Aus der

Tierklinik für Klauentiere

des Fachbereichs Veterinärmedizin

der Freien Universität Berlin

Evaluation of core body temperature by two non-invasive methods of infrared thermography for health monitoring in pigs

Inaugural-Dissertation

zur Erlangung des Grades eines

Doktors der Veterinärmedizin

an der

Freien Universität Berlin

vorgelegt von

Mariana Schmidt/ geborene Werner

Tierärztin aus Herzberg

Berlin 2014

Journal-Nr.: 3718

Gedruckt mit Genehmigung des Fachbereichs Veterinärmedizin
der Freien Universität Berlin

Dekan:	Univ.-Prof. Dr. Jürgen Zentek
Erster Gutachter:	Prof. Dr. Karl-Heinz Lahrmann
Zweiter Gutachter:	Prof. Dr. habil. Reiner Brunsch
Dritter Gutachter:	Univ.-Prof. Dr. Wolfgang Heuwieser

Deskriptoren (nach CAB-Thesaurus):
Pigs, body temperature, thermography, skin temperature, diagnostic techniques

Tag der Promotion: 18.12.2014

Bibliografische Information der *Deutschen Nationalbibliothek*
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.ddb.de> abrufbar.

ISBN: 978-3-86387-561-9
Zugl.: Berlin, Freie Univ., Diss., 2014
Dissertation, Freie Universität Berlin
D 188

Choriner Str. 85 - 10119 Berlin
verlag@menschundbuch.de – www.menschundbuch.de

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List of abbreviations

ALT-pedometer	Activity-Lying-Temperature-Pedometer
IRC	Infrared camera
IRT	Infrared thermometer
IL-1	Interleukin 1
IL-6	Interleukin 6
LPS	Lipopolysaccharide
mRNA	Messenger ribonucleic acid
N	Size of the total population
PRRSV	Porcine reproductive and respiratory syndrome virus
PM	Pyrometer
RT	Rectal temperature
TNF-alpha	Tumor necrosis factor alpha
VL	Vaginal logger
VT	Vaginal temperature

1 Introduction

1.1 Herd health

In modern intensive livestock systems, more and more public attention has been paid to animal health and welfare. A study by Karg and Bilkei (2002) showed that, in indoor units, the majority of mortality events in sows happened during lactation (40.2%). Overall, the mortality in adult crossbred pigs from 2000 to 2010 was 2.6% of 771 mortality records from 6330 total stock of crossbred pigs (Mondal et al., 2012). Engblom et al. (2007) stated that the most common removal reasons in Sweden, next to old age and udder problems, were low productivity, lameness and traumatic injuries. Further, sow death was more common during gestation and lactation than in the breeding phase of production (Sanz et al., 2007). Another trial determined that high prevalences of urinary tract infections, metritis or lameness were significantly associated with increased sow mortality rates (Abiven et al., 1998). Periparturient diseases such as Mastitis-Metritis-Agalactia revealed high losses of 24.5% (N=2876 sows) in indoor units (Karg and Bilkei, 2002). In addition to sows suffering from different illnesses and having to be slaughtered early, out of 10,485 fattening pigs, 5.7% were lost prematurely (Schoder et al., 1993). Besides to the importance of health for the well-being of these animals, increased mortality due to disease can also cause high economic losses. This affects the profitability of farms (Abiven et al., 1998).

Due to increasing herd sizes (Jago and Berry, 2011) in both dairy and pig production, automatic health monitoring becomes more and more important to ensure individual health and herd health. A common first indicator of illness is an increase in body temperature. Therefore, automatic and non-invasive detection of body temperature would be important.

1.2 Infrared thermography

Infrared thermography provides a non-invasive method to measure body surface temperatures. This non-contact method would save time and reduce stress in the animals. A review by Stewart et al. (2005) demonstrated that changes in the peripheral blood flow, which result in alterations of the skin temperature, can be detected with infrared thermography in livestock. Infrared thermography, using an infrared camera (IRC) allows routine measurements of body surface temperatures, and these measurements can be used for early disease detection (Traulsen et al., 2010). A further trial demonstrated that the non-invasive collection of infrared thermography data from cattle at risk of bovine respiratory disease can effectively identify true positive and true negative animals (Schaefer et al., 2012). Areas that are innervated by the sympathetic system are particularly sensitive to changes in blood flow (Nakamura, 2011), and the sympathetic system responds to stress and fever, which may be associated with farrowing and illnesses. Temperature measurements at various body surface locations using an IRC and an infrared thermometer (IRT) demonstrated the possibility of using body surface temperatures for early disease detection in various animals (Röhlinger et al., 1979). Another trial with ponies showed that it is possible to detect fever with an IRC (Johnson et al., 2011). The temperature of the orbital area in calves, measured with an IRC, varied less than other surface locations (Schaefer et

al., 2012). Limitations of these techniques, such as climate changes, circadian rhythms, and dirt or foreign material on the animals, may negatively influence the measurements and the usability of the acquired data, and these factors have to be taken into account. However, Knizkova et al. (2007) concluded that infrared thermography (IRT and IRC) can be used to detect illnesses. When imaging is conducted, it should be conducted at a stable ambient temperature with identical conditions (Okada et al., 2013).

In contrast, Savary et al. (2008) came to the conclusion that joint inflammation in fattening pigs cannot be detected by infrared thermography alone. Work performed by other authors using an IRC in pigs demonstrated that the infrared method is not well suited to detecting fever (Dewulf et al., 2003; Wendt et al., 1997).

1.3 Logger devices

In pigs, various methods to continuously measure the core body temperature have been tested. Krizanac et al. (2010) used an endotracheal tube with three temperature probes to measure the tracheal temperature in pigs. Another trial described the evaluation of wireless sensors to measure pig body temperature. In this trial, thermistor sensors were surgically implanted into boars on the side of the neck (McCauley et al., 2005). Pulmonary artery, urinary bladder, rectal and femoral artery methods, as well as temperature measurements at the fibrous tympanic ring, were tested in pigs (Hanneman et al., 2004). Timsit et al. (2011) used a reticulo-rumen bolus to measure the core temperature in cows. Most of these methods are very invasive and require surgery; therefore, other temperature measuring methods have also been explored. Vickers et al. (2010) and Hoffmann et al. (2013) used less invasive vaginal loggers to determine body temperature. For disease detection, body temperature and further attributes, such as behaviour, are important for disease detection and need to be taken into account. Further, changes in behaviour are discussed in the next paragraph.

1.4 Behavioural patterns

The welfare and health status of animals can be interpreted using behavioural patterns. Harris and Gonyou (1998) described that pigs exhibit restless postural behaviour both five days and one day before farrowing. This behaviour changes one day after farrowing. Furthermore, animals suffering from infections often exhibit a distinct behavioural pattern. Therefore, it is necessary to record their standing and lying behaviour or water and food intake to detect disease and pain (Fraser and Quine, 1989; Hart, 1988; Weary et al., 2006). All sick animals typically increase their resting time (Hart, 1988). Monitoring these traits can be useful to oversee the general health of an animal.

Various methods of recording postures in animals have been used in other studies. One common method is to directly observe the animals. Video recording is another common method. When recording behaviour, no individuals should be present in the stable, so that no disturbances are caused (Broom and Fraser, 2007). ALT-pedometers (**a**ctivity, **l**ying time, **t**emperature), which can give information about activity, lying time and ambient temperature

(Miekley et al., 2013), and movement sensors, which monitor the farrowing-related activity of sows, have been tested by Oliviero et al (2008). With these sensors, they were able to detect the positions of the sows.

1.5 Food and water intake

One highly probable assumption is that inflammatory cytokines mediate the reduction of food intake in sick animals (Johnson, 1998, 2002). One commonly known element of bacteria that increases cytokine production is LPS. There are several common physiologic and pathologic changes that occur due to LPS, such as transient fever, depressed food intake, lethargy, changes in the concentrations of acute phase proteins and activation of the hypothalamic-pituitary-adrenal axis (Harden et al., 2011; Kelley et al., 1994). LPS is part of the outer membrane of gram-negative bacteria; it acts as an endotoxin and causes strong immune responses in animals. Furthermore, this endotoxin activates cytokines such as IL-1 beta, IL-6 and TNF alpha. In pigs infected with porcine reproductive and respiratory syndrome virus (PRRSV), cytokines elicit a mild transient fever and reduced growth performance. Infection by PRRSV also increases mRNA expression of pro-inflammatory cytokines (Miguel et al., 2010). A decreased duration of rumination and hay eating could be found in calves infected with a low dose of LPS (Borderas et al., 2008). Different methods exist to record these changes in food and water intake, as described by these authors. Live observations and weighing methods, including technically supported methods or those measured by hand, can also be used. These data can provide important information about the health status of the animals.

1.6 Objectives and working tasks of this trial

The overall objective of this study was to determine whether various temperature devices can be used to continuously monitor the body temperature of individual sows in a less invasive manner. Furthermore, once a fever was identified in an individual, specific behavioural patterns were monitored to determine which changes in behaviour are associated with disease.

To attain these objectives, the first portion of the study evaluated which method of contactless measurement can be used to monitor body surface temperature and which body measurement locations should be utilized for sows. Therefore, two infrared methods were used, an IRC and an IRT. In comparison with previous studies, both methods are able to continuously measure the temperature of sows. To determine which body surface location is best suited for infrared measurements, various locations were compared. The results of this trial can be found in paper A: “**Assessment of body temperature in sows by two infrared thermography methods at various body surface locations**”.

To compare the continuously measured body surface temperatures with core body temperatures, a more invasive vaginal logger was used. The logging device provided the opportunity for continuous measurements of the core temperature. Sows were vaccinated with a commercial vaccine to induce a mild increase in body temperature. The use of the

vaccine was a very animal friendly method that did not involve euthanasia at the end of the study, in comparison to the use of other agents, such as lipopolysaccharide (LPS), in other studies. This increase was used for the evaluation of the different temperature devices. Paper B: "**Assessment of continuous vaginal logger-based temperature monitoring in fever-induced gilts**" and paper C: "**The suitability of infrared temperature measurements for continuous temperature monitoring in gilts**" (online) show the results from this part of the study.

Next to the body temperature, the behaviour of an animal provides important information about the health status. To gain information about lying down behaviour and food and water intake, the vaccine influence was used. The vaccine not only induced an increase in body temperature but also induced mild sickness. The results of this study are also presented in paper B.

2 Research papers

2.1 Paper A: Assessment of body temperature in sows by two infrared thermography methods at various body surface locations

Schmidt, M., Lahrmann, K.H., Ammon, C., Berg, W., Schön, P., Hoffmann, G., 2013,

Journal of Pigs Health and Production 21(4): 203–209.

http://www.aasv.org/shap/issues/v21n4/v21n4p203.html

This part (5-12) you can get online.
http://www.aasv.org/shap/issues/v21n4/v21n4p203.html

2.2 Paper B: Assessment of continuous vaginal logger-based temperature monitoring in fever-induced gilts

Schmidt, M., Ammon, C., Schön, P., Manteuffel, C., Hoffmann, G., 2013,

American Journal of Animal and Veterinary Sciences 8 (2): 55-65.

Doi: 10.3844/ajavssp.2013.55.65

American Journal of Animal and Veterinary Sciences 8 (2): 55-65, 2013
ISSN: 1557-4555

doi:10.3844/ajavssp.2013.55.65 Published Online 8 (2) 2013 (http://www.thescipub.com/ajavs.toc)

ASSESSMENT OF CONTINUOUS VAGINAL LOGGER-BASED TEMPERATURE MONITORING IN FEVER-INDUCED GILTS

[1]Mariana Schmidt, [1]Christian Ammon,
[2]Peter Schon, [2]Christian Manteuffel and [1]Gundula Hoffmann

[1]Department of Engineering for Livestock Management,
Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), Potsdam, Germany
[2]Department of Behavioral Physiology,
Leibniz-Institute for Farm Animal Biology Dummerstorf (FBN), Dummerstorf, Germany

Received 2013-04-23, Revised 2013-05-22; Accepted 2013-05-30

ABSTRACT

The aim of this study was to identify a low risk method to induce fever in gilts and to evaluate vaginal sensors for temperature monitoring. Therefore, a rhinitis atrophicans vaccine was used to induce fever to evaluate sensors and behavioral patterns. During 11 trials, two of four animals were injected with 2 mL of the vaccine Porcilis AR-T DF (Intervet) and the other two animals were treated with 2 mL of 0.9% NaCl as controls. A temperature logger (TRIX-8, LogTag Recorders, Auckland, New Zealand) was used to continuously monitor the vaginal temperature. Additionally, rectal temperatures were measured four times daily. The water consumption, food intake and locomotion behaviors of the animals were analysed one day before treatment and during the day of the treatment. The vaccine induced fever in all gilts, which occurred approximately 5.87 h after vaccination. The vaginal logger temperatures and the rectal temperatures showed a linear correlation in 21 vaccinated gilts ($r = 0.86$; $p<0.0001$) and 22 non-vaccinated gilts ($r = 0.65$; $P<0.0001$). The vaginal logger can be continuously used to measure the core temperature. Water intake decreased ($p<0.0001$) in the gilts with fever, whereas food intake did not change ($p = 0.9411$). The vaccinated gilts spent 79±16 more minutes per day lying after the vaccination ($p<0.001$) in comparison to the day before the vaccination. Treatment with this vaccine provides the opportunity to induce fever over a short time period (5.13 h) and mild sickness behavior in gilts to investigate disease indicators.

