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The technical manipulation of the behaviour of sows exemplified by call feeding and active crushing prevention

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Abbreviations

AI	agonistic interaction
CFM	call feeding module by which a electronic feeding station becomes a call feeding station
CFS	call feeding station
CUSUM	cumulative sum for monitoring change detection
DI	dominance index
DLM	dynamic linear model
EFS	electronic feeding station
fn	false negative classification
fp	false positive classification
IP##	international protection code
ISOagriNET	specification of a protocol for farm data exchange
LSM	least square mean
oop	onset of parturition
PLF	precision livestock farming
RFID	radio frequency identification
SD	standard deviation
SE	standard error
SNR	signal to noise ratio
STREMODO	stress monitoring and documentation system
tn	true negative classification
tp	true positive classification

General Introduction

During the last 100 years pig husbandry underwent a dramatic change from extensive breeding on pasture to intensive breeding in enclosed stables. The still ongoing intensification entails the maximisation of meat production along with a minimisation of water, feed, energy consumption and space allowance. These optimisation processes often involve an impairment of animal welfare (Fraser, 2005).

Broom (1991) defines animal welfare as the ability of the animal to cope with the given environment in order to satisfy its needs that provide the motivation to maintain its mental and bodily stability. This includes the satisfaction of current needs as well as the confidence to be able to satisfy needs in the future. Actions of the animal that satisfy a need are called *appetitive* in behaviour science. Animals will generally perform appetitive actions because they are motivated to satisfy their needs. In contrast, situations that cause an unsatisfied need are called *aversive*. Animals will generally avoid aversive situations because they are motivated to maintain their mental and bodily stability. With respect to this welfare definition, appetitive situations improve the animal welfare while aversive situations impair it (Broom, 1991).

When a need stays unsatisfied, the animal suffers to a varying extent. However, Broom (1991) gives several examples that suffering and welfare are not synonymous. An injured animal for example has a poor welfare but this could entail no suffering if analgesics prevent an expression of the need for physical integrity through pain. Another example is the physical restraint of sheep for shearing. The sheering usually creates no injuries but the sheep has no control and cannot cope with its future need of physical integrity whilst being restraint. Hence without suffering its welfare during the shearing is poor.

There are several measurable indicators to assess animal welfare (Barnett et al., 1984; Broom, 1991; Manteuffel et al., 2004; Forkman et al., 2007):

- the incidence and severity of injuries and skin lesions,
- the cleanliness of the animals and their housing,
- the concentration of noxious gas in the stable,
- behavioural parameters such as the incidence of maladaptive behaviour, the responsiveness to contacts with fellows and humans or novel objects as well as vocalisation,
- physiological parameters such as the heart rate and stress hormones

The interpretation of such parameters in terms of animal welfare is however still subject of current research. This makes non-controversial comparisons of the livestock friendliness of different husbandry conditions difficult. Sows for example showed no high valuation of environmental enrichment when they had to “work” for it (Pittman Elmore et al., 2012). This uncertainty in the assessment of livestock friendliness is especially distinct in the early developments of intensified pig husbandry when most of the animal welfare indicators were still unknown. Here, studies on the intensification of husbandry conditions often relied on the assumption that the pigs’ innate coping abilities are sufficient to let them adapt to new conditions and procedures (Gehlbach et al., 1966, Legault et al., 1975, Martinat-Botte, 1975). More recent studies also investigated the feasibility of a genetic alteration of pigs in order to increase their coping abilities (Black et al., 2001).

The new approach of precision livestock farming (PLF) in contrast identified the incorporation of the animal as vital factor for the further development of animal husbandry. Moreover, the objectives of PLF are not limited to improved profitability. They also include the improvement of food safety and quality, environmental sustainability and animal welfare (Berckmans, 2006). Its basic concept is the “application of the principles and techniques of process engineering to livestock farming to monitor, model and manage animal production” (Wathes, 2007). This entails usually the adaption of certain aspects of the husbandry environment towards measured animal parameters. The animals themselves have to cope with the dynamically changing environment so that a mutual adaption takes place.

A special case of PLF is the direct manipulation of the animal behaviour by appetitive and aversive stimuli. Under intensive husbandry conditions, the innate animal behaviour is in many cases unfavourable for productivity and livestock friendliness. Technology can enable the animals to behave in ways that improve productivity or the overall animal welfare. This can be achieved by a mutual adaption of the husbandry conditions and the animal behaviour such that an alternative and more appropriate instinctive behaviour is produced. For example Jeon et al. (2005) describe a system that monitors the posture of lactating sows in farrowing crates. Every time the sow starts to recline, the system emits an air-blast below her. The air-blast is ought to dislodge any piglets underneath the sow and thereby prevent them from being crushed. The instinctive behaviour of the piglets of seeking the milk and warmth found in the vicinity of the sow is replaced in this example by the instinctive behaviour to flee wind chill. In doing so, the system occasionally changes the conditions for piglets depending on the behaviour of the mother sow, leading to a more appropriate behaviour. In this respect, it increases the productivity and livestock friendliness of the farrowing pen via a manipulation of the piglets’ behaviour.

In general, behaviour manipulation is widely spread in pig husbandry and often associated with feeding. For example, weaned piglets often abruptly have to explore and employ new feed sources. This requires a vastly changed foraging behaviour (Held et al., 2002). The same holds for gilts in many feeding systems for the group housing of gestating sows such as electronic feeding stations or the mash nozzle. Transfers to new compartments and the integration into new social groups generally entail learning and behaviour adaptation processes for the animals (Wechsler and Lea, 2007). Behaviour manipulation is not synonymous to animal learning, though. It incorporates not only conditioning methods but also employs the innate behaviour. An example is the use of heat lamps and heated piglet nests. These use the piglets’ innate drive to reduce hypothermia in order to avoid the crushing of piglets huddling for warmth next to their mother sow (Malmkvist et al., 2005). In addition, behaviour manipulation can occur inadvertently. For example, Hemsworth et al. (1996) report on pigs recognising individual humans which are connected with appetitive management procedures. In either case, all these occasions form a kind of **blind behaviour manipulation** as it takes place mainly unsupervised. Its effect is usually not measured directly even if the behaviour manipulation is intended. Instead, only indirect effects of the adaptation are observed and measured. This is for example the case with the post-weaning growth-check (Held et al., 2002). Blind behaviour manipulation is either a result of the accidental nature of the manipulation or due to the assumption that the animals on average conform well to the applied procedures.

In contrast, the PLF approach aims at economically employing the appetitive and aversive stimuli. This is achieved by monitoring the animals' reactions and subsequently adapting the procedures to the animals' or to production requirements. In this regard PLF utilises **informed behaviour manipulation**. A simple example for an informed behaviour manipulation would be a piglet localisation system that turns the nest heating off to save energy whilst the piglets are away suckling. The informed approach allows the employment of more challenging coping tasks in animal management procedures without overstraining the capabilities of the animals. Avoiding overstraining is a vital aspect of the livestock friendliness of housing conditions (Korte et al., 2007).

In summary, the development of an informed autonomous behaviour manipulation procedure requires four steps:

Step 1. Investigation of suited appetitive and aversive stimuli.
Step 2. Development of sensors for monitoring the animals.
Step 3. Development of methods for the adaptation of the behaviour manipulation towards animal or production requirements.
Step 4. Investigation of technical and behavioural aspects for the practical application of the methods found.

These steps are a concretisation of the commonly used general PLF implementation approach in terms of a "closed loop, model-based control system" (Wathes, 2007). In general, this approach requires sensors for monitoring the output of a production process. These are the sensors recognising the animal behaviour in the case of behaviour manipulation. Secondly, a model and a target value for the process output are required in order to control the output depending on the process input. This is subsumed here as methods for the adaptation of the behaviour manipulation. Thirdly, actuators are necessary to alter the process input with respect to the process model and the desired target value for the process output. Such actuators are appetitive and aversive stimuli in the case of behaviour manipulation. Step 4 of the behaviour manipulation development process considers the environment in which the PLF system is embedded and that is not monitored by sensors or not included in the process model. The system environment can influence the process output in an indefinite way. Its effects should be determined prior to implementing a PLF system in practice and should eventually be considered by the process model (Fig. 1).

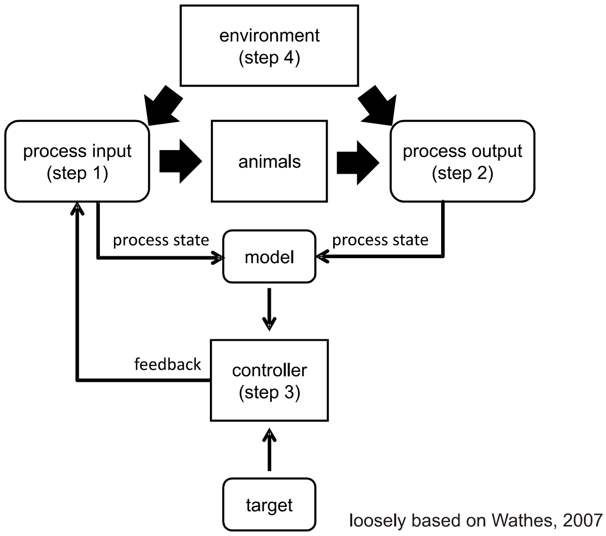

Fig. 1. Closed loop, model-based control system. Process actors are marked by rectangles with sharp corners, components of the control system by rectangles with round corners. Material and information flow within the control system is depicted by slim arrows and within the process by thick arrows.

The exemplary implementation of the 4 development steps for behaviour manipulation systems will be illustrated in the following five chapters of the present research work. To exemplify the appetitive approach, a novel call feeding system for sows using operant conditioning will be presented in section I. Section II will treat the aversive approach exemplified by studies on the feasibility of an active system to prevent piglet crushing.

Section I: Appetitive behaviour manipulation

Operant conditioning was investigated and characterised first by Konorski, Miller and Skinner (Skinner, 1935; Konorski and Miller 1937). In farm animals, this method was widely utilised for studies on general learning behaviour and animal preferences (Kilgour et al., 1991). For farm animals, auditory cues were first used on cattle. The cues were utilised to call cows to a milking parlour using animal attached signal devices in a neck collar (Albright et al., 1966; Wredle et al., 2004). In juvenile pigs, operant conditioning was utilised for fundamental research on the learning capabilities and the behavioural and physiological effects of continuous activity (Ernst et al., 2005). A single triad-composition was used as signal to call 1 of 8 just weaned male pigs to 1 of 4 feeding stations using feed as appetitive stimulus in this study. The association of the signal to a single pig was realised by using different timbres of always the same composition. After a conditioning phase the pigs were called randomly for 12 h, up to 31 times a day. For that matter the pigs had not only to identify their own signal timbre but also the location of the calling feeding station. They also had to “work” for their feed by pushing a button with their nose disk up to ten times, before a single portion of 70-105 g was released. This form of physical and cognitive environment enrichment reduced the maladaptive behaviour “belly nosing” and the overall number of agonistic interactions. The pigs also showed less excitement and fear associated behaviour in an open field test, compared to conventionally kept pigs (Puppe et al, 2007; Zebunke et al., 2013). The correct functioning of the associations of the own signal - feed and the signal of other sows - no feed could by proven by heart rate measurements. A study derived from the original setting revealed an increased arousal of the called pig right after its individual signal was issued. This arousal was not measured when the pig heard the signal of other pigs or sounds of other pigs getting fed (Zebunke et al., 2011).

The sequential feeding approach of the original call feeding system is similar to electronic feeding stations that are commonly used to feed fattening pigs and gestating sows in group housing. Depending on the size of the animal group this feeding approach can lead to animal welfare issues. Gestating sows are usually restrictively fed in order to achieve a uniform weight development throughout the sows' lifetime (Dourmad et al., 1994). The restrictive feeding can lead to queuing behaviour and an increased readiness for agonistic interactions at feeding start (Hunter et al., 1988), as all sows try to acquire their feed at once (Sambraus, 1981). The access to the feeding station is to some degree regulated by the sows' rank position in the social hierarchy of the group, due to an established avoidance order. Lower ranking sows avoid the direct confrontation with higher ranking sows (Jensen, 1982). Therefore, higher ranking sows automatically acquire a better position in front of the feeder. However, the feeding order is regularly re-determined amongst the highest ranking sows through agonistic interactions. Also, the rank order does not regulate feed access for the lower third of the social hierarchy (Ritter and Weber, 1989). In addition, high ranking sows often perform non-feeding visits after they already consumed their feed contingent. This can hinder the ingestion of lower ranking sows and provoke additional agonistic interactions. These agonistic interactions often occur in terms of fights and lead to stress and injuries amongst the animals (Hunter et al., 1988; Ritter and Weber, 1989). In this regard, the innate social and feeding behaviour of the pig impairs the overall productivity and animal welfare if electronic feeding is used. From the animals' perspective, electronic feeding tends to overstrain the innate coping ability of the pig. The results of the earlier studies with juvenile pigs allow the conclusion that call feeding can help to reduce queuing and non-feeding visits (Ernst et al., 2005). It could therefore reduce feeding associated agonistic interactions and subsequent injuries at electronic feeding stations.

C**hapter 1** presents the effects of social hierarchy on the call feeding training as well as on the general learning performance of adult sows. Through the call feeding training the sows should learn to recognise their own signal and discriminate it from the signals of other sows. In this respect the sows operate as classifiers whose performance can be measured in terms of four cases:

1. A signal that leads to the feeding of the sow is a true positive recognition (tp).
2. A signal that entails no feeding is a false negative recognition (fn).
3. A sow that ignores the signal of another sow displays a true negative recognition (tn).
4. A sow that observes the signal of another sow displays a false positive (fp) recognition.

The sensitivity of the classification (correct response rate) would then be calculated as tp/(tp + fn). This parameter provides information on the ratio of observed signals and the overall number of signals emitted for a single sow. The fallout rate (false approach rate) would be fp/(fp + tn). This parameter provides information on the ratio of signals erroneously observed by a single sow and the overall number of signals emitted for the other sows. The precision (learning success) i.e. the extent to which the sow observes its own signals and ignores the signals of others would be calculated as tp/(tp + fp).

The rank of the sows was determined in this study through observations of agonistic interactions when they were mixed to a gestation group of up to 8 sows. All in all, 36 gestating sows in their first to fourth parity were conditioned to an individual feed signal. Each trial lasted 4 weeks, one for mixing and determination of the rank order, one for classical conditioning and two for operant conditioning. The studying of rank effects contributes to the investigation of aspects for a practical use of call feeding (step 4).

Chapter 2 explains the development steps performed for the integration of the call feeding system into commercial electronic feeding stations and for the use by adult sows. This chapter also describes how the behaviour of the sows was monitored (step 2) and what provisions were taken to adapt the feeding system to the sows' behavioural differences (step 3).

Chapter 3 presents the learning results of a study testing call feeding with commercial electronic feeding stations in a larger dynamic group of up to 36 sows. This study was performed to develop best practices and to determine technical parameters for the practical application of call feeding (step 4). In addition, it investigates the dynamic effects when adopting a herd to call feeding by stepwise introducing small groups of conditioned sows into a large group of sows still performing conventional electronic feeding.

Section II: Aversive behaviour manipulation

The concept of aversive behaviour manipulation is exemplified by preliminary investigations for an active piglet crushing prevention system. Pigs pursue a reproduction strategy of delivering "a larger number of relatively undeveloped offspring" (Edwards, 2002). With this strategy, the death of a fraction of the litter allows an adaption to the previously unknown environment conditions after the 4 month lasting gestation period. Thereby pigs are able to proliferate fast under good conditions, while not straining the resources of the mother sow too much under harsh environmental conditions. Piglet mortality can be caused by survival of the fittest when competing for the limited maternal resources (Fraser et al., 1995). Other causes of mortality are illnesses, savaging of the sow and piglet crushing (Edwards, 2002). Even though piglet crushing seems to occur inadvertently, it mainly affects underweight and weak piglets (Weary et al., 1996). In this respect, piglet crushing is at least in parts a natural effect of biological selection mechanisms. Under natural conditions, these selection mechanisms provide for a survival of the fittest. However, these mechanisms are undesirable under husbandry conditions as the maternal resources are no longer restrained with respect to shelter, water and food. At the same time, the number of weaned piglets is a major economical factor for the piggery business. In this regard, the innate reproduction and nursing behaviour of the pig impairs the overall productivity and animal welfare of piggeries. Still, it remains unclear to what extend piglet mortality is an effect of the innate proliferation strategy or of breeding for fast growth and larger litters combined with little opportunity for muscle exercises (Edwards, 2002).

Early approaches to prevent savaging and piglet crushing were the restriction of the contact between the mother sows and their piglets with fenders and farrowing crates (Sommer, 1920; Barker, 1929). By these measures, the welfare of the lactating sow was reduced in order to improve the welfare of the piglets and subsequently the profitability of the piggery. More recent developments of active devices for crushing prevention tend to follow this trend. For example, Friend et al. (1989) studied a device that dispensed electric shocks to the sow in order to induce a posture change when a trapped piglet at risk of beeing crushed was assumed. However, such developments do not necessarily further impair the welfare of the mother sow. These developments could also help to improve the balance of welfare between the sow and her piglets. Compared to the approach investigated in Friend et al. (1989) techniques like the acoustic stress monitoring and documentation system STREMODO allow a more detailed classification of the vocalisation of pigs with respect to stress situations (Schön et al., 2004). This could allow a more precise detection of crushing situations. A technique for triggering posture changes of sows would then allow the transition from permanent welfare impairments such as the farrowing cage towards temporary welfare impairing methods in a free-range pen.

Chapter 4 presents the results of a study that tested floor vibration and air-blasts as aversive stimulation mechanisms to trigger posture changes in adult sows (step 1). For this study, 11 adult sows in farrowing crates were treated twice a day for 14 days during their late gestation and at the beginning of lactation. The chapter also discusses the practicability of provisions to adapt the intensity of the stimulation to the individual reactivity of a sow (step 3). In addition, the study investigated possible side effects of the stimulation on 22 untreated sows in neighbouring pens (step 4).

In order to limit the impairment of the sows' welfare by false alarms and to prevent an early habituation toward the stimulation, the use of the stimulations should be limited to the time period with the highest crushing risk. This is the period of 72 hours after the onset of parturition (Marchant et al., 2001, Wischner et al., 2010). The onset of parturition is usually not easily noticeable more than a few hours beforehand. In addition, many parturitions take place at night times, when there is less personnel observing the sows. A timely advance warning on the upcoming parturition can therefore help to economically schedule the personnel for supervision and management measures. Management measures right after the parturition are shown to improve the general survivability of the piglets (Kirkden et al., 2013). The feasibility of parturition predictions and detection was already realised in Lammers and De Lange (1986). Erez and Hartsock (1990) describe preliminary work on automatically measuring sow activity and her parturition related restlessness using light barriers. The automatic measurement of the sows' activity is the precondition for an automated detection of parturition.

Chapter 5 presents results on measuring the activity of 34 gestating sows using light barriers installed at the head and torso region of the sows. The light barriers can be used to monitor the current posture and the posture history of individual sows (step 2). This can be used to control the activation, intensification and deactivation of the aversive stimulation if a piglet seems at risk (step 3). The activity measurements in terms of posture change frequencies and durations were utilised to give qualified and quantified predictions on the duration until parturition. They were also used for the detection of the actual onset of parturition. This would allow an autonomous control of the general activation and deactivation of the monitoring of a specific pen for signs of piglet crushing (step 4).

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Section I

Chapter 1

Social hierarchy affects the adaption of pregnant sows to a call feeding learning paradigm

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Abstract

The aim of the study was to test whether adult sows are able to learn an individual acoustic signal for call-feeding in groups supplied with an electronic feeder. Further, we investigated whether and how animals of different ranks interact. Thirty-six sows were examined in 6 successive trials. In each, the animals were stalled for establishing a social hierarchy a week before the conditioning started. Agonistic interactions were observed and a dominance index (DI) was calculated for the sows of each trial. Based on the DI sows were categorised as (1) dominant, (2) subordinate, or (3) submissive. Afterwards groups were transferred to the experimental pen which was equipped with one electronic feeder supplemented with a loudspeaker and software, the call-feeding station (CFS). The training started with classical conditioning (7 days) where the animals entered the CFS spontaneously 6 times daily and received a portion of feed immediately after an individual acoustic signal had been played. In the following operant conditioning phase (13 days) the individuals had to learn that they could enter the CFS and receive feed only after they had heard their signal. The animals were called 6 times daily to feed the respective fraction of the daily feed allowance. On the average, after 8 days of operant conditioning the animals reached the learning criterion of following 80% of their calls. The success rates differed significantly between the three rank groups. In the dominant and subordinate groups 93% and 71% of the animals reached the learning criterion at the end of the experiment after 13 days of operant conditioning, while only 64% of the submissive sows did so. If only the number of successful, i.e. rewarded, enters of the station was considered those submissive animals who had reached the learning criterion did not differ significantly from the others. During learning, the time required to approach the CFS decreased significantly as well as the rate of false attempts to enter if another animal was called. At start of the operant training dominant sows blocked the entrance of the CFS. With increasing learning success of these sows this behaviour decreased significantly. The experiment has demonstrated that call feeding can be applied successfully with pregnant sows. It has the potential to increase animal welfare because, by calling them individually to the feeder, it provides the animals with a positive short time anticipation of unaffected feeding.

Key-Words: domestic pig; rank order; acoustic calling; learning; memory; cognitive enrichment; welfare

1. Introduction

In modern group housing of pregnant sows electronic feeding is a common practice. Besides advantages, such as the controlled and protected feeding of individual animals, there are also some drawbacks. Sows may compete for the access to the feeder which may lead to severe injuries (Boyle et al., 2002). In addition, animals who have already received their daily feed allowance may be frustrated when they try to enter the feeder again. Frequently there is a high animal-to-feeding place-ratio so that the animals can hardly know when they will have access to the feeder. This further may intensify aggressive competition for the entrance (Bünger and Kallweit, 1994; Anil et al., 2005). Low ranking young sows may be particularly affected by this situation. An impaired access to the feeding place will also maintain the motivation for oral activity which may lead to misdirected appetitive behaviour exercised on pen equipment or group mates.

In order to overcome these difficulties with electronic feeding we have developed a call feeding system that was derived from a previous research project with growing pigs (Ernst et al., 2005; Manteuffel, 2009). There it had been shown that the animals are well able to discriminate an individual acoustic call to a feeding place from those of other individuals. As a result the animals entered a 'call-feeding-station' only if their individual calling sound was heard being emitted by a particular station where they could receive feed. In this setup four feeding stations were provided for a group of eight animals and feeding occurred up to 31 times a day. Less fearful animals with less maladaptive behaviour and some beneficial health features resulted from this feeding regime (Ernst et al., 2006; Puppe et al., 2007).

By calling individual animals to an electronic feeder it is expected that, after learning, the animals cease to be mutually aggressive in front of the feeding station as they know that if, and only if, their individual call has appeared they surely get feed, but never if the particular sound has not been played before. Hence, mutual aggressiveness while fighting for positions close to the feeder would not lead to any advantage for them.

Call feeding has also the potential to be a 'cognitive enrichment' (Manteuffel et al., 2009 a). Learning an instrumental behaviour, as following an acoustic summons in order to get a reward, includes three consecutive phases: first, the detection of a discriminatory stimulus that is contingent to the primary motivating feed reward, second, shaping of behaviour to get access to the reward, and finally complete control over the task. In the last two phases, anticipating reward after the appropriate instrumental behaviour has a positive emotional effect (Martin and Ono, 2000; Spruijt et al., 2001; Manteuffel et al., 2009 b). Anticipation and behavioural control – the certainty that the appropriate behaviour will result in the expected outcome – are relevant factors for increasing the welfare of animals (Bassett und Buchanan-Smith, 2007).

In order to test pregnant sows for their ability to adapt to individual call feeding we have modified a commercial electronic feeder to call animals out of a small group to feeding. In common electronic feeders individual animal recognition is already included so that an important requirement was already fulfilled. We have added a software routine for training and calling the animals and recorded the speed and quality of learning. With this setup we tested the hypotheses that (1) group housed sows are able to learn an individual acoustic signal as a call for feeding, irrespective of their social position in the group, and that (2) during the training dominant behaviour decreases, particularly blocking the access to the feeder's entrance.

2. Material and methods

2.1. Animals and housing

The present study was conducted in the experimental pig unit of the Leibniz-Institute for Farm Animal Biology (FBN), Dummerstorf, Germany. Forty-eight pregnant sows (German Landrace, 9th/10th week of pregnancy) were gathered in six test groups (n = 8 sows per group) for serially replicated trials. Before being grouped for the experiments all sows had been group housed (group size in each home pen = 4 animals, according to the usual conditions in the institute's pig unit) with feeding boxes (Jyden Dantec JB5000) and an animal to feeding place ratio of one. The feed consisted of standard feed-pellets for pregnant sows (Trede & von Peine, Landhandel und Mischfutterwerke, Dammfleth, Germany, feed allowance 2400 g / day). Water was available *ad libitum*. Within the test groups the ages ranged randomly from 10 months (first parity) to 1 year 8 months (fourth parity).

Twelve animals had to be removed because they were not fertilised (n = 3) or were injured in fights during mixing (n = 4) or had problems with the new feeding situation already with standard electronic feeders (n = 5). Hence, the entire experiment was carried out until the end with 36 animals (trial, number of animals): (1, 7); (2, 5); (3, 6); (4, 5); (5, 6); (6, 7).

2.2. Experimental setup

After one week of social habituation of the experimental groups by joining two adjacent home pens with feeding boxes, the experimental groups were transferred to the experimental pen (Fig. 1) measuring 7.20 m x 5.50 m (partially slatted floor: 7.20 m x 2.00 m) which was partially separated by a wall (L x H: 3.00 m x 1.50 m) to create a hiding area. The pen was equipped with an automatic electronic feeder modified as a call-feeding-station (see below). The experimental schedule and the measured variables are depicted in Fig. 2.

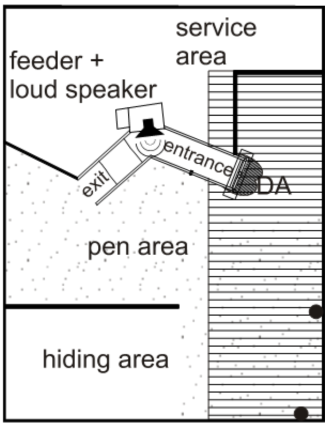

Fig. 1. The experimental pen with the call feeding station. The obliquely hatched region before the entrance of the feeding station marks the area where individual animals were detected automatically as being close to the station's entrance (DA = detection area). The stippled region marks the pen area where the behavioural observations for the determination of the dominance index were made. Horizontal hatching: slatted floor, filled circles: locations of nipple drinkers.

2.3. Determination of the rank groups

Agonistic interactions (AI) were observed as overt fights or displacements of dyads of sows with physical contact initiated by one individual, resulting in any form of submissive behaviour by the opponent (for a detailed description of typical fighting elements see Rushen and Pajor, 1987; Langbein and Puppe, 2004; Puppe et al., 2008). AI were directly observed in each experimental group for two hours on each day during the week of social habituation and on day 1 (after transfer to the pen area) and day 3 of phase I in the pen area (Fig. 1), i.e. without the context of feeding.

The dominance index for each individual (I) and each trial (Langbein and Puppe, 2004) was calculated as

$$DI_I(\%) = 100 \times \frac{\mathrm{N_{subordinates}}}{\mathrm{N_{subordinates}} + \mathrm{N_{dominants}}}$$

where $\mathrm{N_{subordinates}}$ is the number of animals who lost most of the fights against individual I and $\mathrm{N_{dominants}}$ is the number of animals who won most of the fights against I (Lamprecht, 1986).

In each trial the animals were then classified according to their DI into three rank groups: Rank group 1 (dominants, DI 67 – 100), rank group 2 (subordinates, DI 34 – 66), rank group 3 (submissves, DI 0 - 33).

2.4. Call feeding station

The call feeding station based on an electronic feeding station for pregnant sows type INTEC MAC (PIGTEK EUROPE GmbH, Schüttorf, Germany) which was controlled by a main computer.

The station entrance measured L x W = 1.50 m x 0.60 m, the station exit L x W = 1.10 m x 0.60 m and the trough area L x W = 0.55 m x 0.45 m, all with a total height of 1.30 m. Two one-way door traps were installed within the exit area so that no other animal was able to enter via the exit. The access to the station was controlled by a door. A feed dispenser above the trough was lowered only if an animal had to be fed. The call control and protocol program was designed at the FBN. The electronic feeder was additionally equipped with a loudspeaker above the trough.

