean 2001). The specific question in our study was whether the sweet feed stimulus was strong enough to inhibit aggressive or abnormal behaviour and could redirect the animal to the electronic feeder. The results show that ear biting can be successfully interrupted (OR = 0.55). Highly aggressive behaviours such as chase and fight were less likely to be interrupted (OR = 7.89). The number of fights was drastically reduced on the second day (37 versus 130), when such behaviours as the short attacks with biting the opponent and head thrusts occurred more frequently (96 versus 66 for attack with bite; 48 versus 23 for head thrust). These behaviours were also found to be successfully interrupted by the electronic feeder sound. One explanation could be that the majority of fights that had occurred during the first day were to establish group hierarchy. The short aggressive events that dominated during the second day were probably just tests of strength (Huntingford and Turner 1987) of dominant animals. It was found that on the second day the electronic feeder sound distracted the pigs from the majority of behaviours (73.6%), while on the first day piglets were distracted only in 34.4% of cases.

When a behaviour was successfully interrupted by the electronic feeder sound, piglets redirected their attention immediately. The more time passed from the start of an aggression, the more the animals were involved in aggressive actions and the less was the probability to interrupt them by the sound. It appeared that the chance to interrupt an aggressive action is significantly (<0.001) higher when the distracting sound signal follows the initiation of an aggressive action within the first second.

2.3.5 Conclusions

The presented method bears some potential to reduce the frequency and duration of aggressive actions among young piglets. When sufficiently trained, the motivation for an attractive feed bait can in most cases be greater (up to 74%) than the motivation to continue with a just started fight. The exception to this is violent aggressive behaviours, such as fight and chase, probably related to the establishment of a dominance hierarchy within a group, which can rarely be interrupted as this study shows. The results suggest that acoustic-reward treatment can distract pigs from certain aggressive events and ear biting in piglets when properly applied in time.

2.4 Can piglets' learning abilities reduce the prevalence of aggression?

G. Ismayilova[1], E. Tullo[1], L. T. Sonoda[2], M. Oczak[3], S. Viazzi[3], M. Fels[2], E. Vranken[3], C. Bahr[3], J. Hartung[2], D. Berckmans[3], M. Guarino[1]

[1]Department of Veterinary and Technological Sciences for Food Safety, Faculty of Veterinary Medicine, Università degli Studi, Milan, Italy

[2]Institute for Animal Hygiene, Animal Welfare and Farm Animal Behaviour, University of Veterinary Medicine Hannover, Foundation, Germany

[3]M3-BIORES: Measure, Model & Manage Bioresponses, Katholieke Universiteit Leuven, Leuven, Belgium

Submitted to Animal science journal 09 December 2013

Abstract

The aim of the study was to explore the effectiveness of an acoustic-reward method to reduce aggressive interactions among trained. Ninety-five 25 day-old suckling piglets from 10 litters (4 replications, BHZP breed = Bundeshybridzuchtprogramm) were trained during eight days to expect a feed reward from a dog feeder after hearing a specific sound. After the training period the piglets were weaned and 72 piglets were selected according to their weight (10 kg±1) and sex, and mixed in 6 groups of 12 piglets. Immediately after mixing and 24 h later the animals were directly observed for 3 h by a trained observer hidden behind a wooden divider. The sound signal was triggered when aggressive behaviour was noticed by the observer. During the training phase, 62% of the piglets achieved high learning levels (LL4, LL3, in the scale of LL1 to LL4). Significant difference ($p<0.001$) between litters LL of piglets was found. Weight before training and sex did not significantly influence the learning level .During mixing, piglets with the highest learning level were more likely to interrupt an interaction after the sound signal compared to those with lower learning levels. Aggressive interactions between littermates were 1.37 times more likely to be interrupted than those between non-littermates (Odds Ratio=1.37; C.I. 0.96-1.97), indicating that previous relationship or familiarity was a significant factor ($P>0.01$). The logistic regression results showed a highly significant ($P<0.001$) effect of the day of mixing on interruption of aggressive events. Aggressive events that occurred during day 1 had a low probability of being interrupted (OR=0.16; C.I. 0.11-0.23). Piglets reacted to the feeder in 27.5% of events (148 of 539) on day 1 but 66.4% (293 of 443) on day 2 ($\chi^2=147.05$, DF=1, $P<0.001$). The study supports using cognitive and learning abilities of piglets to improve management and the welfare in pig production.

Keywords: Pig, Training, Learning, Aggression, Mixing

2.4.1 Introduction

Pigs are social animals with considerable cognitive and learning abilities (Kornum and Knudsen, 2011), and considered as ‘intelligent’ by the public. Recent research on pigs cognitive and sensory capacities has explored how to improve the welfare of these animals (Meehan and Mench, 2007). Solutions to farm animal welfare cannot be addressed without a thorough understanding of animals’ fundamental psychology and behaviour (Curtis and Stricklin, 1991). Feed is highly motivating for pigs (McLean, 2001). Mendl *et al.* (1997) showed that pigs were able to learn the location of feed, regardless of the introduction of disturbing stimuli, which reduced accuracy of memory but did not eradicate it. Feed rewards are often used in pig studies to increase motivation and the reinforce value (Held *et al.*, 2005). Pigs appear to give a preference to sweet taste (Nofre *et al.*, 2002). Sweet food rewards, such as chocolate raisins, candies and apple have been used in studies researching of pigs’ learning ability (Hagl *et al.*, 2005, Moustgaard *et al.*, 2005). Sound has also shown to be an effective stimulus (Ernst *et al.*, 2005, Puppe *et al.*, 2007). Pig’s hearing range exceeds those of human (42– 40,500 Hz *vs.* 31–17,600 Hz); and pigs can hear is 8 dB louder at minimal sound levels (Heffner and Heffner, 1990). Arnfred *et al.* (2003) showed that pigs can discriminate between tones of different pitch. Authors Ernst *et al.* (2005) and Puppe *et al.* (2007) trained pigs to approach a feed-rewarded system (‘call feeding station’) following an individual acoustic signal. The experimental pigs were able to discriminate between individual tones that were associated with a locally changing feeding site (Puppe *et al.*, 2007). These experiments showed that sound stimulus and feed rewards are an effective combination for instrumental learning. The practical application of sound-feed learning may reduce the negative impact of the confined housing conditions. Aggression among pigs under farming conditions induced by common husbandry procedures is one of the most potent sources of stress in farm animals (Mendl *et al.*, 1992). The current practice of mixing pigs, combined with intensive housing conditions such as fully slatted floors, poor environment, little available space and feeding competition, are factors which are known to increase the level of aggression between pigs (Dybkjær, 1992, Barnett *et al.*, 1994). Violent aggression can cause major physical injuries, social stress and a loss of productivity which affects animal health and welfare as well as the economic efficiency of farms. The most vigorous fighting is induced by mixing unfamiliar pigs trying to establish a social hierarchy (Erhard *et al.*, 1997). Although the hierarchy is usually established within 24-48 h post-mixing (Parratt *et al.*, 2006), it is still possible to observe frequent changes of rank, particularly among the middle ranking pigs. This social instability accounts for the maintenance of a continuous, although minimal, level of aggression even long after grouping (Coutellier *et al.*, 2007). This study is part of a research project aiming to develop a method to for interrupting and redirecting piglets' from aggressive behavior using their ability to learn from positively associated stimuli like sound and feeding. In this case, a prototype feed-rewarding device in form of an automatic dog feeder was used. This equipment was created for training of dogs using positive reinforcement by rewarding desired behaviours and distracting from undesired behaviours, such as barking at the door, jumping on guests, etc. (Premier Pet, 2010). Piglets were trained to approach the feeder, where they found a sweet reward, after hearing a specific sound signal. The questions we have posed in this part of study was what would be the reaction of trained piglets in an aggressive emotional state after mixing to sound and which are the factors that influence the effectiveness of sound-feed redirection.

2.4.2 Material and methods

The study was carried out at the research farm Ruthe of the University of Veterinary Medicine Hannover, Foundation (Germany). Each of the 4 trials included two phases: training and mixing.

<u>Training phase</u>

In total 95 25 day-old piglets from 10 entire litters of the German National Breeding Programme (BHZP) were trained. On the first day of the experiment the piglets were weighted and marked on their backs with standard colour stock marker. The mean initial weight was 7 kg ±1 kg. The piglets were kept with sows from birth until weaning in farrowing pens measured 2,30 x 2,00 m with partially slatted floors, equipped with heated piglet area and provided with dry feed ad libitum. All sows were confined in a farrowing crate throughout lactation.

The training phase aimed to create the association between the sound and the feed reward. The piglets were trained to react to the activation of a commercially available electronic dog feeder (*Manners Minder Treat and Train®, USA*) releasing a sound signal 2s before dispersing chocolate candies. Electric feeders were placed 0.6 m above the floor on the lateral walls of the two opposite pens with selected litters, one per pen. An observer activated the feeders by remote control from outside of the room 5 times per day with 10 min pauses between activations. The training phase lasted 1 h per day (10:00-11:00 AM) over 8 days.

Mixing phase

After 8 days of training, the 35 day-old piglets were weaned and moved to rearing pens. One day before weaning, all piglets were individually marked and weighted again. In order to create homogeneous groups from 10 trained litters (95 piglets), 72 piglets (36 males and 36 females) were selected and mixed in 6 groups of 12 piglets per pen (4 experimental trials), balanced by weight (average 10kg ± 1) and sex. The pens were 2m x 1,8m with slatted floors (0.38 m^2 per animal) and solid walls. The piglets had ad libitum access to dry feed (feeding place ratio 1.5 : 1) and water.

The mixing phase tested the effect of the sound stimulus and electronic feeder on the piglets' post-weaning aggression. Direct observations were carried out by one observer per pen between 09:00 and 12:00 h during the first 3 h after mixing (day 1) and for 3 h on day 2 post-mixing. Simultaneous observations were carried out by two observers, one assigned to each experimental pen. The observer was separated from the piglets by a wooden wall in the front of the pens with a small window. The electronic feeders were placed on the lateral walls of the experimental pen (Fig.2) at height of 0.8 m above the pen floor. The observer distantly activated electronic feeders when noticed the aggressive behaviour from at least one pig, such as biting, head knocking, pushing or chasing.

Video recordings

The experimental phases were recorded by two video cameras (Guppy F-080C and Guppy GC1350) placed at the height of 2.0 m above the floor for a top view of the experimental pens.

Guppy F-080C (Allied Vision Technologies, Germany) with a SV-03514 3.5 mm lens (VS Technology, Tokyo, Japan) had resolution of 1032×778 pixels, Guppy GC1350 (Allied Vision Technologies, Germany) with a Pentax 4.8 mm lens (Pentax Corporation, Tokyo, Japan) had resolution of 1360×1024 pixels. Both cameras were connected to a computer with LabVIEW Software (8.6, National Instrument, TX) that recorded synchronised videos in MJPEG format with frame rate of 20 images per second. The computer's processor was Intel(R) Core(TM) 2 Quad CPU Q9300 @ 2.50GHz with 6 GB of physical memory. The operating system was Microsoft Windows 7 Ultimate.

Analysis of Behaviour data

All recorded videos were analysed using the software "Labelling Tool" (Viazzi *et al.*, 2011) developed in Matlab (R2009a, The MathWorks Inc., MA).

Video recordings from day 8 were analysed to evaluate piglet training. The number of approaches to the feeder by each piglet at the time of feed dispersion (2 s after sound signal) was counted. Recorded videos of the mixing phase were scrutinised to detect aggressive events between the piglets followed by the activation of the electronic feeder. An aggressive event was defined as a close physical contact in an aggressor/receiver interaction when at least one of the interacting pigs bit, head knocked, pushed or chased another pig. When an aggressive event ended, for example due to the retreat of one or both pigs, the sequence was interpreted as finished and any further interaction was considered a new event. Only the aggressive events which led to the activation of the feeder were considered for the analysis.

When one or both interacting pigs reacted to the sound and approached the feeder such that the aggressive between the pigs ended, the interaction was considered interrupted. The aggressor was defined as the pig which initiated the violent interaction (Turner *et al.*, 2001). The receiver was the attacked pig. Where several aggressive acts/receiver response interactions occurred sequentially the aggressor was the pig that initiated a new aggressor/receiver interaction.

For each aggressive event the following information were recorded: (i) the individual number of the aggressor and the receiver; (ii) response to the feeder sound signal of the aggressor and receiver (interrupted/not interrupted).

Statistics

Descriptive statistics (Proc Freq; SAS, 2010) were used to observe frequency distributions. The learning rate (LR) of each piglet achieved at the end of the learning phase was calculated as following:

$$LR = \frac{n\ of\ approaches}{n\ of\ feeder\ activations}$$

Then, the piglets were divided in four groups according to their LR (learning level LL1-LL4) as following:

LL1: LR=0

LL2: $0<LR\leq0.2$

LL3: $0.2<LR\leq0.4$

LL4: $LR>0.4$

The LL was analysed by a GLM procedure (SAS, 2010) with the weight (7 levels), litter of origin (10 levels) and sex (2 levels) as fixed effect. The weight was divided in classes on the basis of the frequency distribution (not shown).

A Chi-square analysis (SAS, 2010) was conducted in order to verify the difference in the occurrence of aggressive interactions involving littermates from those between non-littermates. The same analysis was used to test the influence of mixing day (day 1 *vs* day 2) on the interruption of aggressive events. Descriptive statistics (Proc Freq;

SAS, 2010) were used to observe frequency of the reaction on feeder activation by the aggressor and the receiver involved in aggressive interaction.

The parameter estimate and odds ratios of the interruption of the aggressive event (yes or no; categorical variable) was obtained with logistic regression (Proc Logistic, SAS 2010). In this study the odds ratio is a measure of how much more likely (or unlikely) the outcome (the response to the feeder) occurs with a given risk factor (the sound of the feeder) compared with those without the risk factor (Hosmer and Lemeshow, 1989). Odds ratio equal to 1.0 indicates the absence of association between the risk factor and the outcome, while values higher/lower than 1.0 indicate a higher/lower probability of the outcome. The 95 % confidence interval for an odds ratio implies that the true parameter value lies between the two end point 95% of the time. When this interval includes 1.0 the risk factor is not significant. The model included the litter of origin (10), the learning level (4), the relationship of interacting piglets (2) and the days (2) as the fixed effects.

2.4.3 Results

Training phase

The results from the last day of training showed that 62% of pigs achieved the high learning levels (LL 3 ; 4); 15.5 % of pigs had LL 1 and 22.5% LL 2. Learning level was significantly affected by litter of origin ($p<0.001$). The litters varied considerably in their finally obtained LL values (Fig.1).

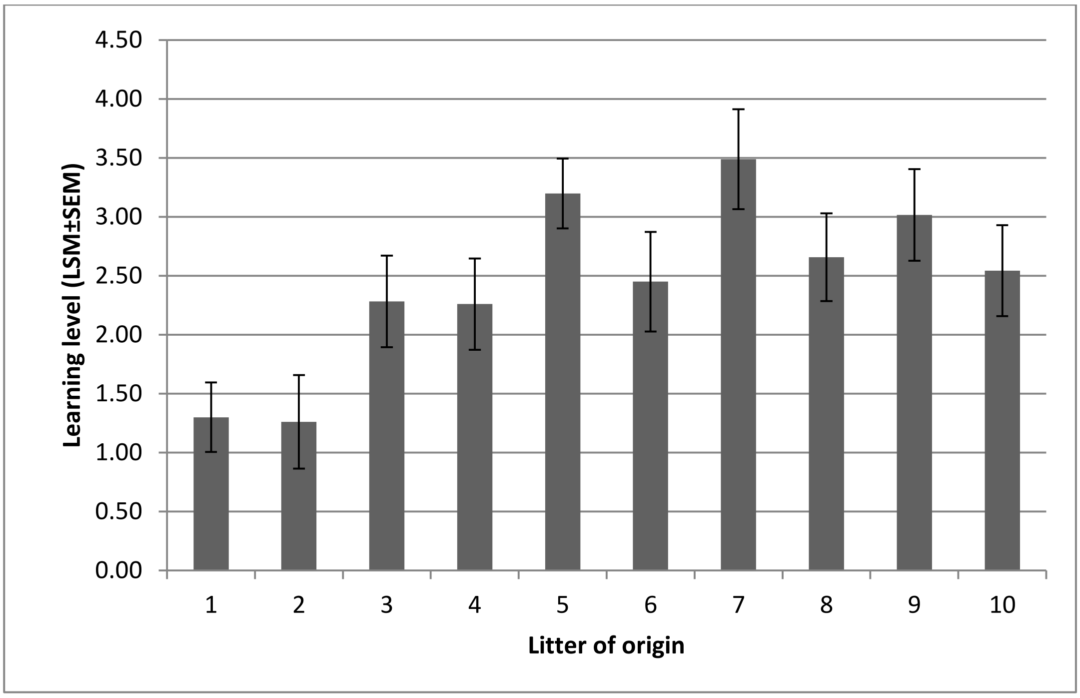


Figure : *Least Squire Means (±SEM) of learning rates of the experimental litters on the last day of training.*

Three out of ten experimental litters reached high LL=3-3.5 (litters 5,7,9). Two litters didn't exceed LL=1.3 (litter 1, 2) and significantly differed from other litters (Table 1).

Table 1: *Matrix reporting the statistical differences of learning levels (LS means) among litters*

Litter	1	2	3	4	5	6	7	8	9	10
1		NS	NS	NS	<0.001	<0.05	<0.001	<0.01	<0.01	<0.05
2			NS	NS	0.001	<0.05	<0.001	<0.01	<0.01	<0.05
3				NS	NS	NS	<0.05	NS	NS	NS
4					NS	NS	NS	NS	NS	NS
5						NS	NS	NS	NS	NS
6							NS	NS	NS	NS
7								NS	NS	NS
8									NS	NS
9										NS
10										

The weight before training and the sex did not significantly influence the LL of piglets.

Mixing Phase

Table 2 shows the results from the logistic regression model where the learning level (LL) acquired by the piglets involved in an aggressive event during the learning phase.

Table 2: *The association of the learning levels (LL) of the piglets involved to aggressive event, their relationship within the mixing group and the days of mixing with interruption of aggressive event.*

Risk factor	Variables compared	β	SE(β)	P value	Odds ratio (OR)	95% Confidence Interval
Learning level	LL 1 v LL 4	-1.63	0.30	<0.001	0.20	0.11-0.35
	LL 2 v LL 4	-2.30	0.28	<0.001	0.10	0.06-0.17
	LL 3 v LL 4	-0.72	0.25	<0.01	0.49	0.30-0.79
Relationship of interacting piglets	Littermates v non-littermates	0.32	0.18	<0.01	1.37	0.96-1.97
Day	day 1 v day 2	-1.83	0.18	<0.001	0.16	0.11-0.23

Their relationship within the group, litter of origin and the day of mixing were included as risk factors for the interruption of aggressive event by the feeder activation. There was a highly significant relation (P<0.001) between the interruption and the learning level of interacting piglets. The comparison among learning levels showed that the piglets with the highest learning level (LL4) were more likely to stop engaging in aggressive interactions at the sound signal to those with lower learning levels (LL1, LL2, LL3). The relationship of piglets within the mixing group significantly influenced (P >0.01) the interruption of aggressive events. Fights between littermates were 1.37 times more likely to be interrupted than those between non-littermates (OR=1.37; C.I. 0.96-1.97). Furthermore, the incidence of aggressive interactions between littermates and between non-littermates differed significantly (26% *vs* 74 %, χ^2=98.42, DF=1, P<0.001). The reaction to the feeder was not associated to the litter of origin in the mixing phase.

The logistic regression results showed a highly significant (P<0.001) effect of the day of mixing (Table 2). Aggressive events that occurred during the day 1 had a low probability to be interrupted (OR=0.16; C.I. 0.11-0.23) piglets reacted to the feeder in 27.5.5% of events (148 of 539) on day 1 and to 66.4% (293 of 443) on day 2 (χ^2=147.05, DF=1, P<0.001).

On day 1 the majority of aggressive events was not interrupted neither by the aggressor nor by the receiver while during day 2 interactions were stopped by both of them (Fig. 2).

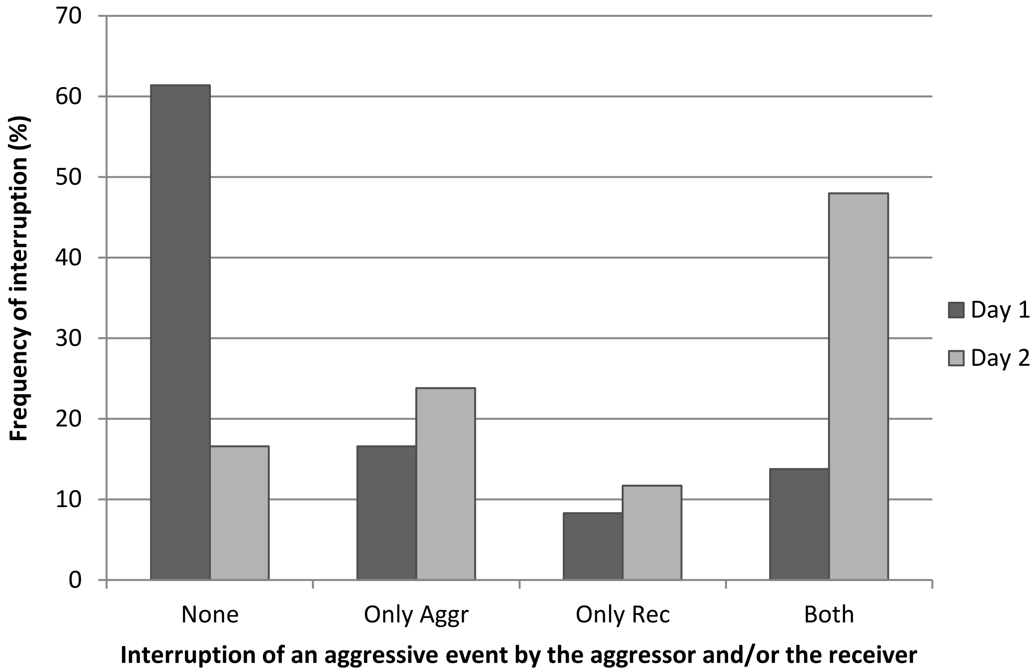


Figure 2: *Comparison of the frequency of the interruption of the aggressive events by piglets involved (aggressor (Aggr) and receiver (Rec)) during the Mixing phase (day 1 ; day 2).*

2.4.4 Discussion

Analysis of the results revealed differences between litters even though the animals had been raised, handled and trained in the same way. These results are similar to those of Hammell *et al.* (1975) who also found significant differences among litters for water-maze learning. Factors that affect individual learning abilities of pigs were investigated by numerous researchers. The studies of Gieling *et al.* (2012) and Murphy *et al.* (2013) compared learning abilities between piglets born at low birth weight and normal-birth weight. They obtained contradictory results; Gieling *et al.* (2012) found that low birth weight piglets performed worse in a conditional discrimination task than normal birth weight controls, while Murphy *et al.* (2013) showed that low birth weight pigs were quicker to learn. In our study, we found that birth weight did not have an effect on weight on piglet learning. Wolff and Hausberger (1996) found that female horses tended to be more successful than males in spatial tasks. Whereas two other studies reported no significant influence of sex on pigs performance in a spatial conditional associative task and social recognition paradigm (Moustgaard *et al.*, 2005, Souza and Zanella, 2008). Our study did not revealed any differences between learning levels of males and females.