Keywords: Gilts, Vaccination, Temperature, Behavior, Disease Detection, Fever

1. INTRODUCTION

Pathogens, adjuvants and vaccines are typically employed to induce fever in research studies or for antibody production (Harden *et al*., 2011; Leenaars and Hendriksen, 2005; Schaefer *et al*., 2004; Stills, 2005). Fever is triggered by the release of endogenous pyrogens from different regions of macrophage-like cells. These pyrogens include cytokines IL-1 and IL-6, which act at the level of the anterior hypothalamus to raise the thermoregulatory set point (Kluger *et al*., 1998). However, fever is also one of the main responses to Complete Freund's Adjuvants (CFA) (Melchior *et al*., 2004; 2005) or to Lipopolysaccharide (LPS) (De Groot *et al*., 2007; Wright *et al*., 2000) in piglets. Often the injection routes are not clear and painful processes occur after the injection (Leenaars and Hendriksen, 2005; Stills, 2005). For example, Nagai *et al*. (1957), who injected CFA into guinea pig nuchal musculature, demonstrated that fibrotic changes were found in the lung. A study by Banji *et al*. (2011) demonstrated that arthritis was induced in rats by a CFA injection. Furthermore, rabbits were injected with CFA in the marginal ear vein, with significant damage to the lung as a result (Brooks *et al*., 1978). LPS activates the Toll-Like Receptor 4 (TLR-4), which results in the production of the pro-inflammatory cytokine IL-1, an

Corresponding Author: Mariana Schmidt, Department of Engineering for Livestock Management,
Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), Potsdam, Germany

important cytokine for the induction of sickness behavior (Konsman *et al*., 2002). LPS can also have negative effects, such as endotoxemia (Noh *et al*., 2012) and can cause periodontal inflammation in rats (Dumitrescu *et al*., 2004), synovitis in horses (Loon *et al*., 2010) and abortion in gilts (Cort and Kindahl, 1990). However, the common physiological and pathological changes that occur due to LPS treatment are transient fever, depressed feed intake, changes in the concentrations of acute phase proteins and activation of the hypothalamic-pituitary-adrenal axis (Kelley *et al*., 1994). Furthermore, animals that have been treated with LPS have to be killed in Germany (EC, 2002) because these animals are not allowed to be used for food production.

In the present study, a vaccination was used to induce fever while circumventing these undesirable side effects. A comparison of the package leaflets of 9 vaccines for pigs, regarding undesirable side effects such as fever induction, indicated that the Rhinitis Atrophicans (RA) vaccine can lead to a temperature increase of up to 2.0°C.

Methods to continuously measure the body core temperature of cattle currently exist. For example, Timsit *et al*. (2011) used a reticulo-rumen bolus to measure the core temperature in cows and Vickers *et al*. (2010) and Hoffmann *et al*. (2013) used vaginal loggers for this purpose. Because a rumen bolus is not appropriate for pigs because of anatomical reasons, a climate monitoring device was used and validated as a vaginal logger in our study.

Infected animals exhibit a distinct behavioral pattern. Therefore, it is also important to record their standing and lying behavior and water and food intake for disease and pain detection (Fraser and Quine, 1989; Hart, 1988; Weary *et al*., 2006). Animals suffering from an illness are often anorectic, lethargic and uninterested in social interactions (Johnson, 2002). For example, water and food intake are reduced in rats injected with endotoxin (Harden *et al*., 2011) and all sick animals typically increase the amount of time that they rest (Hart, 1988). These traits can be a sign of illnesses and can be useful for monitoring the general health condition of an animal.

The aim of the present study was to identify a method that increases the core body temperature to at least 39.5°C without the aforementioned side effects and to continuously monitor the animal's behavior to investigate how fever changes behavioral patterns. By performing continuous monitoring, direct and indirect correlations between body temperature and behavior can be studied in greater detail. In particular, we expect a clear pattern change at a rectal temperature above 39.5°C, defined as fever by Blood and Henderson (1983).

2. MATERIALS AND METHODS

2.1. Animals

The study was conducted at the experimental pig unit of the Leibniz-Institute for Farm Animal Biology (FBN, Dummerstorf, Germany) with 55 German Landrace gilts in 14 trial runs from May to December 2012. The gilts were from 208-to 215-days-old. Four gilts were tested in each trial run. The animals were housed on a solid concrete floor in individual pens side by side, leaving one pen in between empty for the installation of electronic measurement devices. Each pen measured 0.6×2.2 m. The feed consisted of gilt rearing feed pellets (Trede and von Peine, agricultural trade and feed mills, Dammfleth, Germany). The animals were fed twice a day with 1300 g of pellets and water was available *ad libitum*. During the trial, the animals were examined for signs of vaginal discharge caused by the logger. Afterwards, the gilts were culled or kept for breeding.

The RA vaccine can lead to an increase in temperature of approximately 2°C, furthermore the gilts have never been vaccinated with this vaccine before. Therefore we decided to choose the RA vaccine for the fever stimulation.

2.2. Treatment

2.2.1. Dose Test

To determine the dose for the main trial, a dose test was first conducted. For this dose test, three groups of four gilts were treated with three different doses of a commercial vaccine, respectively and one animal out of each group was treated with a placebo. Altogether 12 gilts were part of the dose test. The commercial vaccine Porcilis AR-T (Intervet International B.V., Boxmeer, The Netherlands; RA vaccine) was administered one time to randomly chosen single gilts using 2 mL (single dose), 4 mL (double dose) and 6 mL (triple dose). A dose of 6 mL of 0.9% sterile NaCl solution (Selectavet Dr. Fischer GmbH, Weyarn-Holzolling, Germany) was administered to the fourth gilt.

2.3. Main Trial

The main trial was conducted with 43 animals. During trial run 14, one sow had to be excluded from the trial. During the main trial, the same vaccine was administered one time to two single gilts using a 2 mL dose. A dose of 2 mL of 0.9% sterile NaCl solution was administered to the two other gilts (control). The treatment was conducted on the third day of each trial run between 09:00 and 09:30 in the morning by an intramuscular injection of the corresponding dose into the right side of the neck and directly behind the ear.

2.4. Measurements

The Rectal Temperature (RT), Vaginal Temperature (VT), lying behavior and water and feed intake were measured for four days. On day three, the gilts were injected with the vaccine or NaCl. The data for the day of treatment (day three) were compared to the day before (day two).

During all trial days, the RT was measured four times daily (09:00 a.m., 11:00 a.m., 02:00 p.m., 04:00 p.m.) using a digital thermometer (Microlife MT 1831, Lifeware Rheintal AG, Widnau, Switzerland).

To avoid measurement errors due to too low insertion depths or dirt, the measurement was performed twice with a few minutes delay. Only the higher of both values was included in the evaluation. The VT was measured continuously from day two to day four using a micro-climate monitoring device designed for industrial purposes with an external temperature probe (TRIX-8 recorder with ST100S-15 probe, LogTag Recorders, Auckland, New Zealand). The temperature probe was inserted into the vagina with an insertion depth between 5 to 10 cm. The logging device and sensor cable were fixated at the back and the backside of the gilts using adhesive tape (**Fig. 1**). The Vaginal Logger (VL) took temperature data every three minutes. In the event of the probe being pushed out of the vulva, e.g., by excretion, it was cleaned and reinserted.

To record the lying behavior, a Video Graphics Array (VGA) resolution webcam (IC 3005, Edimax, New Taipei City, Taiwan) was installed in each pen. An additional webcam of the same type monitored all animals at the same time from an elevated position. The video stream was recorded as mpeg-4 video for ten hours per day from 07:00 a.m. to 12:00 and from 12:01 until 05:00 p.m. throughout the entire trial run. Video analysis was evaluated by visual inspection using Windows Media Player (Microsoft Corporation, Redmond, USA) and included the recording of time and duration of the animals' postures based on a network time protocol synchronised timestamp overlay within the video. Postures were discriminated between lying, sitting and standing. The time that the gilts spent in various positions during the day of the vaccination was compared to the day before.

For the measurement of water consumption, each pen was equipped with a bite ball valve (AquaGlobe AB, Uppsala, Sweden) and a digital flow meter (FCH-m-POM, B.I.O-TECH e.K., Vilshofen, Germany). The overall water pressure could be regulated by a ½" ball valve.

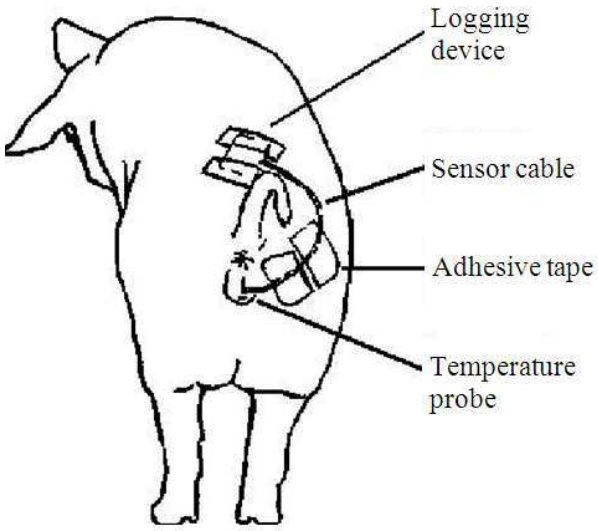

Fig. 1. Placement of the vaginal logger at the rear of a sow (probe is intravaginal)

The water consumption was recorded continuously every day in 60 mL steps using NI 6008 USB data acquisition devices in combination with software developed by ourselves using NI Labview (both National Instruments, Austin, USA). For both groups, the water consumption was compared between the day before vaccination and the day of the treatment.

Feed intake was measured by weighing the feed remains in removable troughs after a feeding time of twenty minutes. The accuracy of the scale was ±50 g. The feed rate was measured starting with trial run eight using a stopwatch (Compact II, servoprax GmbH, Wesel, Germany). The gilts were fed twice a day (08:00 am and 01:00 p.m.) during the dose test. During the main trials, the afternoon feeding time was shifted (01:00 p.m., 03:30 p.m., 03:30 p.m., 01: 00 p.m.) to maximise the expected effect of the vaccination at 03:30 in the afternoon of day three.

2.5. Statistical Analyses

The statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

Temperatures of the VL below 35°C were defined as no body core temperature by the authors because the logger slipped out the vulva. Therefore, we excluded those measurements for the statistical analyses.

2.6. Dose Test

A mixed linear model was used to test the differences between doses regarding VL temperature increase. Observations were mean temperature per hour

and sow, fixed effects beside the intercept μ were dose (D; i=1,…,4), h (H; j = 1,…,24) and interaction between dose and hour. Random effects included sow effect (S; k=1,…,11) and interaction between sow, hour and the independent normally distributed residual ε. This resulted in the model shown in Equation (1):

$$y_{ijk} = \mu + D_i + H_j + (D \times H)_{ij} + S_k + (S \times H)_{jk} + \varepsilon_{ijk} \quad (1)$$

2.7. Main Trial

Pearson correlation coefficients between rectal and vaginal temperatures were calculated separately for both treatments (RA vaccine and NaCl) in the main trial of the study. After the treatment, the time until the temperature exceeded 39.5°C was measured with the vaginal logger and averaged to obtain the average time it took to induce fever. Starting from this point in time, the time span was measured until the temperature fell below 39.5°C again. This time span was also averaged across all gilts to obtain the average fever duration.

Furthermore, a Bland-Altman plot was performed to evaluate the vaginal logger data graphically, according to the method of Bland and Altman (1999) and recommended by Grouven *et al*. (2007), for comparisons of both of the methods under investigation. This statistical procedure is especially recommended for comparing two methods because it not only considers the average difference (bias) but also puts emphasis on the variation of the differences (diff) between pairs of measurement values. The differences between the measurements with both methods are plotted against the arithmetic mean of the two methods. The bias is provided as the mean difference and the 95% limits of agreement are provided by diff ± 2s, where "s" is the standard deviation of the differences.

The respective durations of standing and lying were tested for differences between the treatments using mixed linear models. For each trait, the time per day in seconds was summed. The duration of sitting was tested using a generalized linear mixed model assuming a Poisson distribution and using a Log link function. Fixed effects were the general mean μ, trial (TR; l = 1,…11), dose (D; i = 1, 2), point in time (PIT; m = 1, 2 referring to measurements before and after vaccination, respectively) and interaction between D and PIT. The random sow effect (S; k = 1,…,43) was also included. Residuals were assumed to be independent and N (0,σ^2) distributed for standing and lying, resulting in the model in Equation (2):

$$y_{ijml} = \mu + TR_l + D_i + PIT_m + (D \times PIT)_{im} + S_k + \varepsilon_{ijml} \quad (2)$$

The influence of the treatments on sitting duration was tested using a generalized mixed linear model. In addition to the intercept μ fixed effects of TR, D, PIT and the interaction between D and PIT, the random sow effect S was also included in the model. For sitting duration, a Poisson distribution was assumed. A Log link function was used to link the distribution parameter to the linear predictor η given in Equation (3):

$$\eta_{ijml} = \mu + TR_l + D_i + PIT_m + (D \times PIT)_{im} + S_k + \varepsilon_{ijml} \quad (3)$$

For testing treatment effects on water consumption per day in mL, the same model was assumed. Hence, the linear predictor η from equation (3) was used.