All animals were provided with a commercial ear transponder type MAC Mannebeck Animal Control (PIGTEK EUROPE GmbH, Schüttorf, Germany). This made it possible to register the sows' presence within a 30 cm semicircular transponder detection range in front of the station's entrance (Fig. 1) and at the trough at a rate of 10/min in the operant conditioning phase (II) of the experiment. In the classical conditioning phase (I), when the entrance was always open, the animals were recorded at the trough only.

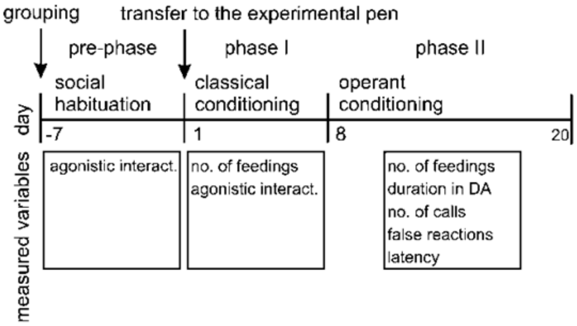

Fig 2. The phases of the experiment and the variables measured.

2.5. Learning Procedures

The animals were conditioned corresponding to the procedure described by Ernst et al. (2005).

2.5.1. Phase I – classical conditioning

The classical conditioning phase (phase I) lasted seven days. The sows could voluntarily enter the electronic feeder six times daily between 06:00 h – 20:00 h with a break between noon and 13:00 h. The station entrance was always open until an animal with a residual feed allowance entered which then triggered closing. The individual call was played and immediately afterwards a 400 g portion of feed was dispensed. If an animal missed one of the 6 feedings the last feed contingent was added to the next amount of feed. During this phase sows should learn the association between their individual call and the food reward.

2.5.2. Phase II – operant conditioning: call feeding

The operant training lasted two weeks starting with experimental day 8 up to day 20. In this phase the station entrance was closed. Hence, the animals could not go into the feeding station voluntarily, but only after the individual call had been played before. Then the station's door opened if the called animal was detected in the area in front of the entrance (DA, Fig. 1). Immediately before the feed was released the call was played again to reinforce the association with the reward.

The general time regime was the same as in phase I, including six daily feedings for each animal. The routine was organised in six feeding cycles including one call for each animal in the group in a random order. The animals obtained a feed portion of 400 g after each successful visit of the station. As in phase I, a missed portion was added to the next feed contingent so that the animal received its daily allowance with one feeding in the extreme case of following only one call. The amount of feed was adapted to the respective learning performance so that the sows got 100% of the recommended daily feed allowance with 80% learning success.

Various trisyllabic 'names' were used as individual acoustic calling sounds. The 'names' were created such that no combination of three vowels occurred twice resulting in a stock of 121 words. Eight of them were chosen for the experiment: (Kassandra, Honolu, Ambrosi, Votavo, Irene, Pireos, Direnum, Fustilim). All names were spoken in German pronunciation. Those with more high vowels (e, i) were spoken by a female, whereas names with more low vowels (a, o, u) were spoken by a male voice in order to make the discrimination as easy as possible. In each group the names were randomly attributed to an animal before the experiment started.

The calls were played with a mean loudness of 60 dB and repeated every 30 sec for 5 min, at maximum. The repetition stopped when the called animal had entered the station but was repeated once immediately before feed was dispensed. The minimum time span between calls of different animals was 7 min.

All calls, animal detections in the entrance region (DA), time between first call and enters of the station as well as number of successful visits (feedings) were recorded automatically by the control software.

2.5.3. Learning behaviour

The data of learning behaviour included the variables latency, correct responses, false approaches, number of calls until the learning criterion was reached, number of effective training runs (successful feedings), and duration of staying in the detection area of the CFS.

$$Latency(s) = delay\ between\ the\ first\ call\ and\ the\ feed\ release$$

$$Correct\ responses(\%) = 100 \times \frac{\text{Number of feedings (correctly responded calls)}}{\text{Number of all calls of the individual}}$$

$$False\ approaches(\%) = 100\ \times \frac{\text{Number of false reactions (approaches to other animals' call)}}{\text{Number of all calls of other animals}}$$

The criterion for completed learning was set to 80 % correct responses.

2.6. Weight development

The weight development of the sows was measured before transfer in the experimental pen and directly after the test period. The expected average daily weight gain of 450 g (standard of FBN sow population) was reached by the experimental animals with no significant difference between the rank groups.

2.7. Statistical analyses

The statistical analyses were generated using SAS/STAT software, Version 9.2 of the SAS System for Windows (© 2009 SAS Institute Inc.). All response variables of the operant learning phase in the experiment were analysed by fitting and testing generalised linear models applying the GLIMMIX procedure (SAS, 2009). In all models repeated measures on the same animal were taken into account by the residual option in the random statement of the GLIMMIX procedure to construct the block diagonal structure of the residual covariance matrix for each animal.

For response variables being a binomial proportion (correct responses, false approaches) a logistic model (distribution=binomial, link=logit) with the fixed effects rank group (levels: dominant, subordinate, submissive), day (levels: days 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20) and repetition of the experiment (levels: trials 1, 2, 3, 4, 5, 6) and the interaction *rank group* × *day* was fitted and tested.

For the count variables number of calls and number of feedings until 80 % success a Poisson model (distribution=Poisson, link=log) was used with the fixed effects rank group (levels: dominant, subordinate, submissive) and repetition of the experiment (levels:trials 1, 2, 3, 4, 5, 6) and their interaction.

The continuous response variables (latency, duration) were analysed by ANOVA (distribution=normal, link=identity) with the fixed effects rank group (levels: dominant, subordinate, submissive), day (levels: days 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20) and repetition of the experiment (levels:trials 1, 2, 3, 4, 5, 6) and the interaction *rank group* × *day* in the final model.

In addition, the models for the variables correct responses and duration were modified by a continuous day effect to estimate and test the intercepts and slopes of the regression lines for the rank groups.

Least-squares means (LSM) and their standard errors (SE) were computed for each fixed effect in the models and all pair-wise differences between these LSM were tested. For LS-means corresponding to the main effects (rank group, day, repetition of the experiment) in the models the Tukey-Kramer procedure was used for multiple comparisons. Meaningful comparisons of LSM corresponding to an interaction term in a model (e.g. comparison of days within a rank group, comparison of the rank groups within a day) were done by the Bonferoni procedure. A probability of 0.05 was chosen as the level of significance.

3. Results

3.1 Learning success

Over all rank groups there was a steady increase of correct responses during the days of operant conditioning ($F_{12,396}$ = 24.66, p < 0.001). The average speed of learning of the groups (slopes of linear regression: +5.36 % per day in dominants, +4.81 in subordinates, and +4.54 in submissive animals) differed significantly from zero (p < 0.001), i.e. learning occurred. However, the slopes were not significantly different between the rank groups (Fig. 3), i.e. their leaning speed was similar. Overall, a significant difference was revealed between the dominant and submissive rank groups (t_{28} = 2.56, p < 0.05) as a result of the different offsets of the learning success at start of the operant phase (Fig. 3). In parallel to increasing learning success, the number of errors, i.e. falsely approaching the CFS when another animal was called, decreased during learning (fixed factor day: $F_{12,396}$ = 4.08, p < 0.001) (Fig. 4). As an overall effect the dominant sows displayed more erroneous approaches than the submissive animals (t_{28} = 3.74, p < 0.01).

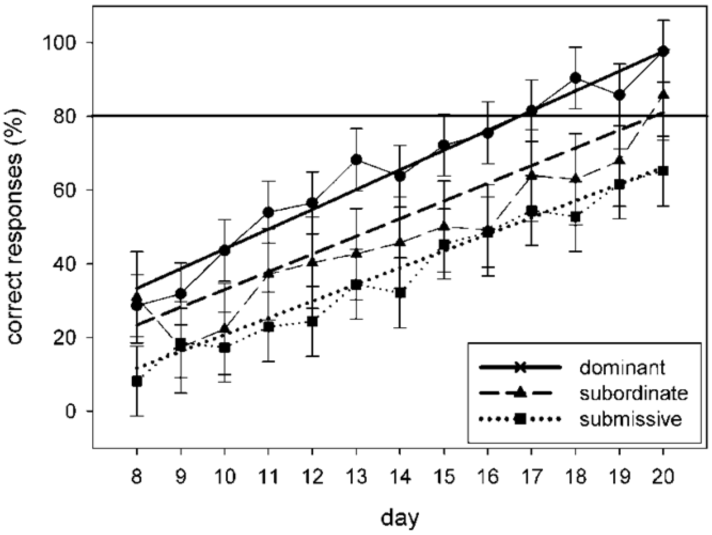

Fig. 3. Learning success and the respective linear regressions in the operant learning phase (experimental day 8 – 20) of the three rank groups (LSM ± SE). The 80 % learning criterion is indicated.

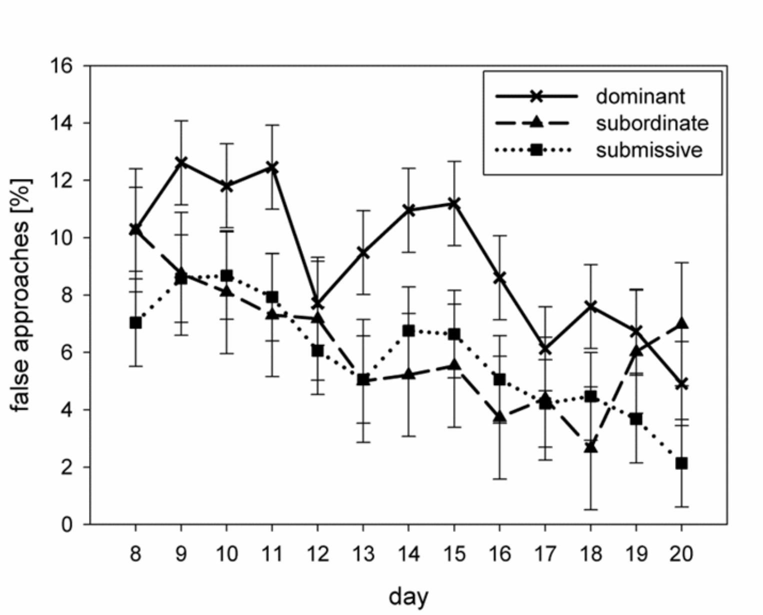

Fig. 4. Percentage of approaches to the CFS when other animals were called in the three rank groups during the operant learning phase (LSM ± SE).

On the average over all rank groups 50.5 ± 6.0 calls, corresponding to 8.4 days, were required to reach the learning criterion of 80 % correct responses. The rank group significantly affected the number of calls needed to reach the criterion ($F_{2,16} = 4.23$, $p < 0.05$). In one trial no submissive animal reached the learning criterion. The submissive sows who reached it (64 %, compared to 71 % of the subordinates and 93 % of the dominants) needed significantly more calls (79.7 ± 13.9) compared to the dominant animals (39.6 ± 6.4, $t_{16} = -2.77$, $p < 0.05$). However, since their correct response proportion was in general lower the submissive sows did not differ significantly in the number of feed rewards (i.e. number of correctly responded calls) until the learning criterion was reached. This means that they roughly needed the same number of operant training runs, rewarded by feed, to reach the same learning success. The dominant sows required on the average 18.9 ± 2.1 feedings, the subordinate sows 19.1 ± 3.7 feedings, and the submissive sows 27.6 ± 3.8 feedings. Averaged over all rank groups 21.5 ± 1.7 rewarded training runs were needed to reach the learning criterion.

3.2. Latency until entering the call feeding station

With an increasing learning success and a decreasing error rate the time which the animals needed from the first call until entering the CFS (latency) also decreased significantly (fixed factor day: $F_{12,396} = 5.27$, $p < 0.001$). The effect was most pronounced in the high and medium raking animals (Fig. 5) resulting in a significant difference to the submissive sows (fixed factor rank group: $F_{2,28} = 3.55$, $p < 0.05$).

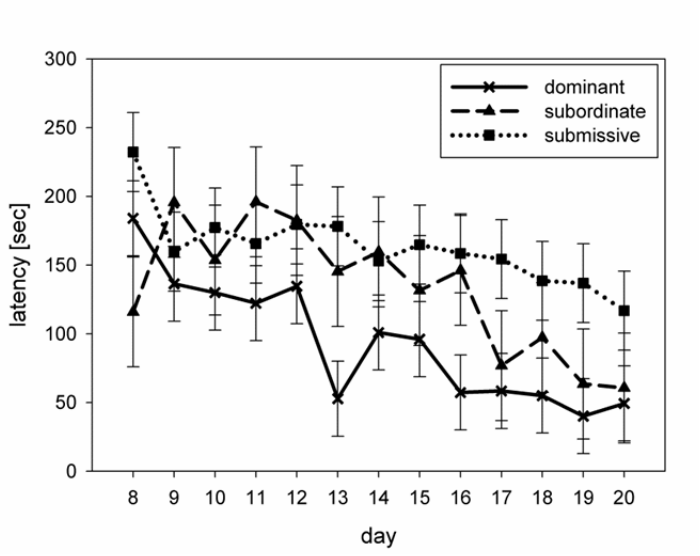

Fig. 5. Time until entering the CFS after the first call in the three rank groups during the operant learning phase (LSM ± SE).

3.3. Time spent in front of the call feeding station

High ranking sows spent more time in front of the CFS than low ranking animals (fixed factor rank group: $F_{2,28} = 3,94$, $p < 0.05$). During learning the animals significantly decreased the time (fixed factor day: $F_{12,396} = 3.36$, $p < 0.01$) of staying in the detection area (Fig. 6). The reduction was most pronounced in the highest ranking animals compared to the lowest ($t_{429} = 2.54$, $p < 0.01$; slopes of linear regressions: dominates: -0.79 min/day, ≠ 0: $p < 0.0001$; submissives: -0.35 min/day, ≠ 0: $p < 0.01$, subordinates non-significant against zero).

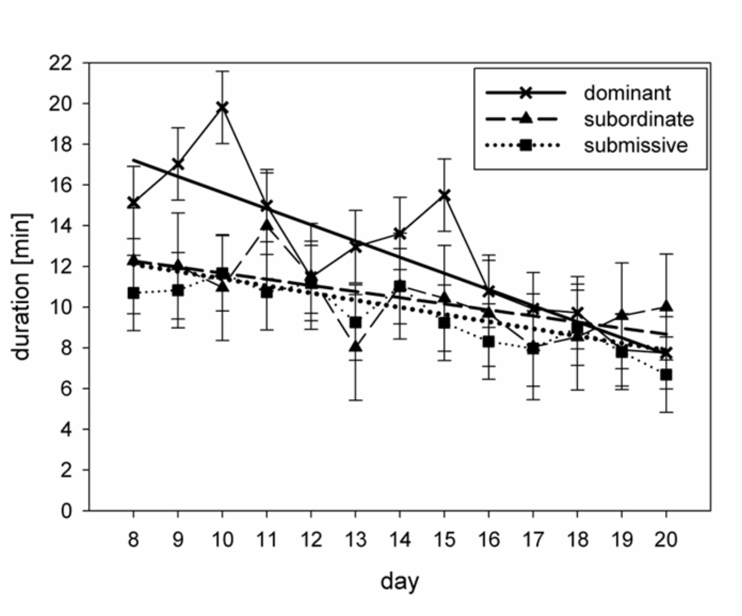

Fig. 6. Duration of staying in the detection area of the CFS and the respective linear regressions in the three rank groups during the operant learning phase (LSM ± SE).

4. Discussion

We could demonstrate that call feeding can be applied successfully to pregnant sows. The chosen acoustic cues, spoken trisyllabic words, seemed to be completely adequate for the sows to be discriminated. Compared to an earlier study with young pigs where harmonic sounds had been applied (Ernst et al., 2005; Puppe et al., 2007) the sows needed less training runs until learning was completed. While these papers reported 4–5 days with 24 calls per day until criterion (hence a total of about 100 calls) the sows in our present study needed about 50 calls. In the studies with growing pigs four call feeding stations with a simpler construction had been installed in a pen with eight animals who had to discriminate the particular station that was signaling with the respective individual calling sound. This higher difficulty probably accounted for the larger number of required calls in the former study.

During the operant conditioning the animals increased their learning success daily. This was displayed by an increasing number of followed calls, a decrease of false approaches to calls of other individuals and a parallel decrease of latencies between the first call of an individual and the appearance at the trough.

Submissive animals reached the learning criterion later. They followed less calls during the same time than the medium and high ranking animals and needed significantly more calls until they reached the learning criterion. Some did not reach the criterion at all until the end of the experiment. However, when they succeeded they needed about the same number of feed rewarded calls until criterion as higher ranking animals. Hence, they were not worse learners. The important factor was that low ranking sows were frequently hindered by higher ranking animals in the first days of operant learning, or they were fearful when such an animal was on the way to the station (Jensen, 1982). Consequently they needed longer time to approach the CFS and they missed a higher number of calls.

Dominant sows stayed significantly more frequently close to the feeding station than submissive animals, which probably were kept away from the feeder by the dominants. After learning had been accomplished by all animals of the group, stays and aggressive encounters in front of the feeder occurred very rarely. Even the dominant animals then obviously had learned that such behaviour did not yield any advantage for getting feed.

The occupation of the area in front of the feeder by dominant animals seems to be a general phenomenon (Wredle et al., 2006). This can happen most easily if only one feeding station is present for a group of animals, largely independent of group size, which was small in our experiment. In the call feeding experiments with growing pigs (Ernst et al., 2005; 2006; Puppe et al., 2007) four feeders were in a pen for eight animals. Then, a dominant animal was hardly able to block a station because it simply could not know which one would be calling next. Various restraints of practical applications will, however, make it highly unlikely that more than one comparatively expensive electronic (call) feeder will be provided for a group of pigs. In the case of pregnant sows group sizes will be even much larger (usually about 50 – 60 animals) than in our experiment. It will be a future task to test call feeding with such group sizes. This will surely demand a further adjustment of the management software. To leave the scientifically justified random calling and instead consider rank positions in the order of calling may be a promising way. Then, high ranking animals could be called first during the initial learning phase so that their motivation to be close to the station's entrance decreases. Based on the data of the present study one can expect that they stop blocking behaviour once that they are well-trained for their individual calls.

It had been proposed that instrumental learning and behaviour might be a source of cognitive environmental enrichment (Manteuffel et al., 2009a,b) that may result in positive emotions in farm animals (Boissy et al., 2007). Compared to a normal electronic feeder the additional calling clearly demands sharp acoustic sensing. During learning the individual sound signature becomes more and more closely associated with the reward. After learning has been completed each animal still has to discriminate the environmental sound steadily in order to get access to feed. This might be even a general training of acoustic attentiveness that can be useful in general, e.g. while nursing piglets (Hutson et al., 1991; Wechsler and Hegglin, 1997). In addition, the reliable anticipation of a primary reward is by itself rewarding (Spruijt et al., 2001; Dudink et al., 2006; Manteuffel et al., 2009a,b) since it activates brain regions that are closely related to positive feelings (Fiorino et al., 1993). By measuring the heart activity during individual call feeding in growing pigs it has been revealed that parasympathetic activity after receiving feed raises quicker and is more sustained than in standard trough feeding. Moreover, well-trained individuals do not react with excitement to other animals’ calls (Zebunke et al., 2008).

Hence, we conclude that if the above would be considered both the mental and physical welfare of pregnant group-housed sows would be increased. Short time anticipation of unaffected feeding is warranted when the animals know that they surely will get feed. In well-trained herds, fights for entrance to the feeder will in parallel be few.

Acknowledgement

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Chapter 2

Beyond electronic feeding: The implementation of call feeding for pregnant sows

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Abstract

Call feeding for pregnant sows is a novel modular extension of a conventional electronic feeder (PigTek INTEC MAC) communicating via ISOagriNET. The call feeding module (CFM) assigns individual calls to each animal of a group supplied by one feeder and trains them to associate that call with feed access. Afterwards it actively calls sows to the feeder in a variable sequence in order to minimise queuing and thereby reducing aggression, stress and injuries associated with feeding. In this paper, we describe the automatic training procedures, the principal technical design and implementation details that make call feeding applicable in practice. The automatic training consists of an initial Pavolvian conditioning during standard electronic feeding and a subsequent operant conditioning. During Pavlovian conditioning the sows may enter the feeder whenever they have remaining feed allowance. An individual acoustic signal is then played immediately before the feed is dispensed. In the operant training the sow learns by experience that she can enter the feeder only after the individual acoustic signal had been presented. The training modes and their durations are individual to each sow's learning success. Undersupply with feed due to incomplete learning is prevented by the training routines without manual intervention by controlling automatically the proportion of operant and Pavlovian conditioning. Thus, introducing call feeding in an existing herd is possible. The implementation is further able to estimate roughly the social hierarchy and incorporates this in the calculation of the call sequence in order to attenuate feeding associated aggressions. It helps to provide the animals with a positive anticipation of safe feeding and thereby offers a suitable way to improve welfare and health of pregnant sows. Being automatically controlled, it is easy to apply and has the potential to become a promising future element of precision livestock farming.

Key-Words: pig farming; pregnant sows; computer controlled feeding; precision livestock farming; animal welfare

1. Introduction

The EU directive 2001/88/EG regulates that, from January 2013, every pregnant sow must be group housed. Electronic feeding is a common feeding technique for group housing. It can be applied in older, angled stables and can be easily adapted to larger group sizes. With electronic feeding, the sows are fed one by one and isolated from the group in a feeding station. The animal recognition and management is performed using radio-frequency identification (RFID) earmarks. Combined with appropriate animal management and handling, electronic feeding has been applied successfully for decades, but not without difficulties.

Feeding is often the only diversion for pigs in an industrial farm environment. Together with a restrictive feed rationing this may result in an increased affinity to the feeding station and an intensified aggressive behavior in its vicinity. Weber et al. (1993) showed that with electronic feeders the number of aggressive interactions is strongly correlated to the time of feeding and that aggressive interactions most frequently occur while queuing at the feeders' entrance. Similar results were found by Jensen et al. (2000) and by Anil et al. (2006). In comparison to other feeding systems for group housing, electronic feeding has an increased number of aggressions (Hunter et al. 1988, Zurbrigg and Blackwell 2006). More aggressions induce more injuries and can have a negative effect on the productivity and fertility of the animals (Arey and Edwards 1998).

The call feeding concept developed by our group at the FBN is a modification of normal electronic feeding, where the feeding order is not competitive, but the animals learn individually that a specific acoustic stimulus signals feed (Ernst et al. 2005, 2006, Puppe et al. 2007). The calling is a reliable feeding indicator and allows each animal to anticipate its own feeding in a short time scale (Bassett and Buchanan-Smith 2007, Manteuffel et al. 2009a). In addition, by allowing feed access only if the sows correctly react to their signal, they learn that fighting for feed access does not lead to any advantage for them (Manteuffel et al. 2010). Hence, with a well established call feeding system, it can be expected that every sow is will wait for its individual feeding call in the resting area and will ignore the feeding of the others. Using an individual feed signal should therefore inhibit the fighting between animals in front of the feeder and diminish negative effects of conventional electronic feeding.

A study on 70 adult pregnant sows using our novel call feeding technique has demonstrated that call feeding can be applied in a farm environment (Kirchner et al. 2010). The same study also has confirmed that call feeding effectively reduces feeding related fights and injuries. In addition, call feeding provides the animals with a demanding task of listening for and reacting properly to a particular sound. Accomplishing this task is rewarded with highly motivating feed. Theoretical considerations (Manteuffel et al. 2009b) as well as behavioural and physiological research (Ernst et al. 2005, Ernst et al. 2006, Puppe et al. 2007, Zebunke et al. 2011) indicate that this induces positive emotions in the animals.

In this paper, we describe the features of the technical implementation of call feeding developed by us for pregnant sows that makes it feasible in farming practice.

2. Material and methods

2.1. Hardware

INTEC MAC electronic feeding stations, provided by the PigTek Europe GmbH (Schüttorf, Germany), were used as the basis for the call feeding installation. The feeder was equipped with two RFID antennas, one at the trough and one at the door that protects the entrance area. The use of two RFID antennas gives more detailed information on animal activity at the station, which was essential for the training explained in Section 3.2. The feeder also featured automatically closing entrance doors and an exit area that was protected by a one way gate using two mechanically coupled doors. This way, a sow was completely isolated from the other animals of the group, while feeding.

For its utilisation as call feeding station the INTEC MAC electronic feeder was equipped with an ACTURION DURIOS notebook (Acturion Datasys GmbH, Sauerlach, Germany) that hosted the call feeding module (CFM) software, a VISATON WB-16 loudspeaker (VISATON GmbH, Haan, Germany) and an IC AUDIO MX-AMP 60T amplifier (ic audio GmbH, Mannheim, Germany). The communication between the INTEC MAC feeders, the central PigTek AGNES-server and the CFM was realised using ISOagriNET. There was one CFM per INTEC MAC feeder with the amplifier and loudspeaker connected directly to the CFM. In addition, the firmware software of the INTEC MAC feeder had been modified to work in a call feeding mode. This setup allows a modular extension of conventional electronic INTEC MAC feeders to become call feeding stations by simply establishing an Ethernet connection to the CFM and updating the feeder’s firmware.

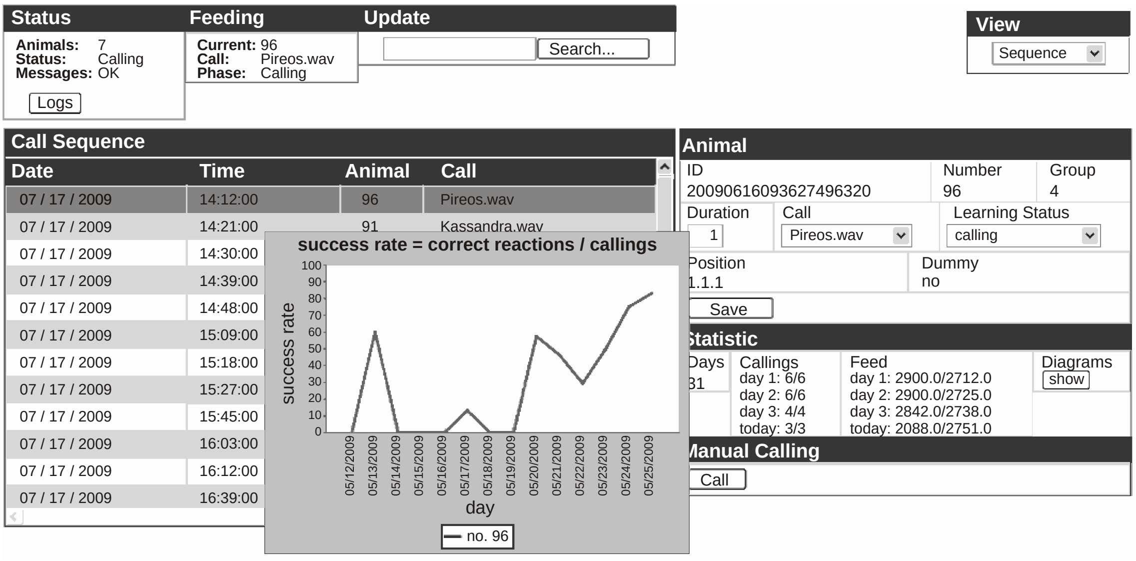
2.2. Program environment

The entire call feeding related software was implemented using the Java programming language (Oracle Corporation, Redwood City, USA). The software component responsible for calling the animals ran as a stand-alone service in a Linux environment (Canonical Group Limited, London, UK). A C++ software implementation of ISOagriNET operations was kindly provided by the PigTek Europe GmbH and was integrated using a Java Native Interface (JNI) wrapper also provided by PigTek.

For the display of the operation status of the CFM, the status of each animal and for configuration purposes a user interface was provided (Fig. 1). It included

- the animals associated calls and their estimated social rank,
- recent and future feedings,
- the total amount of feed fed per animal,
- diagrams that depict the learning success of individual animals and
- a journal of recent events.

The user interface was implemented as a dynamic web application using asynchronous JavaScript and XML (AJAX) technology with the help of the Google Web Toolkit (GWT) (Google Inc., Mountain View, USA). The dynamic diagram generator was realised using the Cewolf framework (Geeknet, Fairfax, USA) which is based on Servlet and Java Server Pages technology. Apache Tomcat (The Apache Software Foundation, Forest Hill, USA) served as application container. A shared MySQL database (Oracle Corporation, Redwood City, USA) was used to store animal data and to establish an interprocess communication between the user interface and other software components.