Further investigation to discover the reason of the differences between the litters would be interesting considering that in this study piglets were trained in the presence of their dam. Hötzel *et al.* (2004) suggested that social interactions between sows and their litters might have a significant role on the development of piglet behaviour. In their study they showed that during the lactation period, confined piglets spent more time interacting with the sow and nursing than outdoor piglets. The lower social contact with the dam and the lower frequency of nursing appear to have encouraged outdoor piglets to eat solid food more frequently and starting at earlier ages than confined piglets. The piglets in our experiment were 2.5 weeks old when training started, they were still not very familiar with solid food, so mother had influence. This would be an asset to investigate how nursing and the social interactions between sow and piglets differ between litters raised in intensive conditions and their possible influence on the passage to solid food and the training results.

Newly weaned piglets are subjected to a number of stressors such as weaning, relocation, a diet change to solid feeds, a novel rearing environment and mixing with unknown piglets (Campbell *et al.*, 2013). Aggressive confrontation between newly mixed piglets is considered as one of the most stressful factors leading to increased stress hormone concentrations (Otten *et al.*, 1999). A number of papers suggest that agitated animals are poorer at making clear choices in preference or avoidance tests (Mendl *et al.*, 1997). The emotional state of an animal can influence its cognitive functioning and ‘‘judgment of stimuli’’ (Mendl *et al.*, 2009). Thus, our aim was to test the reaction of the previously trained newly-weaned piglets on the sound-reward stimuli in aggressive and stress-induced state. The question we posed was what would be the choice of piglets: to interrupt the aggression and to direct towards the feeder or continue the aggression, and which are the factors that influence it. The results showed that the response depends on the learning level acquired by the piglet during the training. Interruption of the aggression was also linked to the relationship of the piglets involved in aggression; piglets fighting with littermates were reacting more to the feeder call than those fighting with non-littermates. The occurrence of aggression between previously familiar animals may be the result of stressful conditions such as mixing, temporary removal from a group (Mendl, 1999). However, the majority of aggression was directed at strangers, similar to the results reported by Turner *et al.* (2001). Otten *et al.* (1999) showed that during confrontation with the unfamiliar group, pigs experienced more fights and showed a higher increase of plasma cortisol levels than during the confrontation with the familiar group. The day after mixing also was found to have a significant effect on reaction to the feeder. An estimated 24-48 hours is needed for a newly-mixed group pigs to establish a social hierarchy (Parratt *et al.*, 2006), although aggression is most severe during the first 24 h post-mixing (Ewbank, 1976). In our experiment piglets were barely reacting to the feeder call during the first 3h after mixing (27.5% of interrupted aggressive events) which could be explained by elevated stress provoked by radical change in social grouping and elevated aggression in order to establish hierarchy order. If aggression persisted into day 2, the number of aggressive events reduced and the reaction to the feeder call doubled (66.5 %). This probably is linked to the gradual familiarization and habituation to novel environment and the majority of hierarchical fights occurring during the first 24 hours of mixing. No difference was noticed between aggressor and receiver in their attention to the feeder - they were equally unresponsive to the feeder on the first day and responsive on the second day. We suppose that this could be connected to the reduced stress level of both interacting piglets on the second day of mixing.

2.4.5 Conclusions

In conclusion, we found that the acoustic-reward method has a potential to reduce the incidence of aggression among piglets. Effectiveness of the method depends on (1) the effectiveness of training; (2) the period of application (ineffective on the first day of mixing when the animals are very agitated and stressed); and (3) the relationship between piglets.

The study supports the scientific application of cognitive and learning abilities as a tool for the improvement of animal welfare and the behavioural management of the pigs.

CHAPTER 3

Image labelling for the assessment of different pigs behaviours through their activity patterns

This chapter consists of two published and one accepted peer reviewed articles. The aim of this chapter is to illustrate image labelling input to pigs activity monitoring through image analysis techniques and its relationship with different behaviours and environmental parameters.

i. Subchapters 3.1 and 3.2 report results from application of image analysis for different behaviours monitoring through pigs activity
ii. Subchapter 3.3 reports results the study aimed to evaluate the relationship between pigs activity and environmental parameters in a piggery by means of image analysis.

3.1 Labelling the behaviour of piglets and activity monitoring from video as a tool of assessing interest in different environmental enrichments

G.Ismayilova[a] , A.Costa[a] , I.Fontana[a], D.Berckmans[b] , M.Guarino[a]

[a]Department of Veterinary Sciences and Technologies for Food Safety, Faculty of Veterinary Medicine,Università degli Studi, Via Celoria 10, 20133 Milan, Italy

[b]Measure, Model and Manage Bioresponse (M3-BIORES), Department of Biosystems, Katholieke Universiteit Leuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium

Published in Annals of Animal Science, Vol. 13, No. 3 (2013) 611–621

Submitted 19 December 2012, accepted 2 April 2013, published July 2013

Abstract

The aim of this study was to explore the preference and the duration of interest of weaned pigs to two different types of environmental enrichments using labelling techniques and activity monitoring. Two pens each housing 14 Dalland piglets were monitored using a video camera. The videos were labelled during the weaning phase from 30 to 60 days of age. During this time, the video recording software continuously calculated the activity index of the pigs. To detect pig exploratory and playing behaviour, a wooden block and chain enrichment were introduced into each pen for 30 days. Each video frame was manually labelled during the Day 1, 5 and 30 (24 hours a day) for each pen using the Labelling Tool software. To identify the duration and frequency of interactive episodes with environmental enrichments, pig behaviour was labelled as either: no activity, interacting with chain or interacting with the wooden block. The mean duration of interactive episodes for the chain was greater than for the wooden block ($P<0.001$), while the frequency of interactive episodes was 28.8% higher for the wooden block than for the chain. By day 5, the mean duration of interaction episodes decreased in both pens and by day 30, only a few interaction episodes were observed. The number of interactive episodes were strictly related to the activity index and depended on the time of the day. The peaks of the mean number of interactive episodes calculated for all days of observations corresponded to the peaks of the mean activity index.

Keywords: *piglets, environmental enrichment, labelling, activity monitoring, camera images*

3.1.1 Introduction

Numerous scientific studies under farm conditions show that pigs tend to display the same habits and behaviour as wild pigs including foraging, playing and explorating (Wood-Gush and Vestergaard, 1991; Van de Weerd and Day, 2009). Many scientific studies have also shown that modern intensive farms compromise the natural behaviours of pigs resulting in negative social behaviours such as tail and ear biting (Meunier-Salaun et al., 1987; Fraser et al., 1991; Van de Weerd et al., 2006) and aggression towards their penmates (Kelly et al., 2000; Melotti et al., 2011). It is widely accepted that environmental enrichments that facilitate the natural motivated behaviours of pigs improve their welfare (Wood-Gush and Beilharz, 1983; Arey, 1993; Beattie et al., 2000) and more specifically can: reduce aggressive behaviour (Grandin, 1989; Schaefer et al., 1990; Beattie et al., 1996; Melotti et al., 2011; Nowicki and Klocek, 2012); reduce belly nosing (Beattie et al., 1996; Rodarte et al., 2004; Bench and Gonyou, 2006); reduce tail biting (Bøe 1993; Petersen et al., 1995; Van der Weerd et al., 2005; Zonderland et al., 2008); and improve production performance (Beattie et al., 1995; O'Connell and Beattie, 1999; Beattie et al., 2000) and ease of handling (Day et al., 2002) In order to enhance animal welfare on farms the EU Directive 2001/93/EC has provided a minimum standard for the protection of pigs stipulating that: "Pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals." However, some substrates suggested by the Directive 2001/93/EC are impractical for industrial production (Fraser et al., 1991; Van de Weerd et al., 2003). For example, large quantities of straw, hay or sawdust in standard pens with partly or fully slatted floors may block the liquid-slurry disposal systems (Van de Weerd and Day, 2009). The effective environmental enrichment provided to the pigs should not only enable the expression of relevant natural behaviours and maintain their interest, but also be practical for the existing farming systems and cost-effective for the farmers. At present, the use of point-source enrichment objects such as chains and wood blocks are a widespread alternative to disposable substrates. Point-source objects are often referred to as ‘toys’ and generally limited in size. Their use is often restricted to a single location in a pen (Van de Weerd and Day, 2009). Despite many scientific studies on the effect of different types of point-source objects on pigs (e.g. Bracke et al., 2006), it is still not clear which of them is most effective and what type of environmental enrichment is the most attractive to pigs and keeps their interest the longest. The material characteristics of point-source objects play a crucial role in the interest and frequency of pigs’ interactions with the object. The objects preferred by weaned and growing pigs have been characterized as ‘chewable’, ‘deformable’ and ‘destructible’ (Grandin, 1989; Feddes and Fraser, 1994; Van de Weerd et al., 2003) which may be linked to engaging in foraging and exploring behaviours. Some authors suggest that the combination of the enrichments are more interesting for pigs (Zonderland et al., 2003; Van de Weerd et al., 2003). It is important that the enrichment provided is able to maintain continuous interest of the animals to minimize the risk of behaviour being redirected towards penmates (e.g. Wood-Gush and Vestergaard, 1991; Fraser et al., 1991; Bolhuis et al., 2005). However, with point-source objects, pigs can become habituated to them within a few days after introduction (Van de Weerd et al., 2003; 2009), indicating that these enrichments lose novelty and pigs’ interest (Nowicki and Klocek, 2012). Understanding how pigs interact with enrichments over time is essential for curbing negative behaviour and promoting positive ones. Using tools to continuously monitor and quantify pig behaviour allows farmers to intervene as suitable. As stated by Cangar et al. (2008), changes in the behaviour of farm animals indicate that human intervention is necessary. The aim of the present study was to evaluate pigs’ interest and preference toward two commonly used point-source environmental enrichments (chains and wooden blocks) through monitoring their activity and labelling playing and exploratory behaviours. The methodology to evaluate animal behaviour was developed with an approach of Precision Livestock Farming (PLF). One of the objectives of Precision Livestock Farming (PLF) is to develop on-line tools for monitoring farm animals continuously and automatically during their life. The objective is to measure criteria calculated on-line from collected data without imposing additional stress to the animals. Besides on-line automatic monitoring, PLF also offers possibilities in automatic control for supporting the management of such complex biological production processes (e.g. feeding strategies, growth rate control, activity control) (Morag et al., 2001; Halachmi et al., 2002; Aerts et al., 2003 a, b; Guarino et al., 2004).

3.1.2 Material and methods

Housing conditions and animals

Experiments were conducted in a swine weaning building located in Pianura Padana, Pavia province, Italy. The building was naturally ventilated, containing six fully-slatted pens (1.90 m × 2.50 m) located in two rows of three on either side of an access area 0.80 m wide. Additional lighting over the experimental pens facilitated video recording.

A total of 28 Dalland piglets (14 males and 14 females) aged 30 days and weighing an average of 13 kg were placed as two uniform groups into adjacent pens. The animals were fed ad libitum from a feed trough and water was available from a drinking nipple. No environmental enrichment was provided in the pen before the experiment commenced.

Animal activity monitoring

Pig activity was video recorded continuously using an infrared-sensitive CCD camera (VCB 35721RP, Sanyo Electric Co. Ltd., Osaka, Japan) for 30 days. The camera was mounted to the roof at 3.25 m above the pen’s floor. The camera lens was placed directly above the corridor separating the two pens and connected to a PC with built-in frame grabber using the coax connection cable. Images were captured at a resolution of 768 × 586 pixels at a sample rate of 1 Hz. The image analysis software Eyenamic analysed these images simultaneously in real time to create the animals' activity index – a measurement that quantifies the activity of animals in the field conditions inside the barn (Leroy et al., 2006; Bloemen et al., 1997). The activity index is determined by dividing the image of each pen into rectangular zones (Fig. 1) and tallying when pixels change between two consecutive frames within each zone.

FIGURE 1: *The two observation pens and the division of the images into areas for the activity index calculation*

The software acquired a monochrome image I*(x, y, t)* from the camera and then calculated the difference between its intensity values and of the previous image I*(x, y, t-1)* taken one second earlier. From this difference image, the binary 'activity image' $I_a(x, y, t)$ was calculated by containing the pixels for which the intensity change exceeded a threshold:

$$\mathbf{I}_a(x,y,t) = \begin{cases} 1 & \text{if } \mathbf{I}(x,y,t) - \mathbf{I}(x,y,t-1) > \tau_1 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

From the activity image Ia(x, y, t), the activity index ai(t) for pen (Zi) was calculated as the fraction of moving pixels with respect to the total number of pixels within the pen Zi:

$$a_i(t) = \frac{\sum_{(x,y)\in Z_i} \mathbf{I}_a(x,y,t)}{\sum_{(x,y)\in Z_i} 1} \qquad (2)$$

The threshold τ1 accounted for small intensity changes due to noise, such as electrical noise in the coax cabling and image acquisition circuits, and small lighting variations. The lower threshold value was set to 10% of the maximal intensity value as estimated by looking at the intensity variation of an ‘empty’ region outside of the pig pen in the first 60 images (equivalent to one minute of recording).

The upper threshold τ_2 was applied to the activity index $a_i(t)$ to compensate for drastic intensity changes (e.g. when lights were switched on/off). In case of such an event, almost all pixels in the activity image I_a were ‘active’ and the activity index $a_i(t)$ was almost equal to 1 in the two pens. The threshold τ_2 was set to 0.5 of the maximal activity index. If this threshold was exceeded, i.e. more than half of the pen was active, the activity index was set to zero.

The pixel area sums in the nominator and denominator of equation (2) have an accuracy of one pixel which, using the camera calibration factor, was equivalent to an area of 2.9 cm^2.

<u>Behaviour labelling procedure</u>

On 1st day of video recording the chain and wooden block enrichments, were introduced to the pens at 10:00 AM. The chain was fixed in vertical position at piglet eye level and the wooden block was placed randomly on the pen floor. The environmental enrichments were kept in the pens for 30 days. The videos of Day 1, Day 5 and Day 30 were analysed to determine the level of object-directed behaviour. These days were chosen to test the initial, short and long term interest of the piglets to the selected environmental enrichments.

The recorded videos were analysed by one observer using the software “Labelling Tool” (Viazzi et al., 2011) developed in Matlab (R2009a, The MathWorks Inc., MA). The image files were visually checked and manually labelled by observing each frame (one frame per second) when the start of manipulation with the environmental enrichment was detected on the video. The labelling procedure permitted the identification of every playing/exploratory event n during Day 1, Day 5 and the Day 30 of the experiment for 24 hours/day (totaling 144 hours of observations for 2 pens). The observations of video recordings from Day 1 started from the moment when the enrichments were introduced to the pens. On Day 5 and Day 30. The observations started at 08:00 AM in the morning.

The recorded images were calibrated in order to define how many square centimeters in the pen correspond to a pixel. At this stage the camera images were subdivided into two equally-sized observational zones, one per each pen to define zones of interest inside the video. By creating multiple zones it was possible to relate the behaviours to a specific pen. For each zone the activity index was measured from the video and displayed on the Labelling Tool interface in order to speed up the manual labelling process. If the activity was close to zero (the animals were not moving in the particular zone), the observer could leave out these intervals.

For each behaviour pattern the following specific buttons were created: no activity, interacting with chain, interacting with wooden block. Each recorded image (one image per second) was visually checked and manually labelled separately per observation zone according to the chosen behaviours of pigs through playing the video or sliding the images frame by frame. When a specific behaviour was observed in the image the matching button was selected, at the same time the labelled behaviour was displayed on the panel of Labelling Tool containing the list of behaviours. It was possible to press multiple buttons in case different playing/exploratory behaviours occur in the same image. It was also possible if the same behaviours take place in consecutive images to register their start and end by pressing the “record” button.

The labelling procedure facilitated an exact record on the true duration of exploratory/playing behaviour, frequency and the time at which interactive episodes with each type of environmental enrichment began and ended. Interactive episodes were measured as the length of time (sec) from first touch of environmental enrichment by pig or group of pigs to termination of action for more than 5 seconds.

3.1.3 Results

The duration of interaction episodes with both environmental enrichments had a similar trend in both pens. No significant difference in duration was identified; therefore, in this case, both pens were taken as one experimental unit. The mean duration of interaction episodes was significantly greater for the chain than for the wooden block (P<0.001), whereas the frequency of interaction episodes was 28.8% higher for wooden block than for chain (Table 1).

TABLE 1: *Least Square Means of duration (sec), frequency of interaction episodes with two types of environmental enrichments and mean day activity index of weaned piglets.*

Enrichment type	Duration LSMean ± SEM		Frequency Interaction		Activity Index Mean±SD
	Chain	Wooden Block	Chain	Wooden Block	
Overall mean	35.45±6.55^{A}	20.12±4.93^{B}	241	436.3	0,012±0.017
Day 1	59.79±6.45^{A}	36.35±4.67^{B}	423	663	0.015±0.019
Day 5	43.06±6.66^{a}	21.50±3.85^{b}	298	643	0.013±0.016
Day 30	3.50±10	2.50±4.01	2	3	0.0079±0.012

(A,B) least means within the same row differ for P>0.001
(a,b) least means within the same row differ for P>0.01

Analysis of the 24-h environmental enrichment use pattern from video records showed that mean duration of interactive episodes with chain as well as with wooden block had already decreased on Day 5 and Day 30, and use had diminished to 2–3 sec with few sporadic interactive episodes (Table 1). A time of day effect was found on interactive episodes (Fig. 2).

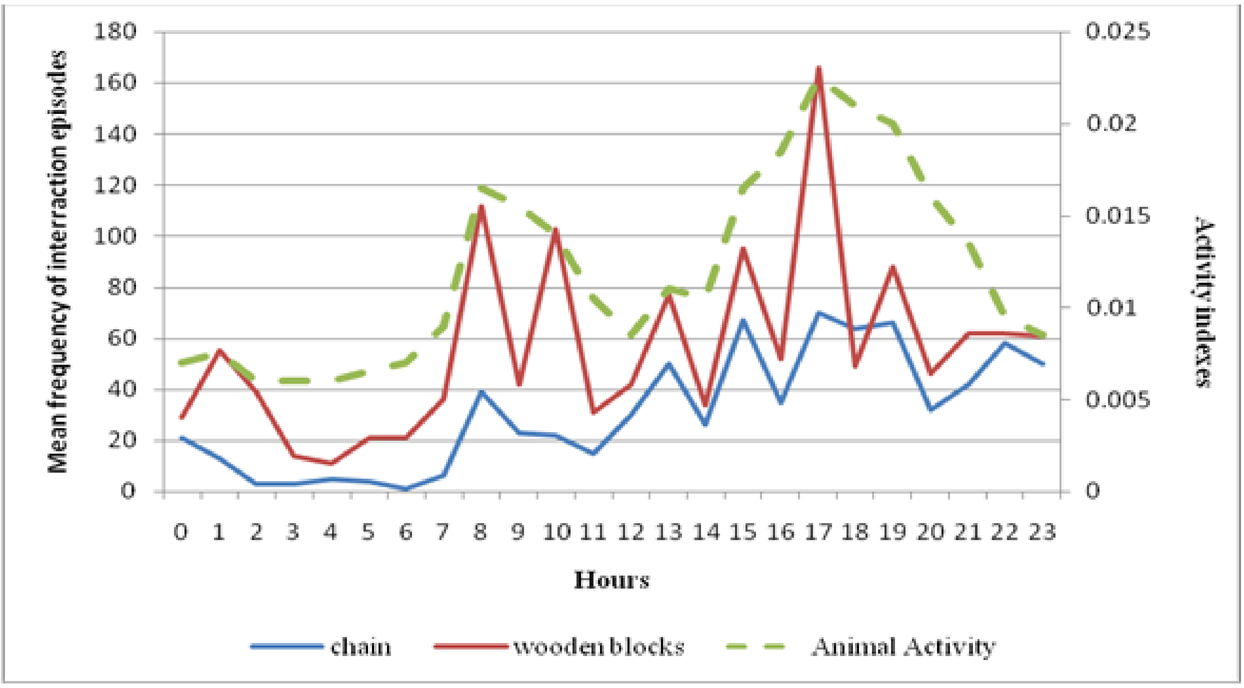


FIGURE 2: *Effect of time of the day (24 h) on frequency of interaction episodes with different environmental enrichments (chain and wooden block) and animal.*

There was a drastic decline of interaction episodes frequency from 02:00 AM. to 07:00 AM, which is expected as the lights were turned off during the night. Activity indexes during this hours showed the lowest values (with a range from 0.005 to 0.008 units). The peaks of activity coincided with with the most frequent interactions of piglets with both types of environmental enrichments.