Differences in feed intake were tested using a generalized linear mixed model. The observed feed remains divided by total feed amount resulted in the percentage of remaining feed and, hence, were assumed to follow a binomial distribution. A logit function was used to link the distribution parameters to the linear predictor. The linear predictor η included the general mean μ and the fixed effects of TR, D, temperature condition (TC; n = 1, 2 referring to temperatures up to and above 39.5°C, respectively), the interaction between dose and temperature condition, random sow effect and logistically distributed residual ε, as shown in Equation (4):

$$\eta_{ik\,ln} = \mu + TR_l + D_i + TC_n + (D \times TC)_{in} + S_k + \varepsilon_{ik\,ln} \quad (4)$$

Differences in the duration of feed intake were tested using the same model, except that the interaction between D and TC was excluded and only 9 trials were considered. The observed variable was the amount of time for feeding in each sow divided by a maximum time of 20 min. For all of the tests using the models (equations 1 to 4), hypotheses were tested at a significance level of 0.05. P-values from pairwise tests between effect levels were adjusted for multiple testing using the SIMULATE option to comply with the global significance level.

3. RESULTS

3.1. Dose Test

Average temperatures per hour ± Standard Error (SE) were 38.46±0.09, 39.54±0.09, 39.07±0.11 and 38.89±0.13°C for the NaCl control (referred to as 0 in **Table 1**), 2 mL dose, 4 mL dose and 6 mL dose, respectively.

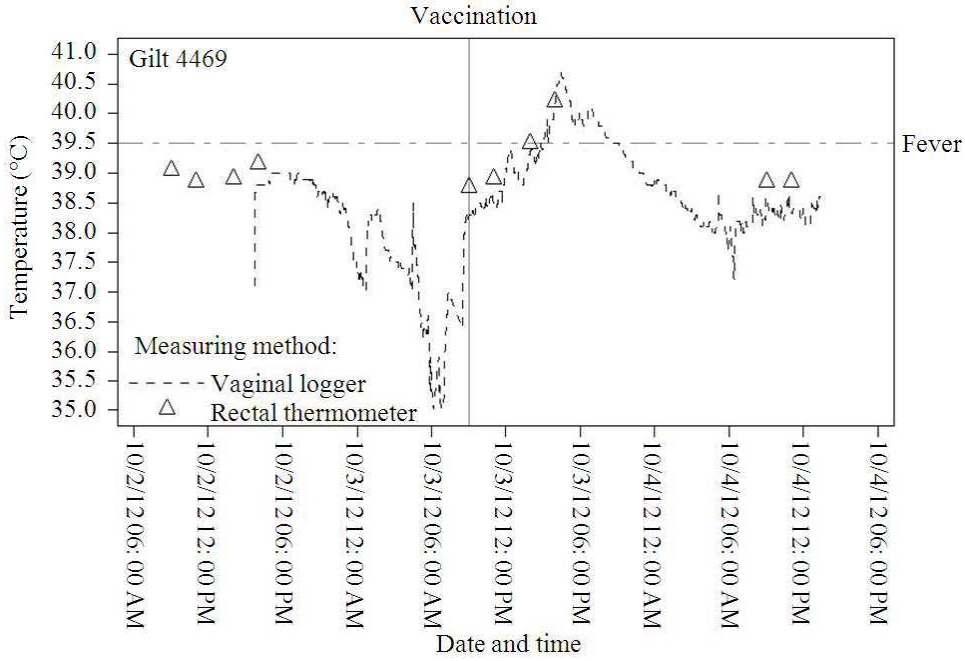

Fig. 2. Course of rectal and vaginal temperatures during the three days of the trial for one sow with the vaccination and the fever limit marked

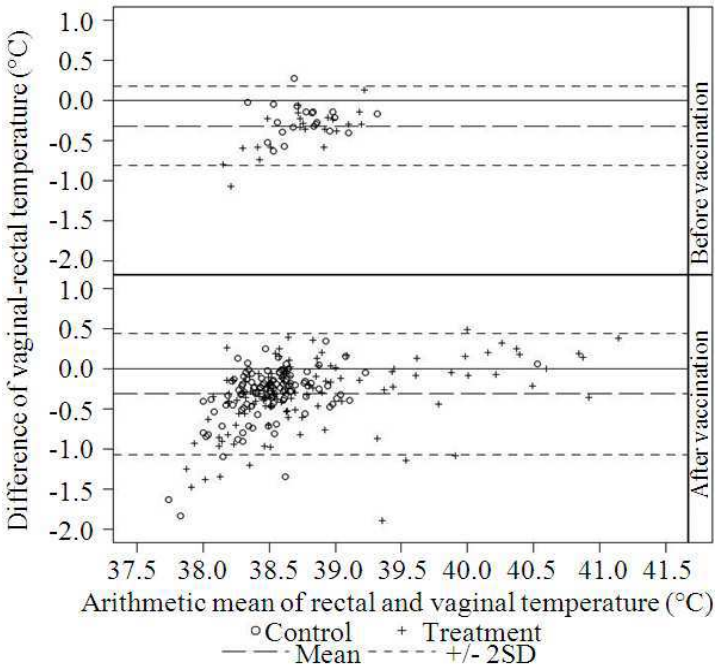

Fig. 3. Bland-Altman plot of the values for the vaginal temperatures compared to the rectal temperatures, based on the observations in the main trial (43 gilts)

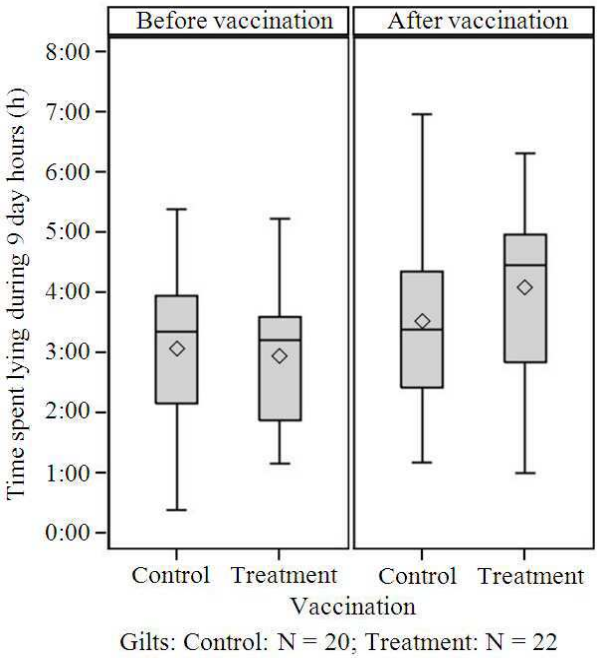

Fig. 4. Lying time of the gilts (42 gilts) before and after treatment with NaCl (0) or with the vaccine (2)

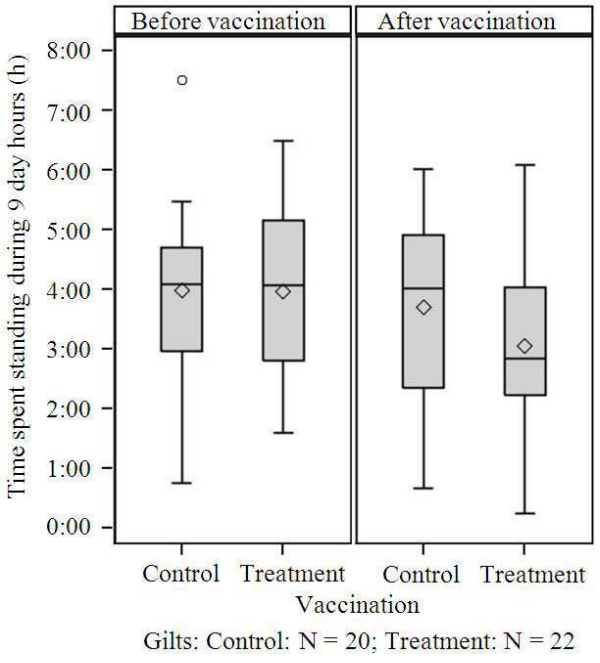

Fig. 5. Time spent standing (42 gilts) before and after treatment with NaCl (0) and with the vaccine (2)

Table 1. The least squares means, estimated differences, standard error, degrees of freedom and adjusted P-value differences for the temperatures per treatment in the dose test

Difference		Standard	Degreeso	
P-value	Estimate	error	ffreedom	Adjusted
Dose 0-Dose 2	-1.09640	0.1546	219	<0.0001
Dose 0-Dose 4	-0.67730	0.1768	219	0.0010
Dose 0-Dose 6	-0.65590	0.1886	219	0.0033
Dose 2-Dose 4	0.41910	0.1773	219	0.0828
Dose 2-Dose 6	0.44050	0.1891	219	0.0894
Dose 4-Dose 6	0.02137	0.2077	219	0.9999

As can be observed in **Table 1**, all treatments lead to a significant increase in body temperature compared to the control. Between the doses, no significant differences occurred. Hence, the lowest dose was chosen for the following trials.

3.2. Main Trial

The linear correlation between the RT and VT was r = 0.65 (p<0.0001) for the 22 non-vaccinated gilts (n = 136) and r = 0.86 (p<0.0001) for the 21 vaccinated gilts (n = 152).

On average, an increase of the VT above 39.5°C could be detected after 5.87 h post-vaccination. An example of the temperature increase of one gilt is shown in **Fig. 2**. The temperature was again below 39.5°C after 11.20 h post-vaccination. Therefore, on average, the fever period lasted 5.13 h.

A Bland-Altman analysis was conducted to validate the use of the vaginal loggers. The Bland-Altman plot (**Fig. 3**) of the difference between VT and RT indicates that most values were within 2 Standard Deviations (SD). The majority of the outliers can be found in the low temperature area, except for one.

The behavioral analysis showed differences between the time before and after vaccination (**Fig. 4 and 5**). The gilts treated with the vaccine spent 79±16 min/day more lying post-vaccination compared to the day before the treatment (p = 0.0003) and 52±18 min/day less standing (p = 0.0251). The vaccinated gilts spent 3.29 min. more sitting compared to the day before (p<0.0001), whereas the sows that were injected with NaCl spent 6.57 min. more sitting per day (p = <0.0001). Water intake clearly demonstrated a rhythmic day by the gilts. The highest water intake for the gilts was between 12:00 PM and 4:00 PM and water intake changed significantly for both the vaccinated (p<0.0001) and non-vaccinated (p<0.0001) gilts.

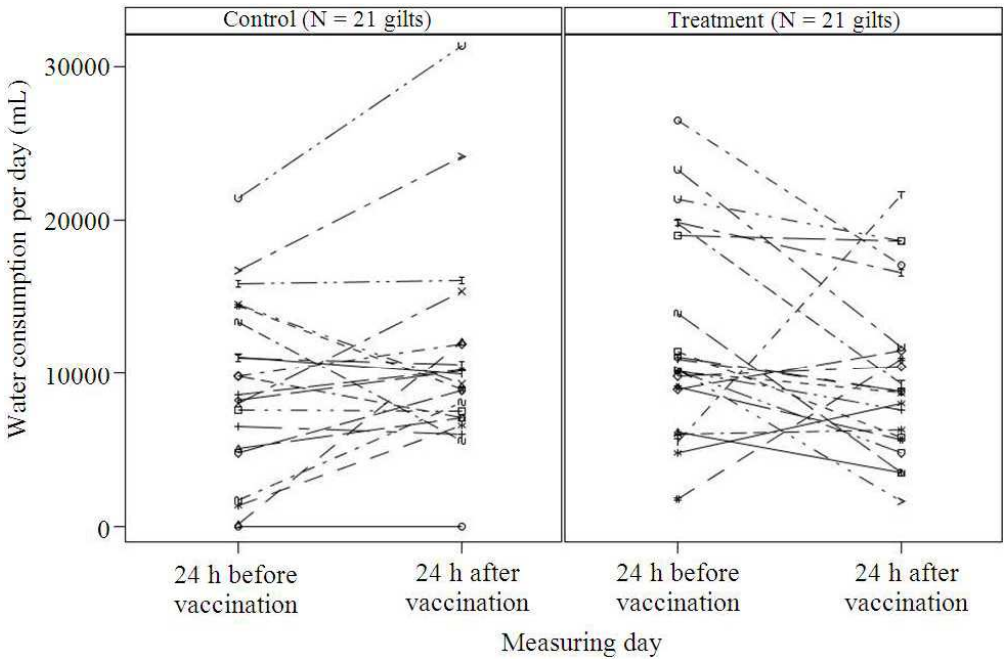

Fig. 6. Water consumption per day for all non-vaccinated and all vaccinated gilts. The first dot marks 24 h before vaccination and the second dot marks 24 h post-vaccination

The difference between both groups was that the non-vaccinated gilts drank 1.1 L more during a 24-h period compared to the day before, whereas the vaccinated gilts drank 2.01 L less compared to the day before (**Fig. 6**).