Animals: 7
Status: Calling
Messages: OK

Current: 96
Call: Pireos.wav
Phase: Calling

Date	Time	Animal	Call
07 / 17 / 2009	14:12:00	96	Pireos.wav
07 / 17 / 2009	14:21:00	91	Kassandra.wav
07 / 17 / 2009	14:30:00		
07 / 17 / 2009	14:39:00		
07 / 17 / 2009	14:48:00		
07 / 17 / 2009	15:09:00		
07 / 17 / 2009	15:18:00		
07 / 17 / 2009	15:27:00		
07 / 17 / 2009	15:45:00		
07 / 17 / 2009	16:03:00		
07 / 17 / 2009	16:12:00		
07 / 17 / 2009	16:39:00		

ID	Number	Group
20090616093627496320	96	4

Duration	Call	Learning Status
1	Pireos.wav	calling

Position	Dummy
1.1.1	no

Days	Callings	Feed
31	day 1: 6/6 day 2: 6/6 day 3: 4/4 today: 3/3	day 1: 2900.0/2712.0 day 2: 2900.0/2725.0 day 3: 2842.0/2738.0 today: 2088.0/2751.0

Fig. 1. CFM user interface. The upper left area displays status information. A selector for different views of the user interface is located in the upper right area. The lower left area shows the current call sequence and the lower right area the details of the currently selected animal. The graph in front depicts the recent rate of successful calls of the animal.

3. Implementation characteristics

3.1. Call feeding

With call feeding, the CFM pre-calculates call sequences for the feeding periods of the next few days. Each day may have one or more feeding periods and breaks where no feeding takes place (resting periods). Each feeding period consists of one call sequence that includes all trained animals fed by this station. This sequence predetermines which sow to feed and when. There is a time interval with a fixed minimum and a variable total length between two adjacent feedings in order to give each sow enough time to feed. The organisation of feeding periods, breaks and feedings is shown in Figure 2.

Figure 3 displays the data, actions and decisions incorporated in call feeding. For each feeding (Fig. 3: “start calling next sow in sequence”), a call is repeated every 30 seconds for an adjustable maximum response time (e.g. three minutes). The repetition is stopped if the called animal enters the feeder (Fig. 3: “feed sow at trough”). If the sow does not appear within the response time, its feeding is re-scheduled as long as there is enough time left in the feeding period (Fig. 3: “schedule repetition” on “timeout”). For animals that completely miss a feeding period, the feed contingent is added to contingent of the next period. If an animal has a remaining feed allowance at the end of the day its feed contingent can be increased manually for the next days.

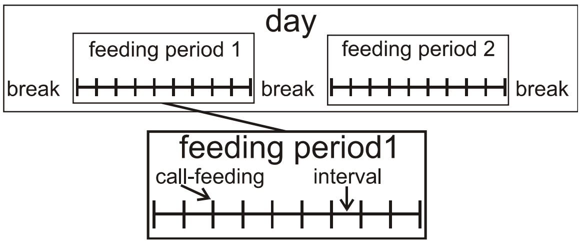


Fig. 2. Organisation of feeding periods. The rectangles labelled ‘‘feeding period’’ stand for one feeding of all animals. In each feeding period one call feeding sequence, depicted as fence structure, determines which sow to feed and when. Each picket of the ‘‘fence’’ stands for the calling of one sow. The space between ‘‘pickets’’ symbolises the time interval between two scheduled feedings.

Call feeding allows a configuration of the feeding time, feeding amount and feeding technique that is individual to each animal. In particular, the CFM distinguishes the three feeding techniques *training*, *call feeding* and *electronic feeding* that can operate in parallel and can be assigned to the sows individually. This is an essential feature for adapting herds to call feeding. The training of inexperienced sows is recommended to be performed in smaller training groups of about 8 animals for a week or two because a higher number of timeouts and false reactions can be expected. Afterwards, these groups can be integrated into large groups that may still consist in part of untrained animals. The feeding of untrained and inexperienced animals in large groups requires enough time without callings. This can be taken into account with the configuration of the call sequence by increasing the minimum call interval and by reserving extra time within the feeding period.

3.2. Conditioning

The call feeding implementation features a mechanism for an automatic and unsupervised training. The training result can be measured in terms of the learning success as the ratio of reactions and correct reactions (Eq. 1). This ratio is one if the sow is well trained i.e. the animal responds only to its own call and does not react otherwise.

$$\textit{learning success} = \textit{correct reactions} / (\textit{correct reactions} + \textit{false reactions}) \qquad (1)$$

, where correct *reactions* = number of successful call-feedings and *false reactions* = appearing at feeder's entrance after callings of other animals. The conditioning mechanism is automatically activated for newly introduced animals. It can also be activated and deactivated manually using the CFM user interface. Figure 4 displays the data, actions and decisions incorporated in the conditioning mechanism.

The CFM decides whether to continue conditioning based on the individual learning success data. In the conditioning mode, Pavlovian conditioning and operant conditioning are applied in a mixed way. With Pavlovian conditioning the sows have an unrestricted access to the feeder. The conditioning is then performed by playing the individual sound just prior to the feed release (Fig. 4: “conditioning”) which causes an association between the feeding and the sound of the individual call. The operant conditioning requires the sows to react on their individual call. This strengthens the sound-feeding association by active experiences. During the training, the feeding mechanism gradually shifts from unrestricted feeder access to call feeding in accordance to the individual learning success of the animal. Because the proportion of Pavlovian and operant conditioning depends on the learning success, a low learning success does not result in a lowered feed intake (Fig. 5).

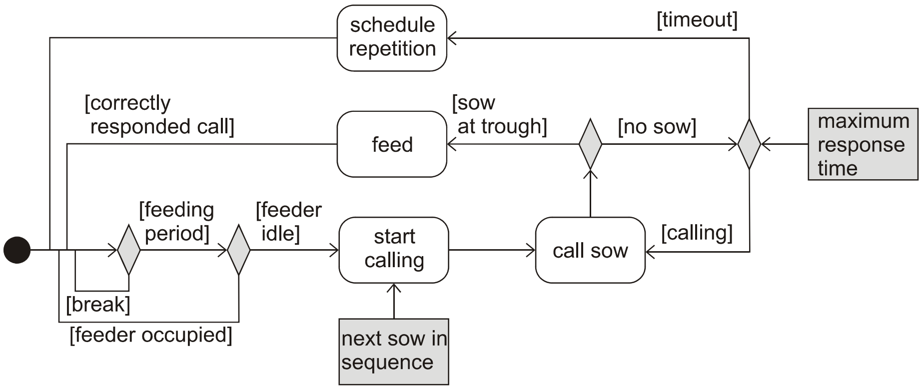


Fig. 3. Call feeding mode of operation. UML activity chart where diamond shapes depict decisions, rectangles with rounded edges stand for activities and filled rectangles for data. Arrows between these elements mark the flow of activities, data and states.

Animals that still do not react to their calls after two weeks of training could rerun the training individually and without removing them from the group. Furthermore, deafness or permanent learning failure should be taken into consideration. Such unsuited animals can be integrated into the group by permanently applying mixed feeding techniques as described in Section 3.1. Our experiences show that these cases occur very rarely (Kirchner et al. 2010).

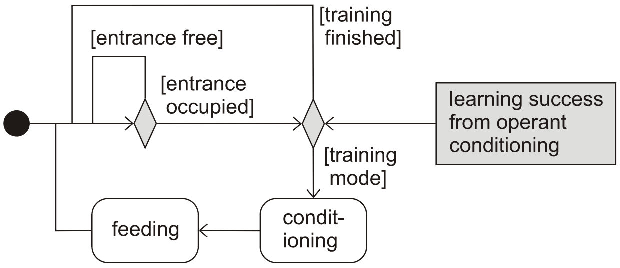


Fig. 4. Pavolvian conditioning. UML activity chart where diamond shapes depict decisions, rectangles with rounded edges stand for activities and filled rectangles for data. Arrows between these elements mark the flow of activities, data and states.

3.3. Feeder efficiency

With normal electronic feeding the feeding sequence depends on the behavior of the sows to compete for restricted resources. This frequently leads to agonistic interactions. The effect is, however, that the time span between two feedings is short, whereas with call feeding it is affected by the performance of the animals. A poor performance of a sow results in a time overhead that increases the time span to the feeding of the next animal. The higher the sum of the time spans between feedings the less sows can be fed with the feeder. The theoretical maximum number of animals per feeding period can be calculated from the feeding period length, the mean latency and the average number of non-responded calls (Eq. 2).

$$pigs(l) = (l - C \times T) / (F + L) \qquad (2)$$

, where l = length of one feeding period, T = mean number of non-responded calls (timeouts) and L = mean time elapsed between the events „start calling“ and „feed“ (latency), C = minimum time between two feedings (Fig. 2 “interval”) and F = mean time elapsed between the events „feed“ and „feeder idle“ (feeder occupation). Here, the mean duration of the feeder occupation, the mean latency and the mean number of timeouts are constants based on practical experience.

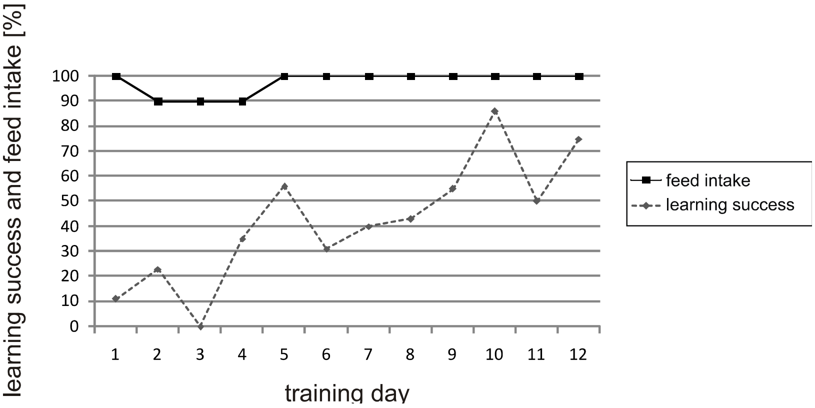


Fig. 5. Decoupling of learning success and feed intake. The continuous curve shows the feed intake and the dashed curve the learning success of a single sow. The diagram presents the first 12 days after the introduction of call feeding. Data were taken from unpublished pretests performed at the FBN.

3.4. Animal management

The CFM is tightly integrated into the PigTek animal management procedures in order to create as little extra effort as possible for the herd manager. Data of newly introduced sows can be configured manually using the standard “PIG-MAC/PC” web application or are configured automatically once they are recognised at the feeder's entrance. Either way, by accessing the data of the PigTek server the CFM notices the animals and automatically assigns non-used calls to them. After at least one sow has been registered, the CFM automatically starts to calculate call sequences and begins to feed. New sows are included immediately in the sequence and displayed in the animal lists of the CFM user interface. Besides the automatic calling, individual sows can also be called manually. This might help the herd manager to select and separate single sows or to visually inspect the learning success of a sow.

The CFM also takes notice when a sow proceeds to farrowing. In this case, the animal's data including the call persist until return. A call is automatically released for a new assignment only if an animal leaves the herd permanently. For the calls, 125 trisyllabic 'names' have been created, where no combination of three vowels occurred twice. These 'names' are stored as single files at the CFM. They can be extended at any time as the number of possible words grows exponentially with every additional syllable.

4. Additional program routines considering animal behavior

4.1. Consideration of social hierarchy

At an electronic feeder the feeding order among the animals is strongly determined by social rank. Higher ranking animals tend to eat earlier than low ranking ones (Hunter et al. 1988, Ritter and Weber 1989, Hoy 2007). There are indications that higher ranking sows actively hinder the feed access of lower ranking sows and can thereby lead to an increased number of timeouts and mean latency (Manteuffel et al. 2010). A rough estimation of the social hierarchy of pigs can be derived from the weight and the age of the animals (Ritter and Weber 1989). Most sow management software keeps track of this information, which can then be utilised by the CFM. In order to minimise latency and the number of timeouts the CFM creates three dominance categories based on age and divides the feeding period into three sections, one for each category. In these sections, members of the corresponding dominance category are called randomly. By calling randomly, the sows are not able to anticipate the time when they are called. This prevents the animals from learning the call sequence instead of their individual calls. Hence, independent of social rank they must be attentively listening.

4.2. Prevention of queuing behavior

With electronic feeding the sows just have to be recognised at the feeder's entrance in order to gain access. This may lead to queuing of several sows in front of the entrance, a behavior often seen with this type of feeding (Anil et. al 2005). Dominant sows may tend to stick to this behavior after call feeding has been established, such that the responses of other sows to their calls are hampered because the entrance is occupied by dominant individuals. This behavior may last up to 10 days until the dominants have realised that this does not lead to success (Manteuffel et al. 2010). Therefore, we have implemented a special automatic call strategy in order to accelerate this process. If a sow is recognised at the entrance immediately before it is about to be fed according to the call schedule this is taken as an indicator that entrance occupation might still have been associated with the chance of feeding. In order to prevent this, the calling of the animal is delayed until another sow has been called.

5. Discussion

Given the society's increasing sensitivity towards animal welfare in agricultural production systems modern herd management procedures are demanded to account for this development. Being the interface between consumers' demands and productivity herd managers will become more and more involved in this raising new issue. Future precision livestock farming has to consider this broadly uttered public opinion. In addition to short term economic returns, long range benefits and even soft factors, as animal welfare, will be worth to be integrated.

We have developed the first call feeding implementation that can be used for practical application in pig farming. Call feeding of pregnant sows has the potential to prevent injuries during feeding caused by mutual aggressiveness and to be a 'cognitive enrichment' (Manteuffel et al., 2009 a, b). Anticipation and behavioural control – the certainty that the appropriate behaviour will result in the expected outcome – are relevant factors increasing the welfare of animals (Bassett und Buchanan-Smith, 2007). It has been revealed that well-trained pigs do not display psychological signs of excitement, i.e. changed heart rate and heart rate variability, to other animals' calls (Zebunke et al., 2011). In growing pigs, Ernst et al. (2005) demonstrated that the pigs do not react to other animals' calls but keep on pursuing their current behaviour. Moreover, the calling demands acoustic sensing. During learning, the individual sound signature becomes more and more closely associated with the reward. After learning has been completed, each animal still has to discriminate the environmental sound steadily in order to get access to feed. This might be even an overall training of acoustic attentiveness that can be useful in general, e.g. while nursing piglets (Hutson et al., 1991, Wechsler and Hegglin, 1997).

Nevertheless, ensuring the feed supply of every sow and maximising the efficiency of call feeding at the same time is conflictive. Well-trained animals are a necessary precondition to attain maximum efficiency. An elaborate strategy for reorganising a herd to use call feeding is indispensable. But when all sows are well trained, call feeding supplies the animals with more frequent feelings of safe control and anticipation, compared to normal electronic feeding (Manteuffel et al. 2009a). With its autonomous control call feeding does not pose much additional effort on the management but has the potential to reduce fights and injuries related to the feeding regime with conventional electronic feeders. It reduces queuing and thereby makes the access to the feeder easier for low ranking sows (Kirchner et al. 2010, Manteuffel et al. 2010).

Taken together, call feeding may be a suitable way for improving welfare and health of pregnant sows. Potential improvements in the overall health state, the fertility of sows and the productivity might compensate for some additional costs of call feeding. Supposed that further tests on pilot farms will confirm these benefits we suggest call feeding as a useful completion of standard electronic sow feeding.

6. Conclusions

We could demonstrate that call feeding can be implemented in a management-friendly automatic software routine that interacts with the standard procedures of electronic feeders. Our novel call feeding implementation features solutions to cope with some common problems in the context of electronic feeding. Properties such as automatic training, considering social rank positions, safety of supplying the animals with enough feed and easy monitoring of learning and feeding related behaviors may make call feeding a valuable element of future precision livestock farming.

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Chapter 3

Call feeding gestating sows in larger groups

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Abstract

In electronic feeding for gestating sows, aggressive interactions most frequently occur while queuing at the feeders' entrance. This may lead to severe injuries. Call feeding has been developed to diminish this drawback while at the same time providing a cognitive challenge for the sows. Results from a total of 67 gestating sows that had been trained for individual acoustic calls have shown that the sows remembered and improved their training over the whole production cycle. The training results at the end of the experiment revealed a theoretical limit of 60 sows per call feeding station, assuming a single 14 hour feeding period and a feed ration of 2800 g on the average.

Keywords: call feeding, electronic feeding, sow gestation, group housing, aggressive behaviour

1. Introduction

Feeding is one of the rare diversions for pigs in an industrial farm environment. Together with a restrictive feed rationing for gestating sows, group housing may result in an increased affinity to the feeding station and intensified aggressive behaviour in its vicinity. Weber et al. (1993) showed that with electronic feeding stations (EFS) the number of aggressive interactions is strongly correlated with the time of feeding. Aggressive interactions most frequently occur while queuing at the feeders' entrance. In comparison to other feeding systems for group housing, electronic feeding has an increased number of aggressions (Hunter et al., 1988; Zurbrigg and Blackwell, 2006), which may lead to severe injuries (Boyle et al., 2002). Derived from a previous research project with growing pigs (Ernst et al., 2005; Manteuffel, 2009), we developed the call feeding system for group housed sows (Manteuffel et al., 2011) to diminish the risk of injuries in the feeding context and to provide a cognitive challenge as an additional environmental enrichment. A large group study with 85 sows showed that the use of call feeding stations (CFS) can lower the number of agonistic interactions in front of the feeder, leading to fewer and less severe injuries (Kirchner et al., 2012). Here, we present results for parameters characterising the call recognition performance in the course of the large group study. In addition, we evaluate the limits on the animal number per feeding station for a commercial introduction of call feeding.

2. Material and methods

2.1. Animals and housing

The study was conducted at the research station Mecklenhorst of the Friedrich-Loeffler-Institute in Mariensee, Germany. Sixty seven gestating sows (German Landrace) of the institute's herd were evaluated. The sows went through the production circle in a three week rhythm, split into seven subgroups of 8 to 12 sows. The gestating sows of a subgroup were held for three weeks in a small pen where replacement gilts were accustomed to electronic feeding and repeat breeders were identified. For the experiment this pen was additionally used as call feeding *learning stable*. Afterwards, the subgroup was transferred for twelve weeks into an open, unheated *gestation stable* where they were integrated into a dynamic large group consisting of all in all four of the small groups. Accordingly, the composition of the large group changed every three weeks. Gestation stable and learning stable had both been equipped with identical commercial EFSs (INTECMAC; PigTek Europe GmbH, Schüttdorf, Germany). For identification, all animals were carrying an ear tag transponder type Mannebeck Animal Control (MAC - PigTek Europe GmbH, Schüttorf, Germany). The station entry was located inside the pens while the exit led to an outside area. Both stables had a concrete floor and provided deep straw litter. Water and roughage (hay and straw) was offered ad libitum. All sows were fed restrictively with concentrate pelleted food. The feed contingent had been increased so that 80% feed uptake corresponded to 100% fulfilment of feed demand. A more detailed description of the animals and the housing conditions is given in Kirchner et al. (2012).

2.2. Experimental setup

The training and management of call feeding was controlled by software developed at the Leibniz-Institute for Farm Animal Biology in Dummerstorf, Germany. The software communicated with the INTECMAC software via an application interface using ISOagriNET (for details see Manteuffel et al. 2011). The experiment was divided into two main phases, the adaption phase in which the herd got stepwise adapted to call feeding and the operation phase where all sows performed call feeding and only replacement gilts had to be trained from time to time. During the adaption phase, the sows got conditioned as described in Ernst et al. (2005) and Manteuffel et al. (2010) using trisyllabic human and artificial names for the calls. This training was conducted in small groups in the learning stable and included an initial Pavlovian conditioning for at least the first four days. Within this time, the sows had unhindered access to the CFS, restricted only by their feed contingent. Subsequently, an operant conditioning was performed for up to 13 days, where only the called sow had access to the station. The exact duration of each training phase was manually adjusted according to the individual training performance of the sows. In the operation phase, the training of replacement gilts was performed with a varied training method as described in Manteuffel et al. (2011) that made manual adjustments unnecessary. The number of feedings in the learning stable was subject to frequent changes. This was an expression of the efforts to minimise the adaption stress for the sows, which had been fed once until the experiment, and to maximise the daily reinforcement to create a consolidated conditioning. Untrained sows performing electronic feeding and sows performing call feeding were kept mixed in the gestation stable until day 169 of the experiment. Within this time and until day 238 the sows had only one feeding per day in the gestation stable. From day 239 until day 373 of the experiment the sows had two feedings, at which 75% of the feed ration was dispensed in the first and the remaining feed in the second feeding. After day 373, the sows were again fed once daily. These changes were performed to investigate a possible cognitive enrichment effect on the animal behaviour (Kirchner et al., 2012).

2.3. Statistical analyses

Call feeding imposes a discrimination task on the animals making them classify whether they or a different sow has been called. In this sense, the sows could be seen as classifiers and their performance can be described by the parameters sensitivity (true positive rate), specificity (false positive rate) and precision (positive predictive value). In matters of call recognition, sensitivity is then defined as ratio between the number of feedings of the specific sow and its number of calls. It will be referred here as *correct response* ratio. Specificity is the ratio between the number of erroneously responded calls (detection at the station entry while a different sow is called) and sum of calls of other sows. It will be referred here as *false approach* ratio. Precision, in matters of call recognition, is defined as the ratio between the number of correct reactions (feedings) and sum of all reactions of a sow. It will be referred here as *learning success*. In addition, *latency,* defined here as the time between the first call and the feeding start of the called animal, provides insight on the time overhead of call feeding with respect to EFS. The statistical analyses were generated using SAS/STAT software, Version 9.2 of the SAS System for Windows (© 2009 SAS Institute Inc.). All response variables in the experiment were analysed by fitting and testing generalised linear models applying the GLIMMIX procedure (SAS, 2009). Repeated measures on the same animal were taken into account by the residual option in the random statement of the GLIMMIX procedure. The response variables latency, correct responses, false approaches and learning success were analysed by ANOVA (distribution = normal, link = identity) with the fixed effects experiment month, repetition of the experiment and experiment phase. Least-squares means (LSM) and their standard errors (SE) were computed for each fixed effect in the models. All pair-wise differences between the LSM were tested using the Tukey–Kramer procedure. As the level of significance a probability of 0.05 was chosen.

3. Results and discussion

The given herd management resulted in gestations groups containing sows of different ages, different gestation phases, and with reoccurring mixing procedures. In addition, the experimental setup led to the mixing of sows with a different training history regarding the training procedure and number of feedings. These constant changes in the fixed factors render a statistical analysis of learning performance alone impossible. Nevertheless, it gives an image of what call recognition performance can be expected from adapting a herd from electronic feeding to call feeding under less than optimum circumstances. Figure 1 shows the development of the reaction latency and of the correct responses, false approaches and learning success in the course of the experiment. Here, no attention is paid to any changing fixed factors such as number of animals in stable (19-36), animals called (2-33), number of feedings (1-2), changes in software and the like. In the progression of the experiment (fixed factor month), latency ($F_{14,373}=14.43$, $p < 0.0001$) and the classification performance measured by correct responses ($F_{14,387}=42.52$, $p<0.0001$), false approaches ($F_{14,387}=82.40$, $p<0.0001$) and learning success ($F_{14,381}=39.53$, $p<0.0001$) all in all significantly improved.

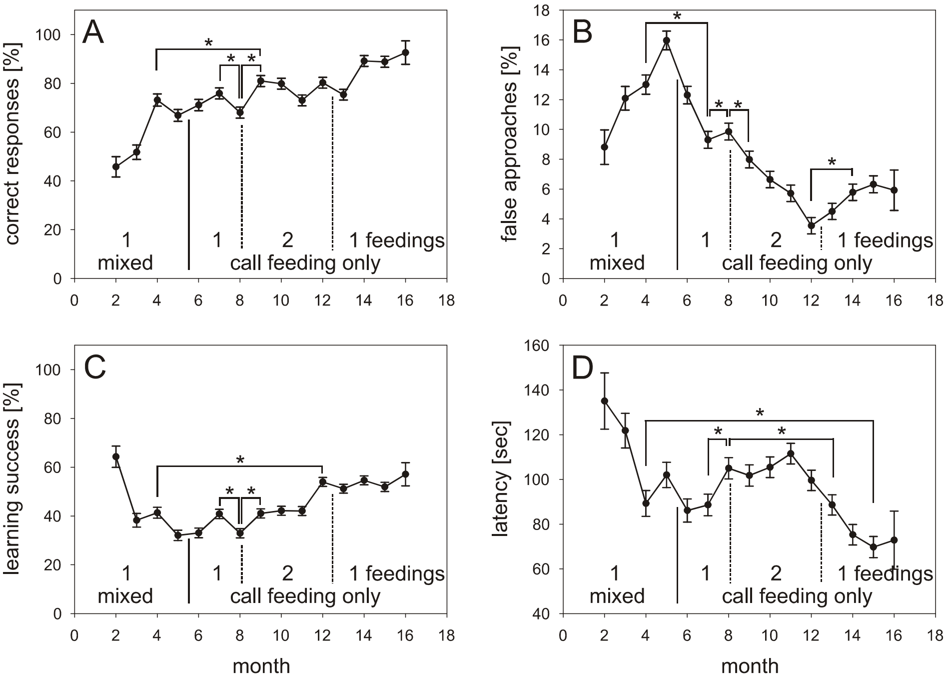

Fig. 1. Call recognition in the gestation stable as a function of the experimental month (LSM±SE). The two feeding settings mixed EFS-CFS feeding and exclusive CFS feeding are indicated in words and separated by a solid vertical line. Changes in the numbers of feedings per day are indicated by numbers and separated by dotted vertical lines. Significantly different values are marked by a star (not all shown).

Three peculiarities can be noted. First of all, the false approaches (month 2<5, $t_{387}=-6.21$, $p<0.0001$) and learning success (month 2>5, $t_{381}=7.29$, $p<0.0001$) worsened during the adaption phase with mixed feeding. In this phase more and more sows were fed with call feeding, while the software did not take the social hierarchy of the group into account. The access to the feeder is often regulated by the social status of sows (Anil et al., 2006). Calls ignoring the social hierarchy in combination with a still unconsolidated conditioning led to more and more high ranking sows queuing in front of the feeder. A software update at the end of the adaption phase solved this by assigning one of three rank classes to each animal and calling the animals ordered by rank class (Manteuffel et al., 2011). The rank class had been estimated from age and weight of the respective sow (Ritter and Weber, 1989).

Secondly, after switching from one to two daily feedings beginning on experiment month eight, all three parameters signalled a worse classification performance for a short period (Figure 1A-C). Latency was elevated and stayed on a higher level during the whole period of two feeding events (Figure 1D). With a single feeding, the calls were distributed over the whole day, while with two feedings all animals had been called at least once during the first half of the day. Also, three-fourths of the feed was dispensed at the first feeding. Thus, the sows might have been at least partially satisfied and less alert which might have contributed to a higher latency.

Thirdly, when switching back to a single feeding, correct responses increased (month 13<14, t_{387}=-9.69, p<0.0001) as well as false approaches (month 13<15, t_{378}=-4.06, p<0.01) while latency decreased again (month 13>15, t_{373}=4.2, p<0.01) and learning success showed no significant change. With just one feeding, the calls were distributed over the whole day again, which might have stressed the patience of the animals that just got used to being feed at the first half of the day. Consequently, they might have been more alert leading to a lowered latency.