3.1.4 Discussion

The importance of environmental enrichment material properties is widely shown in literature. According questionnaire done by Bracke *et al.* (2006), the majority of pig welfare scientists believes that a chain is not sufficient enrichment material for pigs. Pigs play with chains but they prefer to play with pliable objects when they are given a choice (Grandin, 1988). However, in this study long interactions with chain were observed, even if they were not as frequent as interactions with wooden block. This could be connected to "flexibility" characteristics of the chain, the position of the chain suspended at eye level. It was found that pigs played more frequently with wooden block but the duration of playing episodes was short. Unfixed environmental enrichments (laying free on the pen floor) were less attractive for the pigs than fixed ones since they become soiled with excreta (Blackshaw et al. 1997, Jones et al., 2000, Scott et al., 2009; Nowicki et al., 2007; 2012). However, the destructibility features of wooden block, availability in different locations within the pen and ease to manipulate them could be a reason of increased frequency use These results suggest that the the material characteristics and the position of the point-source objects are the important factors, influencing on frequency and duration of of pigs' interactions with them. The combination of the point-sourced environmental enrichments with different characteristics could be an effective solution.

The results of experiment: the duration of interaction episodes with environmental enrichment is remarkably reduced with time is not surprising as it is corresponding with results of other authors (e.g. Van de Weerd et al. 2003, Zonderland et al. 2003; Trickett et al. 2009, Nowicki et al., 2012).

Also the time of the day influenced the frequency of interactions of pigs with environmental enrichments. The activity index showed the hours when the pigs were mostly active during the day and these peaks of activity were corresponding with hours when pigs were interacting most with environmental enrichments. This could be explained by a variety of factors influencing the general distribution of pigs activity during the day such as photoperiod, feed consumption, etc.

3.1.5 Conclusions

The present experiment was a preliminary study to assess the interest of the pigs to different types of environmental enrichments using the combination of the labelling method and the activity index parameter. This method allowed the specific discrimination of behaviour type and duration in order to accurately quantify the interest pigs show in environmental enrichments.

The results received from this experiment suggest that the chain and the wooden block, often used by the farmers as the low cost enrichments, are not effective for the long term use. In case of short term use it is advisable to combine the point-source enrichment objects with different characteristics to increase the playing time during the day.

In both pens, the number of interaction episodes with environmental enrichments were linked to the activity index, which allowed to determine the diurnal behavioural dynamics of the animals.

Low cost cameras, in combination with image analysis techniques, can be used to quantify animal behaviour (De Wet et al., 2003; Leroy et al.,2004). There is a potential for the development of the algorithm for an automatic control of pigs/playing exploration behaviour, basing on the method described in this article.

3.2 The use of image analysis as a new approach to assess behaviour classification in a pig barn

Annamaria Costa[1], Gunel Ismayilova[1], Federica Borgonovo[1], Toon Leroy[2], Daniel Berckmans[2], Marcella Guarino[1]

[1]University of Milan, Faculty of Veterinary Medicine, Department of Health, Animal Science and Food Safety, Milan, Italy
[2]Katholieke Universiteit Leuven, M3-BIORES: Measure, Model & Manage Bioresponses, Leuven, Belgium

Published in Acta Veterinaria Brno Vol. 82, No. 1 (2013), 25-30

Manuscript received August 29, 2011; accepted October 23, 2012; published March 2013

Abstract

The aim of this study was to develop an innovative method for measuring the activity level of pigs in a barn in real time. An infrared-sensitive camera was placed over two pens of the piggery, images were recorded for 24 h a day for eight days during the fattening period, and the activity and occupation indices were calculated every second in real time using software. In the laboratory, the recorded images were visually labelled to score the animals' behaviour adopting the Martin and Bateson's Scan sampling method, and to find a relation with the automatically measured activity index. Pigs' behaviour was assigned in the following way, 0 - no activity, 1 - fighting or struggling, 2 - biting one another, 3 - abnormal behaviour as nuzzling or suckling one another (interacting pigs), 4 - feed assumption time. Pigs spent most of the time lying inactively (82–90% of the time), following a diurnal rhythm with peaks related to the feeding administration routine; fighting episodes occurred very rarely (0.05–0.10% of the time). Based on the analysis of the automatically measured group activity index compared to the manual labelling, a relation was found between the activity index and the behaviour types (no activity, nuzzling and feeding). The novelty presented in this study was the development of on-line tools to monitor farm animals continuously during their life, in a fully automatic way, with objective measures and criteria without imposing additional stress to the animals.

Keywords: *On-line animal observation, labelling, behaviour score, swine*

3.2.1 Introduction

In the past, livestock management decisions have been based almost entirely on visual and auditory observation, judgment and experience of the farmer, since pig behaviour has been used extensively as an indicator of their welfare (Broom 2002). Housing for intensive rearing is usually a long-term condition for farm animals (Rushen 2003) and results in a chronic state for an individual. These intensive systems are responsible for a greater incidence of health diseases compared to extensively reared pigs, moreover, the barren environment does not allow the pigs to express many of their typical behaviours (Gade 2002). The slatted floor, wide-spread on Italian intensive pig farms, can induce mortality in slaughter pigs (Voslářová et al. 2010). This trade-off makes it very difficult to evaluate overall welfare, especially because the value of each welfare problem is assessed differently by different scientists (Fraser 2003). These problems can be identified by using various indicators of a husbandry system, and by evaluating their effect on pig welfare and health. These physical and behavioural abnormalities of pigs can be assessed by examination of the pigs at either the group or individual animal level. In field conditions, together with the increasing scale of the farms and the corresponding high number of animals per farm, this change has resulted in an increasing workload for the farmer and, at the same time, limited the possibilities for the farmer to monitor his or her animals.

The aim of this study was to evaluate animal behaviour on an intensive swine farm through on-line automatic measurements of animal activity, and to rank animal behaviour with labelling procedure.

3.2.2 Materials and Methods

<u>Description of the monitored buildings</u>

The study was conducted in a pig fattening house located in Northern Italy. The barn housed 350 finishing pigs, was open-spaced, 14 m wide × 21.2 m long, mechanically ventilated, subdivided into 16 pens each, 5.9 m wide × 2.6 m long, and with a fully slatted floor. The pens were delimited by a concrete wall 1 m high and 0.2 m thick. The wall with the entrance door and the opposite wall had four windows each to light the building. The windows had a surface area of 1.32 m2 (0.6 × 2.2 m; height × width) and were located 2 m above the floor. The pigs were fed 3 × daily, at 8.30 h, at 15.30 h and at 19.00 h. The troughs were placed on the longitudinal wall dividing the two pens; the drinking bowls were located at the corner of each pen. Lights were switched on 15 min before feed administration and the lighting schedule was 40 min per every feeding release time.

Monitoring system of animal activity, definition of activity and occupation indices.

From the 16 pens in the barn, two pens were selected for the experiments; one pen contained 16 pigs, the other 17. At the start of the finishing stage, the mean weight of the pigs was 60 kg and their mean age was 150 days.

An infrared sensitive CCD camera (VCB 3572IRP) was mounted 5 m above the floor with its lens pointing downward and directly above the wall separating the two pens to get a top view of both pens in the camera image(Plate III, Fig. 1). The camera was connected to a computer with a built-in frame grabber (Data Translations DT 3210) using a coaxial cable. Images were captured with a resolution of 768 × 586 pixels at a sample rate of 1 Hz, i.e. one frame per second. The monitoring phase was performed 24 h a day for eight days, observing each frame (1 frame per second). During this period, the Eyenamic system was running in real-time and video images from the camera were recorded simultaneously. Eyenamic is innovative software that continuously and automatically registers the behaviour of a group of animals.

Prior to the experiment, the camera was calibrated so areas of pixels in the image could be converted to units of cm2 on the pen floor. Because no markers could be added to the pig pens visible in the camera image prior to the experiments, an in-depth camera calibration was not possible. The image was calibrated to establish a linear scale factor in cm/pixel so that the area of pixels in the image could be converted to units of cm2 on the pen floor. Fig. 1 shows the experimental setup and subdivision of the two pens into two areas (pen 1 into areas 1 and 2 with 16 animals, and pen 2 into areas 3 and 4 with 17 animals).

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FIGURE 1: *The two pens each divided in two areas (first pen with 16 pigs in area 1 and 2, second pen with 17 pigs in area 3 and 4). The four areas were monitored by Eyenamic software to calculate the occupation and activity indexes on observed pigs during the trial.*

Every second, the software automatically grabbed a monochrome image **I** (*x*, *y*, *t*) from the camera and calculated the difference of the intensity values with the previous image **I** (*x*, *y*, *t-1*), taken a second earlier. From this difference image, the binary 'activity image' **I***a* (*x*, *y*,*t*) was calculated, containing the pixels for which the intensity change exceeded a threshold:

$$\mathbf{I}_a(x,y,t) = \begin{cases} 1 & \text{if } \mathbf{I}(x,y,t) - \mathbf{I}(x,y,t-1) > \tau_1 \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

From the activity image **I**a(x, y, t) the activity index ai(t) for zone Zi was calculated as the fraction of moving pixels with respect to the total number of pixels within the zone Zi:

$$a_i(t) = \frac{\sum_{(x,y)\in Z_i} \mathbf{I}_a(x,y,t)}{\sum_{(x,y)\in Z_i} 1} \qquad (2)$$

The threshold $\tau 1$ accounted for small intensity changes due to noise, e.g. electrical noise in the coax cabling and image acquisition circuits, small lighting variations, etc. The value of the threshold was set to 10% of the maximal intensity value, estimated by looking at the intensity variation of an 'empty' region, outside of the pig pen, equivalent to one minute of recording. An additional upper threshold $\tau 2$ was applied to the activity index $ai(t)$ to compensate for drastic intensity changes (e.g. when lights were switched on/off). In the case of such an event, almost all pixels in the activity image $\mathbf{I}a$ were 'active' and the activity index $ai(t)$ was almost equal to 1 in all zones. The threshold $\tau 2$ was set to 0.5 of the maximal activity index. If this threshold was exceeded, i.e. more than half of the zone area was active; the activity index was set to zero. The pixel area sums in the nominator and denominator of equation (2) have an accuracy of one pixel which, using the camera calibration factor was equivalent to an area of 2.9 cm2.

Labelling procedure

After downloading recorded data to the laboratory, the image files were visually assessed and labelled observing each frame (one frame per second) in order to evaluate animal behaviour during the day. The observed frames were monitored and analysed 24 h/day for 8 days by Eyenamic software. The behaviour of the pigs was observed according to the Scan sampling method described by Martin and Bateson (1986), a focal animal sampling that scans a whole group of animals to record specific, limited behaviours. The pig behaviour was recorded continuously to provide a correct and accurate record, measuring the variation of animal activity and occupation index when the behaviour started, the true duration, frequency and the time at which behaviour patterns started and stopped. Behaviour pattern scores were assigned as follows: 0 - no activity, 1 – fighting or struggling, 2 - biting one another, 3 - abnormal behaviour intended as nuzzling or suckling one another (interacting pigs), 4 - feed assumption time. When two or more behaviour patterns were observed, they were both labelled, for example, when both fighting and biting was observed simultaneously in the pig group, behaviours were labelled as 12.

Statistical analysis

As mentioned previously, the Activity Index was calculated by Eyenamic as the fraction of moving pixels with respect to the total number of pixels within a certain area, while the Occupation Index was calculated as the fraction of pixels corresponding to a region of the image occupied by pigs with respect to the total number of pixels within the same zone. These two indices, one datum for second for each area, were submitted to a variance analysis (Proc GLM, SAS 9.2, 2010) to evaluate the effect of the areas, time and feeding administration on these two variables. We performed the tests using target significance levels of 0.01 and 0.001. Frequency analysis (Proc FREQ, SAS 9.2, 2010) was performed to investigate the behaviour dynamics of pigs according to Lyons et al. (1995). Finally, another variance analysis (Proc GLM, SAS 9.2, 2010) was performed on all data, either those provided by Eyenamic software or those coming from the labelling procedure, to study the effect of labelled behaviour pattern on animal activity level.

3.2.3 Results

The daily mean activity of pigs for every area is shown in Table 1.

TABLE 1: *Ls means of activity and occupation index calculated by Eyenamic on observed pigs during the experimental period*

Area	Activity index (Units) ± SEM	Occupation index (Units) ± SEM
1	0.0148 ± 0.0033	0.534 ± 0.081
2	0.0123 ± 0.0041	0.203 ± 0.074
3	0.0139 ± 0.0050	0.197 ± 0.053
4	0.0190 ± 0.0029	0.504 ± 0.062

Values in the same column with superscript (A, B), (A,D), (B, C), (C, D) differ for P < 0.001
Values in the same column with superscript (a, b) differ for P < 0.01

Animal activity was higher in area 4 (0.0190, $P < 0.001$) near the corridor, where farmers usually passed for their daily inspections. The maximum activity values in relation to the time of observation occurred in all areas ($P < 0.001$) during feed administration in the barn (8.30 h, 15.30 h, 19.00 h and during the release of extra water at 22.00 h). During the night the activity index showed the lowest values recorded (less than 0.005 units). The activity of the pigs followed a diurnal rhythm with peaks occurring with the management routine procedures (feeding administration, farmer's inspections, Fig. 2A).

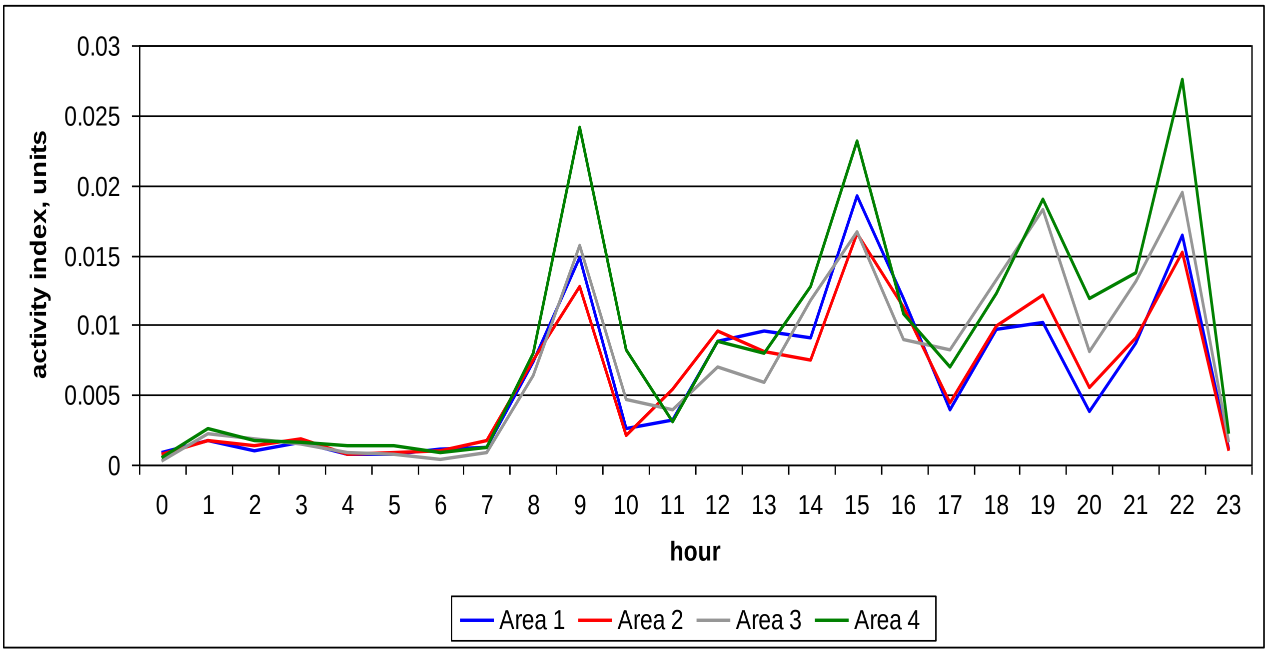

FIGURE 2A: *Hourly mean values of activity index calculated by Eyenamic on observed pigs during the experimental period.*

During feeding time, the pigs moved to the trough distributing themselves in a homogeneous way in all the areas; at the end of the feeding time, most of the pigs moved to areas 1 and 4, near to the corridor, using these areas as a "resting place". As a consequence, the occupation index increased in these two areas (Fig. 2B).

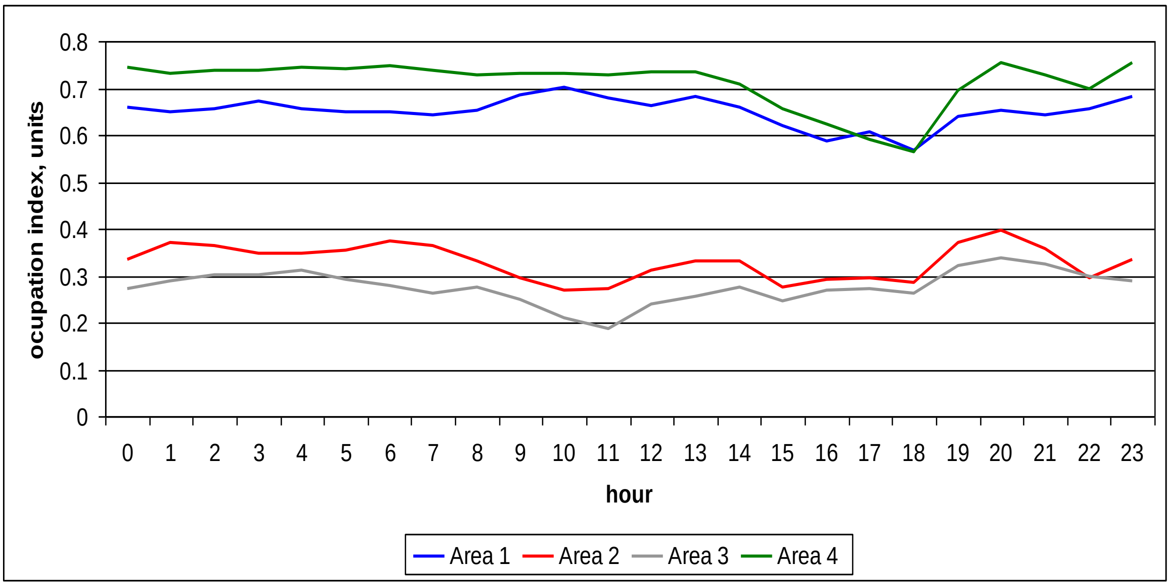

FIGURE 2B: *Hourly mean values of occupation indexes calculated by Eyenamic on observed pigs during the experimental period.*

Table 1 reports the mean Occupation indexes calculated by Eyenamic in pigs during the 24 h in each day of the trial, and Fig. 2B shows the mean daily trend of the Occupation Indexes. Daily Occupation Index was higher in area 1 (pen 1) and area 4 (pen 2), both placed near the corridor (0.504 and 0.534 units, respectively, $P < 0.001$). Hourly values of the Occupation Index reached up to 0.75 units in area 4. Areas 2 and 3 near the external wall characterized by a humid floor surface and limited air flow were essentially utilized by animals as defecation zones. The Frequency Analysis conducted in the laboratory on labelled behaviours showed that the pigs spent most of the time lying inactive (from 81.52% in area 4 to 90.29% of the time in area 3). Fighting episodes or attacks conducted by pigs occurred occasionally and only for a mean value of 18 × a day, i.e. 0.05–0.10% of the observation time. Biting behaviour occurred rarely (0.20–0.52% of the experimental period), nuzzling behaviour was exhibited by the pigs for 7.73–16.41% of the time; 1.69% of the time was dedicated to feed consumption. During the day biting and fighting were observed as an abnormal behaviour pattern following the normal exploratory behaviour of nuzzling (Fig. 3).