Two of the vaccinated gilts did not eat at all during the entire trial. The temperatures of these gilts were 41.2°C and 41.6°C at 4:00 PM. The feeding behavior of the other gilts displayed no changes. Food intake was not influenced by vaccination or fever ($p>0.05$). In addition, the duration of the feed intake was not influenced by vaccination or fever. There was only one significant difference between trial 12 (18.67±0.67 min) and all of the other trials (on average 11.4±3.38 min (mean ± SE) per feed intake).

No side effects on the animals' health due to the logger were observed during the trial (vaginal discharge).

4. DISCUSSION

The dose test demonstrated that there was a significant difference in the temperature increase between the gilts treated with NaCl and the gilts treated with the vaccine. Although there was an increase in temperature for the gilts treated with the 4 mL and 6 mL doses, it was not significant compared to the 2 mL dose. A reason for this increase could be that a dose of 2 mL is sufficient to elicit an immune reaction and that a certain level of saturation is reached.

Temperatures measured with a rectal thermometer are often not accurate enough because of inadequate insertion depth (Naylor *et al*., 2012). A study by Burfeind *et al*. (2010), who recorded temperature data from cows, determined that rectal temperatures are higher when the probe is inserted deeper into the rectum. We tried to minimise measurement errors by performing the measurements twice with a certain time lag. Continuous measurements with a fixed VL can be used as a measure of body temperature in dairy cows (Suthar *et al*., 2013) and could be helpful for avoiding misleading data, as explained by Burfeind *et al*. (2010). In a study by Soede *et al.* (1997), a vaginal sensor was used in sows, indicating that it is possible to measure the body core temperature with such a logger. Similarly, our results demonstrate that the VT is highly correlated to the RT. One reason for outliers in the Bland-Altman plot in the negative area could be that, in some animals, the VL was not inserted deeply enough before it slid out of the vulva, especially when the animals urinated and defecated. Further investigations will be required to find a solution for fixation of the VL to improve the method,

specifically to prevent it from slipping out. However, the VL caused no side effects on the animals' health and core temperatures could be measured. It remains to be determined if this method will be a useful option for research studies. However, this temperature measurement method is not an option for commercial pig farms because the risk of ascending infections would be too high.

It could be shown that the Porcilis AR-T DF vaccination led to an increase in the body temperature of the gilts. Although the increase lasted no longer than a few hours, some behavioral patterns were altered. Furthermore, this method provides the opportunity to induce fever without the common side effects of using methods such as CFA and LPS, which have been described by other authors (Brooks *et al*., 1978; Leenaars and Hendriksen, 2005; Stills, 2005).

The lying behavior increased in the vaccinated gilts. In conclusion, the standing behavior decreased in the vaccinated animals. In addition, the sitting behavior of the vaccinated animals increased. In particular, the non-vaccinated gilts spent more time sitting compared to the vaccinated gilts. An explanation for this finding could be that the vaccinated gilts spend more time lying on the whole than the non-vaccinated gilts. The vaccine contains pyrogenic substances and possibly leads to an IL-1 increase (Kluger *et al*., 1998). This is one of the major cytokines and acts on the hypothalamus. This includes, next to other symptoms, increased sleep (Tizard, 2008). In contrast, pigs generally respond to increasing ambient temperatures by modifying their lying, excretion and wallowing behaviors (Huynh *et al*., 2005). Both factors could be an explanation for our results.

The water intake of the gilts was altered during the present trial. The gilts that were treated with the vaccine drank less compared to the day before, whereas the gilts injected with NaCl drank more compared to the day before. This result is in agreement with the results of Harden *et al*. (2011), who described that rats injected with LPS showed anorexia. Additionally, laboratory rodents injected with proinflammatory cytokines and LPS showed a decrease in food and water intake (Dantzer, 2001). There was no obvious reason for the increase in water intake by the NaCl-vaccinated gilts.

In the present study, the food intake of the gilts did not decrease ($p>0.05$) after vaccination. Sick individuals usually decrease feeding (Weary *et al*., 2009) to promote recovery (Johnson, 2002). In their trial, McCarthy *et al.* (1985) found that food intake is suppressed during the infection of rats and is mediated by the release of IL-1. Furthermore, it has been shown that interleukin-1ß (IL-1ß) has an influence of the motivation to eat. Rats infected with Mycoplasma were lethargic and anorexic and showed body mass stunting (Swanepoel *et al*., 2011). Waldron *et al.* (2006) demonstrated that the feed intake of lactating dairy cows declined in response to LPS. Illnesses and the immune response can also affect the water and food uptake of mammals (Dantzer, 2001; Weary *et al*., 2009). In spontaneously RA-affected pigs, toxin-producing strains of *Pasteurella multocida* are the decisive pathogen factor (Zimmermann and Plonait, 2004). The RA vaccination contains inactivated *Bordetella multocida* cells and a protein component of the *P. multocida* dermonecrotic toxin, which also influences IL secretion and, therefore, has an influence of the animal's sickness behavior. In response to vaccination, we found a modified water intake but a predominantly unaltered feed intake. We have no data to compare the severity of the immune reaction due to the vaccination with that of other studies because we collected no blood samples. Therefore, we cannot conclude why we obtained different results for feed intake compared to other studies. It might be that the amount of pyrogenic substances was not enough to lead to such a strong immune reaction that the appetite would be influenced to a large degree. In addition, the fever period might not have lasted long enough or might have had inappropriate timing to show an effect on the gilts' appetite.

The RA vaccination induced fever for a short period of time and induced mild sickness behavior, such as an increased lying time and a lowered water intake. Thus, we can conclude that the treatment induced a mild defence reaction in the gilts. We were able to establish a quasi-continuous monitoring of the immune reaction by using a commercial temperature logger as a vaginal logger and verified the logger temperature using rectal-measured temperatures. These measurements enabled us to examine minimal changes in animal behavior and their correlation to the current immune status of the animal. From these results, further investigations might lead to findings regarding early disease symptoms before the disease becomes apparent. The use of a vaccine for food-producing animals and a commercial logger provide the means for low cost and low risk research in the fields of immunology and health monitoring. There were no obvious side effects observed for either the vaccine or logger. The RA vaccination is especially useful when a mild immune stimulation is sufficient for research questions. However, subsequent studies will be required to investigate which cytokines are discharged and in what amount.

5. CONCLUSION

In conclusion, RA vaccination is suitable as a low risk method for immune stimulation and to induce fever in gilts. Therefore, it was possible to evaluate different behavioral patterns.

6. ACKNOWLEDGEMENT

The reaches thank Big Dutchman Pig Equipment GmbH for their assistance. This project was supported by funds from the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) via the Federal Office for Agriculture and Food (BLE) in the framework of the innovation support programme.

6.1. Ethical Standards

The authors declare that the experiments comply with the current laws of Germany. The animals were humanely treated both in their day-to-day care by the owner and during our study. Permission from the animal care and use committee of the country was granted.

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2.3 Paper C: The suitability of infrared temperature measurements for continuous temperature monitoring in gilts

Schmidt, M., Ammon, C., Schön, P., Manteuffel, C., Hoffmann, G.,

Archive Animal Breeding 57 (2014) 21, 1-12.

Doi: 10.7482/0003-9438-57-021

Archiv Tierzucht 57 (2014) 21, 1-12

Open Access

Original study

The suitability of infrared temperature measurements for continuous temperature monitoring in gilts

Mariana Schmidt[1], Christian Ammon[1], Peter Christian Schön[2], Christian Manteuffel[2] and Gundula Hoffmann[1]

[1]Department of Engineering for Livestock Management, Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), Potsdam, Germany, [2]Department of Behavioural Physiology, Leibniz Institute for Farm Animal Biology Dummerstorf (FBN), Dummerstorf, Germany

Abstract

The aim of this study was to evaluate whether an infrared thermometer, a pyrometer, could detect the body surface temperature in the orbital area of gilts without contacting them. Furthermore, it was tested whether an increase in the gilts' temperatures could be detected. Therefore, fever was induced. During 11 trials, 43 German Landrace gilts were injected with either a Porcilis AR-T DF (Intervet International B.V., Boxmeer, Netherlands) vaccine or 2 ml of 0.9 % NaCl. A commercial temperature logger (TRIX-8, LogTag Recorders, Auckland, New Zealand) was placed in the vagina to record temperature data every 3 min. The pyrometer (optris cs, Optris, Berlin, Germany) was aimed at where the orbital area of the gilts would be. While they were drinking, temperature measurements were done in that site by the pyrometer. Time periods from 0.25 to 6 h were analysed. Considering the 0.25-h period, a positive correlation (ρ=0.473) between temperatures of the logger and the pyrometer was found for 15 of 39 gilts. The longer the chosen measuring period was, the fewer animals showed a significant correlation between the two temperatures. In contrast to the vaginal logger, the pyrometer cannot detect an increase in the body temperature in all fever-induced gilts. In conclusion, a pyrometer cannot detect the body surface temperature reliably. An increase in the body surface temperature over a short time period (on average 5 h) could not be detected by the pyrometer. The temperature increase measured using the pyrometer was too low and time-delayed compared to the temperature detected by the vaginal logger.

Keywords: infrared thermometer, temperature, sow, gilt, non-invasive

Archiv Tierzucht 57 (2014) 21, 1-12
doi: 10.7482/0003-9438-57-021

Received: 17 December 2014
Accepted: 26 May 2014
Online: 5 August 2014

Corresponding author:
Gundula Hoffmann; email: ghoffmann@atb-potsdam.de
Department of Engineering for Livestock Management, Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany

Abbreviations: IRC: infrared camera, PM: pyrometer, VL: vaginal logger, VT: vaginal temperature,

Introduction

By detecting fever as an early sign of an inflammatory or infectious disease, timely treatment can be provided. To achieve this goal, the authors think, continuous and automatic monitoring is necessary and therefore a highly important topic. In this study, an infrared pyrometer (PM) was used to measure the surface temperature of gilts with fever. This method has the advantage of being non-invasive, contactless and automatically usable, and therefore, it can save time for the staff. In the best case, only the specific sows that were identified as febrile, using the PM, would have to be verified by measuring the rectal temperature by the working staff instead of all or no sows.

Various authors have described the potential of infrared thermography in animals. For example, Johnson *et al.* (2011) measured the eye temperature of ponies using an infrared camera (IRC), and the results of their study support the use of infrared thermography as an additional method for measuring body temperature. In the study of Traulsen *et al.* (2010), the temperatures of different body surface locations (eye, inner part of the ear, back of the ear, mammary gland and vulva) were measured to investigate whether infrared thermography is useful to detect the body temperature of gilts. The temperatures were measured using an IRC, with the result that an increase in the rectal temperature corresponded with an increase in infrared temperature. Another study determined that the temperature of the eye of a cow was a useful indicator of its body core temperature (Gloster *et al.* 2011). Hoffmann *et al.* (2012) measured the body surface temperatures of cows and calves using an IRC and compared them with the vaginal and rectal temperatures. As a result, they stated that the IRC shows potential as a system for monitoring the body temperatures of cattle.

However, there are potential limitations of infrared measurements and factors that can influence the measurements negative. Therefore, the measurements should be collected out of direct sunlight and wind drafts, hair coats should be free of dirt and moisture, and the effects of weather conditions, circadian rhythms and the time of feeding, milking and lying down should be considered (Knížková *et al.* 2007). Furthermore, other authors who used the IRC technique for non-continuous measurements concluded that this technique is unreliable in measuring the body temperature or in allowing predictions of the rectal temperature (Chen & White 2006, Dewulf *et al.* 2003).

Various body-temperature monitoring systems have been investigated by other authors to find a suitable method for contactless monitoring of animals' body core temperatures. Hillman *et al.* (2009) used a vaginal logger in cows to measure the body core temperature and compared it to the rectal temperature, and Soede *et al.* (1997) used a vaginal logger in gilts to measure the body core temperature. Suthar *et al.* (2013), Stiehler *et al.* (2013) and Vickers *et al.* (2010) validated this kind of temperature measuring method. Furthermore, subcutaneous implants in pigs (Lohse *et al.* 2010) or intraruminal boli in cows (Rose-Dye *et al.* 2011) have been used in different studies. However, these methods are invasive and carry a certain risk of damage and, therefore, are more suitable for research than for use in husbandry.

The purpose of this study was to automatically detect an increase in the body core temperature via repeated continuous infrared thermography measurements with a PM targeted at the orbital area in fever induced gilts while they were drinking, using the vaginal

temperature as the control. This control method was validated in a former trial (Schmidt *et al.* 2013a).