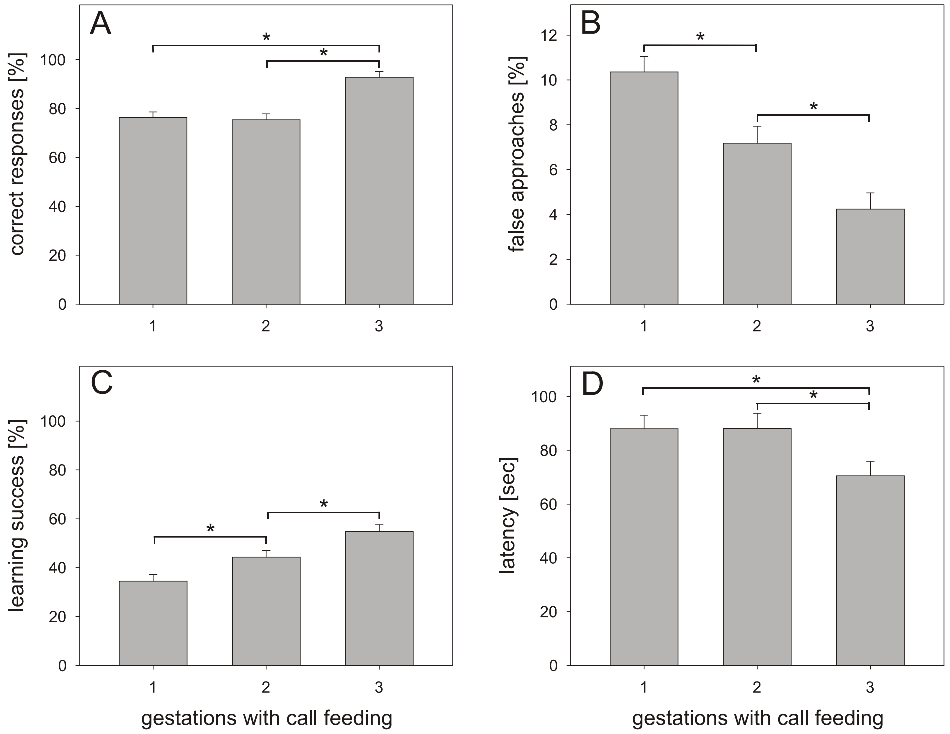

Fig. 2. Call recognition in the gestation stable as a function of the number of gestation periods with call feeding (LSM±SE). Significantly different values are marked by a star. Sows per number of call feeding gestation periods (1:40, 2:30, 3:25).

The number of sows that can be supplied by one CFS is an important parameter of call feeding. Together feed rate, latency and learning performance allow estimating how many animals could have been fed at the CFS during the course of the experiment using the equation

$$sows(p) = \frac{p - C \cdot T}{F + L} \qquad (1)$$

where p is the length of one feeding period, T is the mean number of nonresponded calls (*timeouts*), L is the average latency, C is the minimum time required between two feedings and F is the average time between feed start and end (Manteuffel et al., 2011). Based on measurements in 4762 feedings, we can assume an average feed rate of 4.4 g/sec and on the average 130 seconds to leave the station. This sums up to F=12.68 min for a 2800 g feed ration. A feed interval of C=130 seconds was enough to cover the latency of 80 % of all sows in the 15th experimental month, whereby the average latency L was 70 seconds (4.7 sec SE). Together with on average T=5.7 nonresponded calls per day in month 15 derived from Figure 1A and a feeding period p=12 h, we get from Equation (1) a station capacity of 51 animals in the 15th experimental month compared to 47 animals in the 5th experimental month. With a feeding period of 14 hours the theoretical limit of a single station increases to 60 sows. In any case and number of feeding events the number of calls and sows were well below the maximum capacity of the feeding system.

During the experiment sows repeatedly returned from farrowing to the learning and gestation stable. Figure 2 shows the latency and learning results for different numbers of gestation periods spent with call feeding during the operation phase. In order to attain a better comparability, only days with just one feeding event, where more than 25 sows were present and more than 22 have been called, were evaluated. The evaluation does not consider the different age and parity of the sows. Under these restrictions 40 sows had one gestation, 30 sows had two gestations and 25 had three gestations with call feeding. The results show an improvement of the parameters for almost each gestation (Figure 2). This proves that the training is persistent over the time spent in the farrowing pen and at the insemination. It also shows that the classification performance improvement of the herd throughout the entire experiment is mainly due to the higher proportion of experienced animals. Remarkably, the sows with the most call feeding gestation periods, which are presumably heavy and relatively high ranking, have the least false approaches (Figure 2B). This emphasises the increased importance of longevity associated with call feeding. A well consolidated conditioning is vital for the operation of call feeding. With untrained and inexperienced sows, the social rank becomes a major influence on feed access as high ranking animals tend to block the station entry until they are fed (Manteuffel et al., 2010). Hence, lower ranking sows may be hindered to follow their call even if they correctly had classified it.

The initial training of naive sows in the adaption phase with six feeding events and a small group of up to twelve sows yielded results similar to Manteuffel et al. (2010) (data not shown). At the same time, the training of naive replacement gilts within groups of experienced sows with only two feedings events per day produced even better results. For this comparison, the results of 25 sows from the adaption phase and 11 sows from the operation phase were included. Here, the correct responses over the whole training period were 81 % (5.1 % SE) in the operation phase compared to 37 % (6.0 % SE) in the adaption phase ($t_{34} = -4.58$, $p < 0.0001$). The mean false approaches were 9 % (2.8 % SE) in the operation phase compared to 16 % (2.4 % SE) in the adaption phase ($t_{34} = 2.11$, $p < 0.05$). The mean learning success was 71 % (4.4 % SE) in the operation phase compared to 24 % (4.0 % SE) in the adaption phase ($t_{33} = -7.87$, $p < 0.0001$). The mean feed uptake was 87 % (5.3 % SE) in the operation phase compared to 62 % (5.2 % SE) in the adaption phase ($t_{34} = -3.73$, $p < 0.001$). One could speculate that the gilts learned by example from the experienced older sows. However, the improved learning performance can equally be explained by an eased station access and thus more training opportunities because in the operation phase fewer sows were trained simultaneously. A certain share might also come from the improved training software. Additional test are necessary to identify the regulatory factors here.

Several studies concerning the learning capacity and the acoustic training of pigs have been conducted. Ernst et al. (2005) used 10 seconds lasting harmonies based on the c-major-triad to call 7 weeks old male pigs in groups of eight towards four CFSs. The classification challenge for the pigs was to distinguish their call by an individual timbre of always the same harmony. The pigs have been called 24 to 31 times a day, gaining a reward of 40 g feed pellets. After three days of Pavlovian conditioning and seven days of operant conditioning the pigs reached about 80% correct responses on average. Manteuffel et al. (2010) used spoken human and artificial names to call adult gestating sows in groups of 6 to 8 animals to a commercial electronic feeder. The classification challenge for the sows was to distinguish their call by identifying their individual "name". The sows have been called six times a day gaining a food reward of 400-500 g feed pellets. After seven days of Pavlovian conditioning and thirteen days of operant conditioning the dominant and subordinate sows reached about 80% correct responses on average. Both studies exhibit a better call recognition performance than the sows in the dynamic large group at least in the first half of our experiment. Here, the call feeding of older sows, which were well acquainted to electronic feeding, together with other sows still performing electronic feeding might be an issue. High ranking sows might had have to wait for their call while lower ranking sows easily got access to the station. This on the one hand in combination with a not fully consolidated training on the other hand might have provoked some of the sows to switch their feed strategy back to electronic feeding, by simply waiting in front of the station. Re-establishing the call feeding feed strategy in the operation phase with just one feeding event per day and repeated group mixing presumably takes longer than the training in a steady small group with more frequent feedings and thus more training opportunities. Larger groups would consequently have to be adapted in several steps as it has been carried out in this study. This, together with the need for seamlessly integrating replacement gilts, makes individual training and calling strategies necessary which we successfully tested in this study.

4. Conclusion

We found call feeding applicable for feeding adult sows in larger groups. The capacity of a CFS is at least close to the upper limits of EFSs. Also, pigs are able to localise calls from different CFSs (Ernst et al., 2005), making the procedure probably applicable for small to mid-sized herds with up to four CFS and at most 240 gestating sows in one gestation stable. The results from training replacement gilts in the operation phase seem to suggest that the number of feeding events and thus the size of the training group can still be improved by applying more advanced automated training routines. Furthermore, long term tests are necessary to study the effects of call feeding on animal welfare and performance.

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Section II

Chapter 4

Using air-blow and floor vibration to trigger posture changes in gestating and lactating sows

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Abstract

Recent approaches to minimise piglet crushing are usually active interventions in the behaviour of the piglets or the sow. However, interfering pig behaviour with the help of actuators has rarely been studied with respect to suitability, effectiveness and impact on animal welfare. In this study floor vibration and air-blows as methods to trigger posture changes have been tested on 11 sows in their late gestation and early lactation period. The intention was to quantify the effectiveness and unwanted side effects such as panic reactions as well as effects on neighbouring sows when applied in regular farrowing pens. The observed variables were reactivity, with reaction defined as posture change from lying to sitting, reaction latency and recline latency. In most cases, a reaction was achieved within 25 seconds and the arousal ceased in less than two minutes. In 22% of all stimulations the reaction latency was lower than 3 seconds, which could suggest an alarm reaction. The reactions of neighbouring sows could not be distinguished from natural occurring spontaneous posture changes and no low latency reactions were observed here. The sows in the late gestation phase showed a high reactivity on both actuators of about 80%. After farrowing, the reactivity was reduced to about 50% and nearly no low latency reactions could be observed. Hence, actuators need to be scalable to the individual reactivity level of the specific sow. This level is a complex variable that not only depends on the sow's age and individuality but also on its antecedent and current state. The examined actuators can be dynamically adapted to the individual reactivity level. Together with a posture tracking system and a piglet stress monitoring system, such as the stress monitoring and documentation system STREMODO, this would allow an active piglet crushing intervention. With further research on the effect on piglets this technology might be usable with farrowing crates as well as in loose-housing farrowing systems.

Keywords: farrowing, actuator, piglet crushing, sow behaviour, automated animal interaction

1. Introduction

There is an on-going dispute to what extend intensive captive breeding is responsible for piglet crushing. The increased litter size of modern breeds and subsequently lowered birth weights accompanied by a prolonged parturition are widely accepted as major risk factors. This might be worsened by confining the sows in farrowing crates which seems to result in an impaired maternal behaviour due to hindered nest building behaviour and piglet contact. On the other hand, increased piglet mortality in an early lactation stage is a central part of the evolutionary strategy of sus scrofa (reviewed in Edwards, 2002). Methods for piglet protection originated in the late 19th to early 20th century starting with fenders (Sommer, 1920) and somewhat later farrowing crates (Barker, 1929). At this time, pig breeding was recommended in free-ranging groups on pasture, with open straw bedded shelters (Potter, 1912). Such housing conditions would be called extensive today (e.g. Temple et al., 2011). Given the natural reproduction strategy and current physique of domesticated pigs, it seems even modern extensive breeding could not provide means to avoid piglet crushing altogether. Even pigs with a less commercialisation oriented physique, as it was the case 100 years ago, were obviously not exempt from piglet crushing. Thus, measures complementing the sow's nursing behaviour in their respective husbandry conditions are eligible in any case with respect to piglet welfare.

The most recent approaches to minimise piglet crushing are usually active interventions in the behaviour of the piglets or the sow. However, interfering pig behaviour with the help of actuators has rarely been studied so far with respect to suitability, effectiveness and impact on animal welfare. There are some studies on the general sensory responsiveness of pigs. These studies show that sows react little on olfactory stimulation, but show distinct aversive reactions on some visual, acoustic and tactile stimuli (Cronin and Cropley 1991, Hutson et al., 1993, Talling et al., 1996). On the other hand, some tactile stimuli such as umbrellas and prods can even cause attraction (Hutson et al., 2000). A few studies investigated commercially available actuators. Friend et al. (1989) tested the effectiveness of the commercial ELARM system. This system recognised piglet crushing by monitoring the piglet vocalisation for typical patterns in volume and duration. In case of a supposed crushing event, a posture change of the sow was triggered by administering 100 V shocks through electrodes in a heart girth attached to the sow. This was successful in all five crushing events throughout the study. A different approach targeting the piglets has been reported by Jeon et al. (2005). Here, posture changes of the sow were monitored using photo sensors. In case of reclining, an air-blow was administered underneath the sow to displace the wind chill sensitive piglets. This method resulted in a significant reduction of crushed piglets.

We have tested stimulations with heat, different sounds such as white noise, sinus tones of different frequencies, sow "barks", door slapping and different intensities of floor vibration and air-blows in order to find an actuator that can trigger posture changes in adult sows. From these small-scale screening tests on juvenile sows, the most effective methods - floor vibration and air-blows - have been selected to quantify their effectiveness and unwanted side effects when used with middle-aged gestating and lactating sows.

2. Material and Methods

2.1. Animals and Housing

The study was conducted in the experimental pig unit of the Leibniz-Institute for Farm Animal Biology (FBN), Dummerstorf, Germany. The sows (German Landrace) were housed in two separate farrowing compartments, each containing six farrowing pens (model Scan, Jyden-Dantec, Danmark). Once for each trial run, four sows were selected for treatment from a group of twelve. The remaining sows were not treated but housed in the same compartments. The sows were located in a way that next to each treated sow two untreated sows were kept in the neighbouring farrowing pens. Both treated and untreated sows were distributed equally over the two compartments. The behaviour of the untreated sows was evaluated for indirect effects from noise and vibration of the corresponding treatment. All in all, 12 sows were treated and the behaviour of 24 untreated sows was observed in three successive trial runs.

One farrowing pen measured 3 x 2 m of slatted floor and was equipped with a trough, nipple drinkers for the sow and the piglets and with a variable restriction. A detailed description of the pen and the management system used can be found in Stabenow and Manteuffel (2002). During each trial, the treated sows were restricted for the time of the experiments and held unrestricted otherwise until the farrowing. After farrowing, the treated as well as the untreated sows were permanently restricted for one week. The animals were fed manually at 7:00 a.m. and 12:30 a.m. using pelleted feed for gestating and lactating sows respectively. Water was provided ad libitum. All tests were performed in accordance with directive 2010/63/EU and with permission from the animal care and use committee of the country.

2.2. Selection of the treated sows

On day zero, the sows were weighted and then transferred from the gestation to the farrowing compartments. Along the way, the sows were checked for lameness and other leg injuries or abnormalities. In addition, the general health state of the sows was visually assessed by looking for discharge from nose and eyes, peculiar breathing and by checking the attentiveness, the claws and the leg posture. Sows that seemed to be ill, were lame or had severe leg wounds were not selected for treatment. Furthermore, a basic visual inspection was carried out on each trial day. For sows that developed illnesses, lameness or injuries during the trial, the treatment was stopped and the data excluded from evaluation. Also, only sows having the second or third gestation were taken into consideration for treatment in order to gain a comparable weight and reactivity. The average weight of the sows was 265 ± 34 kg (SD).

2.3. Experimental Setup

The two farrowing compartments were differently adjusted for the experiments. The air-blow compartment was equipped with a 30 m flexible force main (6 x 8 mm polyamide) and a blow gun (model Typhoon, CoilhosePneumatics, USA). This blow gun was equipped with a 600 mm extension pipe and the Coilhose standard nozzle for this model (Fig. 1 B). A 24 l mobile compressor (model BT-AC 200/24 OF, Einhell Germany AG, Germany) was used to supply the blow gun with pressurised air at 6 bar. The compressor was placed outside of the compartment to lower the influence from its compression noise.

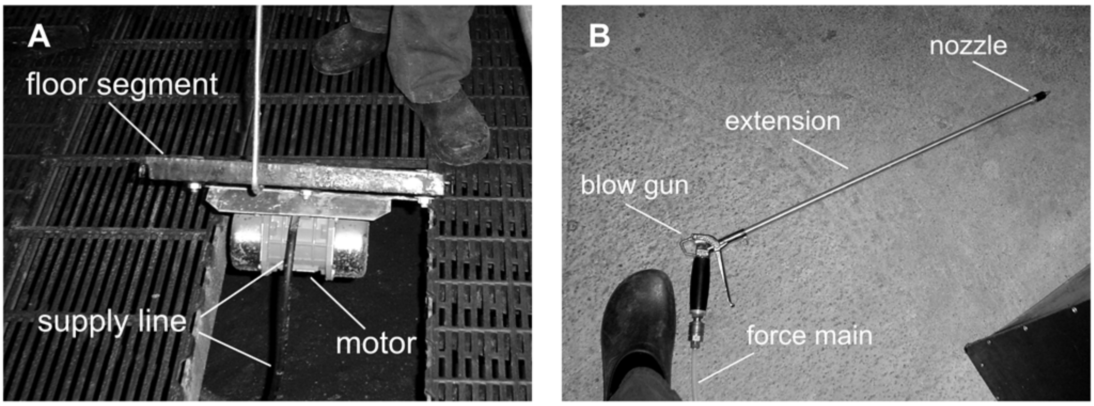

Fig. 2. Installation of the floor vibration and the air-blow actuator. Image A shows the floor segment holding the vibration motor during its inset into the slatted floor. Image B depicts the blow gun and its extension pipe.

In the floor vibration compartment, one floor segment of each of the two trial farrowing pens was equipped with a 12 V direct current vibration motor scaled down to 12% of its original performance (model WEV 12 DC, WEBAC GmbH, Germany). The two motors operated at 10.8 V with a rotation frequency of 45 Hz and about 0.05 mm oscillation amplitude. The intensity level in terms of air pressure, rotation frequency and oscillation amplitude have been determined earlier in small scale screening tests. The motors were powered by one controllable 12 V power supply (model SPV-300-12, MEAN WELL Technology Co., Ltd., Taiwan).

The compartments were continuously observed for 13 hours from 07:00 a.m. to 08:00 p.m. using four webcams (model IC-3100P, Edimax Technology co., Ltd, Taiwan) and a self-developed script utilising the VLC media player (VideoLAN organisation, France). One camera could record the posture changes of three sows at a time.

2.4. Treatments and observations

The treatments were carried out in two periods, one for each compartment. The first period lasted from 01:00 p.m. to 03:00 p.m., the second from 03:00 p.m. to 05:00 p.m. Which compartment was treated first was changed daily on a regular base. At the day of farrowing, the particular sow was excluded from treatments for one day. The farrowing was synchronised, using contraction inducing drugs and generally took place on day eight (Fig. 2).

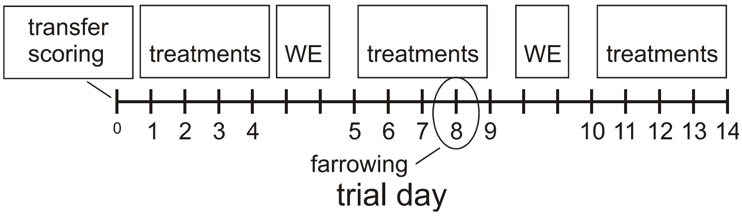

Fig. 3. Course of a trial run. The trial days are consecutive days with treatments, leaving out weekends (WE). The day where the farrowing was expected is marked by an ellipse.

During the treatments the parameters reaction, reaction latency and recline latency were measured for the treated sow and its two direct neighbours and recorded, using the following definitions:

- **reaction:** posture change from lying to sitting
- **reactivity:** ratio of reactions and treatments or observations, respectively
- **reaction latency:** duration from starting the treatment until reaction
- **recline latency:** duration from sitting or standing until lying down again
- **low latency reaction:** reaction with a latency of less than three seconds

Before each treatment, the sow and also its direct neighbours had to lie down. To make sure the sows are really calm and resting, the lying had to last at least five minutes. This way, the sows were guaranteed to be in the same arousal state, with naturally occurring posture changes being unlikely. In addition, this procedure together with a random timing and order of the treatments was ought to prevent a direct association of the treatment and lying down. Similarly, the trial personnel had to enter the compartment at least ten minutes before the first treatment to avoid an association of the trial and the person.

Two different treatments - physical and simulated - were performed each twice a day on the four treated sows. With the physical treatment, the floor vibration and the air-blow actuators physically stimulated the sow. The simulated treatment completely re-enacted the physical treatment including the activation of the actuator. The only difference was here, that the actuator was not powered and therefore produced no physical stimulation. The simulated treatment was performed to control the influence of the treatment situation and the trial personnel on the reactions.

The respective treatment was continued until the sow reacted, to a maximum of up to sixty seconds. With the beginning of the treatment, the sow was observed for ninety seconds to cover delayed reactions. Physical floor vibration was administered continuously, while the air-blow was pulsed to keep the air-pressure at a high level. To apply a simulated or physical air-blow, a person had to enter the farrowing pen and to manually place and trigger the blow gun. The vibration motors could be activated separately from a central place outside the farrowing pen using one electric hand switch per motor (model P1-25/I2, EATON, USA). After the sow changed its posture to sitting, the actuator was deactivated regardless of whether the sow fully stood up or not. This is a realistic scenario with piglet crushing in mind, because there is yet no piggery-suitable technology that is capable of detecting the exact posture of a sow.

Performing the stimulation, measuring durations and recording the reactions of three sows at the same time can be challenging. Therefore, the video recordings served as a backup to measure missed parameters again, if in doubt. In addition, the video recordings delivered information on the frequency of spontaneous posture changes. For this, four randomly chosen ninety-second periods from the morning of the trial day were evaluated for posture changes. A reaction was counted if the sow changed its posture to sitting within the observed ninety-second period. The reactivity has been calculated as reactions divided by observations. Again, the observed sow had to lie for at least five minutes beforehand. The spontaneous reactions served as control for the naturally occurring posture changes within the activity periods of the day.

2.5. Statistical analysis

The statistical analyses were generated using SAS/STAT software, Version 9.2 of the SAS System for Windows (© 2009 SAS Institute Inc., USA). All response variables in the experiment were analysed by fitting and testing generalised linear models applying the GLIMMIX procedure (SAS, 2009). In all models repeated measures on the same animal were taken into account by the residual option in the random statement of the GLIMMIX procedure to construct the block diagonal structure of the residual covariance matrix for each animal. For the binomial response variable "reaction" a logistic model (distribution = binomial, link = logit) with the fixed effects actuator (levels: floor vibration, air-blow), treatment (levels: physical, simulation, spontaneous) and pen (levels: treated, untreated) and their interaction were fitted and tested. The variation in time of the reaction was analysed with a model restricted to physical treatments with the fixed effects actuator, pen and period (levels: start, pre-farrowing, post-farrowing, end) and their interaction. The period was defined by the respective trial day using the values (start, 1-3), (pre-farrowing, 4-7), (post-farrowing, 8-11) and (end, 12-14). The continuous response variables "reaction latency" and "recline latency" were analysed by ANOVA (distribution = normal, link = identity) with a model restricted to physical treatments and the treated pen including the fixed effects actuator and period and their interaction. Least-squares means (LSM) and their standard errors (SE) were computed for each fixed effect in the models. All pair-wise differences between these LSM were tested using the Tukey–Kramer procedure. A probability of 0.05 was chosen as the level of significance.

Only 2804 out of 4032 theoretical possible reaction observations and only 254 out of 336 possible reaction observations on physical treatments of the treated sows were available for the statistical analysis. In the first trial run, an unnoticed error in the video recording system prevented the collection of spontaneous posture changes and most neighbour reactions at 6 trial days. There were several occasions, when the sows were too nervous to lie down for the required five minutes and no stimulation was possible. Around the anticipated day of farrowing this was more often the case. One sow developed lameness during the trial and was excluded from the treatments (floor vibration) and from evaluation together with its neighbouring sows. In addition, all data from the days of farrowing are missing because the sows were not treated that day.

3. Results

Comparing the reactions of the sows on the respective treatment, we see no fixed effect of the actuator used ($F_{1,31} = 0.2$, $p = 0.65$). Yet, there was a significant effect of the treatment ($F_{2,60} = 50.4$, $p < 0.001$) and the pen ($F_{1,31} = 15.1$, $p < 0.001$). Of the effect interactions, actuator × treatment ($F_{2,60} = 6.5$, $p < 0.01$) and pen × treatment were significant ($F_{2,60} = 57.6$, $p < 0.001$), while actuator × pen and actuator × pen × treatment were not. The pen × treatment effect accounts for the distinct difference between physical and other stimulations as well as between the treated and untreated pen. Physically treated sows reacted to 65.1 ± 3.6% (SE) on the stimulation, while about 6 ± 2% (SE) of all other stimulations were responded (Tab. 1). Consequently, the reaction proportion was significantly higher for physical treatments compared to any other treatment ($t_{60} = 9.63$, $p<0.001$). At the same time, neither the reactions of neighbouring sows nor the simulated stimulation could be distinguished from spontaneous reactions.

Table 1. Overview of sow reactivity [%] for different factors.*

Period	Treatment	Pen	LSM	SE	Diff.	Obs.	React.
Entire	Physical	Treated	65.1	3.6	a	254	166
Entire	Physical	Untreated	6.1	1.4	b	452	29
Entire	Simulated	Treated	5.0	1.9	b	254	16
Entire	Spontaneous	Treated	6.5	1.6	b	466	31
Start	Physical	Treated	80.4	6.5	c	64	52
Pre-farrowing	Physical	Treated	72.7	7.1	c d	80	57
Post-farrowing	Physical	Treated	49.3	8.1	d	68	34
End	Physical	Treated	51.7	9.5	d	42	23

* Reactivity least square means (LSM), standard error (SE), significant statistical differences (diff.; $p < 0.05$) denoted by different letters, number of observations (obs.) and number of reactions (react.) incorporated in the comparison of different treatments (upper half of the table) and different time periods (lower half of the table).

Looking at the variation in time of the reactions on physical treatments, the fixed effects period ($F_{3,79} = 3.8$, $p < 0.05$) and pen ($F_{1,31} = 28.8$, $p < 0.001$) turned out to be significant, while none of the interactions did. The influence of the period accounted for the significant differences of the start period compared to the reactions in the post-farrowing period ($t_{79} = 3.8$, $p < 0.01$) and at the end ($t_{79} = 3.1$, $p < 0.05$). In the start period, the sows reacted to 80.4 ± 6.5% (SE) on stimulations, with both actuators considered together. After farrowing, the reaction proportion decreased to 49.3 ± 8.1% (SE) (Fig. 3A). These findings are further supported by the result for the reaction latency, again with respect to physical treatments and limited to the treated pens. Here, the factor period was significant ($F_{3,20} = 8.9$, $p < 0.001$), while actuator and the interaction period × actuator were not. The sows reacted faster at start (11.5 ± 2.9s (SE)), compared to the post-farrowing period (22.7 ± 3.2s (SE)| $t_{20} = -4.35$, $p < 0.01$). Furthermore, the slope of the line diagrams in Figure 3B provides indications for a higher overall reaction latency of floor vibration, though there was no statistical evidence for this. As for the recline latency, it seems that the floor vibration excited the sows more constantly throughout the study (78 sec. at start vs. 81 sec. at end) than the air-blow (106 sec. at start vs. 53 sec. at end), but there was no statistical evidence (Fig. 3C). Neither the main effects actuator and period nor their interaction turned out to be significant.

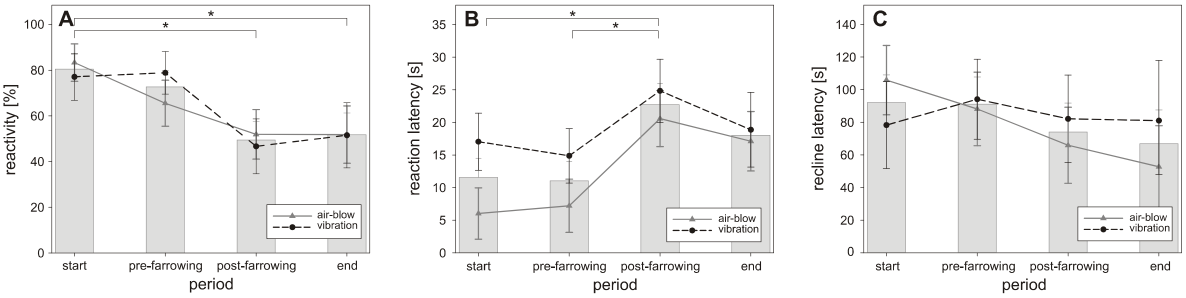

Fig. 3. Development of the reaction parameters on physical treatments throughout the study. Diagram A depicts the reactivity, B the reaction latency and C the recline latency of physically treated sows. The solid grey lines show the LSM and SE for the air-blow actuator and the stippled black lines for the floor vibration actuator. The bar charts depict the LSM for both actuators together. The enlisted significant differences refer to differences in the bar charts ($p < 0.05$) (11 sows / observations per sow: 4-6 (start), 6-8 (pre-farrowing), 6-8 (post-farrowing), 0-6 (end)).

Regardless of the actuator used, on average about 22% of all reactions on physical treatments were low latency reactions (< 3s) that could be considered alarm reactions. In neighbouring pens no low latency reactions have been observed. The most low latency reactions occurred before farrowing, during the first half of the trial (vibration 88%, air-blow 94%). We could observe a certain concentration on trial runs and sows (66% in run 3 with air-blow and 76% in run 1 with floor vibration). In these trial runs, the low latency reactions occurred right from the start and on consecutive days, while in the other trial runs this happened more occasionally. A correlation of low latency reactions and recline latencies was not apparent.