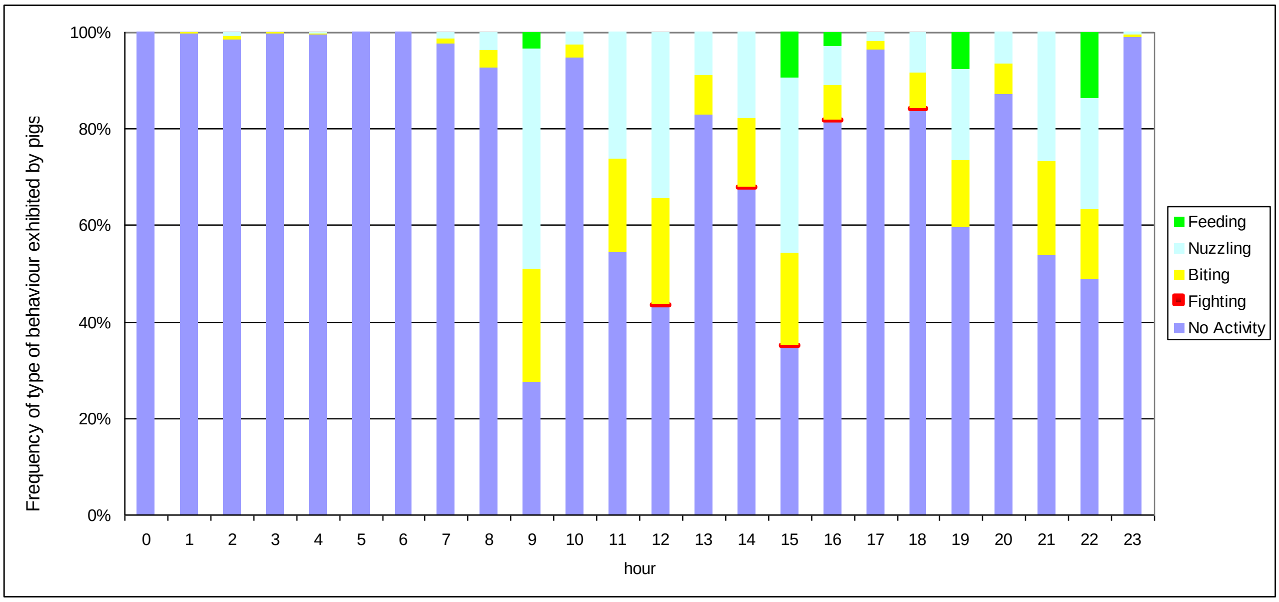

FIGURE 3: *Frequency rate of the labelled pigs behaviour assigned in laboratory during the daytime*

These behaviour patterns were observed mainly during the day and not at night, after the re-mixing of pigs to return to rest on the floor. The pigs became inactive 55 min after feeding time (Fig. 2A). Example of the measured activity index and the behaviour type for area 1 are shown in Fig. 4A. The GLM procedure highlighted the effect of the type of behaviour on the animal activity index, showing that feeding consumption (labelled as 4) corresponded to an activity index of 0.54 ($P < 0.05$), nuzzling (labelled as 3) corresponded to an activity index of 0.19 ($P < 0.01$). The analysis of the automatically measured group activity index compared to the manual labelling reported in Fig. 4A and 4B, highlights the relationship between the activity index and the behaviour types called ‘no activity’, ‘nuzzling’ and ‘feeding’. Feeding represents a period with higher activity. However, behaviour related to aggressiveness of individual pigs (‘fighting’ and ‘biting’, Fig. 4A and 4B) cannot be detected from instantaneous measurements of the group activity index.

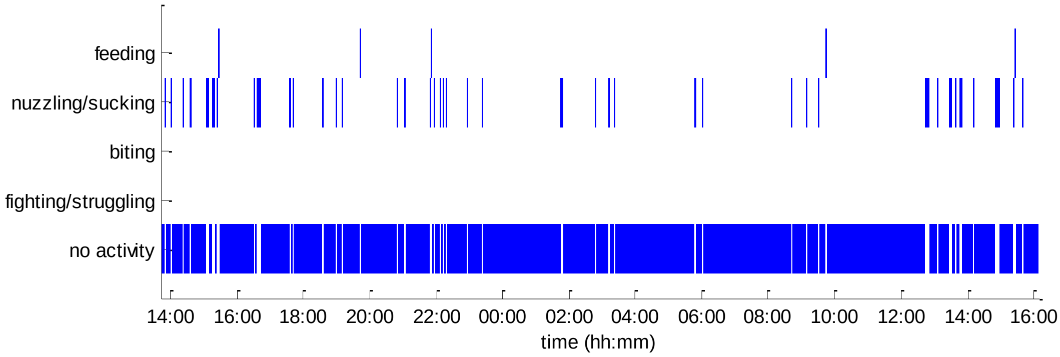

FIGURE 4A: *Example of the manual behaviour labelling of the pigs in zone 1.*

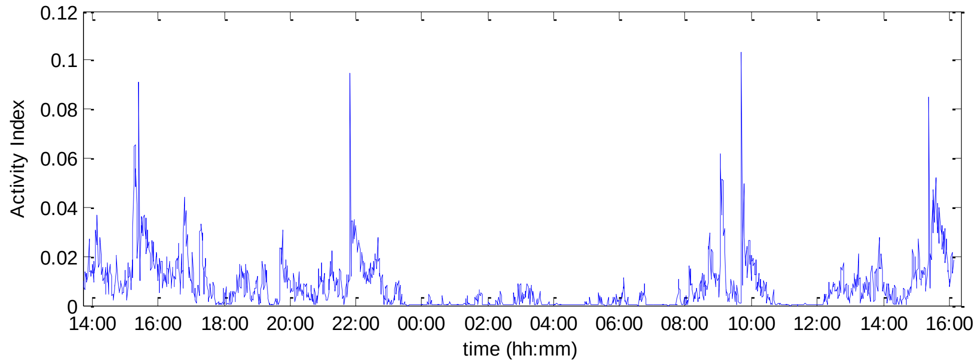

FIGURE 4B: *The automatic activity index in zone 1 as measured by the software during the experimental period.*

Fig. 3 shows that the pigs tended to exhibit exploratory behaviour mainly from 9.00 h to 22.00 h, especially during the hours of the day characterized by higher light intensity (from 12.00 h to 18.00 h). Around feeding times some aggressive behaviour occurred, probably as an expression of the re-establishment of the social hierarchy among the animals.

3.2.4 Discussion

The pigs' activity followed a diurnal rhythm with peaks related to management routine (Lyons et al. 1995). The pigs spent most of time inactive, with fight episodes rarely lasting longer than four seconds. The attacked pig vacated the area and the dominant pig assumed the place previously occupied by the other pig. The high values related to “inactivity” may be due to the slatted floor that makes walking difficult (Lyons et al. 1995). Similar values were found by Ekkel et al. (2003) in a study performed on pigs of various live weights (from 30 to 100 kg) reared on partly slatted floor. There was a significant period effect for the space-sharing data; pigs showed more ‘social lying behaviour’, i.e. tended to huddle more during the night compared to the day, since the space sharing percentages were higher during the night. Fighting episodes occurred very rarely (0.05–0.10% of the time) and were less intense than those recorded by Lyons et al. (1995), whereas nuzzling which can be read as “social behaviour” occurred more frequently in our study (up to 16.41% in area 4) compared to 1.6% measured by Lyons et al. (1995). Nuzzling can be a sign of socialization or interaction among pigs but when it is exhibited for long periods as in our study, it can be also an expression of disease, a frustrated suckling behaviour brought about by early weaning (Lyons et al. 1995) or the beginning of cannibalism episodes. The overhead view was the best way to have a complete coverage of the boxes but presented some difficulty in labelling the pigs’ behaviour. In particular cases, e.g. when pigs were lying to rest, it was hard to distinguish whether they were suckling or nuzzling. It was therefore assigned the subjective score of “3” to indicate all the abnormal behaviours including both nuzzling and suckling. The recorded images showed that pig suckling usually lasted longer than nuzzling (sometimes more than 5 min). At slaughter time, injuries were noticed on the legs of these pigs which could be due to the suckling behaviour observed on the video images. The lack of interest and rare episodes of abnormal behaviour shown by the pigs during the observation period could be explained by lack of environmental enrichment, by the building structure itself and the presence of the fully slatted floor; since previous studies reported that barren housed pigs behave more aggressively and display more abnormal agonistic behaviour than enriched housed pigs (O’Connell and Beattie 1999).

3.3 Image-processing technique to measure pig activity in response to climatic variation in a pig barn

A. Costa[a], *G. Ismayilova*[a] *F. Borgonovo*[a], *S. Viazzi*[b], *D. Berckmans*[b] *and M. Guarino*[a]

[a]Department of Health, Animal Science and Food Safety, Faculty of Veterinary Medicine Università degli Studi di Milano, via Celoria 10, 20133 Milan, Italy.

[b]Measure, Model & Manage Bioresponses (M3-BIORES), Laboratory for Agricultural Buildings Research, Catholic University of Leuven, Kasteelpark Arenberg 30, B-3001 Leuven, Belgium.

Published online in Animal Production Science

DOI: http://dx.doi.org/10.1071/AN13031

Submitted 26 January 2013, accepted 17 September 2013, published online 26 November 2013

Abstract

In the past decades, the increasing scale of intensive pig farms led farmers to use automatic tools to monitor the welfare and health of their animals. Visual observation and manual monitoring, usually practiced in small-scale farms, is unreliable in large-scale husbandry, and is expensive and time consuming. Environmental parameters are crucial information for the efficient management of piggery buildings, as they have a significant effect on production efficiency, health and welfare of confined animals. The aim of the present study was to evaluate the relationship between pig activity and environmental parameters in a pig building by means of image analysis. The barn for 350 fattening pigs was open-space, mechanically ventilated and subdivided into 16 pens with fully slatted floor. The room was equipped to monitor the ventilation rate, internal and external temperature and relative humidity every minute. For the experiments, two adjacent pens were selected, each 5.9 by 2.6 m, with ~16 pigs in each. Pigs were continuously monitored during 30 days using an infrared-sensitive CCD camera that was mounted 5 m above the floor. Recorded data were processed in real time by Eyenamic, an innovative software that continuously and automatically registers the behaviour of a group of animals, intended as the activity and occupation indices of the pigs. A preliminary virtual subdivision of the two pens in four zones (two zones for each pen) was performed to evaluate differences in activity/occupation indices in ‘front’ and ‘back’ zones of the pen. Recorded images were visually observed in the laboratory to estimate pig activity type in relation to the indices calculated by Eyenamic software. The occupation index showed higher values (up to 0.75 units) in Zones 1 and 4 placed near the corridor. There was a significant relation between pig occupation index measured in the two pens and ventilation rate, temperature and humidity. The interaction between ventilation and humidity and temperature and humidity significantly affected pig movements during the day. Pigs tended to stay in the part of the pen far from the external wall, where air velocity was higher, probably because this is a ‘central zone’

in the barn, characterised by a reasonable air movement (~0.30 m/s). On the contrary, the part of the pen nearest to the external wall, characterised by a humid floor surface and by a limited air speed, was occupied by animals at the trough mainly during feeding times and for defecation and urination.

Keywords: *activity index, environmental parameters, image analysis, occupation index, on-line monitoring.*

3.3.1 Introduction

In the past, livestock management decisions have been based almost entirely on the visual observation, being the judgment and the experience of the farmer (Frost et al. 2003). However, together with the increasing scale of the farms and the corresponding high number of animals, this evolution has resulted in an increasing administrative, technical, organisational and logistic workload for the farmer and has limited the possibilities of the same farmer to monitor his animals by himself. Environmental parameters provide crucial information for the efficient management of pig farms. It is well known that confined pigs are highly sensitive to environmental conditions in the barn, which has a significant effect on their production efficiency, health and welfare (Jones et al. 1996; Lee et al. 2005: Banhazi et al.2009).

In wild pigs, the daily activity pattern is highly variable and depends to a large degree on hunting pressure, whereas in domestic animals, in particular in large-scale swine husbandry, animal behaviour is strictly determined by the enclosed rearing situation.

Free-living wild pigs tend to be more nocturnal in their activity rhythms, with hunting and colder temperature occurring during the night; in fact, animals tend to be passive during periods of strong heat (Graves 1984; Sekhar 1998). In a study on outdoor-reared domestic pigs in Sweden, animals were mostly active during some hours in the morning and the late afternoon–early evening, with resting periods in the middle of the day and during nights (Wood-Gush et al. 1990). Since pigs – wild and domestic alike – have very limited sweating and panting abilities, they use to wallow for cooling in hot weather (Baldwin and Ingram 1967; Huynh et al. 2007).

So the activity could be a sensitive indicator of the physiological status of the animals, status that is determined by a wide number of variables, including the structure and the microclimate of the building for indoor farming, since the repartition of the pigs into pen reflects the thermoregulatory status of the animals (Shao et al. 1997).

In intensive pig production, the main objective is to keep the animals in their comfort zone, because within this temperature range, the potential growth will be maximal, while under extensive conditions, pigs may compensate for sudden variations in the climatic environment by altering their feed intake, their behaviour, the physical activity and by seeking protection (Pedersen and Christensen 1977, Sällvik and Walberg 1984).

Xin (1999) observed that pigs showed huddling when cold, spreading when hot, and nearly touching one another on the side when the temperature is comfortable.

Another important variable affecting animal performance is relative humidity; at elevated temperatures, it can reduce animal heat dissipation, while low relative humidity can lead to high dust levels and subsequent respiratory disorders (Guo et al. 2001, MWPS 1983). Bockisch et al. (1999) recommended a relative humidity of 60–80% for sows, 50–70% for sows with piglets, 50–80% for piglet rearing and 50–70% for fattening pigs.

According to environmental conditions, pigs can vary their activity and their occupation time on the floor; these indications have been routinely used by farmer to assess thermal comfort of the animals and to make adjustments on the environmental settings or management schemes. Considering pig occupation time and activity is the most effective way to determine and ensure their comfort, but the increase in the farm scale and the number of reared animals has resulted in an increase in the workload for the farmer who cannot anymore monitor animals by himself. Besides, although the evaluation of animal comfort related to thermal parameters can be performed by the farmer, this judgment will be different from one person to another (Xin 1999). Interesting studies based on optical flow detection have been recently carried out on pigs by several researchers (Shao and Xin 2008; Zhu et al. 2009; Kashiha et al. 2013a), as well as on other species (Bloemen et al. 1997; Cangar et al. 2008, Kashiha et al. 2013b).

The aim of the present trial was to test an automatic method for pig behaviour detection in a field situation and to estimate the association occurring between pig activity and the ventilation rate, temperature and relative humidity in the barn.

3.3.2 Materials and methods

Description of the monitored buildings and animals

The study was conducted in a swine-fattening room located in northern Italy. The open-spaced barn housed 350 finishing pigs, it was 14 m wide × 21.2 m long, mechanically ventilated and subdivided into 16 pens, each 5.9 m wide × 2.6 m long, and with a fully slatted floor. The pens were delimited by a concrete wall 1 m high and 0.2 m thick (Fig. 1). The wall of the entrance door and the opposite one had four windows to light the building. Windows had a surface area of 1.32 m2 (0.6 m heigth × 2.2 m width) and were located 2 m above the floor.

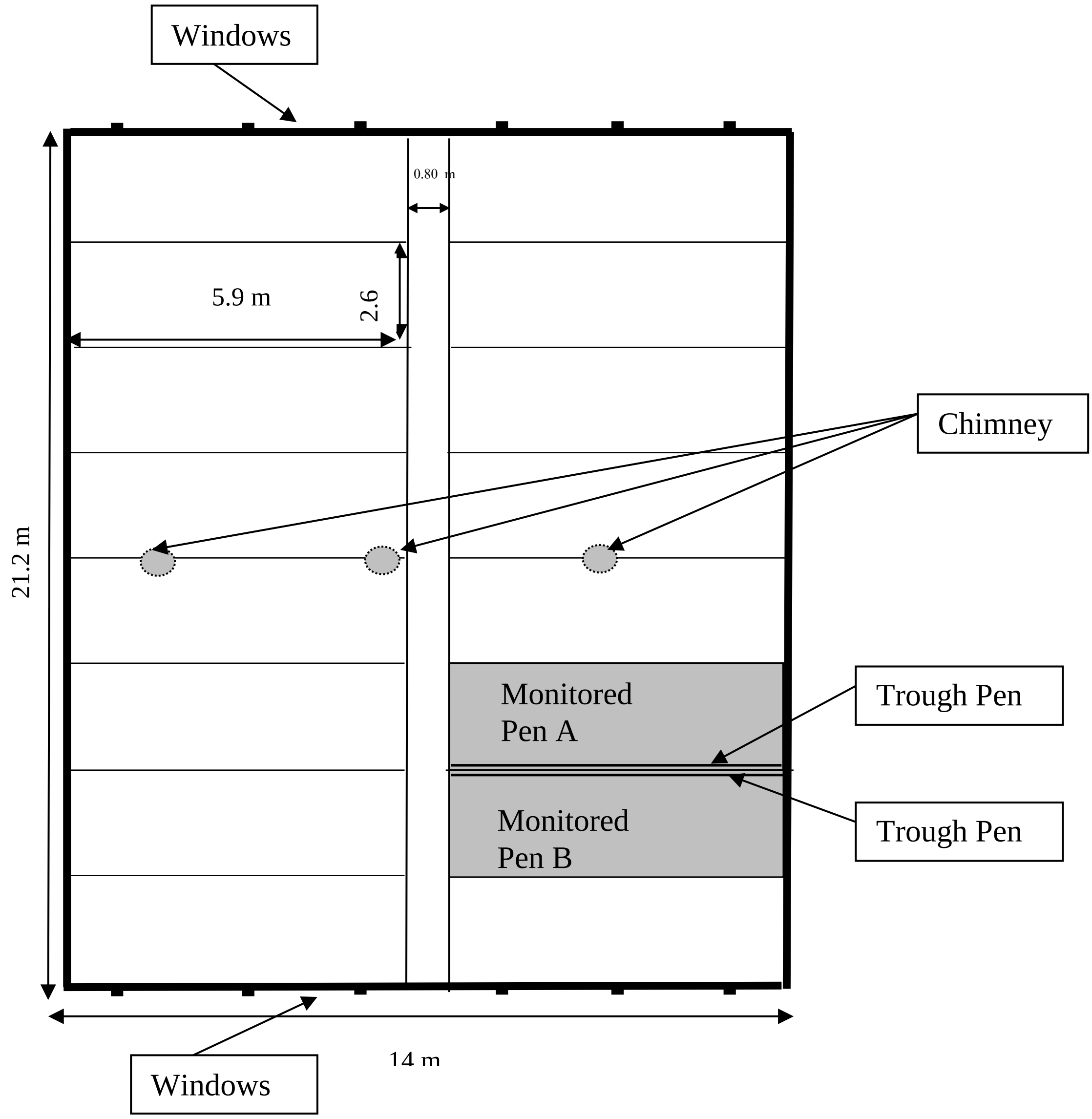

FIGURE 1: *Top view of the pigs barn.*

From the 16 pens in the barn, two pens were selected for the experiments (not in the corner, and not directly under the ventilation chimneys), with one pen containing 16 pigs, the other 17. At the start of the finishing stage, the mean (± s.d.) weight of the pigs was 60 kg (±6.64) and their mean age 150 days (±1.77).

Each pen was virtually subdivided in two zones, which were considered as the experimental unit of the study (see Fig. 3), one being in front of the corridor and the other near the external wall (a ‘ back zone’) since, as found by Olsen etal (2001), Lemay et al. (2002), Aarnink et al. (1996), pigs tend to divide the pen in a dunging area usually a ‘back zone’) and a clean area (a ‘front’ zone) for lying. Animals were fed three times a day, at 0830, at 1530 hours and at 1900 hours. The troughs were placed on the longitudinal wall dividing the two pens; the drinking bowls were located at the corner of each pen. Lights were switched on 15 min before feed administration and the lighting schedule was of 40 min per every feeding release time.

Environmental-variable measurements

The piggery had a ventilation control system (FANCOM) based on a free-running impellers (FANCOM EasyFlow, Panningen, The Netherlands), differing in diameter for each room, for continuous, real-time monitoring of the ventilation rate. The air exhausts were equipped with a calibrated ventilation-rate sensor that had a measurement error of ±45 m3/h (Berckmans et al. 1991).

The ventilation control system of rooms was equipped to monitor and sample ventilation rate every minute. The inside and outside air temperature and relative humidity of the room were also collected every minute by the Fancom FMS system and stored on the central computer of the farm. The inside and outside temperature and relative humidity were measured by sensors placed in the room at a height of 150 cm.

The maximum ventilation rate was 16 352 m3/h for the first and 16 207 m3/h for the other two chimneys. Air speed at animal height was measured in the four zones using a hot-wire anemometer (BSV 105, LSI, Settala, Milano, Italy). The air speed was measured in the middle of each zone every 2 h, since air movements can affect the thermoregulatory status of pigs according to Verstegen and van der Hel (1974) who calculated that each 0.30 m/s increase in air movement was, in its thermal effects, equivalent to an increase of 1°C for groups of pigs.

Images recording

Pig activity was videotaped for 24 h a day during the whole fattening cycle from April to June, using an infrared sensitive CCD camera (Sanyo VCB-3572IRP, Moriguchi, JAPAN) connected to a PC with a built-in frame grabber (Data Translations DT-3210) using a coaxial cable.

During this period, the system was running in real-time and video images from the camera were recorded simultaneously and stored in the hard disk of the PC.

The camera was placed 5 m above the floor with its lens pointing downward, and directly above the wall separating the two pens to get a top view of two pens of this area in the camera image (Fig. 2). Images were captured with a resolution of 768 × 586 pixels and a frame rate of one frame per second.

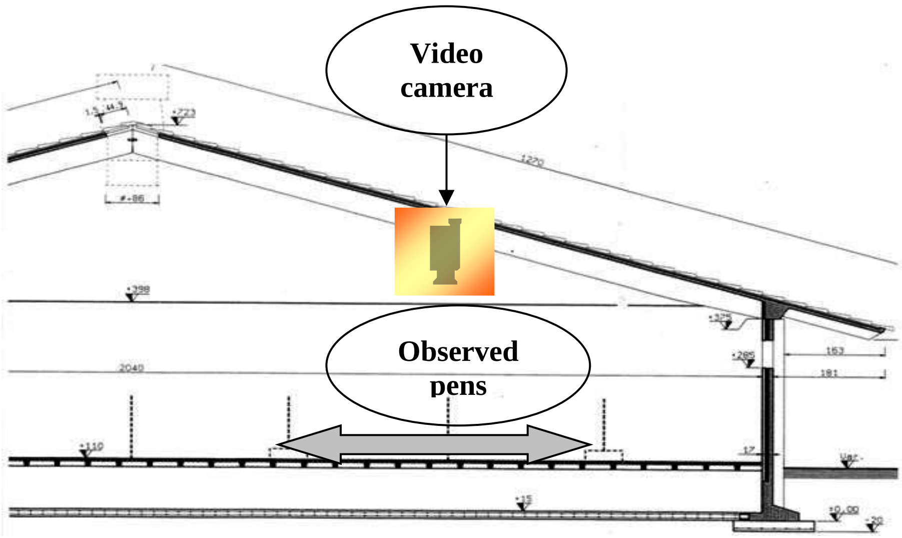

FIGURE 2: *Position of the camera in the piggery*

Animal-activity monitoring system and definition of activity and occupation indices

The monitoring phase was performed for 1 month, 24 h a day, observing each frame (1 frame per second). During this period, the Eyenamic system was running in real-time and video images from the camera were recorded simultaneously.