Material and methods

Animals

This study was approved by the state office for agriculture, food safety and fisheries in Mecklenburg-Vorpommern (number 7221.3-1.1-005/12), Germany. The trial was conducted in the experimental pig unit of the Leibniz Institute for Farm Animal Biology (FBN), Dummerstorf, Germany with 44 German Landrace gilts from May to December 2012. The gilts were 208 to 215 days of age. Eleven trials were conducted; four gilts were tested in each trial. For the installation of the measurement devices, the animals were maintained on a solid concrete floor without straw bedding, in individual side-by-side crates, leaving one empty crate in between. Each crate measured 0.6×2.2 m. The feed consisted of commercial gilt-rearing feed pellets, and the animals were fed 1 300 g of pellets twice a day. Water was available ad libitum from nipple drinkers.

Treatment

To induce fever, 2 ml of the commercial vaccine Porcilis AR-T (Intervet International B.V., Boxmeer, Netherlands) (RA vaccine) was administered intra-muscularly once to two gilts that were randomly chosen from four gilts per trial. A dose of 2 ml of 0.9 % sterile NaCl solution (Selectavet Dr. Fischer GmbH, Weyarn-Holzolling, Germany) was administered in the same way to two control gilts. To acclimatise the gilts to the crates, the treatment was begun on the third day of the trial between 9.00 and 9.30.

Measurements

As a control and a more invasive method, the vaginal temperature (VT) of each gilt was measured during the trial. Furthermore, for a contactless method, a fixed pyrometer (optris cs, Optris, Berlin, Germany) was used to measure the body surface temperature. In addition, the water consumption was measured using a digital flow meter (FCH-m-POM, B.I.O-TECH e.K., Vilshofen, Germany) to detect the exact time and duration of drinking per day, as previously described (Schmidt *et al.* 2013a). The duration of the drinking period of each gilt was recorded in s. If a pause of 15 s was detected, a new drinking session was assumed to have started.

The VT was measured continuously. These measurements were performed for three days, from day two through day four of the trial, using a micro-climate monitoring device that was designed for industrial purposes, using an external temperature probe (TRIX-8 recorder with a ST100S-15 probe, LogTag Recorders, Auckland, New Zealand) as a vaginal logger (VL). The logging device and the respective sensor cable were fixed on the backside of the gilts via adhesive tape, and the probe was inserted in the vagina as described in Schmidt *et al.* (2013a). The VL took temperature data every 3 min. Temperatures below 36 °C were excluded from the data evaluation because they indicated that the VL had slipped out of the vulva, e. g., due to excretion, as no increase of temperature above that threshold was found after dropping

below 36 °C without manually reinserting the VL. As soon this event was noticed, the VL was cleaned and reinserted. Because a staff person was present only during the day time, VL data for the night time was rarely available for many of the gilts; during 35 of the in total 84 observed sows and nights the logger slipped out.

In the 5th trial, one gilt in the control group did not drink at all during the treatment period, and therefore, this gilt was excluded from further evaluation. In the 10th trial, a malfunction occurred in the VL of one of the gilts in the control group. The data from this gilt could not be used for further evaluation.

The emissivity of human skin, ε=0.985, was used for the infrared device. The PM was secured in the neighbouring empty pen, and the target area of the gilt was the orbital area (Figure 1). The distance between the body surface and the pyrometer was approximately 20-30 cm, which resulted in a measuring spot diameter of 1.3 to 2.0 cm. The PM measured continuously with a system accuracy of ± 1.5 °C. The temperature data that were used for evaluation were those taken only when the gilt was drinking, to ensure that the PM had been aimed at the orbital area. Temperature measurements lower than 35 °C were discarded because those values indicated that the sows had moved outside the target area of the PM and therefore the measurements were not measurements of the orbital area. Based on findings in a previous study analysing infrared measurement methods in various body locations (Schmidt *et al.* 2013b) the threshold of 35 °C was chosen by subtracting twice the accuracy of the PM from the lower end of the expected temperature range in pigs of 38 °C. The following monitoring periods: 0.25 h, 1 h, 2 h, 3 h, 4 h and 6 h were chosen for monitoring. For every period the maximum temperatures were calculated in both devices, VL and PM. These intervals were chosen because of the following different reasons. Accordingly, a change in the temperature should be detected as early as possible, which requires short measurement intervals, and it should be possible to follow the change in temperature over the long term, which might be easier in longer intervals, as taking only the maximum temperature in every period will smoothen the shape of the temperature curve. Due to their circadian rhythms, long periods occur during which the animals do not drink at all, which also is an indication for using longer periods to increase the chance to have at least one temperature measurement within that period.

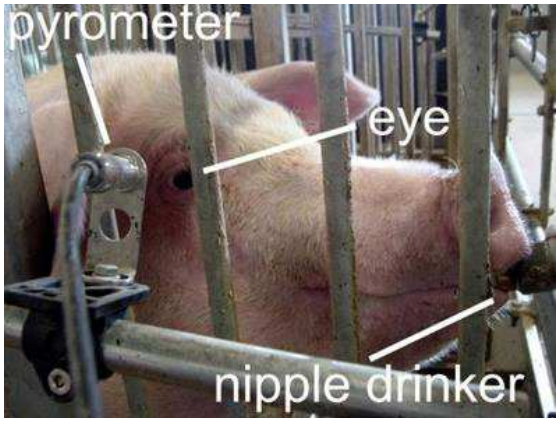

Figure 1
Arrangement of the pyrometer, nipple drinker and sow

Statistical analysis

Statistical analysis was performed using the SAS v. 9.3 software (SAS Institute Inc., Cary, NC, USA). To achieve an initial overview, the Pearson correlation between the vaginal temperature and the pyrometer temperature was calculated for each of the gilts and for each of the six monitoring periods mentioned above, based on the maximum values per time period for each measurement method. For comparison, the pooled Pearson correlations between the VL and PM temperatures for all gilts and for each monitoring period were calculated as well. Overall variation of temperature measurements by period was charted in a Bland-Altman plot (Bland & Altman 1999).

A mixed linear model was used with the MIXED procedure in SAS to compare the ability of two methods (VL and PM) to detect changes in maximum temperature (T) while considering the following factors: measurement method, monitoring period, time of the day, treatment group, vaccine influence and animal effect. The fixed effects were the method (MTH, with i=2 levels, for the VL and the PM), the monitoring period during a day (MID, with j=96, j=24, j=12, j=8, j=6 and j=4 levels for the variants of the 0.25-h period, 1-h period, 2-h period, 3-h period, 4-h period and 6-h period, respectively), the treatment group (GRP, with k=2 levels for the vaccine treatment and the NaCl control groups) and the period of treatment effect during the day (VAC, with l=2 levels for the data obtained between 8.00 and 21.00 on the third day of the trial and for all of the other data). A random effect of the gilts (GLT, m=1,…, 42) that was grouped by the method was included. Repeated measurements for a gilt that were grouped by the method were considered using a spatial power covariance structure. This technique allowed accounting for correlated measurements for a gilt based on differences in the monitoring periods when the data were not evenly spaced in time because there were missing data, e. g., when the gilts did not drink or when the VL slipped out of the vulva for a prolonged period of time.

Because interactions between the fixed effects were expected, the full model including all of the interactions was fitted first, separately for each of the six monitoring periods. Effects that were not significant (>5 %) in at least one of the monitoring periods were then excluded from the model. The resulting model equation was as follows:

$$T_{ijklmn} = \mu + MTH_i + MID_j + (MTH \times MID)_{ij} + GRP_k + VAC_l + (MTH \times VAC)_{il} + (MID \times VAC)_{jl} + (MTH \times MIDxVAC)_{ijl} + (MTH \times GRPxVAC)_{ikl} + (MID \times GRPxVAC)_{jkl} + GLT(MTH)_{im} + \varepsilon_{ijklmn} \quad (1)$$

where T is the observed maximum temperature, μ is the general mean of temperature, *MTH* is fixed effect of method, *MID* is the fixed effect of measuring interval during a day, *MTH*×*MID* is the fixed interaction effect between method and measuring interval, *GRP* is the fixed effect of treatment group, *VAC* is the fixed effect of treatment period, *MTH*×*VAC* is the fixed interaction effect between method and treatment period, *MID*×*VAC* is the fixed interaction effect between measuring interval and treatment period, *MTH*×*MID*×*VAC* is the fixed interaction effect between method, measuring interval and treatment period, *MTH*×*GRP*×*VAC* is the fixed interaction effect between method, treatment group and treatment period, *MID*×*GRP*×*VAC* is the fixed interaction effect between measuring interval, treatment group and treatment period, *GLT(MTH)* is the random effect of gilt nested within method and ε is the random residual.

The factor estimates from the models as well as their standard errors were then used to plot the mean curves of maximum temperatures over a day and the corresponding 95 % confidence intervals by each period, for both measurement methods and for the time of the day under vaccine influence.

To calculate the average differences between the day and night temperatures according to the method and the measuring period as well as the average differences between treatment group and control group during vaccine influence according to the method and the measuring period, the required contrasts were established using the LSMESTIMATE statement. Degrees of freedom were approximated with the method by Kenward & Roger (1997).

For the 1-h and 0.25-h periods no solutions for the required linear contrasts were found.

Results

A significant positive correlation between the VL and PM temperatures was found in 38.5 %, 34.2 % and 28.9 % of the animals when intervals of 0.25 h, 1 h and 2 h were used, respectively (Table 1). The longer the chosen interval, the fewer animals provided a significant correlation between the VL and PM temperatures. The lowest ranges (0.169, 0.176), interquartile ranges (0.076, 0.038) and high medians (0.726, 0.772) were found when intervals of 2 h and 3 h were used, respectively. Figure 2 shows Bland-Altman plots of the overall variation for each period. The figure shows that the difference of PM and VL temperatures have a tendency toward 0 °C with higher arithmetic means of both temperatures.

Table 1
Overview of the period, the number of gilts and the measurements, with the median, 25 % (Q25) and 75 % quantile (Q75) of the individually significant Pearson correlations (ρ_i) as well as pooled Pearson correlations (ρ) with corresponding *P*-values (t-test, n-2 degrees of freedom)

		Period, h					
		0.25	1	2	3	4	6
Number of gilts		39	38	38	38	34	40
Minimum measurements per gilt		6	6	6	6	5	3
Number and percentage of gilts with a significant correlation		15 (38.5 %)	13 (34.2 %)	11 (28.9 %)	5 (13.2 %)	7 (20.6 %)	5 (12.5 %)
ρ_i	Q25	0.463	0.526	0.716	0.762	0.694	0.843
	Median	0.509	0.569	0.726	0.772	0.787	0.846
	Q75	0.635	0.655	0.791	0.8	0.883	0.938
ρ		0.462	0.513	0.246	0.157	0.348	0.208
P-value		0.002	0.021	0.418	0.644	0.359	0.001

As seen in Figure 3, an increase of the temperature was detected with the VL in all of the monitoring periods. This increase lasted on average 5.13 h as described before (Schmidt *et al.* 2013a). A significant increase in the PM temperature of the corresponding group was not detectable. Furthermore, the increase in the PM temperature occurred with a time delay

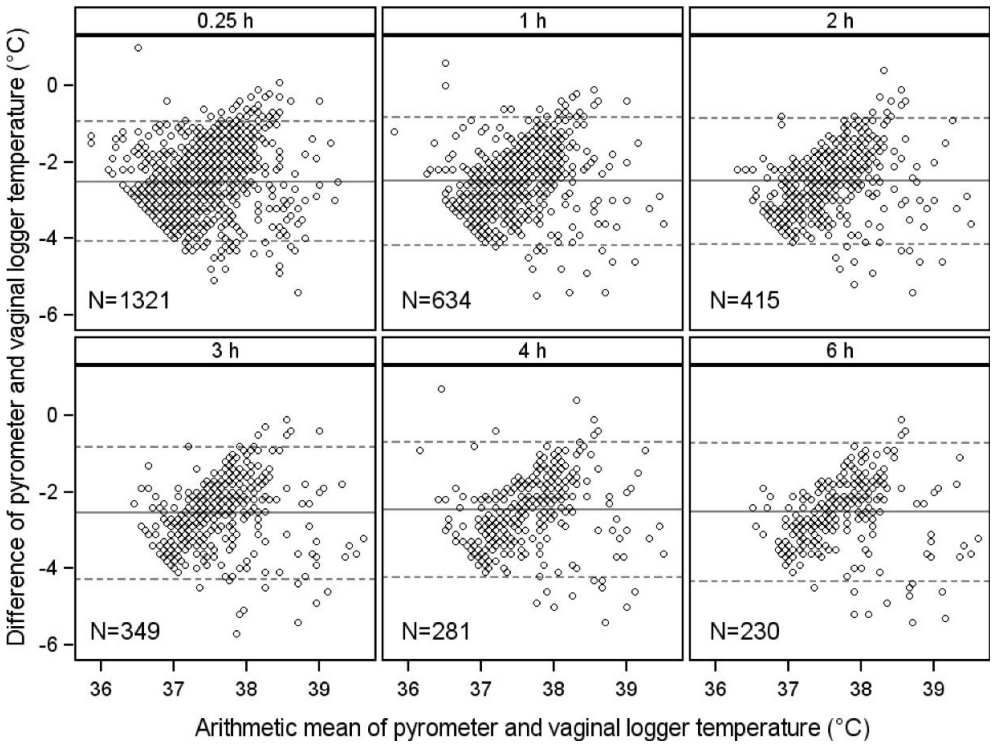

Figure 2
Bland-Altman plot for pooled data of 42 gilts for each of the monitoring periods, each showing mean difference between pyrometer and vaginal logger measurements ±1.96 standard deviations

compared to the temperature measured with the VL. It can be seen that the smaller the period was, the higher the variability.