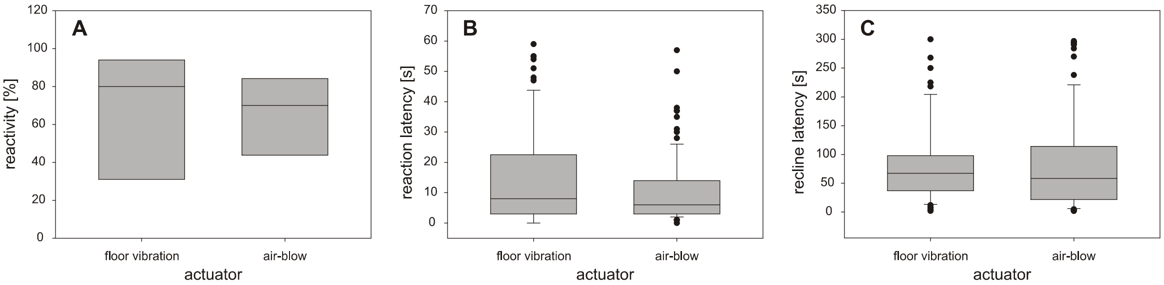

Fig. 4. Distribution of the reaction parameters on physical treatments. Distribution of the reaction ratio (A), reaction latency (B) and recline latency (C) of physically treated sows. The lower boundary of a box indicates the 25th percentile, the line within the box the median, and the upper boundary of a box the 75th percentile. The whiskers above and below the box indicate the 90th and 10th percentiles. Black dots represent outlying points. (11 sows: 5 floor vibration and 6 air-blow / observations per sow: 2-26 (air-blow), 7-22 (floor vibration))

Looking at the distribution of the reaction parameters, the sows reactivity seemed widely spread throughout the individuals, though this might be an effect the low number of sows. Despite the quite high median of 70 to 80% for both actuators, single sows showed only few reactions especially on floor vibration (Fig. 4A). The distribution of the reaction latency resembled the reactivity distribution. More than half of the sows reacted in less than ten seconds on both actuators. However, floor vibration showed more variation towards higher reaction latencies (Fig. 4B). Concerning the recline latency there was no apparent difference in the parameter distribution. About 75% of the sows reclined in less than two minutes giving no indication for a lasting arousal due to the stimulation (Fig. 4C).

4. Discussion

The physical treatments with floor vibration and air-blows elicited on average the same reactions in the treated sows. At the same time, the reactions of neighbouring sows on physical treatments could not be distinguished from spontaneous posture changes, regardless of the actuator used (Tab. 1). Because of the completely different stimulation principles of the actuators, this result was not to be expected. The effect of the air-blow is probably due to cooling and the administration of force on sensitive tissue. Also, the loud sound, comparable to white noise, might contribute to the arousal of the stimulated sow (Hutson et al., 2000). At the applied pressure of 6 bar the nozzle used created a noise level of more than 90 dB in one meter distance. In this regard, the limit for the air pressure was already reached. The air volume could be further scaled though, as the 6 x 8 mm force main was rather small dimensioned. The sound had little effect on neighbouring sows because they probably could locate it in a different pen and were in part accustomed to high frequency sounds from the compartment cleaning procedure. The sound had no effect on the piglets distinguishable from the general arousal due to the trial personal entering the pen. Usually the piglets hid away from the personal kneeing right next to the sows teats and were then generally unimpaired by the air-blow. Using compressed air in an unsupervised automatic actuator and releasing it next to a piglet should have an effect though, as the sound is even louder at a close distance and the piglet might feel the reflected air-blow.

The effect of the vibration is achieved by movements in the scale of some tenths of millimetres. The underlying principle of the stimulation effect is unclear. However, it is well known that whole body vibration is aversive to pigs. Its aversiveness depends on frequency and intensity in terms of body acceleration (Perremans et al., 1998). The intensity of the vibration can be easily scaled ten times higher than applied in this study. However, higher intensities could cause panic reactions and damage the floor structure. Further studies are necessary, to find an intensity where the reactivity of the sows stays high after farrowing while negative side effects are still minimal.

An additional aspect of the vibration actuator is the fact, that the spreading of the vibration can be easily controlled by the coupling strength between floor segments. This way, the vibration can be restricted to the lying area of the sow, automatically creating safe places for the piglets. These might gather outside the lying and vibration area as the vibration starts. This way a farrowing pen without a crate but with a similarly low rate of piglet crushing might be constructible. In our experiments, we observed no obvious elimination reactions of the piglets.

However, the piglets were no subjects of this trial. Optimal vibration parameters effective on them still need to be studied.

Even though applying aversive stimulations always implies animal welfare issues, using attractive stimulations is not an option in the case of piglet crushing. The attractive stimulation would reward unwanted behaviour. This could produce a training effect reinforcing the piglet crushing behaviour while the aversive stimulation will always attenuate the behaviour (reviewed in Walker 1987). Friend et al. (1989) reported a subjectively increased sensitivity of the treated sows against piglet screams after being treated with ELARM. In addition, posture changes seemed to become more careful. On the other hand, one of the sows developed aggressiveness against the trial personnel, which could be associated with the electroshock. Hence, care must be taken in the selection of the actuator and at finding an appropriate intensity where effectiveness of the stimulation and its aversiveness are in balance. We observed about 22% low latency reactions that might have been alert reactions. Yet, no elimination or panic reactions were observed as far as this is possible in a farrowing crate. Low latency reactions were rarely observed at the second half of the trial, indicating a higher tolerance level of the sows or a lessened aversiveness of the stimulation due to the farrowing. Hutson et al. (2000) reported a lessened aversion displaying behaviour on tactile stimulations which might have resulted from a prior accommodation to human contact and handling. This demonstrates that the aversiveness of a stimulation and hence the impairment of welfare depends not only on the stimulation principle and its intensity but also on the individual antecedent and the current state of the treated animal (Levine et al., 1967). This can be taken into account by applying individually adjusted intensity levels, using gradual escalation strategies and by accompanying aversive stimulations with neutral signals that enforce the stimulation and could subsequently allow the elicitation of the wanted reaction without stimulating at all (Miller et al., 1983).

5. Conclusion

Gestating and lactating sows showed a moderate to high reactivity on both examined actuators, whereas neighbouring sows showed no correlative reactions. Eliminations or panic reactions have not been observed. Yet, there are indications that age, temperament and current constitution affect the reactivity level in a complex way. Both actuators can be adapted to this individual reactivity level. With further research on the effect on piglets this technology might be usable with farrowing crates as well as in loose-housing farrowing systems. For this approach, a posture tracking system similar to the one used by Jeon et al. (2005) would be necessary. A crushing detection system could minimise the triggering of the actuators and hence the impairment of the sow's welfare. An example for such detection system is STREMODO which allows recognising distress from piglet vocalisation (Schön, Puppe and Manteuffel, 2001).

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Chapter 5

Towards qualitative and quantitative prediction and detection of parturition onset in sows using light barriers

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Abstract

Piglet mortality can be a large economic and animal welfare issue in breeding facilities. A system that predicts the parturition can help the breeder in economically organising staff assignments in order to achieve an optimal workload levelling. In the current study, light barriers at the head and torso region of a sow were used to measure and classify the activity increase of 34 sows related to their near parturition. Based on this data, 4 different activity frequency and activity duration based qualitative predictors for the near onset of parturition were developed, utilising cumulative sum techniques and a global threshold approach. The threshold optimisation for the qualitative prediction was performed using a random set of 17 sows and validated with the remaining sows. The best performing qualitative prediction yield a validated sensitivity of 88% at a precision of 88%. This prediction generated parturition alerts with a 25th percentile of 13 h and a 75th percentile of 20 h before the parturition started. Based on this indicator, a quantitative prediction of the time remaining until the onset of parturition could be developed. This prediction exhibited a mean prediction error of 0.5 h ±2.5 h (SD) for 88% of the sows over a period of 13-24 h before the onset of parturition. At the same time 12% of the predictions were unusable with a mean prediction error of 12.5 h ±6.9 h (SD). In addition, a method for detecting the parturition onset with an accuracy of ±4 h, a sensitivity of 88% and a precision of 97% for the head sensor could be obtained. With data from the torso sensor, the performance of the various indicators was generally lower and optimality was achieved with different thresholds. The present study follows other studies showing the general detectability of the parturition related increase in activity using video, light barriers and ultrasonic distance sensors. It is also closely based on earlier studies using accelerometers for individual qualitative parturition detection, with the explicit intent to reproduce these results using light barriers.

Keywords: parturition detection; parturition prediction; precision livestock farming; gestating sow; light barrier

1. Introduction

Nest building behaviour of sows related to the near parturition is probably known since the earliest days of pig domestication. Not surprising, this behaviour is still present in modern pig races (Jensen et al., 1987) as breeding and raising pigs on pasture was still common less than 100 years ago (Potter, 1912). Industrial pig breeding using farrowing pens and crates on slatted floor removed the need and mostly also the opportunity for the sow to exercise nest building behaviour. Yet, alike many other ungulates (Lickliter, 1985; Owens et al., 1985a,b; Poole et al., 2007), also captive pigs show an increased activity related to the near parturition (Jones, 1966; Lammers and de Lange, 1986) regardless whether they have access to nest building material or not (Arey et al., 1991). Hence, it seems plausible to use this increase in activity to predict the near onset of parturition (*oop*) of the sow. Such indicators can be useful especially for the organisation of post-parturition piglet supervision in large breeding facilities which can help to lower piglet mortality (Holyoake et al., 1995). First attempts on automated activity measurements using light barriers as activity sensors were published by Erez and Hartsock (1990). They confirmed that the increase in activity related to parturition is detectable using light barriers and conjectured that an individual qualitative prediction of the onset of parturition should be possible. Similar results were achieved using similar (Oliviero et al., 2008; Mainau et al., 2009) and other sensors such as manual video inspection (Vestergaard and Hansen, 1984; Lammers and de Lange, 1986), ultrasonic distance sensors (Huang et al., 2005; Wang et al., 2007) and accelerometers (Cornou and Lundbye-Christensen, 2012; Pastell et al., 2013).

Cornou and Lundbye-Christensen (2012) used accelerometers in neck collars to measure the individual sow activity. For analysis, this study created a model classifying the high frequent (4 Hz) and high resolution (±2g, 16-bit) accelerometer data into the two basic categories active and non-active within 2 minute intervals. They then used the cumulative hourly number of 2 minute intervals classified as active to detect an increasing activity. Based on this data and a cumulative sum (CUSUM) monitoring approach, Cornou and Lundbye-Christensen (2012) developed a qualitative indicator signalling the upcoming onset of parturition. In their study, 18 of 19 parturitions were correctly predicted 0-24 hours before the parturition actually started.

Similar results to Cornou and Lundbye-Christensen (2012) were yield by Pastell et al. (2013), who also measured activity at a high frequency (20 Hz) with accelerometers in neck collars. In this study, the CUSUM approach was somewhat simplified by using normalised log transformed activity frequency data instead of applying a mathematical behaviour model. Pastell et al. (2013) predicted the upcoming onset of parturition in 11 of 12 sows 6-20 hours before the parturition started. In addition, they could detect the actual onset of parturition by monitoring the activity for a sharp drop after the near onset of parturition had been indicated. This behaviour was also reported by Erez and Hartsock (1990) who found that the “sow usually stays in lateral recumbency immediately prior to and during the birth of the litter”. This is consistent with other studies on the parturition behaviour (Hurnik, 1985, Meunier-Salaün et al., 1991).

With current technology, animal attached sensors like accelerometers are hard to establish in a commercial pig breeding facility. They need an autonomous power supply and have to transmit activity data continuously via radio to allow an online analysis of the data. In addition, it is labour intensive to attach and detach sensors off the sows’ bodies. Light barrier as well as ultrasonic sensors work contactless, are low cost, easy to maintain and commercially available in IP67 protected housing. Therefore, the current study tested whether the previous results of qualitatively predicting the upcoming parturition and detecting the actual parturition onset with accelerometer sensors could be transferred back to light barrier sensors. The examined questions concern

- the classification performance of the qualitative predictions using differently transformed curves of the sows activity,
- the suitability of threshold optimisations from small animal sets when transferred to other sows,
- the dependence of the classification performance on the position of the sensor and
- the qualitative predictability of the parturition onset.

2. Material and Methods

2.1. Animals and housing

The study was conducted in a trial compartment of a commercial breeding facility using 36 crossbreed sows (German large white X German landrace) in the 1st-6th parity and a weight between 193 and 368 kg. All sows were housed in 1.84 × 2.6 × 0.6 m farrowing pens (w×d×h) on slatted plastic floor and within adjustable farrowing crates (length: 1.6 - 2.0 m, width: 0.75 m) (Big Dutchman Pig Equipment, Vechta, Germany). The compartment contained four farrowing pens arranged side by side. The farrowing crates were equipped with a nipple drinker and a feed trough. The piglet creep area was equipped with a nipple drinker for piglets, a heat lamp and a warm water floor bedding (0.47 × 1.59 m). Feed consisted of barley, wheat, soy meal, raw fibre and fish oil. The sows were fed twice a day with a quantity adjusted according to the sows’ gestation and lactation state. No nest-building material was provided. For support of the parturition, most of the sows (approximately 80%) got Oxytocin and some of them (approx. 5%) also Prostaglandin $F_{2\alpha}$. The sows stayed in the trial compartment until the weaning of the piglets about 28 days after parturition.

2.2. Experimental setup

Four sows at a time were held in the trial compartment in nine successive trial runs. The parturition started 4 to 13 days after the transfer of the sows to the trial compartment. This large timespan was due to the breeders’ routine of covering the sows unsynchronised, waiting for their natural oestrus. The start of the parturition identified from the expulsion of the first piglet. At the beginning of the study, the time of the parturition onset was noted down manually and supplemented by vocalisation triggered video recordings. Later it was determined using continuous video recordings. Each farrowing pen was equipped with two light barriers (IPF Electronics GmbH, Rosengarten, Germany). The light barriers were installed at the pen board in the head region at 0.4 × 0.8 m (d×h) (*head sensor*) and in the torso region of the sow at 1.15 × 0.8 m (*torso sensor*). They consisted of a transmitter (model OS126103), receiver (model OE1260V1) and an amplifier (model OV640840). The light barrier data was recorded on one industrial PC per pen, using self-developed software. Interruptions of the light barriers were captured every 500ms. The software then recorded the time and duration of the interruption. Because of overheating problems in connection with their IP65 assured housing, the recording PCs failed occasionally. This led to missing data and in consequence to the removal of the results from two sows and a final data set of 34 sows.

2.3. Data analysis

For activity analysis, the frequency of light barrier interruptions was cumulated hourly and quarter-hourly using summation. The same has been done for the total duration of activity, summing up the duration of light barrier interruptions in seconds. The day of transferring the sows into the trial compartment (*transfer*) was excluded from data analysis to eliminate effects from the transfer itself. Based on this aggregated raw data, indicators for

- the near onset of parturition (parturition indicators),
- the actual onset of parturition (onset detection) and
- a quantitative prediction of the timespan until parturition (parturition prediction)

were developed and tested. The performance of the indicators, in terms of true positive (tp), false positive (fp), true negative (tn) and false negative (fn) classifications, was counted using a "per animal" approach. Per animal means, the classifications of the animal behaviour time series at time t: $ALERT(t) \rightarrow \{0,1\}, t \in [transfer, oop]$ were counted once per sow (1) and then summed up for the observed set of sows.

$$\begin{aligned} true\ positive = 1 &\quad \Leftrightarrow \quad \exists t\ with\ ALERT(t) > 0\ and\ oop - t \leq 48 \\ false\ positive = 1 &\quad \Leftrightarrow \quad \exists t\ with\ ALERT(t) > 0\ and\ oop - t > 48 \\ true\ negative = 1 &\quad \Leftrightarrow \quad \forall t\ applies\ ALERT(t) = 0\ while\ oop - t > 48 \\ false\ negative = 1 &\quad \Leftrightarrow \quad \forall t\ applies\ ALERT(t) = 0\ while\ oop - t \leq 48 \end{aligned} \tag{1}$$

The parturition indicators were optimised using the criteria sensitivity=tp/(tp+fn), specificity=tn/(tn+fp) and precision=tp/(tp + fp). Main optimisation criterion was sensitivity and secondary criterion the precision of the indicator. Specificity is related to these two and was therefore optimised indirectly too. The reason why counting was not done per trial day or for each indicator classification was that a lot higher proportion of days was negative with the sows being not near parturition. So, e.g. the specificity would have been about eighty to ninety percent for any classifier, giving no information on the "real life" performance.

For optimising the parturition indicators, the 34 sows were randomly divided into two bipartite sets - the *random* and the *validation set* - of 17 sows each. The random set served as a base for the optimisation of the indicator, while the validation set was used to validate the classification performance of the indicators using the same parameters with different sows. This validation gave an indication what classification performance can be expected when applying parameters found for a small set of sows to a different set of sows. In order to evaluate the limits of the classification performance, a second optimisation was performed using all of the 34 sows (*whole set*).

All statistical calculations were performed using the software R 3.0.2 (R Core Team, 2013). Dynamic linear model (DLM) calculations were done using the R package *dlm* (Petris, 2010). Correlations were calculated using the R method *cor.test* and α=0.05 as significance level.

2.4. Qualitative prediction of parturition onset

The parturition indicators classified the sows' behaviour into the categories "parturition distant" and "parturition near", giving a parturition alert when the onset of parturition was near. In this way, these indicators gave a qualitative prediction of the onset of parturition. To be of any use to the breeder, the parturition alerts should preferably be in close correlation to the start of the parturition, allowing at least a rough prediction of the remaining time. To account for this, a parturition alert was deemed correct (true positive), if the actual onset of parturition was no more than 48 h away (Fig. 1D, E). All other alerts were deemed to be unrelated random alerts. This assumption is also supported by physiological findings. The progesterone level in blood plasma, which is controlling the onset of labour, does not significantly decrease in sows earlier than 48 h before parturition (Meunier-Salaün et al., 1991; Castren et al., 1993). At the same time, the level of prolactin does not increase earlier than 48 h before parturition (Castren et al., 1993). Prolactin is believed to influence the initiation of nest building behaviour.

In addition, the alert should be early enough so that the near start of the parturition is not completely obvious and the breeder has enough time to make some provisions. Hence, the indicator optimisation was focussed on alert distributions limited to a 25th percentile of 12 h for the random set optimisation and 8 h for the whole set optimisation. With these restrictions, an optimal parturition indicator with a sensitivity and precision of 100% would give at least 75% of its alerts within a timespan from 8 to 48 hours before parturition and only 25% later.

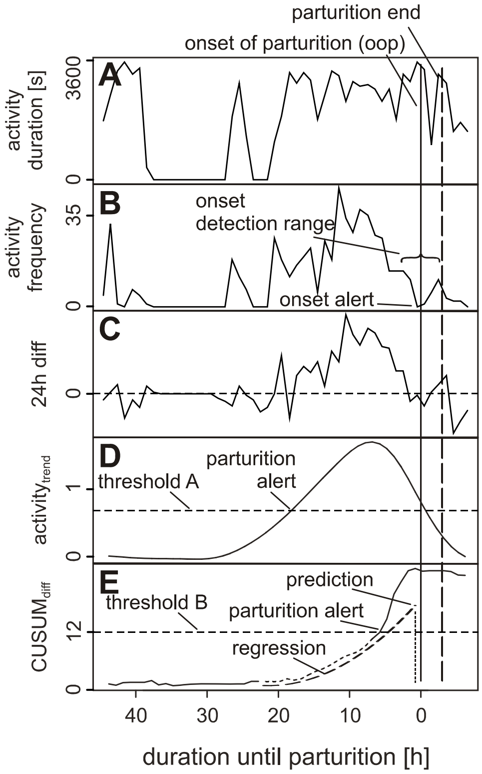

Fig. 4. Visualisation of different curve shapes for the hourly sums of activity duration (A), activity frequency (B), 24h activity frequency differences (C), the dynamic linear model trend of the activity frequency (D) and the cumulative sum of a 24h activity frequency difference (E). Acitivity is defined here as an interrupted light barrier and activity duration as the duration of the interuption. The time is displayed as hours until onset of parturition. The solid vertical line indicates the parturition start, the dashed the parturition end.

The parturition indicators monitored activity frequency and duration of activity curves (*f(t))* using thresholds (*thres*) for the detection of deviations in the curve values. A parturition alert was released, when the monitored curve reached a given threshold, common to all sows (Eq. 2). This threshold was determined by optimisation, using sensitivity and precision as optimality criteria.

$$ALERT(t) \to \begin{cases} 1 \mid & f(t) \geq thres \\ 0 \mid & f(t) < thres \end{cases} \quad , t \in [25, oop] \tag{2}$$

In order to create an indicator with maximal sensitivity and precision, curve deviations not related to parturition should be relatively small compared to parturition related increases (signal to noise ratio). A high signal to noise ratio (SNR) ensures that a common threshold value can be chosen that is low enough to cover the individual variations in the parturition related activity increase. At the same it needs to be high enough to not trigger premature alerts on variations in the animal activity not related to parturition. The average SNR for individual activity curves f_i is defined here as quotient of the average maximal individual curve value when near parturition and the average standard deviation of not parturition related curve values (Eq.

3). This definition is used to deal with the case $\sigma(f_i(t_u)) = 0$ which occurs often in connection with CUSUM curves.

$$\overline{SNR(f)} = \frac{\overline{\max(f_i(t_p))}}{\overline{\sigma(f_i(t_u))}}, \begin{matrix} t_p & \in [oop - 48, oop] \\ t_u & \in [25,\ oop - 49] \end{matrix}, \ i \in [1, 34] \tag{3}$$

The evaluated curves (*f(t)*) were

- $\text{activity}_{\text{trend}}$ - the DLM trend of the activity frequency curve,
- $\text{CUSUM}_{\text{act}}$ - the CUSUM of the DLM trend of the activity frequency curve,
- $\text{CUSUM}_{\text{diff}}$ - the CUSUM of the 24h difference of the activity frequency curve and
- $\text{CUSUM}_{\text{dur}}$ - the CUSUM of the DLM trend of the activity duration curve.

These identifiers were used to denominate the curves describing the behaviour process as well as the corresponding parturition indicator throughout the text. Both were distinguished by the addition of the term curve and indicator respectively. The $\text{CUSUM}_{\text{act}}$ curves shall replicate the approach studied by Pastell et al. (2013), while $\text{CUSUM}_{\text{diff}}$ and $\text{CUSUM}_{\text{dur}}$ were chosen in order to replicate the analysis of CUSUMs of daily differences suggested in the study by Cornou and Lundbye-Christensen (2012). An indicator using CUSUM curves of daily differences of activity durations was also tested but did not produce better results than the $\text{CUSUM}_{\text{dur}}$ indicator (data not shown). The $\text{activity}_{\text{trend}}$ curve was included to examine the drawbacks and benefits from using the CUSUM approach for parameter monitoring and to at least partially reproduce the DGLM monitoring approach also studied in Cornou and Lundbye-Christensen (2012).

With 4 different parturition indicators, a random, validation and whole set of sows and the sensor positions head and torso 24 different classification results were produced in this study. To ease their identification, these results were given distinct names using the scheme *indicator_set_Sensor* (Tab. 1).

Tab. 2. Naming scheme for parturition indicators. The prefix is formed from the indicator subscript, the postfix using the initials of the sensor position and the infix from a shortened set identifier.

Indicator	Set	Sensor	Name
$\text{activity}_{\text{trend}}$	random	head	trend_rnd_H
$\text{activity}_{\text{trend}}$	validation	head	trend_val_H
$\text{activity}_{\text{trend}}$	whole	head	trend_whole_H
$\text{activity}_{\text{trend}}$	random	torso	trend_rnd_T
$\text{CUSUM}_{\text{act}}$	random	head	act_rnd_H
$\text{CUSUM}_{\text{diff}}$	random	head	diff_rnd_H
$\text{CUSUM}_{\text{dur}}$	random	head	dur_rnd_H
…	…	…	…

2.4.1. Trend curves for activity frequency and activity duration

The DLM trend curves were gained from DLMs fitted against log transformed hourly activity frequency and activity duration data to decompose these time series into a dynamic trend and a static diurnal component. The DLM structure was specified as polynomial trend with a 24 h seasonal component using the methods *dlmModPoly* and *dlmModSeas* from the R package *dlm* (Petris, 2010). The model fitting was performed with the *dlmMLE* method from the same package using the data collected up to the monitored time point. For trend extraction, the data was smoothed using the method *dlmSmooth* from the *dlm* package. The trend curve was then normalised by subtracting another trend curve based on same DLM but with a zeroed evolution matrix *W,* as suggested by Cornou and Lundbye-Christensen (2012) (Eq. 4). This resulted in a position corrected trend curve starting at zero and remaining unchanged as long as the animal activity remained unchanged.

$$\begin{aligned} trend_W(data) &= dlmSmooth(\,log(data),\ model)\$s[,1] \\ trend(data,t) &= trend_{W\neq 0}(data)(t) - trend_{W=0}(data)(t) \end{aligned} \tag{4}$$

Increases or decreases of activity led to a deviation of the trend curve from zero (Fig. 1D), that could either be monitored directly or using a CUSUM approach (Eq. 5).

$$\begin{aligned} activity_{trend}(t) &= trend(activity,t) \\ duration_{trend}(t) &= trend(duration,t) \end{aligned}, \ t \in [transfer, oop] \tag{5}$$

2.4.2. Activity difference curve

For the 24h activity difference curve, the difference between the hourly activity frequency at time t and t-24 h was divided by the individual activity difference standard deviation $\mathrm{SD_i}$ (Eq. 6). The standard deviation was calculated using the R method *sd* and data from the second day in the farrowing pen. It was included as normalisation coefficient to account for the individually different activity patterns of the sows as suggested by Cornou and Lundbye-Christensen (2012).

$$\begin{aligned} \mathrm{SD_i} &= sd(activity(t) - activity(t-24)))\,, t \in [25,\ 48] \\ diff_{24}(t) &= \frac{1}{\mathrm{SD_i}}(activity(t) - activity(t-24)),\ t \in [25,\ oop] \end{aligned} \tag{6}$$

Similar to the DLM trend, this curve is centred on zero if the activity level remains unchanged. It deviates to positive or negative values as the activity frequency increases or decreases (Fig. 1C).

2.4.3. CUSUM curve

The CUSUM approach is used for monitoring parameter deviations from a given nominal value. This nominal value was zero for trend and difference curves of activity frequency and activity duration. In (Eq. 7) *type* is a placeholder for the monitored curve and *k* is a constant defining the opening angle of the CUSUM V-mask in terms of a minimum curve gradient. The value for *k* was determined by optimisation using a given data set and sensitivity and precision as optimality criteria.

$$
\begin{aligned}
curve_{type}(t) &= \begin{cases} activity_{trend}(t) & for \quad type = act \\ diff_{24}(t) & for \quad type = diff \\ duration_{trend}(t) & for \quad type = dur \end{cases} \\
CUMSUM_{type}(t) &= max(0, curve_{type}(t) - k + CUMSUM_{type}(t-1))
\end{aligned}
\tag{7}
$$

Compared to the monitored curve, the CUSUM curve shows a clear deviation of its maximum to the right (Fig. 1E). This is due to its nature being a discrete integral of the monitored curve. Therefore, it reaches its maximum slope at the maximum of the monitored curve and its extreme values right when the monitored curve decreases to zero.

2.5. Quantitative prediction of parturition onset

For predicting the duration until the onset of parturition, the rising branch of a parabola $\beta x^2 = c$ was used to model the parturition related increase in activity. The parabola parameters can be gained by linear regression of an appropriate section of one of the activity curves $f(t)$ described in section 2.4 "Qualitative parturition onset prediction". Here, x denotes the duration until parturition, c the final increase in activity shortly before the parturition starts and β the activity gradient. Given known constants c_i and β_i for an individual activity curve of a specific sow i, the duration until parturition x_i can be calculated from (Eq. 8).

$$
x_i = \frac{\sqrt{c_i}}{\sqrt{\beta_i}} \tag{8}
$$

As c_i is generally unknown, it was assumed that it is relatively constant and approximately the same for all sows. This is plausible for "fairly high" coefficients β_i as individual variations in the maximal activity c_i then have only limited effect on the calculated duration until parturition x_i. Given for example a duration until parturition of x_i=16 hours, a prediction error limit of ±3h and an activity gradient β_i =0.016, c_i could vary from 2.7 to 5.8 to stay within the prediction error limit. So, it would induce no larger prediction error than three hours if the sows' increase in activity (c_i) varies by factor two. In conclusion, if the activity gradient became steeper when approaching the parturition, the prediction would become continuously more precise. This would make a prediction based on a common maximum activity constant c converge automatically making an approximation $x \approx g(\beta)$ feasible. From (Eq. 8) can be concluded that $g(\beta)$ is a hyperbola. Calculations involving the whole set of 34 sows indicated a sufficient approximation accuracy (Fig. 2).