Prior to the experiment, the image was calibrated to establish a linear-scale factor in cm/pixel so that the area of pixels in the image could be converted to units of cm2 on the pen floor. The linear factor (F = 1.7 cm/pixel), which gives a rough estimation of distance, was calculated by determining the distance in pixels between the two calibration points defined by the size of the pen (5.9 m × 2.6 m). As a consequence, one pixel corresponds to f2 = 2.9 cm2 on the peen floor.

Before the analysis, the area of each pen in the camera image was further subdivided into two equally sized areas called zones; Fig. 3 shows the experimental setup and the subdivision of the two pens into two zones (Pen 1 – Zones 1 and 2 – with 16 animals; and the Pen 2 – Zones 3 and 4 – with 17 animals).

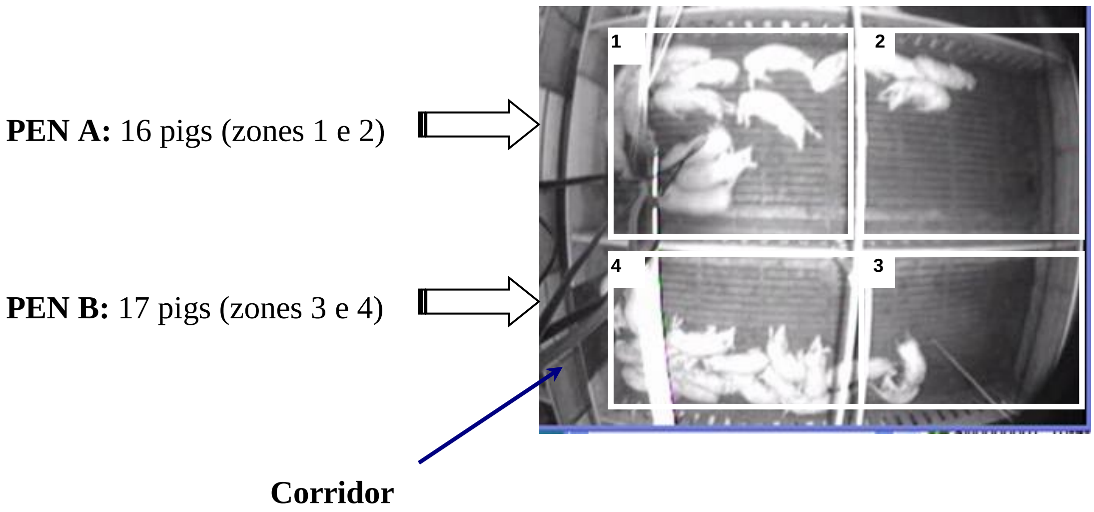

FIGURE 3: *The four zones in the two pens.*

These four zones (two for each pen) each corresponded to a rectangular region Z_i in the image, with i = 1, 2, 3, 4, within which activity was measured and behaviour was labelled.

Every second, the software automatically grabbed a monochrome image $I(x, y, t)$ from the camera and calculated the difference between the pixel intensity value of the image and that of the previous image $I(x, y, t-1)$, taken a second earlier. From this difference, the binary 'activity image' $I_a(x, y, t)$ was calculated by setting all pixels between thresholds to 1, and the other to zero, as follows:

$$Ia(x, y, t) = \begin{cases} 1, \ \tau_2 > I(x, y, t) > \tau_1 \\ 0, \text{otherwise} \end{cases}. \ (1)$$

The threshold τ1 accounted for small intensity changes due to noise, e.g. electrical noise in the coaxial cable and image-acquisition circuits, and small lighting variations. The value of the threshold was set at 10% of the maximal intensity value, estimated by looking at the intensity variation of an 'empty' region, outside of the pig pen in the first 60 images, equivalent to 1 min of recording.

An additional upper threshold τ_2 was applied to the activity index $a_i(t)$ to compensate for drastic intensity changes (e.g. when lights were switched on/off). In the case of such an event, almost all pixels in the activity image I_a were 'active' and the activity index $a_i(t)$ was almost equal to 1 in all areas. The threshold τ_2 was set to 0.5 of the maximal activity index. If this threshold was exceeded, i.e. more than half of the zone area was active, the activity index was set to zero.

From the activity image $I_a(x, y, t)$, the activity index $a_i(t)$ for area Z_i was calculated as the fraction of moving pixels with respect to the total number of pixels within the area $\underline{Z}_i$, as follows:

$$a_i(t) = \frac{\sum_{(x,y)\epsilon Zi} Ia(x,y,t)}{\text{Number of pixel of } Zi}. \ (2)$$

The pixel area totals in the nominator and denominator of Eqn 2 have an accuracy of one pixel, which, using the camera calibration factor, was equivalent to an area of 2.9 cm2.

From the monochrome camera image *I(x, y, t)*, a binary ‘occupation image’ $I_0(x, y, t)$ was calculated by segmenting the pigs from the background by defining a specific threshold τo, as follows:

$$\mathbf{I}_o(x,y,t) = \begin{cases} 1 & \text{if } \mathbf{I}(x,y,t) > \tau_o(t) \\ 0 & \text{otherwise} \end{cases} \quad . (3)$$

The threshold $\tau_o(t)$ was used to separate image pixels that corresponded to pigs from pixels that corresponded to the image background (e.g. floor, walls), based on the image intensity in that pixel. Because an infrared-sensitive camera was used, pigs appeared brighter than the background in the camera image. Therefore, pixels with an intensity above the threshold were classified as pigs using Eqn 3.

Because the intensity values in the image were time dependent, changing between day and night periods, the optimal threshold τo(t) separating pigs from the background was calculated from the intensity histogram of the image, with the algorithm described by Otsu (1979).

From the occupation image $\boldsymbol{I}_o(x, y, t)$ the occupation index $o_i(t)$ for zone Z_i was calculated as the fraction of pixels corresponding to a region of the image occupied by pigs, with respect to the total number of pixels within the zone Z_i, as follows:

$$o_i(t) = \frac{\sum_{(x,y)\epsilon Zi} Io(x,y,t)}{\text{Number of pixel of Zi}}. (4)$$

<u>Visual observations of recorded movies</u>

The recorded videos were also observed in laboratory, as a support to estimating pig activity type in relation to the indices calculated by Eyenamic software.

Statistical analyses

As mentioned previously, the activity index was calculated by Eyenamic as the fraction of moving pixels with respect to the total number of pixels within a certain area, while the occupation index was calculated as the fraction of pixels corresponding to a region of the image occupied by pigs with respect to the total number of pixels within the same zone.

The collected data in the 3-month trial were submitted to variance analysis (PROC GLM for repeated statements, SAS statistical package 8.2, 2011, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414, USA) to evaluate the effects of environmental parameters (temperature, relative humidity and ventilation rate) on the activity and occupation indices of pigs in the four zones calculated by Eyenamic software, using the following model:

$y_{injk} = \mu + O_i + D_n + A_k + T_l + RH_m + VR_j + e_{injk}$,

where y = independent variable of activity index/occupation index, µ = overall mean, O_i = effect of ith observation time (i = 1, ...), D_n = effect of the day of sampling (n = 1, … 30), A_k = effect of the kth zone – subarea of the pen (k = 1,.4), T_l = effect of lth temperature value (i = 1, …), RH_m = effect of mth relative humidity value (i = 1, …), VR_j = effect of jth ventilation value (i = 1, …), $(VR \times T)_{jl}$ = effect of the interaction between ventilation rate and temperature, $(T \times RH)_{lm}$ = effect of the interaction temperature and relative humidity, and e_{inklmj} = residual error of each observation.

Moreover, a correlation procedure was performed (Proc CORR, SAS statistical package 8.2, 2012) to better highlight the relationship between climatic conditions and the activity/occupation indices, keeping the hourly differences of climatic parameters occurring in the four zones.

3.3.3 Results

Activity and occupation

Table 1 reports the mean occupation indeces calculated by Eyenamic during the 1-month trial. The index was higher in Zones 1 (Pen 1) and 4 (Pen 2), which were both placed near the corridor (0.532 and 0.584 units, respectively, $P < 0.001$). Zones 2 and 3, near the external wall, characterised by a humid floor surface and limited air flow, were essentially utilised by animals as defecation zones and showed lower occupation indices by animals, as expected.

The mean hourly occupation index (Fig. 5) showed higher values (up to 0.75 units) in Zones 1 (Pen 1) and 4 (Pen 2), which were near the corridor. During the night, the activity index was very low for all zones, smaller than 0.005 units. During the observation time, the pig activity followed a diurnal rhythm, with peaks occurring with the management routine procedures (Figs 4, 5); when pigs perceived pipe vibrations caused by circulating feed, they moved to the trough distributing themselves in a homogeneous way across all the zones. At the end of the feeding time, most of the pigs moved to Zones 1 and 4, near the corridor. Consequently, the occupation indices increased in these two zones (Zones 1 and 4), since pigs tended to use these as ‘resting places’.

Also in other times of the day, namely, at 1200 hours and at 1800 hours, pigs increased their activity, after a release of extra water in the trough, being procedure that induced the vibration of pipes, as at the feeding time.

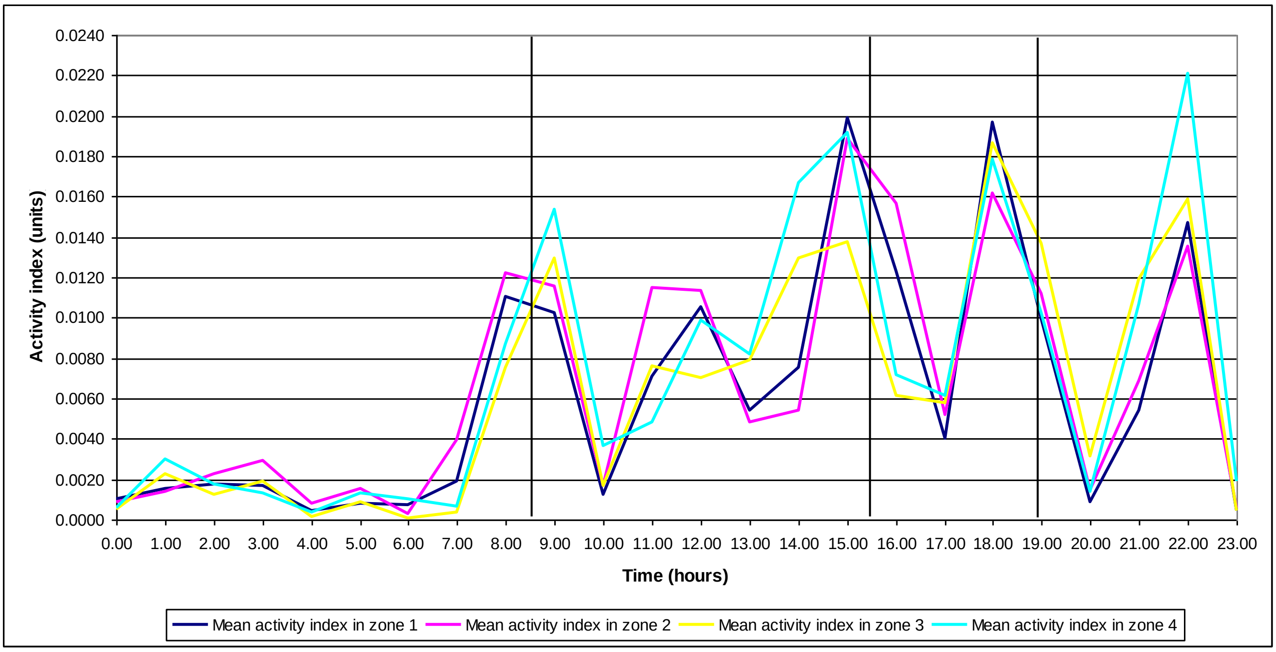

FIGURE 4: *Hourly mean activity index in the four zones.*

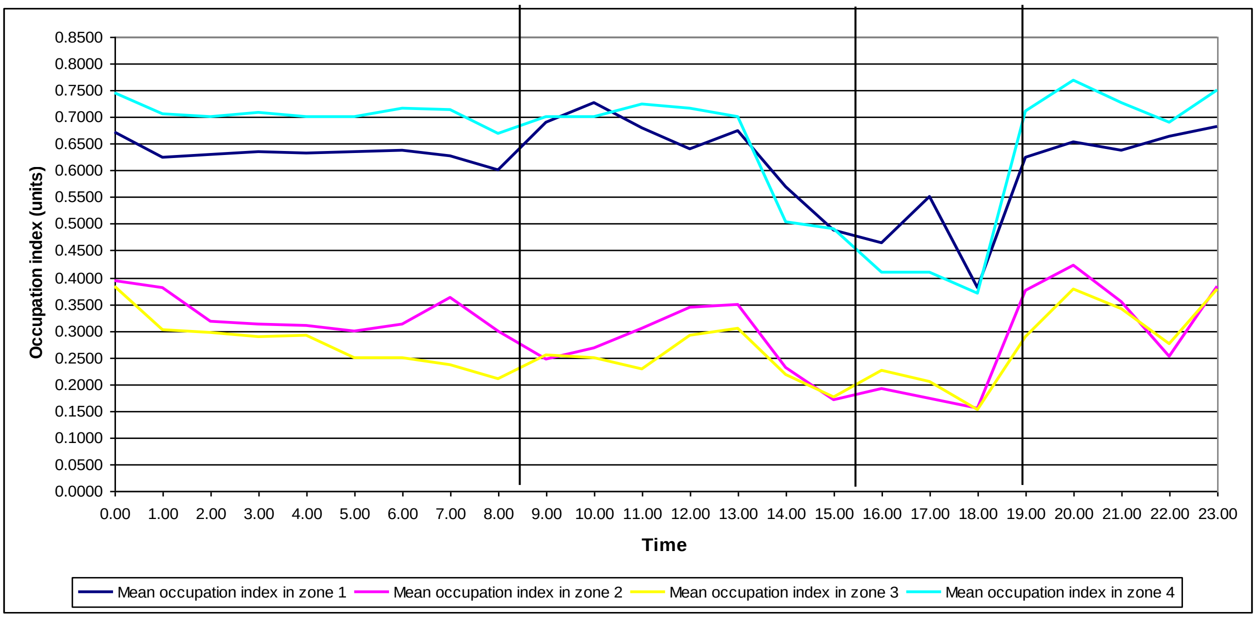

FIGURE 5*: Hourly mean occupation index in the four zones.*

Pig occupation index in relation to environmental conditions in the barn

The mean values of the two indices (pig activity and occupation) and the mean values of temperature, ventilation and relative humidity are reported in Tables 1 and 2.

TABLE 1: *Activity and occupation index (least square means) calculated by Eyenamic on observed pigs during the experimental period*

Area	Activity index (units ± s.e.m.)	Occupation index (units ± s.e.m.)
1	0.0162 ± 0.0029Aa	0.585 ± 0.062Aa
2	0.0111 ± 0.0034B	0.221 ± 0.055B
3	0.0124 ± 0.0040Cb	0.189 ± 0.061Cb
4	0.0185 ± 0.0024D	0.532 ± 0.058D

Values in the same column followed by the same upper-case letter are not significantly different at P = 0.001, and those followed by the same lower-case letter are not significantly different at P = 0.01

TABLE 2: *Effects of environmental condition on pig occupation and activity indices*

Item	Occupation index		Activity index	
	Mean value	*P*	Mean value	*P*
Ventilation rate (m^3/h)[A]	10234 ± 921	<0.01	10234 ± 921	n.s.
Ventilation rate (m^3/h)[B]	10371 ± 1028		10371 ± 1028	
Inside temperature (°C)[A]	23.8 ± 0.2	<0.01	23.8 ± 0.2	n.s.
Inside temperature (°C)[B]	21.38 ± 2.48		21.38 ± 2.48	
Inside relative humidity (%)[A]	69.0 ± 4.7	<0.001	69.0 ± 4.7	<0.001
Inside relative humidity (%)[B]	61 ± 6.45		61 ± 6.45	
Air speed (m/s), Pen 1–4		0.5 <0.01		
Air speed (m/s), Pen 2–3		0.3 <0.001		
Interaction				
Ventilation rate × temperature		n.s.		n.s.
Ventilation rate × relative humidity		<0.001		<0.001
Temperature × relative humidity		<0.001		n.s.
Ventilation rate × humidity × temperature		n.s.		n.s.

[A]*Mean values related to the 1-month trial (24 h a day) conducted through Eyenamic observation.*

[B]*Overall mean values for the fattening period (April–June).*

Hourly mean temperature, relative humidity and ventilation rate, measured in parallel with images recording procedure, are shown in Figs 6 and 7.

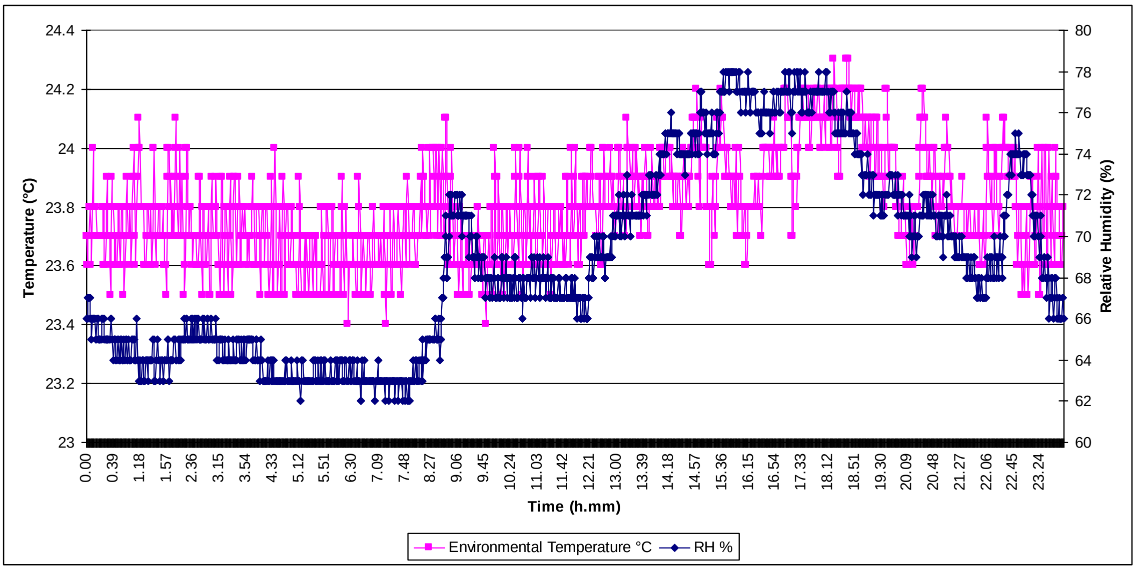

FIGURE 6: *Hourly mean temperature and relative humidity in the pig room.*

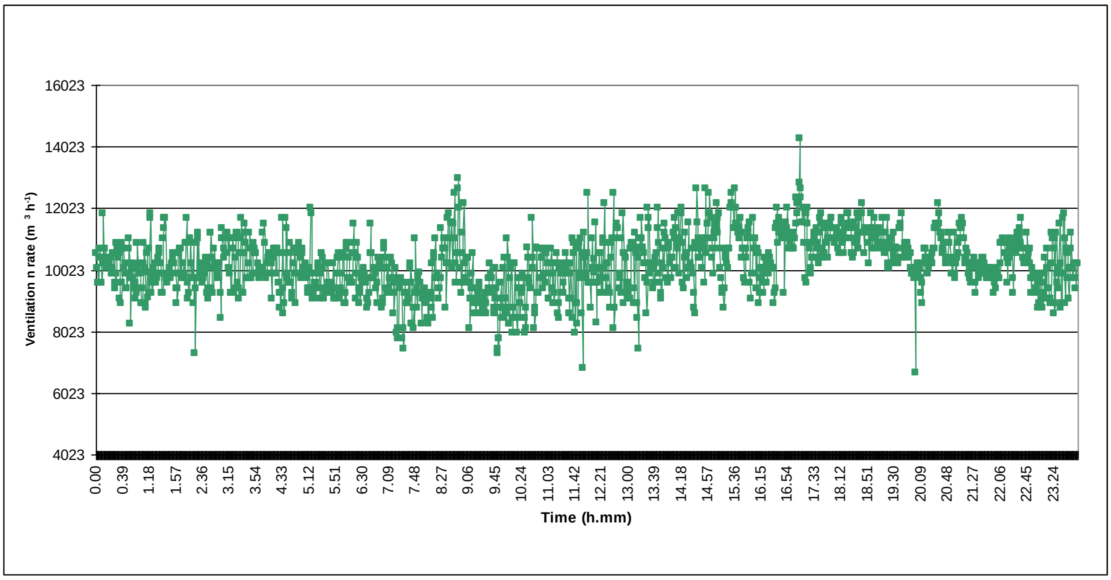

FIGURE 7: *Hourly mean ventilation rate in the pig room*

Over the recording period, mean values of internal temperature, relative humidity and ventilation rate were 23.8°C, 69% and 10234 m3/h, respectively, as would be required for animals of that size. As shown in Table 1, environmental conditions on the experimental day were similar to those registered during the whole fattening period from April to June. Mean air speed at animal height was 0.5 m/s in Zones 1 and 4, and 0.3 m/s in Zones 2 and 3.

Data analysis revealed a significant relation between pig occupation index measured in the four zones and ventilation rate ($P < 0.01$), temperature ($P < 0.01$) and humidity ($P < 0.001$). Also the interaction between ventilation and humidity ($P < 0.001$) and temperature and humidity ($P < 0.001$; Table 1) significantly affected pig movements during the day; the decrease in animal occupation rate, corresponding to the animal huddling, took place after the ventilation-rate increase, followed by a decrease in temperature and humidity. This combination of environmental parameters could be explained as a 'disturbing' effect for pigs, who tended to huddle one another. On the contrary, with low ventilation rate (~7000 m3/h) and low air speed (<0.3 m/s), the animals lied in some contact with pen mates, spreading on the pen surface and increasing the occupation index; it was clear from the visual observations of images, that when the temperature increased, pigs tended to lie with their limbs extended, so the floor surface covered by them increased, as did the occupation index calculated by Eyenamic.