Table 2 shows the differences between the PM temperatures of the vaccinated gilts on the control day (no vaccination) and the day of the vaccination. As seen, the temperature differences did not significantly change in accordance with the length of the measuring periods.

Table 2
Mean differences in the pyrometer temperatures of the gilts in the treatment group (n=21) between the vaccination period and control period by time period, estimated with linear contrasts using the data taken from the results of the statistical model and tested with t-test (α=0.05, degrees of freedom approximated with the method by Kenward & Roger [1997])

Time period, h	Mean difference, °C	Standard error, °C	Total number of measurements	Degrees of freedom	$P>\|t\|$
2	0.12	0.19	189	60.95	0.51
3	0.16	0.20	131	71.42	0.42
4	0.14	0.21	112	71.03	0.50
6	0.21	0.22	54	89.90	0.35

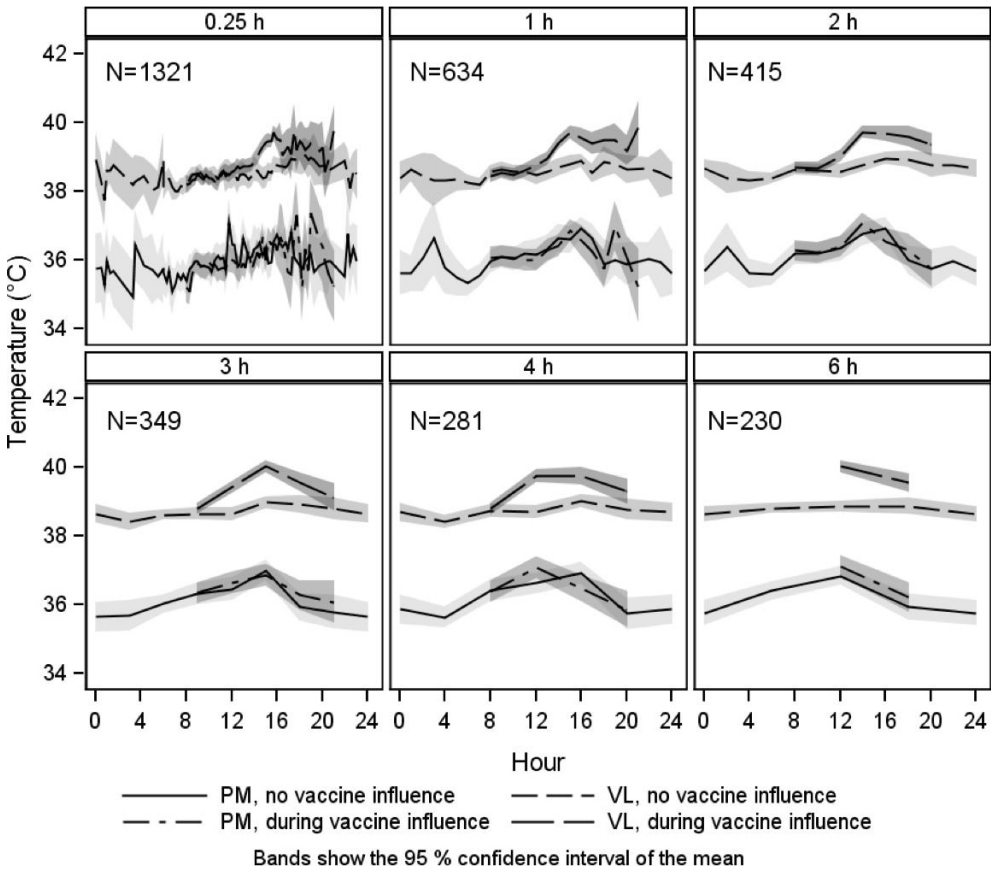

Figure 3
24-h overview of the temperatures of all of the gilts in the treatment group (N=21) taken using the pyrometer (PM) and the vaginal logger (VL)

Table 3
Average difference between the day and night temperatures (excluding the time of vaccination) according to the method and the measuring period based on data of 42 gilts; day=6.00 to <18.00, night=18.00 to <6.00

Period, h	N per method	Method	Estimated temperature difference day – night	95 % confidence interval		Adjusted *P*-value
				Lower	Upper	
6	252	PM	1.66	1.19	2.14	<0.001
		VL	0.05	–0.12	0.21	0.761
4	312	PM	2.84	2.14	3.53	<0.001
		VL	0.34	0.08	0.60	0.009
3	378	PM	2.49	1.57	3.42	<0.001
		VL	0.17	0.00	0.34	0.050
2	466	PM	3.98	2.63	5.34	<0.001
		VL	0.20	0.04	0.36	0.011

For both of the methods and all of the periods, there was a significant difference between the average day and average night temperatures, except for the VL measurements over the 3-h and 6-h periods (Table 3). The *P*-values for all of the PM measurements were close to zero, and the estimated temperature differences for every set of PM measurements were higher than for the VL measurements. The smallest difference between the day and night measurements was found when using a 6-h period.

The arithmetic mean value of the daily duration of drinking was 8.12 min (N=44) and the standard deviation was 6.34 min per day.

Discussion

As other studies have shown, temperature measurements taken with a rectal thermometer are often not accurate because of an inadequate insertion depth of the thermometer (Naylor *et al.* 2012). Stiehler *et al.* (2013) demonstrated that rectal temperature is a repeatable diagnostic method in sows, when the method is standardized and when the penetration depths and the type of thermometer is taken into account. Taking measurements with a fixed VL can be used as a method to measure the body temperature in dairy cows (Suthar *et al.* 2013) and in gilts (Schmidt *et al.* 2013a). This method provides the advantage of continuous measurements for experimental studies, and a previous study showed that the VT correlated with the rectal temperature in sows (Schmidt *et al.* 2013a). However, a limitation of the VL was the high percentage of slipped-out loggers. A better vaginal fixation would be useful, but also more invasive and with the risk of injuries, what should be avoided in the gilts of this study because of following breeding processes.

Confined sows and outdoor sows spend only 2.1 % (approximately 0.5 h) and 0.5 % (approximately 7 min) of the day drinking, respectively (Hötzel *et al.* 2005). In our study, the arithmetic mean value of the drinking duration of the gilts was 0.6 % (approximately 8 min) of the day. This is less time in comparison to that spent by the confined sows that were examined by Hötzel *et al.* (2005). One reason why our results differ from the results of other authors could possibly be a different water flow rate (50 ml/s in our trials). Therefore, the 0.25-h period is very short and will lead to much missing temperature data during the day because sows do not drink at regular time periods. For continuous temperature monitoring, periods of 2 h appear to be more useful because the corresponding correlation coefficients were higher and more exact compared to those for the shorter periods. However, the number of gilts showing significant correlation between the VL and PM temperatures was lower (only 11 of 38 gilts). In contrast, the 0.25-h period yielded the highest number of gilts with significant correlations between their VL and PM temperatures (15 out of 39 gilts). This can be explained to a certain extent by having more pairs of data available in shorter periods, which is less likely to produce significant results, but in our case leads to lower absolute correlations due to the fluctuations between the different times of the day, especially for the PM (see also Figures 2 and 3). In longer periods there is less fluctuation between different times of the day, as due to our approach to use only the maximum temperature in every period the shape of the maximum temperature curve throughout the day is smoothened. The lower number of values in the longer periods will make it more difficult to find significant correlations, but often the smoothing effect will lead to higher absolute correlation values.

Independent of the period, the variability of the measurements taken with the PM was too high to detect the occurrence of low temperature differences.

There was a significant difference between the average day and night temperatures obtained using both methods and in all of the periods, as shown in table 3, except for the VL measurements with the 3-h and 6-h periods. However, the 95 % confidence limits showed that the average differences between the day and night temperatures that were measured with the VL did not exceed 0.6 K, whereas they were at least 1.19 K for the PM measurements. This result implies that there was a much stronger diurnal rhythm in the temperature measurements with the PM than in the measurements with the VL, which must be considered when using a PM for temperature monitoring. The reason for the stronger diurnal rhythm in the PM measurements could be that the core temperature is regulated more strictly than is the surface temperature. When considering a monitoring system, this fact needs to be taken into account. Detecting an increase in the body surface temperature that correlated with an increase in the core temperature was not possible. Changes in the temperature level could likely be better detected if they were large and/or sufficiently prolonged. A better accuracy of the PM could also improve the results, because the system of this study works with an accuracy of ± 1.5 °C. The PM appeared to be unsuitable for detecting short-term temperature increases and decreases within the period of 12 h post-vaccination because the variability in its measurements compared to that of the VL was too high. However, the induced temperature increase should have lasted for at least 12 h, so the effect of the circadian rhythm would not have such a strong influence, and the PM detected a higher temperature level over a longer period than during the previous days. Furthermore, the animals drank less during the night, and hence, the standard error for the measurements taken during the night was higher compared to that for the measurements taken during the day. These results partially agree with the results of other authors. Franze *et al.* (2012) found no correlations between the infrared temperatures of the lower leg areas that were measured using an infrared camera and the rectal temperatures of cows. Another study conducted with humans showed that the sensitivity-specificity combination might not be high enough for screening febrile conditions using an infrared thermography camera aimed at the forehead (Chan *et al.* 2013). In contrast, Traulsen *et al.* (2010) concluded that infrared thermography provided the opportunity to collect regular body surface temperatures. However, it must be noted that all of these authors performed the infrared measurements using an infrared camera with which extremely good targeted measurements are possible, whereas in our study, a PM was used and the measurement spot was more variable. In addition, the other authors used one-time measurements, whereas in this study, continuous measurement was applied. Furthermore, the PM was permanently installed, whereas the infrared camera had been aimed at the target area for each measurement. Therefore, it is not certain whether the PM was always aimed at the same intended target (the eye) but may have been instead aimed only at the greater spot at the orbital area, which would lead to a lower correlation with the VL data due to comparing different body-surface locations with differing surface temperatures at every point in time. In a former study, locations which also represented adequate results were mamma and vulva (Schmidt *et al.* 2013b). But because of the positioning of the animals and the practicability of measuring, these locations proved as not adequate.

Six different time periods were utilised in this study. The data from the 0.25-h and 1-h periods showed very high variability compared to that from the periods of 2-h, 3-h and 4-h (Figure 2). However, a change in temperature does not occur as rapidly (e. g., in approximately 15 min), and furthermore, the surface temperature most likely reacts more slowly compared to the central regulation systems. If the chosen period was shorter (15 min, 1 h) the variability in the temperature data was higher.

In conclusion, a short-duration increase in the body surface temperature could not be detected automatically with the PM in the orbital area of fever-induced gilts, as opposed to the increase in the body core temperature that was measured using the VL. This result might be different for longer term temperature increases, which would require additional animal experiments or more extensive on-farm studies with naturally occurring inflammatory or infectious diseases that lead to longer feverish periods. The PM measurements were subject to a more noticeable circadian rhythm compared with the VL measurements.

Acknowledgements

The authors thank the staff of the experimental pig unit Dummerstorf for their assistance. This project was supported by funds of the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) via the Federal Office for Agriculture and Food (BLE) in the framework of the innovation support program.

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3 Discussion of the results

3.1 First part of the trial (Paper A)

The objective of the first part of the trial was to determine which body locations are best suited for the measurement of body surface temperatures of sows and to record the changes in temperature using two different infrared methods. A hand-held IRT and an IRC were used to investigate eight body surface locations. The infrared temperatures measured at the body surface locations were all lower and more variable than the rectal temperature. This result corresponds with the results of Piccione et al. (2013). One possible reason for this finding is that the core body temperature is higher because of anatomical and physiological factors like the blood flow differences between the body core and the skin. This trial showed that the eye and the back of the ear were promising locations in terms of usability for IRT and IRC in sows. In ponies, the eye also seemed to be the best location for temperature detection (Johnson et al., 2011). Furthermore, the skin at these locations contains less subcutaneous fat than body areas such as the dorsal neck region (Sumena et al., 2010), which could lead to better heat transfer in these regions. Additionally, the median difference between the IRT and rectal temperature (RT) was higher than the median difference between the IRC temperatures and RT. One explanation for this finding could be that environmental influences, such as evaporation, can have more influence on one method than on the other. Knizkova et al. (2007) and Okada et al. (2013) described different environmental conditions that can have important influences on infrared measurements. Moreover, it could be shown that the sensitivity of IRC measurements was greater at the ear, followed by the eye, compared to the other locations. This result indicates that a febrile response in sows can be detected with infrared thermography, especially with an IRC. This finding is in agreement with the results of the study of Loughmiller et al. (2001), who also used an infrared thermal imaging camera in pigs. However, the Bland-Altman plot showed a lack of agreement between the rectal and infrared temperatures. This likely prohibits the replacement of rectal temperature measurements in clinically normal sows.