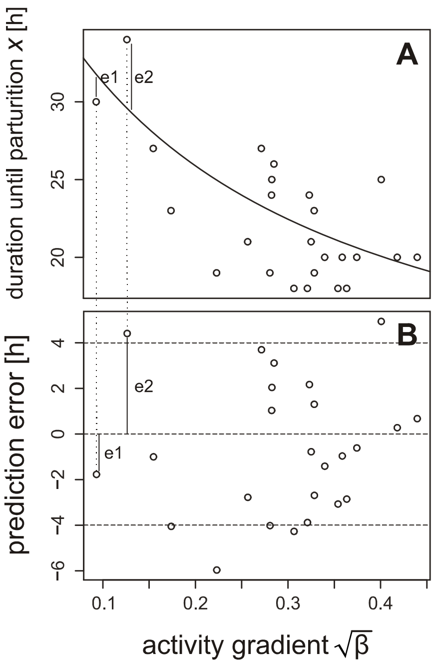

Fig. 5. A) The points represent actual durations until parturition x_i in relation to the individual activity gradients β_i, with respect to parabolas fitted to activity curves of the whole set of sows $i \in [1,34]$. The solid hyperbola depicts the curve progression of an optimised function $x = g(\beta)$. B) Points illustrate the error in the prediction of an individual parturition distance x_i introduced by assuming a generalised relation $x_i \approx g(\beta_i)$ for the distance of parturition. This error corresponds to the distance between the points and the hyperbola depicted in A). The dotted vertical lines exemplarily indicate which sows are identical in A and B. The solid vertical lines exemplarily depict the prediction errors e1 and e2 for these two sows.

Fig. 2A shows the individual parturition distances x_i in relation to the activity gradients β_i of the fitted parabola, yielded by linear regression of the $\text{CUSUM}_{\text{act}}$ curves from the whole set of sows. The parabolas were checked for sanity using the requirement $\beta_i > 0$. If the parabola for the activity of a certain sow did not comply with this requirement or the data set used for regression had less than four elements, there was no valid prediction for the corresponding sow at time t. These sows are missing in Figure 2. The solid curve in Figure 2A depicts an optimised hyperbola $x = g(\beta)$ found by linear regression using the R method *lm*. This hyperbola describes the approximate relation between the activity gradients and actual parturition distances. An example of the prediction error induced by assuming this relation is shown in Figure 2B. Based on these results, a range of ±4 h around the actual onset of parturition was chosen as true positive range for calculating the classification performance for the quantitative prediction of parturition.

Figure 2 already indicates that the approximation approach is not equally suited for all sows. By visual inspection of the data, a set of 8 young (1-2 parity) and lightweight (193-290 kg) sows was identified that possessed a different optimal approximation function $g(\beta)$ than the rest of the sows. Parity and weight of the sows are known beforehand and can be applied to create a more detailed prediction approach. Thus, two different approximation functions were used at each sensor position to create different predictions for head and torso sensor readings and for young and lightweight and older and heavier sows.

2.6. Detection of parturition onset

The detection of parturition onset was based on the CUSUM$_{act}$ indicator. After a CUSUM$_{act}$ parturition alert was released, the parturition onset detection monitored the quarter-hourly activity data for a sharp and lasting activity drop as described in Pastell et al. (2013). For this, a 6 h window of the quarter-hourly activity frequency curve was smoothed using the R method *smooth* and then fitted to a second order polynomial using the R method *lm*. The slope of this model was then inspected for a change from positive to negative model parameters (Fig. 3).

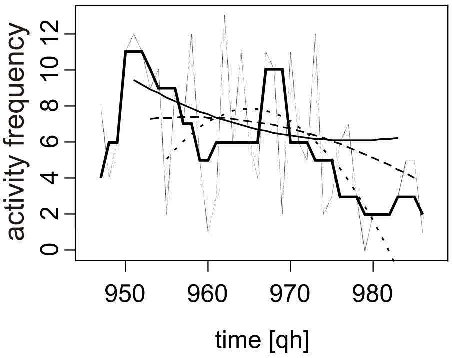

Fig. 6. Illustration of the detection of the onset of parturition. The light curve shows the quarter-hourly (qh) activity frequency and the solid strong curve its smoothed counterpart. The three parabolas depict the change from positive to negative model coefficients as the activity frequency decreases.

Pastell et al. (2013) reported a detection accuracy of ±0.5 h around the actual onset of parturition. After inspection of preliminary optimisation results, a range of ±4 hours around the onset of parturition was chosen for true positive classifications. Since the onset detection was based on the CUSUM$_{act}$ indicator, the classification performance of the CUSUM$_{act}$ indicator formed an upper limit for the classification performance of the onset detection.

3. Results

3.1. Threshold validation of the parturition indicators

For the threshold validation, an optimal threshold of the respective parturition indicator was chosen, using the data of the sows from the random set. The classification results of the random set where then compared to the classification results of the validation set using the same threshold. This gave an indication how the indicator performs if the same threshold is used on different sows.

Using the trend_rnd_H data for threshold optimisation, the activity$_{\text{trend}}$ indicator yield a 25th percentile of 18 h at a sensitivity of 94% and a precision of 89% (Tab. 2). The 25th percentile of trend_rnd_H was the highest of all indicators, but was somewhat lower with trend_val_H (16 h). The trend_val_H specificity of 65% indicates that one third of the validation sows triggered at least one premature alert. The sensitivity dropped to 82% and the precision to 70%. For the torso sensor, the trend_rnd_T optimisation results display a somewhat lower classification performance than with trend_rnd_H. In addition, the optimal threshold was 0.4 compared to 0.7 at the head position. With trend_rnd_T, the indicator achieved a 25th percentile of 17 h. It did not detect the near parturition of two sows, resulting in a sensitivity of 88%. Two premature alerts also account for the 88% precision of the indicator. With trend_val_T, four sows triggered premature alerts, resulting in a lowered sensitivity of 76%.

Tab. 3. Classification performance (sensitivity – sens., specificity – spec. and precision – prec.) of the qualitative parturition indicators for a randomly selected set of 17 sows with a 25th percentile (25th p.) of at least 12 hours and its validation based on the remaining 17 sow using the same threshold (thres) and CUSUM V-mask constant (k). The indicators were based on a dynamic linear model trend curve of activity frequency (trend_), its one-sided CUSUM curve (act_), a one-sided CUSUM curve of 24h activity frequency differences (diff_) and a one-sided CUSUM curve of the dynamic linear model trend curve of activity duration (dur_).

Sows & Indicator	k / thres	Sens.	Spec.	Prec.	25th p. [h]
		head sensor			
trend_rnd_H	- / 0.7	0.94	0.88	0.89	18
trend_val_H		0.82	0.65	0.70	16
act_rnd_H	0.3 / 6.0	0.82	1.00	1.00	12
act_val_H		0.82	1.00	1.00	10
diff_rnd_H	0.0 / 20	0.94	0.88	0.89	12
diff_val_H		0.88	0.88	0.88	8
dur_rnd_H	0.3 / 8.5	0.82	0.71	0.74	16
dur_val_H		0.77	0.77	0.77	15
		torso sensor			
trend_rnd_T	- / 0.4	0.88	0.88	0.88	17
trend_val_T		0.76	0.76	0.76	15
act_rnd_T	0.2 / 1.0	0.94	1.00	1.00	15
act_val_T		0.88	0.88	0.88	13
diff_rnd_T	0.0 / 15	0.88	0.82	0.83	12
diff_val_T		0.88	0.71	0.75	14
dur_rnd_T	1.1/ 0.2	0.59	0.35	0.48	44
dur_val_T		0.53	0.24	0.41	43

The act_rnd_H optimisation of the $\text{CUSUM}_{\text{act}}$ indicator yield perfect precision (100%) for the head sensor. Yet, with a sensitivity of 82% the near parturition of three sows was not recognised. This performance was preserved at the validation with the act_val_H set. Here, the indicator failed to stay within 25th percentile limit (10 h) when using the k and thres parameters found for act_rnd_H (0.3, 6.0). For the torso sensor position the $\text{CUSUM}_{\text{act}}$ indicator even yield a sensitivity of 94%, detecting the near parturition of all but one sow from act_rnd_T. This missed sow triggered no alert at all, which led to a 100% precision and specificity again. The threshold changed from 6.0 to 1.0 for the torso position. When validating with act_val_T, all results of the $\text{CUSUM}_{\text{act}}$ indicator were somewhat weaker. The indicator gave premature alerts and failed to give timely alerts for two sows, leading to 88% sensitivity, specificity and precision. The 25th percentile of 13 h was clearly above the 12 h limit.

For diff_rnd_H, the $\text{CUSUM}_{\text{diff}}$ indicator yield classification results comparable to the $\text{activity}_{\text{trend}}$ indicator and trend_rnd_H. The validation with diff_val_H even performed considerably better than for the $\text{activity}_{\text{trend}}$ indicator but clearly failed to stay within the 25th percentile limit of 12 hours (8 h). With diff_rnd_T, the $\text{CUSUM}_{\text{diff}}$ indicator threshold changed from 20 to 10 for the torso sensor. The indicator failed to give alerts for two sows, resulting in 88% sensitivity. Even more sows triggered premature alerts, leading to the lowest precision of all activity frequency based indicators (83%). For diff_val_T, the indicator yield the same sensitivity (88%) but an even lower precision (75%).

The $\text{CUSUM}_{\text{dur}}$ indicator failed to indicate the near parturition of three sows resulting in a sensitivity of 82% for dur_rnd_H. It gave premature alerts for about one fourth of all sows leading to a precision of 74%. Its 25th percentile of 16 h indicates that most alerts occurred sufficiently early. These results were basically confirmed by dur_val_H. At the torso sensor position, the $\text{CUSUM}_{\text{dur}}$ indicator exhibited no temporal connection to the onset of parturition, resulting in a 25th percentile of 44 h for dur_rnd_T. The precision (48%) indicates that alerts were given long before the 48 h range for nearly all sows. Of these alerts, at least one was finally within the target range for about half of the sows (sensitivity 59%). The dur_val_T set shows similar results.

3.2. Whole set optimisation of the parturition indicators

Performing the threshold optimisation of the parturition indicators over the whole animal set gave some insight to what extend the random set optimisation results could be generalised. Here, a 25th percentile limit of 8 h was chosen to get a notion of the best possible classification performance. Under these conditions, the optimisation for the indicators based on $\text{activity}_{\text{trend}}$ and $\text{CUSUM}_{\text{dur}}$ curves yield nearly the same CUSUM V-mask parameters and thresholds at the head sensor position as with the random set optimisation (Tab. 2). Consequently, the classification performance was intermediate to their random and validation set performance. The indicators $\text{CUSUM}_{\text{act}}$ and $\text{CUSUM}_{\text{diff}}$ could both benefit from the relaxed 25th percentile limit. They exhibit a somewhat higher sensitivity at a comparatively high precision level using the head sensor data. The optimal threshold and V-mask parameter k for act_whole_H (0.2 / 6.0) was similar to the result of the act_rnd_H optimisation (0.3 / 6.0). Due to a higher V-mask parameter (0.5 vs. 0.0) the optimal threshold for diff_whole_H was lower than for diff_rnd_H (12 vs. 20)

For the activity$_{trend}$, CUSUM$_{act}$ and CUSUM$_{dur}$ indicators, the whole set optimisation again yield at the torso sensor position thresholds and classification results similar to the random set optimisation. Only diff_whole_T for the CUSUM$_{diff}$ indicator could improve its sensitivity and precision due to the lowered 25th percentile limit of 8 h ((91%, 89%) vs. (88%, 83%) (sens., prec.)). Its optimisation produced different threshold and V-mask parameter (1.0 / 4.0 vs. 0.0 / 15). The CUSUM$_{act}$ curve based indicator stood out, demonstrating the highest sensitivity (94%) and the best precision (97%) at the same time. For the CUSUM$_{dur}$ indicator, the nearly non-existent association with the onset of parturition was confirmed (Tab. 3). These results also conform to the order of magnitude of the respective curve's $\overline{SNR}$.

Tab. 4. Classification performance (sensitivity – sens., specificity – spec. and precision – prec.) of the parturition indicators for the whole set of 34 sows with a 25th percentile (25th p.) of at least 8 hours, after optimisation of the alert threshold (thres) and CUSUM V-mask constant (k). The indicators were based on a dynamic linear model trend curve of activity frequency (trend_), its one-sided CUSUM curve (act_), a one-sided CUSUM curve of 24h activity frequency differences (diff_) and a one-sided CUSUM curve of the dynamic linear model trend curve of activity duration (dur_). The average signal noise ratio ($\overline{SNR}$) characterises the respective curve level ratio of the normal and the parturition related behaviour.

Sows & Indicator	k / thres	Sens.	Spec.	Prec.	25th p.	$\overline{SNR}$
		head sensor				
trend_whole_H	- / 0.75	0.85	0.82	0.83	16	7.6
act_whole_H	0.2 / 6.0	0.91	0.97	0.97	11	42.4
diff_whole_H	0.5 / 12	0.91	0.94	0.94	9	36.5
dur_whole_H	0.3 / 8.5	0.79	0.74	0.75	15	11.9
		torso sensor				
trend_whole_T	- / 0.35	0.85	0.79	0.81	17	6.5
act_whole_T	0.1 / 3.0	0.94	0.97	0.97	12	40.2
diff_whole_T	1.0 / 4.0	0.91	0.88	0.89	8	51.5
dur_whole_T	1.1 / 0.5	0.59	0.32	0.47	42	3.1

Figure 4 depicts the alert distributions of the parturition indicators after optimisation using the whole set of sows. The activity duration based indicators are clearly distinguished from the activity frequency based indicators. All activity frequency based indicators gave most of their alerts in a close temporal relation to the onset of parturition. For the head sensor position, the 24 h activity frequency difference indicator CUSUM$_{diff}$ exhibited the densest distribution. Yet, about 25% of all alerts were given with less than 8 h remaining until parturition. With the CUSUM$_{act}$ indicator these were only 10% of all alerts. The activity$_{trend}$ indicator alert distribution was well above the 8 h limit but more than 10% of all alerts were given earlier than 48 h before the onset of parturition.

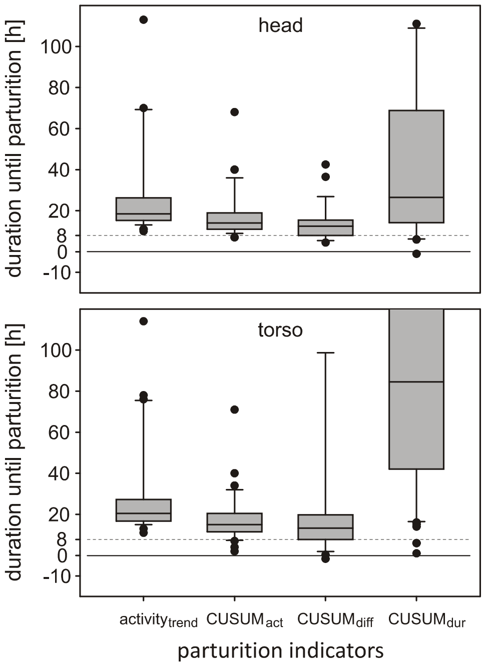

Fig. 7. Alert distribution for the qualitative parturition indicators and the sensor positions head and torso. The solid horizontal line marks the onset of parturition. The dashed horizontal line indicates 8 hours until parturition. The boxes depict the median and the 25th and 75th percentile. Whiskers stand for the 10th or 90th percentile, respectively. Black dots mark outliers beyond the whisker percentiles. The diagrams cut off parts of the outliers and the box plots to improve the distinctness of the 48 h period before parturition. The indicators were based on a dynamic linear model trend curve of activity frequency (activity$_{trend}$), its one-sided CUSUM curve (CUSUM$_{act}$), a one-sided CUSUM curve of 24h activity frequency differences (CUSUM$_{diff}$) and a one-sided CUSUM curve of the dynamic linear model trend curve of activity duration (CUSUM$_{dur}$).

Compared to the head position, the alert distributions were mostly somewhat widened for the torso sensor (Fig. 4). The activity$_{trend}$ indicator gave 50% of its alerts within a range of 17-27 h before parturition. The 90th percentile was located at 76 h compared to 69 h with the head sensor position. Nearly 75% of all alerts of the CUSUM$_{act}$ indicator were given within the 8-48 h range. In contrast, the CUSUM$_{diff}$ indicator alert distribution was considerably wider. Its 90th percentile was at 99 h compared to 26 h and its 75th percentile was at 19 h compared to 15 h with the head sensor. The alert distribution of the CUSUM$_{dur}$ indicator confirms that only about 25% of the alerts were within the 48 h range, while the remaining alerts were premature.

3.3. Quantitative prediction of parturition onset

Figure 5 depicts the average error of the predicted duration until parturition in relation to the actual duration until parturition using the CUSUM$_{act}$ curves for regression. The error curve for the head sensor and the whole set of sows (Fig. 5A - light curve) started with a prediction error around 4.5 h and had a standard deviation ranged from 5 h to 7.5 h over the full prediction period. Predictions that met the true positive criterion of ±4 h around parturition onset showed an average prediction error near zero right from start (Fig. 5A - dark curve). Their standard deviation ranged from 2 h to 3 h with slight signs of convergence towards the actual onset of parturition. There was a significant correlation between the average predicted and the actual duration until parturition (r=0. 996, p<0.001). The differences between the light and dark curve in Figure 5A were produced by the removal of 4 sows with unsuited predictions that also did not meet the true positive criterion. Their predictions behaved generally poor, showing no sign of convergence and having a high error throughout the whole observed period of 24 h before parturition onset. Averaged over 24 h, these predictions exhibited a mean error of 12.5 h ±6.9 h (SD) (data not shown). At the same time, the predictions that did meet the true positive criterion also behaved generally well. With the head sensor, a prediction error below ±4 h around the actual onset of parturition was achieved at least once for 88% of all sows (30). Averaged over 24 h, these predictions exhibited a mean error of 0.5 h ±2.5 h (SD) (data not shown).

The predictions based on the torso sensor showed a behaviour similar to the head sensor based predictions. The mean of the predicted and the actual duration until parturition were significantly correlated (r=0.998, p<0.001). The whole set of sows had a standard deviation of 7 h to 11 h over the full 24 h period (Fig. 5B – light curve). The standard deviation of the prediction error for the dark curve ranged from about 3 h to 5 h with one outlier at 22 h before parturition with 8.5 h standard deviation. These differences between the light and dark curve were produced by the removal of 9 (26%) sows with unsuited predictions that also did not meet the true positive criterion (Tab. 4).

Since the predictions were depending on the detection of a sufficiently lasting activity increase, predictions were not available for all sows over the full 24 h time period. The upper scale of the diagrams A and B displays the number of sows with well suited predictions included in the dark curves. In general, predictions were available for about 90% of all sows from 15 h before parturition on.

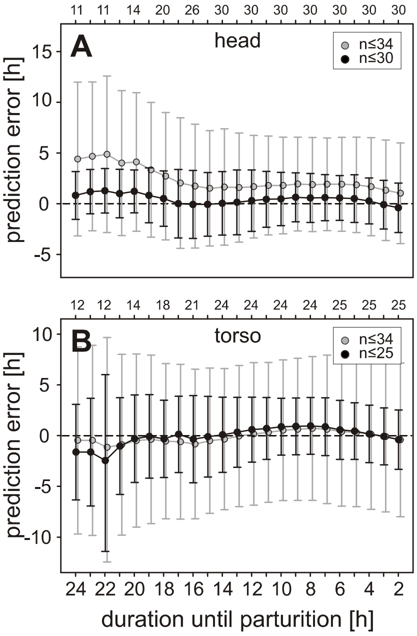

Fig. 8. Errors of the predicted durations until parturition onset in relation to the actual duration until parturition onset using data from the head (A) and torso sensor position (B). The light dots and error bars represent the average prediction error and the prediction error standard deviance for the whole set of 34 sows. The dark dots and error bars represent the prediction results for sows with true positive predictions (Tab. 4 - 88% head, 74% torso). The scales at the top of each diagram display the number of sows included for the calculation of the dark error curves at the corresponding point in time.

The error distributions for the well behaving predictions using the head sensor are depicted in Figure 6A. The diagram starts at 15 h before the onset of parturition as from this time on a prediction is available for nearly all sows. From Figure 6A can be inferred that about 80% of all suited predictions were continuously within the ±4 h error range starting at 15 h before parturition. The specificity of the predictions for the head sensor indicates that 41% of all sows also earlier than 15 h before parturition never produced prediction errors beyond ±4 h (Tab. 4). There are also slight signs of convergence, leading to a prediction error of ±2 h and less for 50% of the 30 sows, starting at 9 h before the onset of parturition.

For the torso sensor, 21% of all sows (7) never had prediction errors beyond ±4 h and 74% of the predictions were at least once within ±4 h of the actual onset of parturition (Tab. 4). Of the 25 suited predictions, 50% achieved errors of ±3 h and less (data not shown).

Figure 6B depicts exemplarily the progression of the prediction error during the last 15 h before parturition for six single sows. The predictions of the sows I, III and V stay relatively stable while IV and VI display marked signs of convergence to a smaller prediction error. The predictions for sow II turned from underestimating to overestimating the duration until parturition.

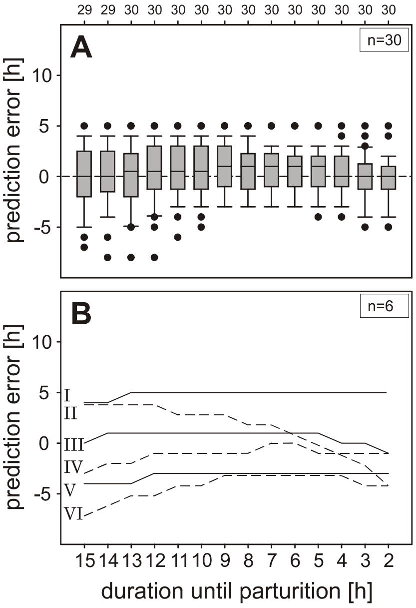

Fig. 9. A) Distribution of the prediction error for suited predictions relation to the actual duration until the onset of parturition. The stippled horizontal line indicates a zero prediction error. The boxes depict the median and the 25th and 75th percentiles. Whiskers stand for the 10th and 90th percentiles. Black dots mark outliers. The upper scale displays the number of sows included at the corresponding point in time. B) Exemplary progression of the prediction error for 6 sows. The sows are distinguished by Roman numerals and different line dashes if at the same value level. All predictions were based on $\text{CUSUM}_{\text{act}}$ curves with data from the head sensor.

3.4. Parturition onset detection

Based on a ±4 h detection range (Fig. 1B), the detection of the actual onset of parturition reached a sensitivity of 88% (Tab. 4). For one sow the onset detection gave an alert outside the ±4 h range, resulting in a precision of 97%. Using the data from the torso position led to a lowered sensitivity of 85%. Here, the parturition of five sows was not correctly detected. This was in part an effect from the lowered precision of 88%, due to alerts outside the ±4 h range. Since the monitoring was stopped once the onset of parturition was detected, a lower precision had a direct impact on the detection sensitivity.

Tab. 5. Whole set optimisation results for the quantitative parturition prediction and the parturition onset detection. True positive classifications were assumed if the distance to the actual onset of parturition was no more than 4 h from the detected or predicted onset of parturition.

Indicator	Sensitivity	Specificity	Precision
	head sensor		
onset (±4h)	0.88	0.97	0.97
prediction (±4h)	0.88	0.41	0.60
	torso sensor		
onset (±4h)	0.85	0.88	0.88
prediction (±4h)	0.74	0.21	0.52

4. Discussion

The results of this study show that light barrier sensors are suited for activity measurements with parturition prediction and detection results similar to previous accelerometer based studies. The measurement frequency of the light barriers can be configured similarly to accelerometer measurements. Yet, the measurement sensitivity of single light barriers is much lower compared to an accelerometer. In particular, the light barrier configuration used in this study was unable to detect small scale movements of the body, leg movements and movements when the sow was lying on the floor. Therefore, not all characteristics of parturition related restlessness could be detected. However, the light barriers were well suited for detecting posture changes and far-reaching head movements. Increased head movements conform to typical pre-farrowing behaviour such as floor rooting, sniffing and biting (Lammers and de Lange, 1986). Therefore, the head activity should increase more marked than the number of posture changes. This was partially confirmed by the parturition indicator results. Here, the upcoming parturition could be detected somewhat easier using the head sensor compared to the torso sensor data except for the $\mathrm{CUSUM}_{\mathrm{act}}$ indicator. The typical nest building behaviour probably also led to more consistent and continuous activity measurements that provided for more consistent quantitative predictions when using the head sensor data.

The effects of the lower sensitivity of the light barriers were especially observable at the detection of the parturition onset. Here, the real decrease of activity that marks the onset of parturition had to be distinguished from periods where the sow's activity could not be detected by the light barrier. Hence, the parturition detection results for the torso sensor were weaker than the head sensor results, as this sensor was insensitive to the more frequent and more continuous head movements. At the same time, the head sensor results were weaker than accelerometer results because the head sensor was insensitive towards the more frequent and continuous small scale movements and towards movements while the sow was lying. This led to the necessity to observe a longer time period to detect a real activity decline. In result, a detection range of ±4 h was necessary to achieve a similar sensitivity and precision as reported by Pastell et al. (2013) for a detection range of ±0.5 h. Comparing the two sensor positions head and torso also confirmed that the activity measurements are sensitive to the position of the sensor. Using several light barriers at the same time might compensate this disadvantage. It could also allow the use of light barriers for activity measurements on non-crated sows. The subjection to precise positioning and the limited sensitivity of light barriers might also be overcome by using more sensitive and position independent contactless sensor techniques such as video image-processing (Costa et al., 2013).

In spite of all normalisation efforts, the use of global thresholds for parturition indicators seemed not fully adequate to address the individual differences in the parturition associated activity development. Even with the activity measured relative to the individual normal activity, its gradient and magnitude could vary heavily amongst the animals. To get an indicator with an acceptable sensitivity, the threshold had to be assessed such low that often some sows triggered premature alerts. This also led to broader and more unspecific alert distributions. One aspect of this issue was the fact that the observation period between transferral to the farrowing pen and the onset of parturition could vary between 4 and 13 days due to the breeder's animal management. Thus, the identification of individual activity normal values did not take place at the same day before parturition. Therefore, it was probably not always possible to measure a suitable normal activity level for sows with an early onset of parturition, resulting in deviant normalised activity curves. These curves also contributed to some of the unsuited quantitative predictions in the results of this study.

Comparing the examined variants for transforming and normalising the sensor raw data into a suitable activity curve, the $\text{CUSUM}_{\text{act}}$ curves provided for the best classification performance at both sensor positions. Disadvantage of the DLM based methods was the high calculation effort for the individual model fitting especially compared to the computationally simple 24 h activity difference approach. The $\text{CUSUM}_{\text{diff}}$ indicator exhibited the densest alert distribution for the head sensor position. However, the 25th percentiles of the head and torso alert distributions were also the lowest of all examined curves. The $\text{activity}_{\text{trend}}$ indicator produced alert distributions with the highest 25th percentiles. Its classification performance was generally mediocre. Surprisingly, the activity duration based $\text{CUSUM}_{\text{dur}}$ indicator turned out inadequate. The 2 minute activity intervals measured by Cornou and Lundbye-Christensen (2012) correspond basically to activity duration measurements but allowed for a satisfactory qualitative parturition prediction. One possible explanation of this divergence could lie in the use of neck collars. At this body position, the accelerometers must have recorded the intensified head activity. In the current study, this had a positive effect on the classification performance of the $\text{CUSUM}_{\text{dur}}$ indicator as well.

The classification performance of the parturition indicators roughly corresponded to the order of magnitude of the average SNR of the underlying curves. It did not fully comply, as the average SNR holds no information on the actual SNR distribution. In general, the SNR was clearly highest for the activity frequency based CUSUM curves. However, the highest value of the CUSUM curve is reached right when the parturition starts. Therefore, optimising the precision of CUSUM based indicators will make the alert distribution move closer to parturition, rendering it useless for practical purposes in worst case. By imposing a 25th percentile limit for the alert distribution, a necessary optimisation criterion beyond classification performance alone was introduced. This approach could be extended by also imposing a limit for the 75th percentile of the alert distribution.