Pig activity index was significantly ($P < 0.001$) related to relative humidity and there was interaction between ventilation and humidity (Table1).

The correlation analysis highlighted a remarkable relation between the variation of temperature ($r = 55\%$, $P < 0.01$), relative humidity ($r = 68\%$ $P < 0.001$) and ventilation rate ($P < 0.01$). From Figs 4 and 6, it was noticeable that there was an increase in relative humidity, together with animal activity in the afternoon, ~1600 hours, probably because of the increase in animal respiration rate.

The occupation index was strongly related to air-speed change at animal level (r = –68%, P < 0.01) and to temperature variation (r = 72%, P < 0.001).

3.3.4 Discussion

Continuous monitoring of pigs performed through image processing techniques put in evidence a relationship between pig activity and the barn microclimate. This relationship could be explained by previous findings (Ekkel et al. 2003) that demonstrated that, at high temperatures, pigs lie down in a fully recumbent position, with their limbs extended, so as to be able to transfer as much heat as possible to the external environment, whereas at low environmental temperatures, pigs adopt a body posture that minimises their contact with the floor.

In our study, when pigs were given a reasonable amount of ventilation, they preferred to lie down and rest scarcely touching other pigs, avoiding a close contact with pen mates, whereas, with the increase of ventilation rate, the percentage of pigs lying in a huddling position was higher.

This is in agreement with Xin (1999), who observed that pigs usually show huddling when cold, spreading when hot, and nearly touching one another on the side when the temperature is comfortable. This can be clearly seen from the figures regarding occupation index and ventilation rate (Figs 5, 7) at 0830 hours and at 1400 hours, with these being periods of remarkable variation in ventilation rate; the occupation index decreased in all zones, corresponding to animals huddling one another, as also observed in the related videotaped frames. In particular, pigs preferred to lay in pen zones (1 and 4) near the corridor and near the chimney for the extraction of exhaust air.

The environmental temperature increased also when the liquid feeding was administered to animals, and consequently, there was a quick increase in pig activity; when there is higher respiration rate, the evaporative heat loss and relative humidity increase, resulting in an increase in pig occupation index and a decrease in activity index (Baldwin and Ingram 1967).

The variation in animal occupation index followed the increase or decrease of the ventilation rate, temperature, humidity and the interaction among these variables. As a consequence of low ventilation rates, high temperature or high relative humidity, the pigs tended to spread, and so, the occupation index increased.

The continuous online image analysis revealed that pigs preferred to stay and lay most of the day in ‘front’ zones, near the corridor. These zones are characterised by a discrete air velocity (0.5 m/s), while the ‘back’ zones in the pen, near the external wall, have a lower air speed (0.3 m/s), and were chosen by pigs as a defecation and urination zone, according to Lemay et al.(2002), except for the feeding times, when pigs tended to distribute at the trough.

Also, relative humidity seemed to affect pig occupation and activity indices ($P < 0.001$); a possible explanation for a relationship between pig occupation and activity indices and relative humidity has been provided by previous studies that demonstrated that when the temperature increases, sensible heat loss (radiation, convection, conduction) decreases quickly (Huynh et al. 2005). So the evaporative heat loss through panting is the best way for pigs to eliminate heat load; in that way, the relative humidity tends to increase.

The pig is more adapted to live in humid conditions than in a dry atmosphere. In fact, a dry environment can be a cause of irritability (Smith and Penny 1986) and humid or frequently wet skin is fundamental for thermoregulation. When relative humidity is very high, the pigs become more dependent on water loss from skin, even though the respiration rate increases. This leads to the necessity to wallow or to lie on a wetted floor (Huynh et al. 2007).

So the occupation and the activity indices could be sensitive indicators of the physiological status of the animals, in continuous dynamic response to external inputs, such as variations in temperature, relative humidity and air movement.

In conclusion, pig occupation and activity indices were influenced by the microclimate of the barn, in particular by temperature, relative humidity and ventilation rate. The combination of ventilation rate–humidity and temperature–humidity affected animal activity and movements.

The present study showed that the sudden variation of ventilation rate, followed by a decrease in temperature and humidity, affected the occupation index, and acted as a ‘disturbing effect’ on animals.

Pigs tended to stay in the part of the pen far from the external wall and where air velocity was higher, probably because this is a ‘central zone’ in the barn, characterised by a certain air movement. On the contrary, the part of the pen nearest to the external wall, characterised by a humid floor surface and limited air speed, was occupied only during feeding times and for the defecation and urination.

This last consideration highlighted the importance of a correct planning and structure of the building and a good ventilation system to improve animal conditions in a livestock building.

With the increasing interest in animal welfare, this kind of optical real-time monitoring tool offers interesting possibilities in fully automatic control, for supporting the climatic controller and the management directed to improve animal health and welfare in modern large-scale farms

CHAPTER 4

GENERAL CONCLUSIONS

4. General Conclusions

The main element of the PLF system is the continuous monitoring of the animal itself as the most crucial element in the biological production process. The behaviour of animals is the most informative indicator of the farm status, reflecting animal responses to the change of their welfare, health or surrounding environment. Complex and continuously changing animal responses could be monitored through automated and real time measurements offered by PLF. The most crucial component of an effective PLF system is a precise real-time algorithm able to detect, quantify or even predict the target behaviour, considering that animals are individually different in their responses. During the process of the development of such an algorithm the input of the expertise in animal ethology and biology is indispensable. Understanding of biological mechanisms is a key element in comprehension of the message given by animal behaviour. This message should be interpreted by the algorithm and transferred to the farmer in a simple and comprehensive way, in this case transmission of excessive data is avoided and only necessary information is reported.

One of the most important contributions of the specialist with biological background in algorithm development is labelling, described in detail in Chapter 1. This thesis was particularly dedicated to the labelling and its importance in the process of the development of successful PLF system.

The objective of this thesis was application of image labelling technique to contribute to the development of an automatic PLF systems to monitor behaviours of pigs. Chapter 2 is devoted to the pigs aggression monitoring and control tool. The basic component of the system is an automatic monitor able to detect aggressive attacks automatically by dynamic analysis of the interactions between animals. The second component of the system is the utilisation of the combination of a trigger (i.e. sound, smell) and reward to redirect pigs from aggressive behaviour. To understand causes and pattern of execution of aggressive behaviour of weaned pigs in order to define the variables to be detected by the algorithm, post-mixing pigs behaviour was video recorded and analysed through labelling techniques. The pre-signs of aggression that could be used by the algorithm for predicting when the animal is entering in a particular status that leads to aggressive behaviour and particular patterns of aggressive interaction were determined. The created database and labelling reference allowed the development of an algorithm analysing motion features of fighting pig with a classification accuracy of 89%, a sensitivity of 88.7% and a specificity of 89.3%. This might be a first and very important step towards the development of a fully automated system that can detect aggressive interactions among pigs. Continuous, real time measurement of aggressive behaviour of pigs should in the first instance allow creating an objective and accurate information system that a farmer can use in order to reduce the aggression on his farm. In the second instance it should give a possibility to automatically lower the aggression level by activating the control component of the system. The control component aimed to reduce aggressive behaviours was designed basing on pigs ability to learn and motivation for food. Piglets were trained to associate a sound given by the electronic feeder with a feed reward (sweet) . Experiments showed that sound and sweet feed rewards are an effective combination for learning in piglets. Testing of this combination on the piglets after mixing showed that the method bears some potential to reduce the frequency and duration of aggressive actions when applied early, at the start of aggression.

In conclusion, it can be said that that invented approach has a potential to be a base for the development of a commercial product for monitoring and control of pigs aggression. However, more experiments need to be conducted to prove that aggression control effect is lasting over a longer time period and able to maintain continuous interest of the animals. Additionally, the improvement of an algorithm ability to detect aggressive behaviours at early stage would be an asset.

Chapter 3 described the possibilities of use of image analysis in automatic monitoring for supporting farm management directed to improve animal health and welfare of animals. Labelling of pigs behaviours allowed to assess the effectiveness of application of image analysis for monitoring of different behaviours and environmental parameters through pigs activity. The image analysis of animal activity proves to be a promising tool for monitoring of pigs behaviour.

The contribution of this thesis in the field of Precision Livestock Farming is an introduction of an innovative approach of using the intelligence of animals for the control of undesired behaviours and application of different labelling approaches with a goal of behaviour monitoring tools development.

Bibliography

Aarnink AJA, van den Berg AJ, Keen A, Hoeksma P, Verstegen MWA (1996) Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Research 64, 299–310. doi:10.1006/jaer.1996.0071

Aarnink AJA, Wagemans MJM (1997) Ammonia volatilization and dust concentration as affected by ventilation systems in houses for fattening pigs. Transactions of the ASAE 40 (4), 1161-1170.

Aerts J-M, Lippens M, De Groote G, Buyse J, Decuypere E, Vranken E, Berckmans D (2003a) Recursive prediction of broiler growth response to feed intake by using a time-variant parameter estimation method. Poultry Science 82, 40–49.

Aerts J-M, Van Buggenhout S, Lippens M, Buyse J, Decuypere E, Vranken E, Berckmans D (2003b). Active control of the growth trajectory of broiler chickens based on on-line animal responses. Poultry Science 82, 1853–1862.

Aerts J-M, Wathes CM and Berckmans D (2003c).Dynamic Data-based Modelling of Heat Production and Growth of Broiler Chickens: Development of an Integrated Management System. Biosystems Engineering, 84(3), 257-266.

Aerts J-M, Jans P, Halloy D, Gustin P, Berckmans, D (2005) Labeling of cough datafrom pigs for on-line disease monitoring by sound analysis, American Society of Agricultural Engineers, 48 (1) 351-354.

Andersen IL, Bøe KE, Foerevik G, Janczak AM, Bakken M (2000) Behavioural evaluation of methods for assessing fear responses in weaned pigs. Applied Animal Behaviour Science 69, 227–240. doi:10.1016/S0168-1591(00)00133-7

Angermeier WF (1994) Grundlagen des operanten Verhaltens. In 'Operantes lernen'. (Eds WF Angermeier, P Bednorz, SR Hursh) pp. 35–36. (Ernst Reinhard Verlag: München).

Arey DS (1993) The effect of bedding on the behaviour and welfare of pigs. Animal Welfare, 2, 235–246.

Arnfred SM, Lind NM, Moustgaard A, Hansen AK , Gjedde A (2003) Minipig negative slow wave demonstrates target/nontarget differences in P300 paradigm. Neuroimage 20, 587-590.

Baldwin BA and Ingram DL (1967) Behavioural thermoregulation in pigs. Physiology and Behavior 2, 15–21. doi:10.1016/0031-9384(67)90005-4

Banhazi TM, Currie E, Reed S, Lee IB, Aarnink AJA (2009) Controlling the concentrations of airborne pollutants in piggery building. In 'Sustainable animal production: the challenges and potential developments for professional farming'. (Eds A Aland, F Madec) pp. 285–311. (Wageningen Academic Publishers: Wageningen, The Netherlands.)

Barnett JL, Cronin GM, McCallum TH, Newman EA (1994) Effects of food and time of day on aggression when grouping unfamiliar adult pigs. Applied Animal Behaviour Science 39, 339-347.

Beattie VE, Walker N and Sneddon IA (1995) Effects of environmental enrichment on behaviour and productivity of growing pigs. Animal Welfare, 4, 207–220.

Beattie VE, Walker N and Sneddon A (1996) An investigation of the effect of environmental enrichment and space allowance on the behaviour and production of growing pigs. Applied Animal Behaviour Science, 48, 151–158.

Beattie VE, O'Connell NE, Kilpatrick DJ, Moss BW (2000) Influence of environmental enrichment on welfare-related behavioural and physiological parameters in growing pigs. Animal Science 70, 443–450.

Bench CJ and Gonyou HW (2006) Effect of environmental enrichment at two stages of development on belly nosing in piglets weaned at fourteen days. Journal of Animal Science, 84, 3397–3403.

Berckmans D (2003) Precision livestock farming research. Keynote lecture at the first European Conference on Precision Livestock Farming, Berlin, Germany, June 15-19.

Berckmans D (2004) Automatic on-line Monitoring of Animals by Precision Livestock Farming. In: Proceedings of International Society for Animal Hygiène -Saint-Malo- p 27-30.

Berckmans D (2013) Basic principles of PLF: gold standard, labelling and field data. In: Proceedings of Joint European Conference on Precision Livestock Farming -Leuven- p 21-29.

Berckmans D and Guarino M (2008) Guest editors for the Special Issue on Smart sensors in precision livestock farming. Computers and Electronics in Agriculture, 64(1), pp. 84.

Berckmans D, Vandenbroeck PH, Goedseels V (1991) Sensor for continuous ventilation rate measurement in livestock buildings – Integration in the control system. ASAE paper 91-N° 4031

.

Blackshaw JK (1981) Environmental-effects on lying behavior and use of trough space in weaned pigs .Applied Animal Ethology 7(3), 281-286.

Blackshaw JK, Thomas FJ and Lee JA (1997). The effect of a fixed or free toy on the growth rate and aggressive behaviour of weaned pigs and the influence of hierarchy on initial investigation of the toys. Applied Animal Behaviour Science, 53, 203–212.

Bloemen H, Berckmans D, Aerts JM, Goedseels V (1997) Image analysis to measure activity of animals. Equine Veterinary Journal. Supplement 23, 16–19.

Blokhuis HJ, Keeling LJ, Gavinelli A, Serratosa J (2008) Animal welfare's impact in the food chain. Trends in Food Science and Technology, 19 (1), S75-S83.

Blokhuis HJ, Veissier I, Miele M, Jones RB (2010) The Welfare Quality® project and beyond: safeguarding farm animal well-being. Acta Agriculturae Scandinavica A, Animal Science, 60, 129-140.

Bobick A and Davis J (1996) Real-time recognition of activity using temporal templates. Proceeding. Third IEEE Workshop on Applications of Computer Vision. WACV'96 (Cat. No.96TB100084).

Bockisch FJ, Jungbluth T, Rudovsky A (1999) Technical indicators for the evaluation of housing system for cattle, pigs and laying hens in relation to animal welfare aspects. Züchtungskunde 71, 38–63.

Bøe KE (1993) The effect of age at weaning and post-weaning environment on the behaviour of pigs. Acta Agriculturae Scandinavica Section A – Animal Science, 43, 173-180.

Bolhuis JE, Schouten WGP, Schrama JW., Wiegant VM (2005) Behavioural development of pigs with different coping characteristics in barren and substrate-enriched housing conditions. Applied Animal Behaviour Science, 93, 213–228.

Botreau R, Veissier I, Butterworth A, Bracke MBM, Keeling L (2007) Definition of criteria for overall assessment of animal welfare. Animal Welfare, 16, 225-228.

Botreau R, Veissier I, Perny P (2009) Overall assessment of animal welfare: strategy adopted in Welfare Quality. Animal Welfare, 18 (4), 363-370.

Bracke MB, Metz JH Spruijt BM, Schouten WG (2002) Decision support system for overall welfare assessment in pregnant sows b: Validation by expert opinion. Journal of Animal Science 80(7),1835-1845.

Bracke MBM, Zonderland JJ, Lenskens P, Schouten WGP, Vermeer H, Spoolder HAM, Hendriks HJM, Hopster H (2006) Formalised review of environmental enrichment for pigs in relation to political decision making .Applied Animal Behaviour Science, 98, 165–182.

Brehme U., Stollberg E, Holz R., Schleusener, T., (2004) Safer oestrus detection with sensor aided alt-pedometer. In :Abstracts of the Third International Workshop on Smart Sensors in Livestock Monitoring, Leuven, Belgium.

Broom DM (1983) Stereotypies as animal welfare indicators. In: Smidt, D (Ed), Indicators Relevant to Farm Animal Welfare

Broom DM (1986) Indicators of poor welfare. British Veterinary Journal 142, 524–526.

Broom DM (1991) Animal welfare: concepts and measurement. Journal of Animal Science, 69,4167-4175.

Broom DM (1998) Psychological indicators of stress and welfare in Ethics, Welfare, Law and Market Forces: the Veterinary Interface, ed by Michell AR and Ewbank R UFAW, Wheatampstead, UK, 167–175.

Broom DM (2010) Cognitive ability and awareness in domestic animals and decisions about obligations to animals. Applied Animal Behaviour Science 126, 1–11. doi:10.1016/j.applanim.2010.05.001

Cangar Ö, Leroy T, Guarino M, Vranken E, Fallon R, Lenehan J, Mee J, Berckmans D (2008) Automatic real-time monitoring of locomotion and posture behaviour of pregnant cows prior to calving using online image analysis. Computers and Electronics in Agriculture 64, 53–60. doi:10.1016/j.compag.2008.05.014

Campbell J, Crenshaw J , Polo J (2013) The biological stress of early weaned piglets. Journal of Animal Science and Biotechnology 4, 19.

Chedad A, Aerts JM, Vranken E, Lippens M, Zoons J, Berckmans, D (2003) Do heavy broiler chickens visit automatic weighing systems less than lighter birds?. British Poultry Science, 44(5), 663–668.

Christison GI (1996) Dim light does not reduce fighting or wounding of newly mixed pigs at weaning. Canadian Journal of Animal Science 76, 141–143. doi:10.4141/cjas96-019</jrn>

Costa A, Borgonovo F, Leroy T, Berckmans D, Guarino M (2009) Dust concentration variation in relation to animal activity in a pig barn. Biosystems Engineering 104(1),118-124.

Coutellier L, Arnould C, Boissy A, Orgeur P, Prunier A, Veissier I Meunier-Salaün M-C (2007) Pig's responses to repeated social regrouping and relocation during the growing-finishing period. Applied Animal Behaviour Science 105, 102-114.

Csermely D, Wood-Gush DGM (1990) Agonistic behaviour in grouped sows. II. How social rank affects feeding and drinking behaviour. Bollettino di Zoologia 57, 55–58.

Cumby TR. and Phillips VR (2001) “Environmental impacts of livestock production”, in Integrated Management Systems for Livestock, Wathes, C. M., Frost, A. R., Gordon, F. & Wood, J. D. (editor), Selwyn College, Cambridge, UK, BSAS, Edinburgh, pp. 13-21.

Curtis SE and Stricklin WR (1991) The importance of animal cognition in agricultural animal production systems: an overview. Journal of Animal Science 69, 5001-5007.

Dalmau A, Velarde A, Scott K, Edwards S, Veissier I, Keeling L, Butterworth A (2009) Welfarequality® assessment protocol for pigs (sows and piglets, growing and finishing pigs). Lelystad, the Netherlands.

Dawkins M, Lee H, Waitt,C, and Roberts S(2009) Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait. Applied Animal Behaviour Science, 119(3-4), 203–209.

Day JEL, Spoolder HAM, Burfoot A, Chamberlain HL, Edwards SA (2002) The separate and interactive effects of handling and environmental enrichment on the behaviour and welfare of growing pigs. Applied Animal Behaviour Science, 75, 177–192.

De Jonge FH, Bokkers EAM, Schouten WGP, Helmond FA (1996) Rearing piglets in a poor environment: developmental aspects of social stress in pigs. Physiology and Behavior 60, 389-396.

De Wet L, Vranken E, Chedad A, Aerts J-M, Berckmans,D (2003) Computer-assisted image analysis to quantify daily growth rates of broiler chickens. British Poultry Science 44, 524–532.

Duncan IJH (1987) The welfare of farm animals: an ethological approach. Science Progress (Oxford), 7, 317-326

Durrell JL, Sneddon IA, Beattie VE (1997) Effects of enrichment and floor type on behaviour of cubicle housed sows. Animal Welfare 6, 297–308.

Dybkjær L (1992) The identification of behavioural indicators of ‘stress’ in early weaned piglets. Applied Animal Behaviour Science 35, 135-147.

EFSA (2007) Scientific report on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. Annex to the EFSA Journal 611, 1–13.

Ekkel ED, Vandoorn CEA, Hessing MJC, Tielen MJM (1995) The specific-stress-free housing system has positive effects on productivity, health, and welfare of pigs. Journal of Animal Science 73, 1544–1551

Ekkel ED, Spoolder HAM, Hulsegge I, Hopster H (2003) Lying characteristics as determinants for space requirements in pigs. Applied Animal Behaviour Science 80, 19–30. doi:10.1016/S0168-1591(02)00154-5

Erhard HW, Mendl M, Ashley DD (1997) Individual aggressiveness of pigs can be measured and used to reduce aggression after mixing. Applied Animal Behaviour Science 54, 137–151. doi:10.1016/S0168-1591(97)00068-3

Ernst K, Puppe B, Schön PC, Manteuffel G (2005) A complex automatic feeding system for pigs aimed to induce successful behavioural coping by cognitive adaptation. Applied Animal Behaviour Science 91, 205–218. doi:10.1016/j.applanim.2004.10.010

Ernst K, Tuchscherer M, Kanitz E, Puppe B, Manteuffel G (2006) Effects of attention and rewarded activity on immune parameters and wound healing in pigs. Physiology & Behavior 89, 448–456. doi:10.1016/j.physbeh.2006.07.001

EU Directive 2001/93/EC amending Directive 91/630/EEC laying down minimum standards for the protection of pigs.

European Commission (2004) Fact Sheet : New Perspectives for EU Rural Development. Office of Official Publications of the European Communities, Luxembourg, pp 16.

European Commission (2001) Commission Directive 2001/93/EC of 9 November 2001 amending Directive 91/630/EEC.