In conclusion, the results of this trial showed that the eye and the back of the ear are appropriate locations for the measurement of body surface temperature. But the detection of fever seems yet not possible because of the low sensitivity of 70 %. Additionally, the IRC appeared to be a more appropriate device to monitor body temperature than the IRT.

3.2 Second part of the trial (Paper B)

The aim of the second trial was to evaluate the sensors for core body temperature monitoring and to detect the illness behaviours of sows. Therefore, a low risk method was used to induce fever and illness behaviours.

A rhinitis atrophicans vaccine was used to induce fever in gilts, and a temperature logger continuously monitored the sow's vaginal temperature. Furthermore, water consumption, food intake and the locomotion behaviour of the animals were analysed. During this trial, the vaccine, at the dose recommended by the manufacturer, led to a significant increase in core body temperature compared to the control group. However, the increase in vaginal

temperature, above 39.5°C, did not last very long. Therefore, this method seems to be a good alternative for the induction of a short increase in body temperature without the severe side effects described by authors who used different substances, such as LPS (Chen et al., 2013; de Groot et al., 2007; Melchior et al., 2004). The vaginal logger temperatures and the rectal temperatures showed a positive correlation in the 21 vaccinated gilts ($r= 0.86$, $p< 0.0001$). In conclusion, the logger might be a useful and less invasive tool for continuous core body temperature monitoring in sows. Stiehler et al. (2013) also demonstrated that vaginal temperatures and rectal temperatures were highly correlated. However, it is important to note that the logger is still invasive and seems inappropriate for the use in livestock production systems due to the risk of infection and the possibility of losing the logger. Furthermore, the results showed an increase in illness behaviour. After vaccination, the animals that were treated with the vaccine spent more minutes per day lying than they had on the day prior to treatment. In conclusion, these animals spent fewer minutes per day standing and more minutes sitting when compared to the day before. Water intake clearly demonstrated a daily rhythm in both groups. This result is in agreement with those of other authors (Ingram and Dauncey, 1985; Ingram et al., 1980; Mroz et al., 1995). The non-vaccinated gilts drank 1.1 L more during a 24-hour period in comparison to the day before, while the vaccinated gilts drank 2.01 L less than the day before. One explanation for this result could be that sick animals decrease both the amount of food they eat and the amount of water they drink (Weary et al., 2009). During the trial, food intake was not influenced by vaccination and showed no differences compared to the day before or to the control group. Food intake may have not been affected because the influence of the vaccination was too short or not strong enough to suppress the urge to eat. When the animals really suffered from fever or sickness behaviour, they spent more time lying down and did not stand up to drink. The vaccine induced fever and mild sickness behaviour in the gilts, and it was shown that it is possible to continuously detect core body temperature with a fixed vaginal logger. These temperature data were highly correlated with the rectal temperatures, but the fixation of the logger remains a problem. During urination and defecation, the logger slipped out in some sows; during this time, no or little temperature data were measured.

The evaluation of different behavioural patterns was possible while under the vaccine's influence. Mild sickness behaviours were observed. The vaginal logger (VL) is a good alternative method for continuous temperature monitoring in sows, but this method seems more appropriate for use in research and is not appropriate for use in husbandry.

3.3 Third part of the trial (Paper C)

The purpose of the third trial was to evaluate if a rise in core body temperature in fever-induced gilts could be detected automatically and continuously using a non-invasive IRT. Therefore, an IRT (pyrometer) was aimed at the orbital area, and the data were compared with the vaginal temperatures, which were considered control temperatures.

For these measurements, the pyrometer was fixed in the neighbouring pen. Water consumption was measured to detect the drinking duration each day. The pyrometer continuously measured the temperatures, but the temperature data were only used for evaluation when the gilt was drinking at the same time point, to ensure that the pyrometer was aimed at the orbital area. The data were analysed for temperature monitoring, and the

maximum temperatures were calculated for the different time periods (0.25 hours, one hour, two hours, three hours, four hours and six hours), which were then compared to the respective vaginal temperatures. These intervals were chosen to examine different aspects of temperature changes. On the one hand, it should be possible to detect a change in temperature as early as possible, whereas, on the other hand, it should be possible to follow the change in temperature in the longer intervals. Circadian rhythms also influence water intake (Madsen and Kristensen, 2005). These rhythms explain why long periods of missing data occur when the animals did not drink at all.

The results showed a significant positive correlation between the vaginal logger temperature and the pyrometer temperature at 0.25 hours, 1 hour and 2 hours. As a result, it appeared that at the larger time intervals, there was a significant correlation between the pyrometer and vaginal logger in fewer animals. However, the mean for the Pearson's correlation coefficients of the higher intervals was higher than that of the lower intervals. For continuous temperature monitoring with the pyrometer, an interval of 2 hours seems to be the most useful. Hötzel et al. (2005) showed that confined sows spend only 2.1% (about half an hour) of the day drinking. In our trial, it could be shown that the arithmetic mean of the drinking duration of the gilts was 0.6% (approximately 8 minutes) of the day. This is even less time than that observed by Hötzel et al. (2005). This fact also supports the statement that a higher interval might be better for continuous temperature monitoring and may lead to less missing temperature data during the day, as sows do not drink in regular time intervals. Detection of a change in temperature during a day is possible, depending on the drinking frequency. However, the pyrometer was not able to detect short-term temperature increases over a period of 12 hours post-vaccination, which would have been correlated with an increase in the core temperature. Ramey et al. (2011) came to the conclusion that the IRT also does not correlate well with equine body temperatures. In our study, the variability was too high compared to that of the vaginal logger (VL). To improve this study, the primary rise in temperature should continue for at least 12 hours, this increase should last for a longer time period and should differ from the days before. Then, the influence of circadian rhythm would not be as strong, and it might be possible for the PM to detect a higher temperature. Furthermore, the animals drank less during the night; therefore, the standard error for the measurements during the night time was quite high compared to the measurements during the daytime. In our trial, a PM was used, and the measurement spot was more variable compared to other studies (Franze et al., 2012; Traulsen et al., 2010). Additionally, other authors used one-time measurements with an IRC, whereas in this trial, a continuous measurement was applied with an IRT. These different methods likely led to different results. Additionally with our study, the pyrometer was permanently installed, while the IRC used in the studies of Traulsen et al. (2010) or Poikalainen et al. (2012) was aimed at the target area during each measurement. Consequently, we cannot be certain that the pyrometer was always aimed at the same intended spot (the orbital area). The PM could only be aimed towards the orbital area, and verification of the measured location was not possible. Comparing different body surface locations with differing surface temperatures every time led to a lower correlation with the VL. The PM measurements were influenced by circadian rhythms more than the VL measurements. This influence should be taken into account when a PM is used in a monitoring system. Furthermore, a short increase in body surface temperature could not be automatically detected with the PM in the orbital area in fever-induced gilts. This might be different for longer-term temperature increases, but this would require additional animal experiments.

3.4 Additional trial results

To investigate whether a temperature threshold could be helpful in determining the presence of a fever when using infrared measurement devices, quantiles were determined using the data from the last trial. By determining a 95% quantile for the rectal temperature (40.3°C) and the pyrometer temperature (38°C), one match could be found. However, this was not an ideal result, as 13 sow temperatures were above the quantile for the rectal temperatures and 16 sow temperatures were above the quantile for the infrared thermometer temperatures. When setting the 90% quantile for rectal temperatures (39.5°C) and infrared thermometer measurements (37.7°C), eight matches could be found. Choosing this quantile, 27 sow temperatures for the rectal temperature and 26 sow temperatures for the infrared thermometer temperatures were above the quantile temperatures ($N_{overall}$=264). These analyses also did not lead to ideal results. Therefore, the use of infrared thermometers in our study was not appropriate for the monitoring of a sow's body surface temperature to detect an increase in temperature or even a fever.

Table 1 gives a final overview of all of the temperature measurement devices and their correlations. Further correlations between RT or VT and IRC are not presented because the number of IRC measurements is not sufficient to present correlations. As observed, the best results were observed between the rectal temperature measurements and the vaginal logger measurements. The correlations between the infrared device temperatures and the core body temperatures were not promising. This table gives just an overview of the IRT measurements. This device does not seem appropriate so far. Better results were obtained using the IRC. This method seems more useful as a temperature monitoring tool. It is worth noting that the correlations in table 1 are not for measurements taken from one sow, and no other factors have been taken into account.

Table 1. Correlations of the different temperature measurement devices (taken during all parts of the trial) of the sows when the three temperature devices were used at the same time point (± two hours); (RT= rectal temperatures, IRT=infrared thermometer temperatures, VL=vaginal logger temperatures, CI=confidence interval)

Trial part	Correlation between	p	r	N	Upper limit 95% CI	Lower limit 95% CI
1	RT and IRT eye	n.s.	0.115	60	0.358	-0.143
1	RT and IRT ear	<0.05	0.362	60	0.564	0.119
2	RT and VL	<0.05	0.903	264	0.923	0.878
2	VL and IRT	<0.05	0.218	264	0.330	0.1
2/3	RT and IRT	<0.05	0.224	264	0.336	0.106

3.5 Overall discussion

The infrared technique can contribute to the development of a system for the detection of body surface temperature in a contactless, non-invasive and automatic manner. However, for the detection of short increases in body surface temperature, these various infrared techniques do not seem useful. This work also demonstrated the limits of this technique. During this study, a suitable body surface location, such as the eye or the back of the ear, could be evaluated using the infrared measurements. Unfortunately, neither the IRC nor the IRT led to the desired results. The mean temperatures for the IRC measurements were higher compared to the IRT measurements, and an IRC is most likely more appropriate for the intended measurements than the IRT. With regard to monitoring systems, the IRC may not yet be useful because of the high costs and computer techniques required. Furthermore, the variation between the IRC and RT temperatures was higher than the variation between IRT and RT. Additionally, measurements with the IRT that were conducted over a longer time period did not detect a short, transient increase in body surface temperature in the orbital area of fever-induced gilts. Additional animal experiments are needed to prove if this result might be different for temperature increases over a longer period of time. In terms of a monitoring system, the fact that the IRT measurements were subject to a more noticeable circadian rhythm, when compared with the VL measurements, must be considered. One of the major difficulties is to aim the IRT, whether fixed or unfixed, at the right measuring spot. The infrared camera has better aim, and the infrared movies provide more information. In contrast, the VL has shown to be suitable alternative to rectal temperature measurements. The fixation method of the logging device and the loss of the logger during urination and defecation are problems that require more research to be solved. Because of its limitations, the use of the VL seems practical only for research and not for measurements in practice.

The vaccine provides a safer method of inducing an increase in body temperature and mild sickness behaviour. The lying behaviour and water intake significantly changed while the animals had mild fevers. Detecting parameters such as the lying down behaviour and water intake in conjunction with body surface temperatures at defined locations can be helpful for early disease detection so that early treatment can be initiated.

4 Conclusions

The following conclusions can be drawn:

- Neither device produced satisfactory results with regard to fever detection. The correlations between both infrared devices and core body temperature were poor. The sensitivities in this studies were too low.
- Continuous measurements are needed to compare and detect an early increase in temperature.
- Continuous measurements should be carried out in even time intervals. Linking measurements to water consumption did not seem appropriate, especially because the animals reduce their water intake during illnesses.
- The best suited locations for the detection of body surface temperature were the back of the ear and the eye. To compare the measured values with each other, a better system for the detection of these location is required.
- The pyrometer could not detect a short, transient increase in body surface temperature in the orbital area of fever-induced gilts during continuous and automatic measurements. However, an increase in core body temperature could be measured using the VL.
- In future research a better method needs to be found to use the infrared devices automatically on the animals.

5 Summary

Evaluation of core body temperature by two non-invasive methods of infrared thermography for health monitoring in sows

The well-being of animals, especially those used for food, has become a focus of public attention. Early detection of sickness may lead to better therapeutic results and, consequently, to increased animal welfare. Furthermore, because of increasing herd sizes and decreasing staff, individual animal care is becoming less common. Therefore, continuous monitoring of animal behaviour seems to become more and more important to improve prognoses. Following, early treatment of disease can be performed. One meaningful parameter for monitoring the health of the animals is body temperature. Rectal temperature measurements are invasive and time consuming; therefore, new methods would help improve the automatic detection of the body temperature.

The overall objective of this dissertation was to validate various temperature devices to continuously monitor the body temperature of individual sows in a less invasive manner and to compare these data to rectal temperature data. Furthermore, specific behavioural patterns during fever were monitored to determine which changes in behaviour occur during disease states. These patterns could be used as a basis for automatic health detection systems.