Considering its average error range, the newly developed quantitative prediction of parturition already allowed a rough prediction of parturition distance in categories such as now, today, tonight and tomorrow. Predictions were available for nearly 90% of the sows, at least 15 h in advance. Yet, the applicable prediction distance and the variation in the prediction error still need improvement. Such improvements could be achieved by developing better methods for the normalisation of individual activity curves. Another approach could be the intensified consideration of animal groups with similar physiologic properties such as age, weight, breed, injuries, infections, housing or exercise for optimising the method parameters. The differing occurrence of these properties could influence at least in its extremes the development and maximum value of the parturition related activity increase. Hence, applying different threshold values or other approximation functions according to previously known parameter categories such as *gilt*, *lame* or *heavy* and their combinations could improve the classification performance of qualitative and quantitative predictions or the detection of parturition. In the current study, an improvement of the quantitative prediction results was achieved by using a different approximation function for very young and lightweight sows. Yet, no studies exist that substantiate any relation between physiologic properties and the pre-parturient behaviour of sows as it was assumed in this study.

5. Conclusions

The evaluated methods for acquiring individual parturition indicators basically confirm the earlier results of studies on body attached accelerometers. It could be shown that the methods proposed there can be transferred to contactless sensors like light barriers. However, the accuracy decreased with the lower sensitivity of the light barrier sensors. In addition, the qualitative and quantitative predictions were sensitive to the position of the light barrier relative to the sow’s body. Comparing the whole set optimisation results of the parturition indicators with the classification performances obtained with the validation sets reveals that optimisation results should not be mistaken as the real life performance. In a practical application, the classification performance might be considerably lower than its theoretical maximum. Improvements in the classification performance could be achieved by further studies on general differences in parturition behaviour of groups of sows with common physiologic properties such as age, weight and similar.

While based on a single sensor, the quantitative and qualitative prediction of parturition distance together with the detection of the onset of parturition provide a complete set of tools for parturition management. The qualitative prediction provides an early warning for the near onset of parturition. The quantitative prediction then offers regularly updated information on when the parturition will start, while the actual start is detected by the parturition onset detection. This toolset is not only beneficial for the breeder and manual management tasks. It can also provide decision support for automated active crushing prevention systems (Jeon et al., 2005, Manteuffel et al., 2014). Here, the parturition distance and onset indicators enable an automatic activation and deactivation of the system, entailing no administration effort for the breeder.

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General Discussion

The previous chapters described the informed behaviour manipulation at the example of call feeding and preliminary studies on an autonomous crushing prevention system. These systems utilised aversive and appetitive stimulations to improve the overall productivity and animal welfare in its particular husbandry environment. The development of these procedures included four basic steps:

- **Step 1.** Investigation of suited appetitive and aversive stimuli.
- **Step 2.** Development of sensors for monitoring the animals.
- **Step 3.** Development of methods for the adaptation of the behaviour manipulation towards animal or production requirements.
- **Step 4.** Investigation of technical and behavioural aspects for the practical application of the methods found.

The call feeding procedure presented in **section I** exemplified the utilisation of conditioning methods to achieve an appetitive behaviour manipulation whilst conditioning was explicitly tried to be avoided with the aversive crushing prevention system discussed in **section II**.

Section I: Appetitive behaviour manipulation

Chapter 1 described a study that aimed to prove the practicability of call feeding with small groups of up to 8 adult gestating sows. The study also tested the feasibility of using a commercial electronic feeding station for this purpose. No experiences on call feeding adult sows were available by the time when the study was conducted. The results of the former call feeding studies were obtained with juvenile pigs. These might be more adaptive than adult sows (Kratzer, 1969), so that the feasibility of the training procedure for sows needed to be proven. A further aim of the study was to explore the effect of the social structure of the gestation group on the learning performance. In addition, the general feeding behaviour during the training was investigated. The investigation of suited appetitive stimulations, as required by step 1 for the development of a behaviour manipulation mechanism, was not necessary here. Feed is the original appetitive motivator used in behaviour research (Pavlov, 1927). The electronic feeding station already provided mechanisms to dispense feed to the sows and to control the dispensation process. Hence, the suitability of feed as stimulation and of the feeding station as dispensation device could be assumed without further investigation.

The social structure of the gestation groups was determined in the first week of each trial right when two smaller groups of up to 4 sows were mixed into one group of up to 8 sows. The change in the group composition induced the establishment of a new social hierarchy through agonistic interactions (Meese and Ewbank, 1973). The outcome of each agonistic interaction gives an indication on the hierarchy of the observed dyad so that ideally a complete social order of the group can be determined. In practice, not all dyads are observable and animals at a similar social rank may manifest no strict hierarchy in repeated agonistic interactions (Moore et al., 1994; Rushen, 1996). Therefore, the determined rank order of the sows is always incomplete and an approximate classification in several rank classes is legitimate. For the study presented in chapter 1, a sub-division in the 3 rank classes *dominant*, *subordinate* and *submissive* was chosen.

The sows received 7 days of classical conditioning at a modified commercial electronic feeding station. Here, the animals could enter the feeding station spontaneously up to 6 times a day. Whilst feeding, an individual acoustic signal was emitted by the station immediately before the next 60 g portion was dispersed. During the subsequent 13 days the sows received an operant conditioning. In this phase, the sows had to learn that they could enter the feeding station and receive feed only after their individual signal was played.

At the end of the training, the sows followed on the average less than 8% of the signals of other sows. Hence, their performance in recognising the signal of others was well below the value of 50% that would result from random reactions. The present study results show, that dominant sows achieved a level of 80% correctly responded signals on average three days earlier than all other rank classes. At the same time, dominant sows had the lowest latency from the emitted signal until the start of feeding. However, dominant sows also spend more time in front of the station entrance than the sows of the other rank classes. They also approached the station more often erroneously during the calls of other sows. This shows that dominant sows are better able to cope with the changed feeding situation due to their alleviated station access as a result of the natural avoidance order (Jensen, 1982). At the same time, the high ranking sows encumbered the station access for lower ranking sows by physical presence and by actively displacing other sows through agonistic interactions. Hence, only 64% of the submissive sows were able to respond to at least 80% of their own signals until the end of the experiment. These rank specific differences in the ratio of responded signals, however, do not document an improved learning performance of the dominant sows. The learning speed in terms of the daily increase of correctly responded signals was not different between the rank groups. Instead, the study documents that call feeding is able to diminish the influence of the social rank on feed access. At the end of the training, sows of all ranks spend approximately the same time in front of the feeder. In addition, the number of false approaches by high ranking sows decreased significantly. These reductions were yet not early enough to allow lower ranking sows to catch up to the same level of correct responses until the end of the trial.

Chapter 2 gave a description of how a commercial electronic feeding station was modified to work as call feeding station. It also specified the methods used to monitor the individual behaviour and learning performance of the sows. A further part dealt with the implementation of an autonomous training method that is individual to each sow. In addition, provisions necessary for a stepwise adaptation of large herds were discussed.

The current call feeding implementation incorporates an automated training procedure that works with a combination of Pavlovian and a stepwise advanced operant conditioning. Similar studies were performed by Wredle et al., (2004 and 2006) with the aim to call cows to a feeder connected to an automatic milking system. These studies used a manual training procedure lasting 12 days that had to be continuously supervised. In Wredle et al. (2004), three variations of appetitive operant and classical conditioning were tested. Of these, only the combination of classical conditioning with a stepwise advanced operant conditioning led to a successful conditioning of 8 out of 10 cows.

Wredle et al. (2006) found, that only 16% of the correctly observed calls were rewarded because the reward was connected to a prior visit of the milking unit. This unit was often occupied by the time the called cow arrived. This led in at least one case to the extinction of the conditioning. An elaborate planning of the signal emission is therefore vital for the continuous functioning of call feeding especially when conditioned and naive animals exist in the same group. This planning requires a detailed knowledge of the current station occupancy and of the animals in the vicinity of the feeding station.

In the present study, the sensors for an individual monitoring of the animal behaviour were already comprised in the electronic feeding station. The sows were identified by a RFID-antenna (radio frequency identification) at the trough that read the ear transponder of the sow in front of it. The immediate surroundings of the entrance could be monitored by an RFID-antenna inside the entrance doors. In addition, the amount of feed dispensed was already determined by the portion release mechanism. Together these sensors provided the parameters

- successful feedings,
- entry attempts,
- entry success and
- latency from call to feeding

which were necessary for to assess the general sow behaviour and the individual reactions on the calls (step 2). Based on these parameters, derived parameters especially for determining the learning performance of the sows in terms of signal classification could be calculated. This information was supplemented by information from an animal database that contained the approximate social rank, the next planned feeding and the feed contingent of the sows. With this data, the planning of the signals could account for the current station occupancy. It could also account for the number and identity of the sows at the station entrance and it considered the general social structure and training status of the whole group.

Utilising this information allowed the development of autonomous animal management strategies that are necessary for a practical use of call feeding (step 4). For example it allowed an autonomous separation of the feeding of naive and already conditioned animals as well as a separation according to the rank classes. In addition, it prevented the sows from successful autonomous operant conditioning on deviant environmental cues. Such cues can be for example signals of other sows opening the entrance inadvertently for a dominant sow waiting at the entrance.

The assessment of the individual animal reaction is one key element at the design of an appetitive behaviour manipulation mechanism utilising operant conditioning. This parameter allows the system to provide an individual progression for each animal when increasing the difficulty of the task. Without such an individual progression (step 3), the positive stress of solving a task to receive a reward could turn into overstraining and frustration because of individual limits in the coping capabilities (Korte et al., 2007). The current call feeding implementation considers such individual differences by allowing a prolonged or repeated training of single sows while others already perform call feeding. In addition, it permits encumbered individuals and individuals incapable of learning to perform conventional electronic feeding at the same station where the other sows of the gestation group perform call feeding. In this regard it enables the practical application of call feeding without a need to manually assist less suited or cull unsuited sows (step 4).

Chapter 3 presented the results of a study that compared the operation of a conventional electronic feeding station and call feeding in a herd of in total 67 sows during 2 years. Up to 36 sows were held in a dynamic gestation group that was recomposed every 3 weeks with one subgroup leaving for farrowing and one subgroup arriving from mating. After farrowing and mating the sows returned to the gestation group. Hence, the memorisation of the individual signals during the production cycle and the long-term development of the learning performance could be observed. The aim of the study was to compare the previously used electronic feeding with using call feeding after its complete establishment (Kirchner et al., 2012). In addition, the study tested and documented the stepwise adaptation of the whole herd to call feeding. This adaptation was performed by training a small subgroup after mating in a separate learning compartment prior to its transfer into the gestation group.

The study reveals a general difference in the learning capacities of sows and cows. Wredle et al. (2004) reported that successfully conditioned cows were to a large extent unable to reach the feeder when they were not located in the same experimental environment where the training was performed. In contrast, the sows conditioned in a separate learning compartment, were able to acquire feed after their transfer to the large gestation group in a different stable. However, their success in following their individual signal dropped in the first days after the transfer compared to the learning compartment (Kirchner et al., 2014). The sows were fed in the learning compartment before their transfer to the gestation group. This lowered the feed intake in the gestation group at day 1. At the same time, normal agonistic interactions occurred when the learning and gestation groups were mixed. This might have hampered their access to the feeding station. Hence, the effects of the environment can here not be distinguished from effects due to the necessity to generalise the conditioning.

The chronological progression of the learning and feeding results presented in chapter 3 reveals that the average learning performance of larger groups reaches the level of small groups delayed. In this study, it took about 8 month to adapt the whole gestation group and reach an 80% level of observed signals. This was in part caused by the stepwise adaption procedure that required 5 months. Other causes were ongoing software corrections and improvements at the beginning of the study including improvements at incorporating the social hierarchy in the call planning.

In the course of the study, a level of more than 80% observed signals was achieved. The signals of other individuals were in the end ignored to more than 90%. The average duration from emitting a signal until the start of the feeding reduced from 140 s to less than 80 s. These performance improvements were largely influenced by experienced sows reentering the gestation group. In general, the sows remembered their signal during the lactation and mating period. They significantly improved their learning performance (positive predictive value) even further during the second 44.3 ±2.7% (SE) and third 54.8 ±2.7% (SE) gestation period with call feeding. These values show that each sow on average appeared within 12h and 1 feeding per day not more than once at the station entrance while a different sow was called. In conclusion, the sows on average observed their own signal and mostly stayed away from the entrance while up to 35 other sows were called.

Section II: Aversive behaviour manipulation

Regarding the prevention of piglet crushing, several approaches are possible to detect piglets at risk and to avoid risky situations. The most basic approach is to separate the mother sow and its piglets especially when the sow is reclining. For this purpose, fenders at the walls of farrowing pens and the farrowing crate have been invented (Sommer, 1920; Barker, 1929) and are commonly used today. More elaborate approaches try to create an additional physical barrier in risky situations by either actively lowering the piglet nest (Hodkinson and Booth, 1963) or raising the platform of a crated sow (Geerkens, 1990). Such systems are today commercially available. Yet they appear to be hard to install and maintain under piggery conditions because they include moving parts that need to fit tightly and can be jammed by dirt. Another method tries to dislodge piglets beneath the sow by utilising their sensitivity to wind chill. The air flow is here either produced by a ventilator (Thacker and Barber, 1987) or by releasing compressed air (Jeon et al., 2005). Both systems are acting blind, as they don’t monitor the piglet behaviour or the reaction on the stimulation. Hence they are activated very often. Nevertheless, both studies report to have successfully reduced the number of crushed piglets. A more restrictive application of aversive stimulations was tested by Friend et al. (1989). They tested an approach to trigger a posture change of the sow through electric shocks when a certain level of piglet noise was exceeded. Such a system could allow renouncing the use of farrowing crates. It would allow limiting the use of welfare impairing measures on the sows that crush piglets and on the time when a piglet is being crushed. However electric shocks implicate physical pain that can result in a severe and lasting inference in the animal reactions. Friend et al. (1989) for example reported a lasting more cautious reclining of the sows as well as occasions of aggressive behaviour against the personnel. Therefore, the author of the present research work investigated less severe stimulation principles that are aversive but not painful. These stimulation principles and appropriate stimulation intensities were tested on gilts in several unpublished preliminary studies.

Chapter 4 presents the results of a detailed investigation of stimulations with air-blasts and floor vibration that were most effective in the preliminary studies. Earlier studies on rats already indicate the general aversiveness of vibration (Wike and Wike, 1972) and air-blasts (Ray, 1966). The propagation of these stimulation methods on farm animals yielded similar results. Juvenile pigs subjected to floor vibration in a choice test learned to switch off the vibration by operant conditioning, while the vibration noise alone had no training effect (Bailey et al., 1983). Air-blasts were shown to be effective to elicit fear in cattle (Boissy et al., 1995). A similar effect was also found by Wredle et al. (2004) where the stimulation was able to extinct a feed conditioning in one individual.

The stimulation intensity applied in the study presented in chapter 4 needed to be suited for gestating sows weighting 150 to 400 kg. Pressures of 2-2.7 bar were used in studies on rats and mice (Ray, 1966; Clark et al., 2003). Studies on humans show that air-blasts of 4 bar are an effective aversive stimulus (Monk et al., 2003). Experiments on cattle used pressures of up to 10 bar (Wredle et al., 2004). Considering the size and weight of adult sows, pressures between 4 and 10 bar should be effective. However, the parameters physically describing the effective intensity of air-blasts are the size of the affected area and the force affecting the area. Because these parameters are harder to measure, it is common in literature to measure and specify secondary parameters. The applied force is the product of the air mass and its acceleration. It therefore depends on the accelerated air mass and its speed when it is decelerated by hitting the surface. Given that an unlimited output rate, air mass, speed and affected area are depending on the pressure of the compressed air, the distance from the surface (by friction and turbulence) and the nozzle characteristics. Specifying air pressure, surface distance and the nozzle type is therefore sufficient to ensure reproducibility. However, the assumption of an unlimited output rate usually does not hold. Every component of the experimental setup such as the mounting of the force main, coupling links and the source of the compressed air can have limiting effects on the air-mass flow. A low air-mass flow reduces the accelerated mass and therefore the applied force. Conversely a high air-mass flow increases the applied force. This effect can be utilised to amplify the intensity of the stimulation without using a higher air pressure. The loudness of air-blasts increases with higher pressures. Depending on the nozzle characteristics, an air-blast of 6 bar can create a noise level of more than 90 dB in one metre distance. Hence, the loudness of compressed air and the health risks connected to it form a limit for amplifying the stimulation intensity through higher pressures. This limit could be overcome by increasing the applied air-mass flow instead.

For the study described in chapter 4, a pulsed 6 bar air-blast was administered above the mammary line from a distance of 20 cm. Due to the limited capacity and the mounting of the flexible force main, the applied air volume was variable and declined in the progression of the application. The applied air volume also decreased when the compressor automatically started to fill-up its internal reservoir. This happened occasionally towards the end of the 60 s administration period and was the reason for the pulsed mode of operation used in this study.

Regarding floor vibration, typical acceleration intensities of whole body vibration experiments on humans are 0.008 to 1.4 ms^{-2} (Morioka and Griffin, 2006). In experiments with rats accelerations between 0.8 and 5.8 ms^{-2} were used (Wike and Wike, 1972 - calculated from amplitude and frequency). For studies on pigs accelerations between 1.0 and 3.0 ms^{-2} are reported (Perremans et al., 1998). The acceleration value depends on the weight of the vibrated object and can hence depend on the weight and posture of the animal and on installation properties.

For the present study of the effects of floor vibration on adult sows, an acceleration value of about 0.2 ms^{-2} was chosen. This values was based on own experience from unpublished preliminary tests with gilts. The effective acceleration ranged between 0.1 and 0.3 ms^{-2} depending on the weight and posture of the sow.

To modify the acceleration apart from subject weight, the vibration force has to be modified. For the present study, the vibration was created by a commercial vibration motor whose centrifugal force was reduced from 1670 N to 163 N by the manufacturer. This was realised by physically altering the imbalance of the motor, which requires a manual adaptation of the motor setup.

Changing the revolution speed of the motor also alters the centrifugal force and thereby allows its fine adjustment. But this additionally changes the vibration frequency which in turn can change the subjective sensation of the vibration. Studies on rats and pigs found that changed frequencies had little effects on the perceived aversiveness of vibration (Wike and Wike, 1972; Perremans et al., 1998). These results are supported by studies on humans for vertical vibrations. Here, an increase from 2 to 315 Hz created only a slight decrease of the perceived intensity at higher frequencies. Lateral as well as fore-and-aft vibrations, however, show a much higher subjection to frequency (Morioka and Griffin, 2006).

The stimulation subjects of the study presented in chapter 4 were selected to be in their second or third gestation to achieve a similar weight. The average weight of the sows was 265 ± 34 kg (SD). The treated sow and at least one neighbouring sow had to be reclined for at least five minutes prior to each treatment to achieve a similar arousal state in each repetition of the stimulation. Both stimulation methods resulted in a reactivity of about 80% for pre-parturient and 50% for post-parturient sows (step 1). The reactions of neighbouring unstimulated sows (6.1% ±1.4% SE) were in each case undistinguishable from natural spontaneous posture changes (6.5% ±1.6 SE). Hence, the stimulation of a sow in one farrowing pen created no disturbance in neighbouring pens (step 4). In this regard, both tested methods were equally suited whereat floor vibration had a higher potential for higher stimulation intensities that are not harmful to the animals. The intensity of both methods is easily autonomously adjustable (step 3). For floor vibration this can be achieved by altering the revolution speed of the vibration motor through a change of its supply voltage. For air-blasts this can be achieved by using an electronic pressure reducer to control the air speed produced by the nozzle and an electronic valve to control the applied air-mass flow.

For an application without a farrowing cage, further adjustments of the tested installation are necessary. In fact, air-blasts require a short application distance and an aimed application. Without fixation of the sow in a farrowing cage, this would require assured information on the reclining habits of the sows (e.g. always against a wall) or a precise localisation system. In any case a multitude of nozzles and force mains would have to be installed below the floor or in the walls which makes this approach probably unfeasible. In comparison, vibration can be relatively easy applied to a larger surface. This requires only having some floor segments more rigidly coupled whereas others have a weak coupling. Thereby, a single sufficiently strong vibration motor can vibrate a whole area where the sow is presumably located. At the same time other areas can be spared to prevent a spreading of the vibration into neighbouring pens and into the piglet nest.

A selective triggering of the aversive stimulation requires a technology to determine risky situations. Especially when the sow is crated, simple mechanisms such as photo cells and light barriers can be used to determine, whether the sow is standing (Mainau et al., 2009). For sows not held in a farrowing crate, sensors attached to the animal are applicable (Ringgenberg et al., 2010). These techniques can be utilised if the piglet saving mechanism is activated every time the sow changes her posture. However, such frequent activations are only applicable with non-averse or very mildly averse mechanisms. In any other case it is desirable to limit the activation of the mechanism on situation with an increased crushing risk in order to avoid an overly impaired animal welfare or habituation.

There are various methods known that allow the recognition of risky behaviour. One is to visually trace every movement of the piglets and the sow. The tracking has been implemented and tested for sows (Tu et al., 2014) and piglets (McFarlane and Schofield, 1995) using 2D video image analysis. Such a system would trigger a crushing alert if the sow is about to recline and piglets are in the direct vicinity or below the sow. A more indirect approach recognises the stress vocalisation of the piglets that already trapped below a sow. The recognition and classification of stress vocalisation is generally possible (Schön et al., 2001). A microphone array could be used to locate the source of the vocalisation (Brandstein et al., 1997). Yet, the installation and maintenance of a microphone array in a stable environment could be costly. A single microphone per compartment would be sufficient at least for a limited number of sows if the classification data is combined with posture sensors such as light barriers. In this setup, a crushing alert would be triggered for the sow that reclined last when the stress vocalisation is detected. To avoid confusion if several sows changed their posture recently, the alert could exclude sows that haven't any piglets yet or where the risky period of 72 h after parturition has already passed.

This approach requires a technology for detecting the onset of parturition. Video tracking systems could allow the direct recognition of newly farrowed piglets (McFarlane and Schofield, 1995). A different approach would be the detection of the parturition related restlessness of the sows and the subsequent decrease of activity after the parturition has begun (Hurnik, 1985). This has already been implemented and tested by Pastell et al. (2013) using accelerometers attached to sows. Apart from accelerometers, a variety of sensors to measure the activity of pre-parturient sows were studied. A common approach was the use of light barriers and photo cells that were also used to identify the posture of sows (Erez and Hartsock, 1990; Oliviero et al., 2008; Mainau et al., 2009). Furthermore, ultrasonic distance sensors were utilised in a similar manner to detect the sow posture and activity in terms of posture change frequency (Huang et al., 2005; Wang et al., 2007).

Chapter 5 presented results demonstrating that the rough activity measurements by a single light barrier are already sufficient to predict and detect the onset of parturition in gestating sows. The basis for the applicability of such a comparatively simple method was the uniform activity progression of the sows. The monitored sows showed a clearly recognisable diurnal activity pattern and a homogeneous disruption of this pattern as the sows approached the parturition. Parts of the reason for this uniformity were certainly the uniform husbandry conditions. All sows were individually kept in crates with little space for individual movements. Environmental factors such as the weather had little impact on the sows. Human interaction was limited to feeding, cleaning and inspection activity. The uniformity in the husbandry conditions and in the course of the day allowed the creation of precise activity models and the extraction of undisturbed activity trends. This was the precondition for the small number of false positive identification of upcoming parturitions. A high precision of these classifications was in turn the precondition for precise numeric predictions for the duration until the onset of parturition.

In the present study, the 88% of the upcoming parturitions were detected up to 48 h beforehand. The newly developed quantitative prediction method for the duration until parturition exhibited a mean prediction error of 0.5 h ±2.5 h (SD) from the actual duration until parturition of 13-24 h. The onset detection method using light barrier data achieved a sensitivity of 88% and a precision of 97% within a range of ±4 h around the actual onset of parturition. In addition, the light barrier can be utilised as posture sensor to localise trapped piglets and to individually trigger an aversive stimulation of the sow (step 2). It also allows recognising a subsequent posture change by the sow so that the stimulation can be deactivated well-timed (step 3). These measures limit the impairment of animal welfare for the mother sows to a minimum. However, especially the detection of the onset of parturition is much less sensitive than accelerometer based detection methods (Pastell et al., 2013). While accelerometers can also recognise movements of reclined sows, such movements are invisible for a light barrier. Therefore accelerometer based methods can more easily detect the activity decrease connected to the onset of parturition. In contrast, light barrier methods have to distinguish the temporary reclining of the sow from lasting inactivity. Thus, the onset detection with light barriers required the identification of longer inactivity periods in order to minimise false alerts and was consequently less sensitive than accelerometer based methods.

Implications for animal welfare in both systems investigated.

The results of earlier studies on call feeding juvenile pigs indicate a potential of a sustained improvement of the emotional wellbeing of the animals by providing a demanding but solvable task (Manteuffel et al., 2009). This assessment was substantiated by welfare parameters acquired in open field tests and heart rate measurements. Here, the juvenile pigs showed less activity and a reduced excitement and fear in open field tests compared to pigs fed at a trough (Puppe et al., 2007; Zebunke et al., 2013). There are indications that these differences could increase the longer the pigs experience the cognitive enrichment (Puppe et al., 2007). Heart rate measurements prior und during feeding indicated a positive arousal of the juvenile pigs on being called. This arousal was only observed after the operant conditioning started. There were also indications of relaxation during feeding compared to the control group fed at a trough. Measurements during the operational conditioning phase while resting indicated a positive emotional basal arousal that was not detected in the control group (Zebunke et al., 2013).

Regarding the crushing prevention system, so far no information is available on how many of the crushed piglets are able to vocalise and how long a once trapped piglet usually survives. An open issue is also, how many of the piglets can free themselves and independently leave the risky area once the sow changed her posture. Generally, even the average number of crushed piglets is not settled. Piglets that died from infections, starvation or hypothermia might afterwards be overlain by the mother sow (Edwards, 2002). The pressure marks and post mortem injuries of the piglets could then be misinterpreted as piglet crushing evidence. In fact, the average reported mortality due to crushing varies between 5% and 10% (Jeon et al., 2005; Weber, 2006) for comparable litter sizes. However, with the ongoing trend of increased litter sizes, the number of crushed piglets will also increase steadily (Weber, 2006). This will make additional provisions for the reduction of piglet crushing justifiable in long-term view.

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General Conclusions

The results presented in chapter 1-3 demonstrate, that call feeding is a successful application of appetitive behaviour manipulation of gestating sows in a practicable setting. The natural behaviour of agonistic interactions and queuing is manipulated by call feeding in a way that allows all sows an unhampered access to feed. In this respect, the animal behaviour is adapted to the requirements of the husbandry conditions. At the same time, the husbandry conditions are adapted to the requirements of the sows through different automated management approaches:

- The progress of the training procedure adapts to the individual learning speed of the sows.
- Sows unable to learn call feeding or being deaf can stay in the group and perform conventional electronic feeding.
- Sows hindering the feed access for others are automatically identified and dealt with separately.
- The planning of the feedings respects the approximate social hierarchy of the group and thereby takes the avoidance order into account.

Call feeding directly increases the overall animal welfare by reducing injuries and stress for each member of the gestation group. In addition, it indirectly increases animal welfare by making the health and longevity of the experienced sows a major profitability factor. The profitability of call feeding is at a similar level but as yet somewhat lower than conventional electronic feeding. This could be overcome by improving the planning software and by improving the acceptance of call feeding by revenue increasing animal welfare product labels. Additional economic effects such as a lowered culling rate for constitutional reasons and management alleviations from the option to manually call single sows at any time e.g. for treatments could then suffice to make call feeding profitable.

Chapter 4 demonstrates that relatively mild aversive stimulations are sufficient to allow an individual behaviour manipulation in adult sows. For floor vibration and air-blasts could be shown that

- Depending on the current state and the stimulation intensity, posture change reactions in 80% of the stimulations are possible.
- The stimulations induce no eminent reaction in neighbouring pens.
- The stimulations trigger no panic and elimination reactions of the treated sows.

Triggering a posture change in situations with an assumed crushing risk can potentially free trapped piglets and allow them to move to a safer location. This manipulation is therefore able to reduce the incidences of piglets being slowly suffocated or crushed to death. In this respect, the behaviour of the mother sows would be adapted to the requirements of the husbandry conditions. At the same time the husbandry conditions could be adapted to the requirements of the sows through different automated management approaches. Monitoring the piglet vocalisation and the posture of the mother sows allows to individually adapt the use and the intensity of the stimulation with respect to the risk assessment and the reactions of the sow.