European Parliament, Science and Technology Options Assessment (STOA) (2009) Animal-based Welfare Monitoring Final Report IP/A/*STOA*/FWC2005-28/SC28/40. IP/A/*STOA*/2007-09 PE 417.479.

Ewbank R (1976) Social hierarchy in suckling and fattening pigs: A review. Livestock Production Science 3, 363-372.

Exadaktylos V, Silva M, Aerts J-M, Taylor CJ , Berckmans D (2008) Real-time recognition of sick pig cough sounds. Computers and Electronics in Agriculture 63(2), 207-214.

Exadaktylos V, Silva M and Berckmans D (2011) Real-time analysis of chicken embryo sounds to monitor different incubation stages. Computers and Electronics in Agriculture, 75(2), 321-326.

Faucitano L (2001) Causes of skin damage to pig carcasses. Canadian Journal of Animal Science 81(1), 39-45.

Feddes JJR, Fraser D (1994) Non-nutritive chewing by pigs, implications for tail biting and behavioural enrichment. Transactions of the ASAE, 37, 947–950.

Ferrari S, Silva M, Guarino M, Berckmans D (2008) Analysis of coughs sounds for diagnosis of respiratory infections in intensive pig farming. Transactions of the ASAE. Vol 51(3), 1051-1055.

Fletcher NH (2004) A simple frequency-scaling rule for animal communication. Journal of the Acoustical Society of America 115, 2334–2338.

Fraser AF and Broom DM (1990) Farm Animal Behaviour and Welfare. Sannders, New York.

Fraser D (2003) Assessing animal welfare at the farm and group level: the interplay of science and values. Animal Welfare 12, 433–443.

Fraser D, Phillips PA, Thompson BK, Tennessen T (1991) Effect of straw on the behaviour of growing pigs. Applied Animal Behaviour Science, 30, 307–318.

Freson L, Godrie S, Bos N, Jourquin J, Geers R (1998) Validation of an infra-red sensor for oestrus detection of individually housed sows. Computers and Electronics in Agriculture. 20(1), 21-29.

Frost AR, Schofield CP, Beaulah SA, Mottram TT, Lines JA,Wathes CM (1997) A review of livestock monitoring and the need for integrated systems. Computers and Electronics in Agriculture 17, 139-159.

Frost AR, Parsons DJ, Stacey KF, Robertson AP, Welch SK, Filmer D, Fothergill A (2003) Progress towards the development of an integrated management system for broiler chicken production. Computers and Electronics in Agriculture 39, 227–240. doi:10.1016/S0168-1699(03)00082-6

Gade PB (2002) Welfare of animal production in intensive and organic systems with special reference to Danish organic pig production. Meat Science 62, 353–358.

Gieling ET, Park SY, Nordquist RE, Van der Staay FJ (2012) Cognitive performance of low- and normal-birth-weight piglets in a spatial hole-board discrimination task. Pediatric Research 71, 71-76.

Gonyou HW, Rohde Parfet KA, Anderson DB, Olsson RD (1988) Effects of Amperozide and Azaperone on aggression and productivity of growing-finishing pigs. Journal of Animal Science 66, 2856–2864.

Grandin T (1988) Environmental enrichment for confinement pigs Livestock Handling Committee Proceedings of the 1988 Annual Meeting, Kansas City, Missouri.

Grandin T (1989) Effect of rearing environment and environmental enrichment on behaviour and neural development in young pigs. Dissertation University of Illinois, Urbana-Campaign, IL.

Graves HB (1984) Behaviour and ecology of wild and feral swine (Sus scrofa). Journal of Animal Science 58, 482–492.

Guarino M, Costa A, Van Hirtum A, Jans P, Ghesquiere K, Aerts J- M, Berckmans D (2004) Field tests of an algorithm to predict infected pig coughing. Annals of Animal Science Suppl,1, 61-65.

Guo H, Lemay SP, Barber EM, Crowe TG, Chénard L (2001). Humidity control for swine buildings in cold climate. Part II: development and evaluation of a humidity controller. Canadian Biosystems Engineer 43, 5.37–5.46.

Hagl C, Weisz DJ, Khaladj N, Griepp MM, Spielvogel D, Yang B-Y, de Asla RA, Bodian CA , Griepp RB (2005) Use of a Maze to Detect Cognitive Dysfunction in a Porcine Model of Hypothermic Circulatory Arrest. The Annals of Thoracic Surgery 79, 1307-1314.

Halachmi I, Metz JHM, Van't Land A, Halachmi S, Kleijnen JPC (2002) Case study, Optimal facility allocation in a robotic milking barn Transactions of the ASAE, 45 (5), 1539-1546.

Hammell DL, Kratzer DD and Bramble WJ (1975) Avoidance and Maze Learning in Pigs. Journal of Animal Science 40, 573-579.

Held S, Baumgartner J, Kilbride A, Byrne RW, Mendl M (2005) Foraging behaviour in domestic pigs (Sus scrofa): remembering and prioritizing food sites of different value. Animal Cognition 8, 114–121. doi:10.1007/s10071-004-0242-y

Hosmer DW, Lemeshow S (1989) 'Applied logistic regression.' (John Wiley & Sons, Inc.: New York)

Hötzel MJ, Pinheiro Machado F° LC, Wolf FM and Costa OAD (2004) Behaviour of sows and piglets reared in intensive outdoor or indoor systems. Applied Animal Behaviour Science 86, 27-39.

Hoy JB, Koehler PG, Patterson RS (1996) A microcomputer-based system for real-time analysis of animal movement. Journal Neuroscience Methods 64, 157–161.

Huntingford FA, Turner AK (1987) 'Animal conflict.' (Chapman and Hall: London) 448 pp.

Huynh TTT, Aarnink AJA, Verstegen MWA, Gerrits WJJ, Heetkamp MJW, Kemp B, Canh TT (2005) Effects of increasing temperatures on physiological changes in pigs at different relative humidities. American Society of Animal Science 83, 1385–1396.

Huynh TTT, Aarnink AJA, Heetkamp MJW, Verstegen MWA, Kemp B (2007) Evaporative heat loss from group-housed growing pigs at high ambient temperatures. Journal of Thermal Biology 32, 293–299. doi:10.1016/j.jtherbio.2007.03.001

Jansen J, Bolhuis JE, Schouten WG, Spruijt BM, Wiegant VM (2009) Spatial learning in pigs: effects of environmental enrichment and individual characteristics on behaviour and performance. Animal Cognition 12, 303–315. doi:10.1007/s10071-008-0191-y

Jones JB, Burgess LR, Webster AJF, Wathes CM (1996) Behavioural responses of pigs to atmospheric ammonia in a chronic choice test. Animal Science 63, 437–445. doi:10.1017/S1357729800015332

Jones JB, Wathes CM, White RP, Jones RB (2000) Do pigs find a familiar odorant attractive in novel surroundings?. Applied Animal Behaviour Science, 70, 115-126.

Kashiha M, Bahr C, Amirpour Haredasht S, Ott S, Moons CPH, Niewold TA, Ödberg FO, Berckmans D (2013a) The automatic monitoring of pigs water use by cameras. Computers and Electronics in Agriculture 90, 164–169. doi:10.1016/j.compag.2012.09.015

Kashiha M, Pluk A, Bahr C, Vranken E, Berckmans D (2013b) Development of an early warning system for a broiler house using computer vision. Biosystems Engineering 116, 36–45. doi:10.1016/j.biosystemseng.2013.06.004

Kashiha M, Bahr C, Ott S, Moons CPH, Niewold TA, Ödberg FO, Berckmans D (2013c). Automatic identification of marked pigs in a pen using image pattern recognition. Computers and Electronics in Agriculture 93, 111-120.

Kelly HRC, Bruce JM, English PR, Fowler VR, Edwards SA (2000) Behaviour of 3-week weaned pigs in Straw-Flow, deep straw and flat-deck housing systems. Applied Animal Behaviour Science, 68, 269‑280.

Kleinbaum DG, Kuper LL, Morgenstern H (1982) 'Epidemiologic research, principles and quantitative methods.' (Van Nostrand Reinhold Company Inc.: New York), 314 pp.

Kohler SD and Kaufmann O (2003) Quarter-related measurements of milking and milk parameters in an AMS-herd. Milk Science International, 58, 3–6.

Kongsted AG (2004) Stress and fear as possible mediators of reproduction problems in group housed sows: A review. Acta Agriculturae Scandinavica, Section A – Animal Science 54(2), 58-66.

Kornum BR and Knudsen GM (2011) Cognitive testing of pigs (Sus scrofa) in translational biobehavioral research. Neuroscience & Biobehavioral Reviews 35, 437-451.

Kuipers M and Whatson, TS, (1979) Sleep In Piglets - Observational Study. Applied Animal Ethology 5 (2), 145-151.

Ladewig J (1991) Development of the concept of stress and its application to farm animal behaviour research. In: Appleby, MC, Horrell, RI, Petherick, JC and Rutter, SM (Ed), Applied Animal Behaviour: Past, Present and Future Universities Federation for Animal Welfare, England, pp 114-117.

Lee C, Giles LR, Bryden WL, Downing JL, Owens PC, Kirby AC, Wynn PC (2005) Performance and endocrine responses of group housed weaner pigs exposed to the air quality of a commercial environment. Livestock Production Science 93, 255–262. doi:10.1016/j.livprodsci.2004.10.003

Lehner PN (1996) 'Handbook of ethological methods.' (Cambridge University Press: Cambridge).

Lemay SP, Welford EL, Zyla L, Gonyou HW, Chenard L, Godbout S, Barber E (2002) Pig urination behaviour related to ammonia emissions. Paper 02-507. In 'AIC 2002 meeting'. (CSAE/SCGR: Saskatoon, Saskatchewan, Canada).

Leroy T, Vranken E, Aerts J-M, Silva M, Struelens E, Sonck B, Berckmans D (2004) A real-time computer vision system for the quantification of animal behaviour and motor function. In: Proceedings of the Book of Abstracts of the Third International Workshop on Smart Sensors in Livestock

Leroy T, Vranken E, Van Brecht A, Struelens E, Sonck B, Berckmans D (2006) A computer vision method for on-line behavioural quantification if individually caged poultry. Transactions of the ASABE, 49, 795-802.

Leroy T, Borgonovo F, Costa A, Aerts J-M, Guarino M, Berckmans D (2008) Real-Time Measurement of Pig Activity in Practical Conditions. In: Proceedings of the

Eighth International Livestock Environment Symposium (ILES VIII), ASABE, Iguassu Falls, Brazil.

Lind NM, Vinther M, Hemmingsen RP, Hansen AK (2005) Validation of a digital video tracking system for recording pig locomotor behaviour. Journal of Neuroscience Methods 143, 123-132.

Lyons CAP, Bruce JM, Fowler VR (1995) A comparison of productivity and welfare of growing pigs in four intensive systems Livestock Production Science, 43, 265–274.

Madsen, TN, Andersen S and A. R. Kristensen (2005) Modelling the drinking patterns of young pigs using a state space model. Computers and Electronics in Agriculture.48(1), 39-62.

Marchant-Forde JN (2010) Social behaviour in swine and its impact on welfare. In ‘Proceedings of the 21st International pig veterinary society (IPVS) congress (Eds S D’Allaire, R Friendship), pp 36-39.

Martin E (1968) Stimulus meaningfulness and paired-associate transfer: an encoding variability hypothesis. Psychological Review 75, 421–441. doi:10.1037/h0026301

Martin E (1971) Stimulus component independence. Journal of Verbal Learning and Verbal Behavior 10, 715–721. doi:10.1016/S0022-5371(71)80080-4

Martin P and Bateson P (1986) Measuring behaviour. An introductory guide. Ed Cambridge University Press

McBride, G, James JW and Wyeth GSF (1965) Social behaviour of domestic animals .7. Variation in weaning weight in pigs. Animal Production , v7, 67-74.

McGlone JJ, Kelley KW, C. T. Gaskins (1980) Lithium and porcine aggression. J. Anim. Sci. 51(2), 447-455.

McGlone JJ (1985) A quantitative ethogram of aggressive and submissive behaviours in recently regrouped pigs. Journal of Animal Science 61, 559–565.

McLean AN (2001) Cognitive abilities – the result of selective pressures on food acquisition. Applied Animal Behaviour Science 71, 241–258. doi:10.1016/S0168-1591(00)00181-7

Meehan CL and Mench JA (2007) The challenge of challenge: Can problem solving opportunities enhance animal welfare? Applied Animal Behaviour Science 102, 246-261.

Melotti L, Oostindjer M Bolhuis JE, Held S Mendl M (2011) Coping personality type and environmental enrichment affect aggression at weaning in pigs. Applied Animal Behaviour Science, 140, 137– 145.

Mendl M (1999) Performing under pressure: stress and cognitive function. Applied Animal Behaviour Science 65, 221-244.

Mendl M, Laughlin K and Hitchcock D (1997) Pigs in space: spatial memory and its susceptibility to interference. Animal Behaviour 54, 1491-1508.

Mendl M, Burman OHP, Parker RMA, Paul ES (2009) Cognitive bias as an indicator of animal emotion and welfare: Emerging evidence and underlying mechanisms. Applied Animal Behaviour Science 118, 161-181.

Meunier-Salaun MC, Edwards SA, Robert S (2001) Effect of dietary fibre on the behaviour and health of the restricted fed sow. Animal Feed Science and Technology 90, 53–69. doi:10.1016/S0377-8401(01)00196-1

Meunier-Salaun MC, Vantrimponte MN, Raab A, Dantzer R (1987) Effect of floor area restriction upon performance behaviour and physiology of growing-finishing pigs. Journal of Animal Science, 64, 1371-1377.

Mishra A, Koene P,Schouten W, Spruijt B, van Beek P, Metz JH (2005) Temporal and sequential structure of behavior and facility usage of laying hens in an enriched environment. Poultry Science, 84(7),979-91.

Mitchell KD, Stookey JM, Laturnas DK, Watts JM, Haley, DB, Huyde T (2004) The effects of blindfolding on behaviour and heart rate in beef cattle during restraint. Applied Animal Behaviour Science, 85(3-4), pp. 233–245.

Moberg GP and Mench JA (2000) The Biology of Animal Stress: basic principles and implications for animal welfare.CAB International, Oxon, UK

Moinard C, Mendl M, Nicol CJ, Green LE (2003) A case control study of on-farm risk factors for tail biting in pigs. Applied Animal Behaviour Science 81, 333–355. doi:10.1016/S0168-1591(02)00276-9

Morag I, Edan Y and Maltz E (2001) An individual feed allocation decision support system for the dairy farm. Journal of Agricultural Engineering Research, 79 (2), 167-176.

Moreaux B, Beerens D and Gustin P (1999) Development of a cough induction test in pigs: effects of SR 48968 and enalapril. Journal of Veterinary Pharmacology and Therapeutics. 22, 387–389.

Morrison RS, Hemsworth PH, Campbell RG, Cronin GM (2003) The social and feeding behaviour of growing pigs in deep-litter, group housing systems. Applied Animal Behaviour Science 82, 173–188. doi:10.1016/S0168-1591(03)00067-4

Moura, D, Silva W, Naas I, Tolon Y, Lima K, Vale M (2008) .Real time computer stress monitoring of piglets using vocalization analysis. Computers and Electronics in Agriculture, 64(1), pp. 11–18.

Moustgaard A, Arnfred SM, Lind NM, Hansen AK, Hemmingsen R (2004) Discriminations, reversals, and extradimensional shifts in the Gottingen minipig. Behavioural Processes 67, 27–37. doi:10.1016/j.beproc.2004.02.002

Moustgaard A, Arnfred SM, Lind NM, Hemmingsen R and Hansen AK (2005) Acquisition of visually guided conditional associative tasks in Göttingen minipigs. Behavioural Processes 68, 97-102.

Müller-Graf C, Candiani C, Barbieri S, Ribó O, Afonso A, Aiassa E, Have P, Correia S, De Massis F, Grudnik T, Serratosa J (2008) Risk assessment in animal welfare – EFSA approach. AATEX 14, Special Issue, March 31, 789-794.

Murphy E, Kraak L, Nordquist R and Staay F (2013) Successive and conditional discrimination learning in pigs. Animal Cognition, 1-11.

MWPS (1983) ‘Swine housing and equipment handbook. MWPS-8.’ (Midwest Plan Service, Iowa State University: Ames, IA)

Nofre C, Glaser D, Tinti JM, Wanner M (2002) Gustatory responses of pigs to sixty compounds tasting sweet to humans. Journal of Animal Physiology and Animal Nutrition 86, 90-96.

Nowicki J, Kopyra M and Klocek C (2007) The behavioural reaction of weaners to hanging toys, wooden ball and aromatized wooden ball – way to reduce aggression after mixing .Journal of Central European Agriculture, 4, 447–452.

Nowicki J and Klocek C (2012) The effect of aromatized environmental enrichment inpen on social relations and behavioural profile of newly mixed weaners. Annals of Animal Science, 12, 403–412.

O’Connell NE, Beattie VE, 1999 Influence of environmental enrichment on aggressive behaviour and dominance relationships in growing pigs. Animal Welfare 8, 269–279.

Olesen LS, Nygaard CM, Friend TH, Bushong D, Knabe DA, Vestergaard KS, Vaughan RK (1996) Effect of partitioning pens on aggressive behavior of pigs regrouped at weaning. Applied Animal Behaviour Science 46, 167–174. doi:10.1016/0168-1591(95)00650-8

Olsen AW, Dybkjær L, Simonsen HB (2001) Behaviour of growing pigs in pens with outdoor runs. II. Temperature regulatory behaviour, comfort behaviour and dunging preferences. Livestock Production Science 69, 265–278. doi:10.1016/S0301-6226(01)00173-7

Organisation for Economic Co-Operation and Development and Food and Agriculture Organization of the United Nations. (2011) OECD-FAO agricultural outlook 2011-2020.

Otten W, Puppe B, Kanitz E, Schon P, Stabenow B (1999) Effects of dominance and familiarity on behaviour and plasma stress hormones in growing pigs during social confrontation . Journal of Veterinary Medicine Series A-Physiology Pathology Clinical Medicine 46, 277-292.

Pascoe PJ (1986) The effect of Azaperone on the agonistic behaviour of boars: a pilot study. The Canadian Veterinary Journal. La Revue Veterinaire Canadienne 27, 272–277.

Parratt CA, Chapman KJ, Turner C, Jones PH, Mendl MT,Miller BG (2006) The fighting behaviour of piglets mixed before and after weaning in the presence or absence of a sow. Applied Animal Behaviour Science 101, 54-67.

Pavlov IP (1927) ‘Conditioned reflexes.’ (Oxford University Press: London).

Pedersen S, Christensen B (1977) Lufthastighedens indflydelse på slagtesvineproduktionen. [Influence of air velocity on fattening pig production]. SBI – Landbrugsbyggeri 52/DLU-Beretning 19. De Landbrugstekniske Undersoegelser, Otterup, Denmark.

Pereira D, Naas I, Romanini C, Salgado D (2004) Assessment of behavioural responses of arrays of broilers in climatic chamber. In: Proceedings of the 33 Brazilian Congress of Agricultural Engineering, Sao Paulo, Brazil.

Petersen V, Simonsen HB, Lawson LG (1995) The effect of environmental stimulation on the development of behaviour of pigs. Applied Animal Behaviour Science 45, 215–224. doi:10.1016/0168-1591(95)00631-2

Pluk A, Bahr C, Leroy T, Poursaberi A, Song X, Vranken E, Maertens W, Van Nuffel A., Berckmans D (2010) Evaluation of step overlap as an automatic measure in dairy cow locomotion. Transactions of the ASABE 53, 1305-1312.

Pluk A, Bahr C, Poursaberi A, Maertens W, Van Nuffel A., Berckmans D (2012) Automatic measurement of touch and release angles of the fetlock joint for lameness detection in dairy cattle using vision techniques. Journal of Dairy Science 95(4),1738-1748.

Poursaberi A, Bahr C, Pluk A, Van Nuffel A, Berckmans D (2010) Real-time automatic lameness detection based on back posture extraction in dairy cattle: Shape analysis of cow with image processing techniques. Computers and Electronics in Agriculture, 74(1), pp. 110-119.

Poursaberi A; Bahr C, Pluk A, Berckmans D, Veermae I; Kokin E, Poikalainen V(2011) Online lameness detection in dairy cattle using Body Movement Pattern (BMP). In: 11th International Conference on Intelligent Systems Design and Applications (2011) : ISDA 2011, November 22-24, 2011 - Córdoba, Spain. IEEE, 2011, 732 – 736.

Puppe B, Ernst K, Schön PC, Manteuffel G (2007) Cognitive enrichment affects behavioural reactivity in domestic pigs. Applied Animal Behaviour Science 105, 75–86. doi:10.1016/j.applanim.2006.05.016

Richardson J (1971) Cue effectiveness and abstraction in paired-associate learning.

Psychological Bulletin 75, 73–91. doi:10.1037/h0030306

Rodarte LF, Ducoing A, Galindo F, Romano MC, Valdez RA (2004) The effect of environmental manipulation on behaviour, salivary cortisol and growth of piglets weaned at 14 days of age. Journal of Applied Animal Welfare Science, 7, 171–179.

Ruckebush Y (1972) The relevance of drowsiness in the circadian cycle of farm animals. Animal Behaviour 20, 637–643.

Rushen J (2003) Changing concepts of farm animal welfare: bridging the gap between applied and basic research. Applied Animal Behavioural Science 81, 199–214.

Rushen J (2004) Stereotypies, aggression and the feeding schedules of tethered sows. Applied Animal Behavioural Science 14, 137–147.