- Sows showing a fast reaction that also effectively stops the stressful piglet vocalisation can receive shorter and less intense stimulations while sows with a delayed or ineffective reaction would receive stimulations with an increasing intensity.
- Depending on previously known individual risk assessments or parameters such as injuries and weight, the stimulation intensity could be higher right from the start for some sows. This could increase the probability of a successful intervention.
- The individual activity monitoring permits a parturition prediction that helps the personnel to focus on the right farrowing pens at the right time. It also allows an autonomous activation and deactivation of the crushing prevention system. Automatically activating and deactivating the individual observation of a particular farrowing pen for a limited period after the onset of parturition lowers the risk of erroneous stimulations caused e.g. by vocalisation from a neighbouring pen.

Comparing the impact of welfare impairment from a time-limited aversive stimulation of the sow and a premature forceful death of a piglet, an active crushing prevention undoubtedly increases the overall animal welfare. This applies especially if such a system is used as a replacement for farrowing cages. In this case, most sows gain improved husbandry conditions while only crushing sows experience welfare impairment for exactly the time when the crushing occurs.

However, additional studies are necessary for a practical utilisation of this approach. The described components need to be aggregated into a working system for a large scale test. This test would have to document each crushing event in a conventional and an enhanced farrowing compartment to determine

- how many piglets vocalise in a crushing situation,
- which of these vocalisations are recognised and correctly localised,
- how many stimulated sows change their posture in a crushing situation,
- how many crushings are thereby circumvented and
- how many piglets survive the circumvented crushing.

In addition, further studies are necessary for an improved sensitivity at the detection of the onset of parturition described in chapter 5. This could be achieved by additional light barriers or different contactless sensor technologies such as video based methods. Furthermore, the applicability of the methods for indicating the upcoming parturition and predicting the duration of parturition on other species and husbandry conditions requires additional investigation. Livestock with more moving space or with more human interaction could exhibit a less uniform diurnal activity pattern than sows kept in crates. This could render the methods proposed in the present research work unusable.

In summary, both call feeding and active crushing prevention represent effective applications of aversive and appetitive stimuli for the manipulation of the innate animal behaviour to achieve improved productivity and animal welfare. Their implementation facilitates a mutual adaption of animal behaviour and husbandry conditions though individual monitoring techniques. In this respect, this work contributes to the further development of the PLF approach.

General Summary

Behaviour manipulation is a method that triggers an alternative instinctive behaviour of animals by utilising aversive or appetitive stimuli. It is however not synonymous to animal learning as it incorporates not only conditioning methods but also utilises the innate behaviour to improve animal welfare and productivity. Inadvertent and intended behaviour manipulation is common in the feeding systems and management procedures of current animal husbandry. Generally two forms, the blind and the informed behaviour manipulation, can be distinguished. Blind behaviour manipulation is either inadvertent or relies on the assumption that the animals on average conform well to the applied procedures. In contrast, the informed behaviour manipulation monitors the results of its procedures and the individual animal reactions. This allows an individual adaptation of the procedures to each animal's requirement and an economic utilisation of the appetitive and aversive stimuli.

The individual adaptation of behaviour manipulation is the precondition for the employment of more challenging coping tasks in animal management procedures without risking to overstrain the animal capacities. Such an adaptation of the husbandry conditions based on certain animal parameters is the core concept of precision livestock farming (PLF). PLF in the shape of behaviour manipulation utilises a mutual adaptation of the animal behaviour and the husbandry conditions to increase the total productivity and livestock-friendliness of animal husbandry. The current work exemplifies this concept using call feeding of sows as representation for informed appetitive behaviour manipulation and active crushing prevention as representation for informed aversive behaviour manipulation. Call feeding makes thereby use of Pavlovian and operant conditioning while the active crushing prevention uses innate aversions of pigs without an intended conditioning.

Two experiments are described for call feeding sows. A first study on small gestation groups of up to 8 sows and a total of 36 sows investigated the influence of the social hierarchy on the learning and feeding behaviour. According to an observed social hierarchy, the sows were classified in one of the rank classes dominant, subordinate and submissive. Afterwards, the sows received 7 days of Pavlovian conditioning and 13 days of operant conditioning at a modified commercial electronic feeding station. On average 80% of the signals were observed after 8 days. Dominant sows reached the 80% criterion on average three days earlier than sows of the other rank classes. Altogether, 93% of the dominant sows reached the 80% criterion within 13 days, while only 71% of the subordinate and 64% of the submissive sows did so. However, the learning speed in terms of correct reaction increase per day did not differ between the rank groups. Instead the responses displayed a negative offset for subordinate and submissive sows right from the start. At the same time dominant sows exhibited more frequently reactions to calls of other sows. They also spend more time in front of the feeder's entrance during the first days of operant conditioning. These results suggest that the behaviour of dominant sows encumbered the station access for lower ranking sows. The effects disappeared with the increasing learning success of the dominant sows. Simultaneously, the dominant sows stopped queuing at the station entrance because they learned that this is no longer beneficial for them.

The first study also allowed the development of an autonomous training procedure using a commercial feeding station. The training procedure coordinated the transition from Pavlovian to operant conditioning with respect to the current individual learning success of each animal. The study also gave an indication how to organise the feeding of a gestation group to minimise hampering effects from the group’s social hierarchy. The results regarding the queuing behaviour already indicated that call feeding is able to diminish queuing and thereby feeding related agonistic interactions and injuries. These indications were supported by the results of a second study.

The second study was conducted with a herd of 67 sows in a dynamic gestation group with up to 36 sows. The gestation group consisted of four sub groups with up to 12 sows. The study investigated the dynamic of the learning progress whilst the gestation group was gradually adapted to call feeding by the integration of conditioned subgroups. In the course of this study autonomous management procedures were developed that allow the feeding of naive and fully conditioned sows as well as of sows still in the conditioning process at the same station and the same time. The study results show that a stepwise adaptation of large herds is possible. Yet, the results also reveal that the group dynamics of a larger gestation group has a slowing effect on the learning progression. Therefore learning results achieved for 8 sows within 3 weeks were achieved in the dynamic gestation group within 8 month. This was probably due to the amplified effect of not or poorly conditioned dominant sows encumbering the station access for others during the adaptation phase. However, at the end of the experiment all sows on average observed more than 80% of their own signals and ignored the signals of other sows to more than 90%. At the same time, the latency from the emission of the signal to the start of feeding reduced from 140 s to less than 80 s. This was in part an effect from experienced sows returning to the gestation group from farrowing and mating. The sows were able to retain their signal conditioning during this period without the need for further training. They even improved their conditioning during the second and third stay in the gestation group. The number of observed signals and the latency until the sows arrive for feeding significantly determine the sow capacity of a call feeding station. In this regard, longevity and livestock friendliness of the husbandry conditions could become an economic factor for pig breeders.

Other results of the same experiment document a reduction of queuing in front of the feeding station and subsequently a reduction of agonistic interactions and injuries in connection with call feeding compared to conventional electronic feeding. This indicates that behaviour manipulation with call feeding is able to improve the livestock friendliness of husbandry conditions. In this respect the animal behaviour is adapted to the requirements of the husbandry conditions. At the same time the call feeding technique utilises sensor technology to adapt the feeding procedure towards the individual requirements of each sow. Hence, call feeding successfully demonstrates a mutual adaptation of animal behaviour and husbandry conditions with the result of an improved animal welfare and maybe productivity.

Two further studies were performed in the present research work to evaluate the feasibility of an active piglet crushing prevention system. This system is based on vocalisation classification and on monitoring the posture of lactating sows. The first study tested the effectiveness of aversive stimulations by floor vibration and air-blasts for the triggering of posture changes in adult sows. For this study 11 sows in their 2nd and 3rd gestation were physically stimulated twice a day. During phases without stimulations, the normal posture change frequency was determined from continuous video recordings. Beside the reactions of the 11 treated sows also the reactions of 22 neighbouring untreated sows were observed and evaluated to control the precision of the physical stimulation.

Floor vibration as well as air-blasts triggered posture changes in about 80% of all physical stimulations for pre-parturient and in 50% for post-parturient sows. An additionally amplified reactivity due to the experimental procedure could be ruled out by applying simulated stimulations without physical impact. With the stimulation intensities applied in this study no effect on neighbouring pens could be detected. The reactions on simulated stimulations (5.0% ±1.9% SE) as well as of neighbouring unstimulated sows (6.1% ±1.4% SE) on physical stimulations were in each case undistinguishable from natural spontaneous posture changes (6.5% ±1.6% SE). The results show that lactating sows are less reactive to aversive stimulations during the first days after farrowing. However, this effect cannot be fully distinguished from habituation effects due to the repeated application of the stimuli. Higher stimulation intensities are presumably necessary to achieve more frequent stimulation reactions with lactating sows.

The latency from the initiation of the stimulation until a posture change significantly increased from 11.5 ± 2.9 s (SE) to 22.7 ± 3.2 s (SE) in the curse of the experiment. On average 75% of the treated sows reacted within 25 s and reclined again after less than 120 s. About 22% of the reactions occurred within less than 3 s and could be considered alarm reactions. These low latency reactions were mainly observed before farrowing and were connected to certain particularly reactive sows.

In general, the sows displayed a high individual variability in their reactivity towards the physical stimulations. Hence a prior assessment of the reactivity e.g. based on age and weight could allow an individual adjustment of the stimulation intensity. Additionally, the actual reaction needs to be monitored to either stop the manipulation when the sow changed her posture or to increase the stimulation intensity until the trapped piglet is freed. This could be achieved by using light barriers as posture sensors as it is already done for other piglet saving devices.

Light barriers are generally suited for a rough posture differentiation if the barrier is closed when the sow is reclining and interrupted otherwise. The monitoring of posture change frequencies and durations of gestating sows and its interpretation as activity measure were investigated in the second study on crushing prevention. For this study the farrowing pens of 34 gestating sows in farrowing crates were equipped with light barriers in the torso and the head region of the sows. The duration and frequency of the posture changes was recorded for up to 35 days starting at the 4^{th} to 13^{th} day before parturition. The recorded activity time series were then analysed for common characteristics that allow a qualitative and quantitative prediction of the actual parturition time as well as to detect the onset of parturition. The best performing method for a qualitative prediction of parturition achieved a sensitivity of 88% at a precision of 88% with validation data from 17 sows. This indicator triggered 25% of its parturition alerts less than 13 h and 75% of its alerts less than 20 h before the parturition started. A novel quantitative prediction method achieved an average prediction error of 0.5 ±2.5 h (SD) over a period of 13-24 h before the onset of parturition for 88% of the sows. For the remaining 4 sows (12%) no usable quantitative prediction was possible. Here, the mean prediction error was 12.5 ±6.9 h (SD). The actual onset of parturition could be detected for 88% of the sows with a precision of 97% within a time range of ±4 h around the actual onset of parturition. These results demonstrate that already rough activity measurements from a single light barrier are sufficient to predict and detect the onset of parturition in gestating sows. However, especially the detection of the onset of parturition is much less sensitive than accelerometer based detection methods.

In summary, an improved form of the tested methods could be used to limit the use of aversive stimulations on the time period with the highest crushing risk until 72 h after parturition onset. The automatic detection of the parturition onset could thereby provide for an autonomous activation and deactivation of the crushing monitoring of individual farrowing pens. The same sensor used for the activity measurements could also enable the localisation of the piglet crushing incident, even with just one microphone per compartment by identifying the sow that just reclined. In addition, this sensor could observe the reaction of the stimulated sow and allow a timely deactivation after the trapped piglet was freed. Especially if such a system is operated without farrowing crates, this would allow limiting the impairment of the welfare of the sows. The impairment of animal welfare would then affect only to those sows that crush piglets and would be limited to the time when a piglet is actually trapped. Such a system would manipulate the behaviour of the mother sow to increase the overall livestock friendliness of the farrowing environment. At the same time, the aversive stimulation of this system could be individually adapted to the presumed reactivity of the sow and to the observed sow behaviour. In this regard, the active crushing prevention system sketched here would be demonstration for a mutual adaptation of animal behaviour and husbandry conditions with the result of improved animal welfare and maybe productivity.

Allgemeine Zusammenfassung

Verhaltensbeeinflussung ist eine Methode, welche das instinktive Verhalten von Nutztieren mit Hilfe von appetetiven und aversiven Stimulationen ändert. Sie ist jedoch nicht gleichzusetzen mit dem Abrichten von Tieren, da sie nicht nur Methoden zur Konditionierung sondern auch das angeborene Tierverhalten ausnutzt, um Tierwohl und Produktivität zu steigern. Unbeabsichtigte und beabsichtigte Verhaltensbeeinflussung sind in den Fütterungssystemen und Haltungsverfahren moderner Haltungssysteme weit verbreitet. Allgemein können die Varianten „blinde“ und „informierte“ Verhaltensbeeinflussung unterschieden werden. Dabei ist die blinde Verhaltensbeeinflussung entweder unbeabsichtigt oder beruht auf der Annahme, dass die Tiere im Allgemeinen gut mit den Haltungsverfahren zurechtkommen. Im Gegensatz dazu überwacht die informierte Verhaltensbeeinflussung die Ergebnisse ihrer Methoden und das Tierverhalten. Dies ermöglicht eine individuelle Anpassung der Methoden an die tierindividuellen Ansprüche und eine ökonomische Verwendung der appetetiven und aversiven Reize.

Die individuelle Anpassung der Verhaltensbeeinflussung ist die Grundvoraussetzung für den Einsatz herausfordernderer Anpassungsaufgaben bei Tierhaltungsverfahren, um nicht eine Überbeanspruchung der Fähigkeiten der Tiere zu riskieren. Solche das Nutztier in den Mittelpunkt stellenden Haltungsverfahren stellen das Kernkonzept des Precision Livestock Farming (PLF) dar. PLF in der Ausprägung als technische Verhaltensbeeinflussung nutzt eine gegenseitige Anpassung des Tierverhaltens und der Haltungsbedingungen, um die Produktivität und die Tiergerechtheit der Haltungsumwelt insgesamt zu steigern. Die vorliegende Arbeit stellt dieses Konzept am Beispiel der Aufruffütterung für Sauen als Verfahren zur informierten appetetiven Verhaltensbeeinflussung und am Beispiel einer aktiven Erdrückungsverhinderung als Verfahren zur informierten aversiven Verhaltensbeeinflussung dar. Die Aufruffütterung verwendet dazu klassische und operante Konditionierung während die Erdrückungsverhinderung angeborene Aversionen von Schweinen nutzt ohne dass eine Konditionierung beabsichtigt ist.

Zur Aufruffütterung werden zwei Experimente dargestellt. In einer ersten Studie über kleine Gruppen von bis zu 8 Sauen und insgesamt 36 Sauen, wurde der Einfluss der sozialen Hierarchie auf das Lernverhalten und den Fütterungsablauf untersucht. Entsprechend einer beobachteten sozialen Hierarchie wurden die Sauen in die Ranggruppen dominant, untergeordnet und unterwürfig eingeteilt. Anschließend erhielten alle Sauen eine 7 Tage dauernde klassische und an 13 Tagen operante Konditionierung an einer modifizierten kommerziellen Abrufstation. Nach im Mittel 8 Tagen wurden 80% der Signale befolgt. Dominante Sauen erreichten dabei das 80% Erfolgskriterium im Mittel drei Tage vor Sauen der anderen Rangklassen. Insgesamt erreichten 93% der dominanten Sauen das 80% Kriterium innerhalb von 13 Tagen, während dies untergeordnete Sauen nur zu 71% und unterwürfigen Sauen nur zu 64% erreichten. Die Lerngeschwindigkeit bezogen auf die tägliche Zunahme der korrekt befolgten Signale war jedoch zwischen den Ranggruppen nicht verschieden.

Stattdessen war die Anzahl korrekt befolgter Signale von Beginn an für untergeordnete und unterwürfige Sauen geringer. Gleichzeitig reagierten die dominanten Sauen während der ersten Tage der operanten Konditionierung am häufigsten auf die Signale anderer Sauen und zeigten die längste Verweildauer vor dem Stationseingang. Die Daten und Beobachtungen während der Versuche legen die Vermutung nahe, dass die dominanten Sauen niederrangige Sauen beim Zugang zur Futterstation behinderten. Diese Effekte verschwanden mit dem zunehmenden Lernerfolg der dominanten Sauen. Gleichzeitig hielten sich die dominanten Sauen seltener vor dem Stationseingang auf, weil sie gelernt haben, dass dieses Verhalten keine Vorteile mehr bringt.

Diese erste Studie an einer kommerziellen Abrufstation ermöglichte die Entwicklung eines unbeaufsichtigten Trainingsverfahrens. Das Trainingsverfahren steuert den Übergang von klassischer zu operanter Konditionierung unter Berücksichtigung des individuellen Lernerfolges der Tiere. Die Studie gab zudem Hinweise, wie die Fütterung zu organisieren ist, um behindernde Effekte der Sozialstruktur der Gruppe zu minimieren. Erste Ergebnisse zum Aufenthalt der Tiere vor dem Stationseingang deuteten bereits an, dass durch die Aufruffütterung Queuing und damit auch fütterungsbezogene agonistische Interaktionen und Verletzungen verringert werden können. Diese Hinweise wurden durch die Ergebnisse einer zweiten Studie gestützt. Bei dieser Studie wurde die Aufruffütterung in einem Bestand von 67 Sauen in einer dynamischen Großgruppe mit bis zu 36 Sauen eingesetzt. Im Wartestall befanden sich dabei 4 Teilgruppen mit bis zu 12 Sauen. Die Studie untersuchte die Dynamik des Lernerfolgs in der Großgruppe während diese schrittweise durch die Integration konditionierter Teilgruppen auf Aufruffütterung umgestellt wurde. Im Verlauf der Studie wurden automatisierte Managementverfahren entwickelt, die an einer einzigen Station gleichzeitig die Fütterung naiver, konditionierter sowie von Tieren im Konditionierungsverfahren ermöglichen. Die Ergebnisse der Studie zeigen, dass die schrittweise Umstellung eines Bestandes machbar ist. Allerdings belegen die Ergebnisse auch, dass die Dynamik einer größeren Gruppe einen verlangsamenden Effekt auf den Lernfortschritt insgesamt hat. Dadurch werden Trainingsergebnisse, für die mit 8 Sauen drei Wochen Konditionierung erforderlich waren, in der dynamischen Großgruppe erst nach 8 Monaten erreicht. Dies ist vermutlich ein Resultat des verstärkten Einflusses von nicht oder unzureichend konditionierten dominanten Sauen, die während der Umstellungsphase andere Sauen am Stationszugang hinderten. Zum Ende des Versuchs reagierten im Mittel jedoch alle Sauen zu mehr als 80% auf ihre Aufrufe. Gleichzeitig ignorierten sie die Aufrufe anderer Sauen zu mehr als 90%. Außerdem verringerte sich die Latenzzeit von der Ausgabe eines Signals bis zum Start der nächsten Fütterung von 140 s auf weniger als 80 s. Das ist auch auf erfahrene Sauen zurückzuführen, die nach der Laktation und Besamung in den Wartestall zurückkehrten. Die Sauen waren in der Lage, ihre Signal-Konditionierung während der Zeit außerhalb des Wartestalls zu behalten, ohne dass ein erneutes Training notwendig wurde. Sie verbesserten ihre Konditionierung sogar noch während der zweiten und dritten Trächtigkeit. Die Tierkapazität einer Futterstation wird maßgeblich von dem Anteil befolgter Signale und von der Latenzzeit bis zur Fütterung bestimmt. In dieser

Hinsicht werden Langlebigkeit und Wohlbefinden erfahrener Sauen ein ökonomisch relevanter Faktor für die Schweinezucht.

Zudem zeigen weitere Ergebnisse desselben Versuchs, dass durch die Aufruffütterung das Queuing am Stationseingang und entsprechend auch agonistische Interaktionen und Verletzungen im Vergleich zur Abruffütterung verringert wurden. Daraus folgt, dass eine Verhaltensbeeinflussung durch die Aufruffütterung in der Lage ist, die Tiergerechtheit der Haltungsbedingungen zu verbessern. In dieser Hinsicht wurde das Tierverhalten an die Erfordernisse der Haltung angepasst. Gleichzeitig wurde bei der Aufruffütterung das Fütterungsverfahren mit Hilfe von Sensortechnik an die individuellen Bedürfnisse der Sauen angepasst. Somit stellt die Aufruffütterung eine erfolgreiche gegenseitige Anpassung von Tierverhalten und Haltungsbedingungen dar, durch die das Tierwohl und möglicherweise auch die Produktivität gesteigert werden.

Die Machbarkeit eines aktiven Systems zur Verhinderung von Ferkelerdrückungen wurde in zwei weiteren Studien der vorliegenden Arbeit untersucht. Das System beruht auf der Klassifikation von Ferkelvokalisation und der Überwachung und gezielten Änderung der Körperhaltung ferkelführender Sauen. In der ersten Studie wurde dazu die gezielte Auslösung von Änderungen der Körperhaltung durch Bodenvibration und Luftstöße getestet. Während dieser Studie wurden 11 Sauen in der 2. und 3. Trächtigkeit zweimal täglich physisch stimuliert. Außerhalb der Versuchszeiträume wurde mit Hilfe von Videoaufnahmen die normale Häufigkeit von Änderungen der Körperhaltung erfasst. Zusätzlich zu den Reaktionen der 11 behandelten Sauen wurden außerdem die Reaktionen von 22 unbehandelten Sauen erfasst, um Seiteneffekte der physischen Stimulation auf benachbarte Sauen zu bestimmen.

Sowohl Bodenvibration als auch Luftstöße bewirkten in 80% der Stimulationen bei hochträchtigen Sauen und in 50% der Stimulationen bei laktierenden Sauen eine Änderung der Körperhaltung. Eine erhöhte Reaktionsbereitschaft aufgrund der Versuchssituation konnte dabei durch die Durchführung simulierter Stimulationen ohne physische Wirkung ausgeschlossen werden. Die Reaktionen mit simulierter Stimulation (5.0% ±1.9% SE) wie auch die benachbarter Sauen bei physischer Stimulation (6.1% ±1.4% SE) waren jeweils nicht unterscheidbar von natürlichen spontan auftretenden Änderungen der Körperhaltung (6.5% ±1.6% SE). Die Ergebnisse zeigen, dass laktierende Sauen während der ersten Tage nach der Geburt weniger Reaktionen auf aversive Stimulationen zeigen. Allerdings kann dieser Effekt nicht vollständig von Habituationseffekten durch die wiederholte Anwendung der Stimulationen unterschieden werden. Um bei ferkelführenden Sauen ähnliche Ergebnisse wie für trächtige Saue zu erreichen, sind vermutlich stärkere Stimulationen erforderlich. Die Latenzzeit bis zur Reaktion auf die Stimulation erhöhte sich im Verlauf der Versuche signifikant von 11.5 ± 2.9 s (SE) auf 22.7 ± 3.2 s (SE). Im Mittel reagierten die behandelten Sauen innerhalb von 25 Sekunden und legten sich nach weniger als 120 Sekunden wieder ab. Etwa 22% der Reaktionen fanden innerhalb von 3 Sekunden statt und könnten Schreckreaktionen darstellen. Diese geringen Reaktionszeiten wurden hauptsächlich vor der Geburt der Ferkel und nur bei einzelnen Sauen beobachtet.

Insgesamt zeigten die behandelten Sauen eine hohe individuelle Varianz in ihrer Reaktion auf die physische Stimulation. Deshalb könnte die Reaktionsbereitschaft im Vorfeld z.B. anhand des Alters und Gewichts abgeschätzt werden, um die Intensität der Stimulation individuell anzupassen. Zudem sollte die tatsächliche Reaktion der Sauen überwacht werden, um entweder die Stimulation nach einer Änderung der Körperhaltung zeitnah zu stoppen oder um die Intensität zu steigern, bis das eingeklemmte Ferkel befreit wurde. Dies könnte mit Hilfe von Lichtschranken erreicht werden, wie bereits heute als Sensor zur Bestimmung der Körperhaltung in anderen Ferkelschutzsystemen verwendet werden.

Lichtschranken ermöglichen eine grobe Bestimmung der Körperhaltung wenn der Lichtstrahl geschlossen ist während die Sau liegt und ansonsten unterbrochen wird. Die Überwachung der Häufigkeit und Dauer von Änderungen der Körperhaltung als Maß für die Aktivität einer Sau wurden in der zweiten Studie zur Erdrückungsverhinderung untersucht. Für diese Studie wurden die Abferkelbuchten von 34 Sauen im Kastenstand mit Lichtschranken in der Kopf- und Torso-Region ausgestattet. Die Dauer und Häufigkeit von Änderungen der Körperhaltung wurden für bis zu 35 Tage beginnend zwischen dem 4. und 13. Tag vor der Geburt aufgezeichnet. Die aufgezeichneten Zeitreihen der Tieraktivität wurden anschließend verwendet, um nach Gemeinsamkeiten zu suchen, die eine qualitative und quantitative Vorhersage des Geburtszeitraumes und die Erkennung des Geburtsbeginns ermöglichen. Die beste qualitative Abferkelvorhersage erreichte eine Sensitivität und eine Präzision von 88% für einen Datensatz von 17 Sauen zur Validierung der Methode. Dieser Indikator lieferte 25% seiner Warnungen innerhalb von 13 Stunden und 75% seiner Warnungen innerhalb von 20 Stunden vor dem Beginn der Geburt. Für 30 Sauen (88%) war zudem eine quantitative Vorhersage der verbleibenden Zeit bis zum Beginn der Geburt möglich. Diese Vorhersage erreichte einen mittleren Vorhersagefehler von 0.5 ±2.5 h (SD) über einen Zeitraum von 13 bis 24 Stunden vor Geburtsbeginn. Für die verbleibenden 4 Sauen (12%) war keine brauchbare quantitative Vorhersage möglich. Bei diesen Sauen lag der Vorhersagefehler bei 12.5 h ±6.9 h (SD). Der Geburtsbeginn konnte ebenfalls für 88% der Sauen (30) innerhalb einer Zeitspanne von ±4 Stunden um den tatsächlichen Geburtsbeginn und mit einer Präzision von 97% erkannt werden. Diese Ergebnisse zeigen, dass bereits die groben Messungen mit einer einzigen Lichtschranke ausreichen, um den Geburtszeitpunkt bei Sauen vorherzusagen und zu erkennen. Allerdings ist dabei insbesondere die Erkennung des Geburtszeitpunktes erheblich weniger sensitiv als Methoden, die auf Beschleunigungsmessern am Tier beruhen.

Zusammengefasst könnte eine verbesserte Variante dieser Methoden eingesetzt werden, um die Verwendung aversiver Stimulationen auf den risikoreichsten Zeitraum 72 Stunden nach Beginn der Geburt zu beschränken. Eine automatische Erkennung des Geburtsbeginns könnte dabei die Erdrückungsüberwachung in einzelnen Abferkelbuchten automatisch aktivieren und deaktivieren. Derselbe Sensor der für die Messung der Tieraktivität verwendet wird, könnte gleichzeitig eine Lokalisierung von Erdrückungssituationen ermöglichen, auch wenn nur ein Mikrofon pro Abteil verwendet wird. Zudem könnte der Sensor die Reaktion der stimulierten Sau überwachen und die Stimulation zeitnah deaktivieren, wenn das eingeklemmte Ferkel befreit wurde. Insbesondere in Verbindung mit Freilaufbuchten würde dies es ermöglichen, eine Verringerung des Tierwohls bei den Sauen selektiv zu beschränken. Diese würde dann nur die Muttersauen betreffen, die tatsächlich Ferkel erdrücken und auf Zeitpunkte begrenzt sein, wenn tatsächlich ein Ferkel eingeklemmt ist. Ein solches System würde das Verhalten der Muttersauen beeinflussen und dabei die Tiergerechtheit der Haltungsbedingungen insgesamt verbessern. Gleichzeitig könnte das Verfahren an das Erdrückungsrisiko, die vermutliche Reaktionsbereitschaft der Sau und ihr tatsächliches Verhalten individuell angepasst werden. In dieser Hinsicht stellt das hier skizzierte Verfahren zur Verhinderung von Ferkelerdrückungen eine gegenseitige Anpassung des Tierverhaltens und der Haltungsbedingungen mit dem Ergebnis eines verbesserten Tierwohls und möglicherweise einer verbesserten Produktivität dar.

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