Sällvik K, Walberg K (1984) The effect of air velocity and temperature on the behaviour and growth of pigs. Journal of Agricultural Engineering Research 30, 305–312. doi:10.1016/S0021-8634(84)80031-1

SAS (2008) ‘SAS/STAT User's Guide: Statistics (Version 9.2) SAS Inst Inc, Cary, North Caroline, USA

SAS (2010) SAS/STAT User's Guide: Statistics (Version 9.2) SAS Inst Inc, Cary, North Caroline, USA

Schaefer AL, Salomons MO, Tong AKW, Sather AP, Lepage P (1990) The effect of environment enrichment on aggression in newly weaned pigs. Applied Animal Behaviour Science, 27, 41–52.

Schofield CP, Marchant A., White, R. P., Brandl, N. & Wilson, M. (1999) Monitoring Pig Growth using a Prototype Imaging System", Journal of Agricultural Engineering Research, Vol. 72, No. 3, pp. 205-210.

Schofield CP, Wathes CM and Frost AR (2002) Integrated Management Systems for Pigs – Increasing Production Efficiency and Welfare", in Animal Production in Australia, Revell, D. K. & Taplin, D. (editor), Adelaide, South Australia, Vol. 24, pp. 197-200.

Schrøder-Petersen DL, Simonsen HB (2001) Tail biting in pigs. Veterinary Journal (London, England) 162, 196–210. doi:10.1053/tvjl.2001.0605

Scott K, Taylor L, Gill BP, Edwards SA (2009) Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems: 3. Hanging toy versus rootable toy of the same material. Applied Animal Behaviour Science, 116, 186–190.

Sekhar NU (1998) Crop and livestock depredation caused by wild animals in protect areas: the case of Sariska Tiger Reserve, Rajasthan, India. Environmental Conservation 25, 160–171. doi:10.1017/S0376892998000204

Shao J, Xin H, Harmon JD (1997) Neural network analysis of postural behaviour of young swine to determine their thermal comfort state. Transactions of the ASAE. American Society of Agricultural Engineers 40, 755–760.

Shao B, Xin H (2008) A real-time computer vision assessment and control of thermal comfort for group-housed pigs. Computers and Electronics in Agriculture 62, 15–21.

Silva M, Guarino M, Ferrari S, Costa A, Aerts JM, Berckmans D (2008) Cough localization for the detection of respiratory diseases in pig houses. Computers and Electronics in Agriculture, 64, 286–292.

Simonsen HB (1990) Behaviour and distribution of fattening pigs in the multi-activity pen. Applied Animal Behaviour Science 27, 311–324. doi:10.1016/0168-1591(90)90127-Y

Smith WJ, Penny RHC. (1986) Behavioral problems including vices and cannibalism. In: Leman AD, Straw BE, Glock RD, Mengeling WL, Penny RHC, Scholl E, eds. Diseases of Swine. 6th ed. Ames, Iowa: Iowa State University Press. 1986;762-772.

Sneddon IA, Beattie VE, Dunne L, Neil W (2000) The effect of environmental enrichment on learning in pigs. Animal Welfare (South Mimms, England) 9, 373–383.

Sorensen JT and Fraser D (2010) On-farm welfare assessment for regulatory porposes: issues and possible solutions. Livestock Science, 131, 1-7.

Souza AS and Zanella AJ (2008) Social isolation elicits deficits in the ability of newly weaned female piglets to recognise conspecifics. Applied Animal Behaviour Science 110, 182-188.

Spicer HM and Aherne FX (1987) The effects of group size/stocking density on weanling pig performance and behaviour. Applied Animal Behaviour Science,19, 89-98.

Spoolder HAM, Edwards SA, Corning S (2000) Aggression among finishing pigs following mixing in kennelled and unkennelled accommodation. Livestock Production Science 63, 121–129. doi:10.1016/S0301-6226(99)00121-9

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, and de Haan C. (2006a) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations. Available at ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e00.pdf.

Steinfeld H, Wassenaar T, and Jutzi S. (2006b). Livestock production systems in developing countries: status, drivers, trends. Rev. sci. tech. Off. int. Epiz. 25(2):505 -516. Available at http://www.oie.int/doc/ged/D3537.PDF.

Stookey JM and Gonyou HW (1994) The effects of regrouping on behavioral and production parameters in finishing swine. J. Anim. Sci. 72(11), 2804-2811.

Stukenborg A, Traulsen I, Puppe B, Presuhn U, Krieter J (2011) Agonistic behaviour after mixing in pigs under commercial farm conditions. Applied Animal Behaviour Science 129, 28–35. doi:10.1016/j.applanim.2010.10.004

Tan S, Shackleton DM (1990) Effects of mixing unfamiliar individuals and of azaperone on the social behaviour of finishing pigs. Applied Animal Behaviour Science 26, 157–168. doi:10.1016/0168-1591(90)90095-U

Taylor NR, Main DC, Mendl M, Edwards SA (2010) Tail-biting: a new perspective. Veterinary Journal (London, England) 186, 137–147. doi:10.1016/j.tvjl.2009.08.028

Tillett, R.D., Onyango, C.M., Marchant, J.A., 1997. Using model-based image processing to track animal movements: livestock monitoring. Computers and Electronics in Agriculture 17 (2), 249–261.

Trickett SL, Guy JH, Edwards SA (2009) The role of novelty in environmental enrichment for the weaned pig. Applied Animal Behaviour Science, 116, 45–51.

Turner SP, Horgan GW and Edwards SA (2001) Effect of social group size on aggressive behaviour between unacquainted domestic pigs. Applied Animal Behaviour Science 74, 203-215.

Turner SP, Farnworth MJ, White IMS, Brotherstone S, Mendl M, Knap P, Penny P, Lawrence AB (2006) The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Applied Animal Behaviour Science 96(3-4), 245-259.

Turner SP., Roehe R, D'Eath RB, Ison SH, Farish M, Jack MC, Lundeheim N, Rydhmer L, Lawrence AB (2009) Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions. J. Anim. Sci. 87(10),3076-3082.

Van de Weerd HA, Docking CM, Day JE, Avery PJ, Edwards SA (2003) A systematic approach towards developing environmental enrichment for pigs. Applied Animal Behaviour Science 84, 101–118. doi:10.1016/S0168-1591(03)00150-3

Van de Weerd HA, Docking CM, Day JEL, Edwards SA (2005) The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. Animal Science, 80, 289–298.

Van de Weerd HA, Docking CM, Day JEL, Breuer K, Edwards SA (2006) Effects of species-relevant environmental enrichment on the behaviour and productivity of finishing pigs. Applied Animal Behaviour Science 99, 230–247. doi:10.1016/j.applanim.2005.10.014

Van de Weerd HA and Day JEL (2009) A review of environmental enrichment for pigs housed in intensive housing systems Applied Animal Behaviour Science, 116, 1–20.

Van Hirtum A and Berckmans D (2001a) Fuzzy approach for improved recognition of pig coughing from continuous registration, Noise and vibration engineering, Vols 1 - 3, 1535-1541.

Van Hirtum A and Berckmans D (2001b) An intelligent alarm for early detection of swine epidemics based on neural networks. Transactions of ASAE 44 (1), 167–174.

Van Hirtum A, Berckmans D (2003) Fuzzy approach for improved recognition of citric acid induced piglet coughing from continuous registration. Journal of sound and vibration 266, 677-686.

Van Hirtum A and Berckmans D (2004) Objective recognition of cough sound as biomarker for aerial pollutants. Indoor Air 14 (1), 10-15.

Verstegen MWA, van der Hel W (1974) The effect of temperature and type of floor on metabolic rate and effective critical temperatures in groups of growing pigs. Animal Production 18, 1–11. doi:10.1017/S0003356100017190

Viazzi S, Ismayilova G, Sonoda LT, Oczak M, Leroy T, Costa A, Bahr C, Guarino M, Fels M, Hartung J, van den Berg G, Vranken E, Berckmans D (2011) Labelling of video images: the first step to develop an automatic monitoring tool of pig aggression. In ‘Proceedings of the 15th ISAH congress, Vienna, Austria. Vol. 2’(Eds Köfer J. Schobesberger H) pp 751-754.

Viazzi, S., Bahr C, Schlageter Tello A, Van Hertem T, Romanini CEB, Pluk A, Halachmi I, Lokhorst C, Berckmans D (2013) Analysis of individual classification of lameness using automatic back posture measurement in dairy cattle. Journal of Dairy science 96(1), 257-266.

Vranken E, Chedad A, Aerts J-M, Berckmans D (2004) Estimation of average body weight of broilers using automatic weighing in combination with image analysis. In :Abstracts of the Third International Workshop on Smart Sensors in Livestock Monitoring, Leuven, Belgium.

Wathes C, Kristensen H, Aerts J. M, Berckmans D (2008) Is precision livestock farming an engineer’s daydream or nightmare, an animal’s friend or foe, and a farmer’s panacea or pitfall? Computers and Electronics in Agriculture, 64(1), 2–10.

Wathes CM (2010) The prospects for precision livestock farming. Journal of the Royal Agricultural Society of England, 171, 26-32.

Welfare Quality®, 2009b. Welfare Quality® assessment protocol for pigs. Welfare Quality® Consortium, Lelystad, Netherlands, 122 p.

Weng RC, Edwards SA, English PR (1998) Behaviour, social interactions and lesion scores of group-housed sows in relation to floor space allowance. Applied Animal Behaviour Science 59, 307–316. doi:10.1016/S0168-1591(97)00143-3

White RP, Schofeld CP, Green DM, Parsons DJ, and Whitehorse, C. T. (2004) The effectiveness of a visual image analysis (via) system for monitoring the performance of growing/finishing pigs. Animal Science, 78(3), pp. 409–418.

Wolff A and Hausberger M (1996) Learning and memorisation of two different tasks in horses: The effects of age, sex and sire. Applied Animal Behaviour Science 46, 137-143.

Wood-Gush DGM, Beilharz RG (1983) The enrichment of a bare environment for animals in confined conditions. Applied Animal Ethology, 10, 209–217.

Wood-Gush DGM., Vestergaard K, Petersen HV (1990) The significance of motivation and environment in the development of exploration in pigs. Biology Behaviour 15, 39-52.

Wood-Gush DGM, Vestergaard K (1991) The seeking of novelty and its relation to play. Animal Behaviour, 42, 599–606.

Wu JH, Tillett R, McFarlane N, Ju XY, Siebert JP, Schofield P (2004) Extracting the three-dimensional shape of live pigs using stereo photogrammetry. Computers and Electronics in Agriculture. 44(3), 203-222.

Xin H (1999) Assessing swine thermal comfort by image analysis of postural behaviours. Journal of Animal Science 77, 1–9.

Zhu W, Pu X, Li X, Zhu X (2009) Automated detection of sick pigs based on machine vision. In ‘Intelligent computing and intelligent systems, 2009. Intelligent Computing and Intelligent Systems, 2009. IEEE International Conference on (Volume:2 790-794) Shanghai, China, (2009). 10.1109/ICICISYS.2009.5358295

Zimmerman PH, Koene P and Van Hooff J (2000) The vocal expression of feeding motivation and frustration in the domestic laying hen, Gallus gallus domesticus. Applied Animal Behaviour Science, 69(4), 265-273.

Zonderland JJ, Vermeer HM, Ter Avest A, Vereijken PFG, Spoolder HAM (2003) Measuring a pig's preference for suspended toys by using an automated recording technique. In: Proceedings of the International Symposium of the CIGR Animal Welfare Considerations in Livestock Housing Systems, second Technical Section, pp147–156.

Zonderland JJ, Wolthuis-Fillerup M, van Reene CG, Bracke MBM, Kemp B, den Hartog LA, Spoolder HAM (2008) Prevention and treatment of tail-biting in weaned piglets. Applied Animal Behaviour Science, 110, 269-281.

Publications

Internatonal Journal Publications

1. Ismayilova G, Oczak M, Costa A, Sonoda LT, Viazzi S., Fels M, Vranken E, Hartung J, Bahr C, Berckmans D, Guarino M (2013) How behave pigs before starting an aggressive interaction? – Identification of typical body positions in the early stage of aggression using video labelling techniques. Berliner und Münchener Tierärztliche Wochenschrift journal 126, 113–120.

2. Ismayilova G, Costa A, Fontana ., Berckmans D, Guarino M (2013) Labelling the behaviour of piglets and activity monitoring from video as a tool of assessing interest in different environmental enrichments. Annals of Animal Science 13:3, 611–621.

3. Ismayilova, G., Sonoda, L.,. Fels M., Rizzi R., Oczak M., Viazzi S., Vranken E., Hartung J., Berckmans D., Guarino M. (2013) Acoustic reward learning as a method to reduce the incidence of aggressive and abnormal behaviours among newly mixed piglets. Animal Production Science, http://dx.doi.org/10.1071/AN13202

4. Costa A, Ismayilova G, Borgonovo F, Leroy T, Berckmans D, Guarino M (2013) The use of image analysis as a new approach to assess behaviour classification in a pig barn. Acta veterinaria Brno, 82:1, 25-30.

5. Sonoda L, Fels M, Oczak M, Vranken E, Ismayilova G, Guarino M, Viazzi S, Bahr C, Berckmans D, Hartung J (2013) Tail Biting in pigs – Causes and Management intervention strategies to reduce the behavioural disorder. A

review. Berliner und Münchener Tierärztliche Wochenschrift journal 126, 104-112

6. Sonoda L, Fels M, Rauterberg S, Viazzi S, Ismayilova G, Oczak M, Bahr C, Guarino M, Vranken E, Berckmans D, Hartung J (2013) Cognitive enrichment in piglet rearing – an approach to enhance animal welfare and to reduce aggressive behaviour. ISRN Veterinary Science 2013, 1-9

7. Rauterberg S, Sonoda LT, Fels M, Viazzi S, Ismayilova G, Oczak M, Bahr C, Guarino M, Vranken E, Berckmans D, Härtung J (2013) Cognitive enrichment in the farrowing pen - A first approach to use early behavioural conditioning of suckling piglets to reduce aggressive behaviour during rearing. Zuchtungskunde 85, 376-387

8. Costa A, Ismayilova G, Borgonovo F, Viazzi S, Berckmans D, Guarino M (2013) Optical flow technology to detect animal activity in response to climatic variations in a pig barn. Animal Production Science, http://dx.doi.org/10.1071/AN13031

9. Oczak M, Ismayilova G, Costa A, Viazzi S, Sonoda L, Fels M, Bahr C, Hartung J, Guarino M, Berckmans D, Vranken E (2013) Analysis of aggressive behaviours of pigs by automatic video recordings. Accepted in Computers and Electronics in Agriculture

Conference Proceedings

Ismayilova G, Costa A, Borgonovo F, Leroy T, Berckmans D, Guarino M (2011) The Precision Livestock Farming (PLF): an innovative methodology for measuring the interest of piglets on environmental enrichments. In ‘Proceedings of the 5th

European Conference on Precision Livestock Farming. Prague, Czech Republic, pp 251-260.

Ismayilova G (2011) Precision Livestock Farming: looking to the future. In 'Book of abstracts of the Marie Curie Researchers Symposium, Warsaw, Poland, 98

Ismayilova G, Oczak M, Costa A, Sonoda LT, Viazzi S, Fontana I, Fels M, Vranken E, Hartung J, Berckmans D, Guarino M (2012) Aggressive behaviours of pigs analysed through video labelling techniques. In 'Proceedings of the 63rd Annual Meeting of EAAP, Bratislava, Slovakia, p 345

Ismayilova G, Oczak M, Costa A, Sonoda L, Viazzi S, Fels M, Vranken E, Hartung J, Berckmans D, Guarino M (2012) Body positions of pigs in an early stage of aggression. In 'Proceedings of the 46th Congress of the International Society for Applied Ethology, Vienna, Austria, p 213

Ismayilova G, Sonoda L , Fels M, Rizzi R, Oczak M, Viazzi S, Vranken E, Hartung J, Berckmans D, Guarino M (2013) Can aggressive behaviour among piglets be stopped by a sound signal and reward treatment? In 'Proceedings of the 16th International Congress on Animal Hygiene, Nanjing, China, pp 425-428

Ismayilova G, Sonoda L, Fels M, Rizzi R, Oczak M, Viazzi S, Vranken E, Hartung J, Berckmans D, Guarino M (2013) Acoustic reward learning as a method of reducing the incidence of aggressive and abnormal behaviours among newly mixed piglets. In 'Proceedings of the 6th European Conference on Precision Livestock Farming, Leuven, Belgium, pp 253-262

Oczak M, Ismayilova G, Sonoda LT, Fels M, Hartung J, Guarino M, Viazzi S, Berckmans D, Vranken E (2012) Identification of behaviour of weaner pigs in the early phase of aggressive interaction for the development of an automatic monitoring system of pig aggression. In ‘Proceedings of the 7th International joint Conference on Biomedical Engineering Systems and Technologies, Vilamoura Algarve , Portugal, pp 24-29

Oczak M, Costa A, Ismayilova G, Sonoda LT, Fels M, Hartung J, Guarino M, Viazzi S, Berckmans D, Vranken E (2012) Analysis of sequences in aggressive interactions of pigs for the development of an automatic aggression monitoring and control system. Measuring Behaviour conference, Utrecht, Netherlands, pp 341-345

Oczak M, Viazzi S, Ismayilova G, Sonoda LT, Fels M, Hartung J, Guarino M, Berckmans D, Vranken E (2013) Classification of aggressive behaviour of pigs by multilayer feed forward neural network. International Conference on Artificial Neural Networks, Amsterdam, Netherlands

Oczak M, Viazzi S, Ismayilova G, Sonoda LT, Fels M, Hartung J, Guarino M, Berckmans D, Vranken E (2013) Classification of aggressive behaviour of pigs by multilayer feed forward neural network. In ‘Proceedings of the 6th European Conference on Precision Livestock Farming, Leuven, Belgium, pp 379-388

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2012) How to reduce and prevent aggressive behaviour in pigs? – Current methods and new perspectives of Precision Livestock Farming. In ‘Proceedings of the II PSI Animal Conference, Lisbon

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2012) Electronic feeding system used as environmental enrichment tool for young piglets In ‘Proceedings of the II PSI Animal Conference, Lisbon

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2013) Reducing aggressive behaviour in young piglets by cognitive environmental enrichment. In ‘Proceedings of the 4th Congress of the International Society for Applied Ethology , Florianopolis, Brazil, p 82

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2012) Development of Precision Livestock Farming Solutions for Animal Health and Welfare . In ‘Proceedings of the Marie Curie Conference, Dublin, Ireland

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2013) Reducing aggressive behaviour by an electronic feeding system used as environmental enrichment tool for young piglets. In ‘Proceedings of the 6th European Conference on Precision Livestock Farming, Leuven, Belgium, pp 269-278

Sonoda LT, Fels M, Oczak M, Ismayilova G, Viazzi S, Guarino M, Vranken E, Berckmans D, Hartung J (2013) Reducing aggressive behaviour by an electronic feeding system used as environmental enrichment tool for young piglets. In book of abstracts of the 64th annual Meeting of the European Federation of Animal Science Nantes, France, p 207

Viazzi S, Ismayilova G, Sonoda LT, Oczak M, Leroy T, Costa A, Bahr C, Guarino M, Fels M, Hartung J, van den Berg G, Vranken E, Berckmans D (2011) Labelling of video images: the first step to develop an automatic monitoring tool of pig aggression. In ‘Proceedings of the 15th ISAH congress, Vienna, Austria. Vol. 2’ pp 751-754.

Acknowledgements

I am deeply grateful to the EU Marie Curie ITN Program for funding my study and making possible to live this great professional and life experience. I would also like to take this opportunity to thank all the persons who have contributed in the different aspects of this study and my life. They have all made it possible for me to commence and complete this enormous task. First and foremost, I must thank my research supervisor, Dr. Marcella Guarino for, for her guidance, support, caring, and providing me with an excellent atmosphere for doing research. Her enthusiasm, encouragement, and faith in me have been extremely helpful for being creative and keep me going straight to my goals.

I can never hope to thank adequately my friend Annamaria Costa for her warm welcoming when I just arrived, she made me to feel a part of the group. Her guidance and scientific and friendly support were essential for me. Thank you so much for always being there when I needed you.

I would like to express the deepest appreciation to Prof. Daniel Berckmans. The impact of his leadership was felt and helped maintain the tempo and belief in my capacities . He was always available to talk with me on many occasions and gave generously of his time and vast knowledge. My special thanks go to Dr. Kees Lokhorst , who kindly agreed to be a member of the Committee.

I would like to thank Federica, Emanuela, Cecilia, Ilaria, Davide, Damiano who really made my stay in Milano one I'll always remember. Federica , thanks for being such a dear friend and an awesome officemate, for all the emotional support and caring you provided to me. Emanuela, thank you so much for always willing to help and advice.

I would like to acknowledge and commend my colleagues and friends Maciej, Lilia and Stefano for their effort, cooperation and collaboration that have worked towards the success of our project. Together we are the force, guys! Stefano, who else could introduce me better to the world of technology and algorithms. You are a great engineer, colleague and friend. Maciek, thank you so much for always being ready to support, help and understand me. Lilia, thank for all the great time we spend together, for friendly assistance when I stayed in Hannover and always willing to help.

A special thought is devoted to my friends and co-fellows Nancy Roulston, Qin Tong, Eduardo Romanini, Andres Schlageter Tello, Tom Van Hertem, Hakim Bergoug. Thank you my friends for all this great moments we have spent together, I will never ever forget them. Nancy, I am so happy that I found you, your friendship is a most precious gift of the BioBusiness project for me. Thank you so much for endless and friendly support when I needed it most. Qin, you are my little sister, I will never forget all that precious moments and fun we have had together.

And my last words are dedicated to my father Faik Ismayilov, I will never be able to express by words all my infinite love, admire and deepest respect to him. Папа, я никогда не смогу выразить словами всю мою любовь и благодарность за безграничную поддержку и веру в меня, которые словно яркий луч в конце туннеля заставлают меня идти вперед и не боятся никаких преград, ведь я знаю что ты у меня есть.