An infrared camera and an infrared thermometer were used to measure body surface temperature at various body locations. The eye and the back of the ear were determined to be good locations to measure the body surface temperature of sows in a contactless, non-invasive and automatic manner. The median differences between the infrared camera and the rectal temperatures were lower than those between the infrared thermometer temperatures and the rectal temperatures. The sensitivity of the measurements with the infrared camera was greater when measured at the back of the ear, followed by the eye, when compared to the other locations. Next to the eye and the back of the ear, the mammary gland and the vulva also generated acceptable results; however, these locations are not as practical. Unfortunately, this study showed that single body temperature measurements using the infrared technique are not able to detect fever in pigs. This work also presented the limits of this technique. One of the major difficulties is to aim the infrared device at the right measuring spot. Regardless, when measuring with just an infrared thermometer, fixed or unfixed, the appropriate spot and diameter at which to aim cannot be secured. However, an infrared camera has better aim, and infrared movies provide more information. Regardless of the limitations, these methods provide an advantage and allow for contactless continuous temperature measurements in animals.

Furthermore, to test alternative methods for automatic measurement of body temperature, sows were vaccinated with a commercial vaccine to induce fever and mild sickness behaviours. It was shown that the rhinitis atrophicans vaccine was a low risk method for immune stimulation and for the induction of mild sickness behaviours and fever in gilts. During this trial, a vaginal logger was evaluated. A positive correlation between rectal temperatures and the temperatures from the logger were detected in the 21 vaccinated gilts. Hence, the logger might be a useful and less invasive tool for core body temperature monitoring. Unfortunately, due to urination and defecation, the measuring device often

slipped out and needed to be reinserted. Therefore, this device might be useful in research, but not for commercial use.

While under the influence of the vaccine, infrared thermometers, also known as pyrometers, were also tested. The pyrometer was aimed at the orbital area of each gilt and was able to collect continuous and contactless measurements. The pyrometer temperatures were taken while the gilts were drinking. Correlation was observed when continuous temperature monitoring was performed in two hour intervals. However, no satisfactory results could be retrieved. It was shown that the standard error of the measurements with both devices (the infrared thermometer and the vaginal logger) increased during the night and decreased during the day. This variation is likely linked to drinking frequency, as the sows clearly demonstrated a rhythmic pattern of drinking throughout the day and night. A short increase in body surface temperature could not be automatically detected using the pyrometer. The variability compared to the vaginal logger was too high; however, this variability might be different for longer-term temperature increases. However, using the rhinitis atrophicans vaccine to induce mild sickness behaviour and an increase in gilts' body temperature is less risky than the injection of LPS. Using this vaccine is a good alternative method of inducing fever without causing severe side effects so as to monitor sickness behaviour or to evaluate sensors.

As an alternative method for continuous temperature measurements, the vaginal logger may be a good choice, when its limits are taken into account. These limits include the fixation of the logging device and the loss of the logger during urination and defecation. Therefore, this device could be used for research endeavours, but is not suitable for use in practical application. The detection of illness behaviours showed that parameters such as lying down and water intake changed while the animals exhibited higher temperatures. For the detection of these parameters, long-term measurements of body surface temperature at defined locations using an infrared camera could provide helpful information for the early diagnosis of disease. Thus, early treatment could be performed, leading to better performance of the animals and the improved well being of the sow.

6 Zusammenfassung

Bewertung der Körperkerntemperatur durch zwei nicht invasive Infrarot-Thermometrie-Methoden zur Gesundheitsüberwachung von Schweinen

Das Wohlbefinden von Tieren, insbesondere derer für die Lebensmittelproduktion, hat sich zu einem Zentrum der öffentlichen Aufmerksamkeit entwickelt. Die Früherkennung von Krankheiten kann im Allgemeinen zu besseren Therapieergebnissen führen und damit zur Verbesserung des Tierschutzes. Außerdem nimmt die individuelle Pflege der Tiere auf Grund von zunehmenden Herdengrößen und sinkenden Mitarbeiterzahlen immer weiter ab. Daher wird die kontinuierliche Überwachung des Tierverhaltens mehr und mehr an Bedeutung gewinnen. Damit lassen sich bessere Prognosen treffen und die Behandlung von Krankheiten kann früher erfolgen. Ein aussagekräftiger Parameter für die Überwachung der Gesundheit von Tieren ist die Körpertemperatur. Rektale Temperaturmessungen sind invasiv und zeitaufwendig, daher sollten neue Verfahren zur Verbesserung der automatischen Erfassung der Körpertemperatur führen.

Das übergeordnete Ziel dieser Arbeit war es, verschiedene Temperaturgeräte zu validieren, um die Körpertemperatur der einzelnen Sauen auf eine weniger invasive Art und Weise kontinuierlich zu überwachen und diese Daten mit den rektalen Temperaturdaten zu vergleichen. Darüber hinaus wurden bestimmte Verhaltensmuster bei Fieber überwacht, um festzustellen, welche Verhaltensänderungen bei Krankheitszuständen auftreten. Diese Muster können als Basis für automatische Gesundheitsdetektionssysteme verwendet werden.

Eine Infrarot- Kamera und ein Infrarot-Thermometer wurden verwendet, um Körperoberflächentemperaturen an verschiedenen Körperstellen zu messen. Das Auge und die Rückseite des Ohres erwiesen sich als geeignete Lokalisationen um die Körperoberflächentemperatur der Sauen kontaktlos, nicht-invasive und automatische zu messen. Die mittleren Unterschiede zwischen den Temperaturen der Infrarotkamera und den rektalen Temperaturen sind niedriger als die Temperaturen zwischen dem Infrarotthermometer und dem Rektalthermometer. Die beste Sensitivität der Messungen mit der Infrarotkamera wurde erzielt, wenn an der Rückseite des Ohres gemessen wurde, gefolgt von der Lokalisation Auge. Neben dem Auge und der Rückseite des Ohres, konnten ebenfalls an dem Gesäuge und der Vulva akzeptable Ergebnisse erzielt werden. Messungen an diesen Lokalisationen erwiesen sich jedoch als weniger gut umsetzbar unter Praxisbedingungen. Die Auswertung dieser Studie zeigt des Weiteren, dass man mit Einzelmessungen der Körpertemperatur mit der Infrarottechnik nicht in der Lage ist, Fieber bei Schweinen zu erkennen. Diese Arbeit präsentiert auch die Grenzen der Infrarottechnik. Eine der Hauptschwierigkeiten besteht darin, mit den Infrarotgeräten auf den richtigen Messfleck zu zielen. Bei der Messung mit einem Infrarotthermometer, egal ob fixiert oder nicht fixiert, kann nicht sicher gesagt werden ob die anvisierte Stelle mit dem entsprechenden Durchmesser getroffen wurde. Allerdings lässt sich mit einer Infrarotkamera besser zielen und Infrarotfilme liefern mehr Informationen als das Infrarotthermometer. Unabhängig von den Einschränkungen, haben diese Verfahren den Vorteil, berührungslos und kontinuierlich Temperaturmessung an Tieren durchführen zu können. Darüber hinaus, um diese alternativen Methoden für die automatische Messung der Körpertemperatur testen zu können, wurden Sauen mit einem kommerziellen Impfstoff geimpft. Fieber und leichte

Krankheitssymptome wurden dadurch induzieren. Es konnte gezeigt werden, dass der Rhinitis atrophicans Impfstoff eine geeignete Methode zur Induktion von milden Krankheitssymptomen und Fieber bei Jungsauen ist. In dieser Studie wurde ebenfalls ein Vaginallogger zur Erfassung der Körpertemperatur genutzt und die gewonnenen Daten wurden ausgewertet. Eine positive Korrelation zwischen den rektalen Temperaturen und den Temperaturen des Loggers konnte in den 21 geimpften Sauen nachgewiesen werden. Daher könnte der Logger ein nützliches und weniger invasives Messinstrument für die Überwachung der Körperkerntemperatur darstellen. Diese Methode eignet sich allerdings eher für die Forschung, weniger für den kommerziellen Einsatz, da auf Grund von Miktion und Defäkation der Logger häufig herausgepresst wurde und erneut eingesetzt werden musste.

Unter dem Einfluss des Impfstoffs wurden ebenfalls Infrarotthermometer, welche auch als Pyrometer bekannt sind, getestet. Das Pyrometer wurde auf den Orbitalbereich der Sauen ausgerichtet und war in der Lage, kontinuierliche und berührungslose Temperaturmessungen zu erstellen. Die gemessenen Pyrometertemperaturen wurden immer dann gespeichert, wenn die Sauen tranken. Korrelationen konnten hergestellt werden, wenn eine kontinuierliche Temperaturüberwachung in zwei Stunden-Intervallen durchgeführt wurde. Die Ergebnisse sind jedoch nicht zufriedenstellend. Es wurde gezeigt, dass der Standardfehler der Messungen mit beiden Geräten (Infrarotthermometer und Vaginallogger) während der Nacht höher war und während des Tages abgenommen hat. Diese Änderung sind voraussichtlich Trinkfrequenz verbunden, da die Sauen ein deutliches rhythmisches Tag-Nacht- Muster in Ihrem Trinkverhalten zeigen. Ein Anstieg der Körperoberflächentemperatur von nur kurzer Dauer konnte mit dem Pyrometer nicht automatisch erkannt werden. Die Variabilität im Vergleich zum Vaginallogger war zu hoch, jedoch könnte diese Variabilität sich bei längerfristigen Temperaturerhöhungen anders darstellen. Das Risiko mit dem Rhinitis atrophicans Impfstoff ein mildes Krankheitsverhalten und eine Zunahme der Körpertemperatur zu induzieren, ist weniger hoch als das bei einer Injektion von LPS. Die Nutzung dieses Impfstoffs ist ein gutes alternatives Verfahren zur Induktion von Fieber ohne schwere Nebenwirkungen. Damit können bestimmte Verhaltensmuster überwacht und auch Sensoren ausgewertet werden. Als alternatives Verfahren für die kontinuierliche Temperaturmessung kann auch der Vaginallogger eine gute Wahl sein, wenn die technischen Grenzen, wie die Fixierung oder der Verlust bei Miktion/Defäkation ausreichend berücksichtigt werden. Des Weiteren wurde gezeigt, dass Parameter wie die Liegezeit und die Wasseraufnahme sich ändern, während die Tiere unter einer höheren Körpertemperatur leiden. Für den Nachweis dieser Parameter könnten weitere Langzeitmessungen des Liegeverhaltens und auch der Körperoberflächentemperatur an definierten Stellen mit einer Infrarotkamera hilfreiche Informationen zur Früherkennung von Krankheiten bereitstellen. Damit könnte eine frühzeitige Behandlung der Tiere durchgeführt werden, was letztlich zu einer besseren Leistung und zu einem verbesserten Wohlbefinden der Sauen führt.

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8 Annex

8.1 Publications

Schmidt, M., Lahrmann, K.H., Ammon, C., Berg, W., Schön, P., Hoffmann, G., 2013, **Assessment of body temperature in sows by two infrared thermography methods at various body surface locations**. Journal of Swine Health & Production 21 (4): 203–209.

Schmidt, M., Ammon, C., Schön, P., Manteuffel, C., Hoffmann, G., 2013, **Assessment of continuous vaginal logger-based temperature monitoring in fever- induced gilts**. American Journal of Animal and Veterinary Sciences 8 (2): 55-65.

Schmidt, M., Ammon, C., Schön, P., Manteuffel, C., Hoffmann, G., **The suitability of infrared temperature measurements for continuous temperature monitoring in gilts**. Archive Animal Breeding 57 (2014) 21, 1-12 (online: 05.08.2014)

Schmidt, M.; Hoffmann, G.; Ammon, C.; Schön, P.; Manteuffel, C. and Amon, T., 2013, Application of infrared thermography on lactating sows. Landtechnik 68(4), 228–231.

Hoffmann, G.; **Schmidt, M**.; Ammon, C.; Rose-Meierhöfer, S.; Burfeind, O.; Heuwieser, W.; Berg, W., 2013, Monitoring the body temperature of cows and calves using video recordings from an infrared thermography camera. Veterinary Research Communication 37, 91–99; DOI 10.1007/s11259-012-9549-3.

Manteuffel, C.; Tuchscherer, A.; **Schmidt, M.**; Hoffmann, G.; Schön, P.C., submitted November 2013: Two methods to compel posture changes in gestating and lactating sows. Computers and Electronics in Agriculture.

8.2 Posters at conferences

Schmidt, M.; Hoffmann, G.; Manteuffel, C.; Schön, P., 2013, Immune stimulating of gilts and measuring various behavioural patterns. 15th International Conference on Production Diseases in Farm Animals (ICPD), Uppsala, Sweden, 24.-28.06.2013. Dalin,G. (Ed.): Book of abstracts, 132.

Hoffmann, G.; **Schmidt, M.**, 2013, Investigation with a video-based infrared thermography camera for measuring the body temperature of cows and calves. 15th International Conference on Production Diseases in Farm Animals (ICPD), Uppsala, Schweden, 24.-28.06.2013. Dalin, G. (Ed.): Book of abstracts, 136.

Hoffmann, G.; **Schmidt, M**.; Ströbel, U.; Burfeind, O.; Lahrmann, K.-H.; Brunsch, R., 2013, Infrared thermography in cows and pigs (Infrarotthermografie bei Kühen und Schweinen). 11th Conference Construction, Engineering and Environment in Livestock Farming Vechta (BTU), Germany, 24.-26.09.2013, KTBL-Tagungsband, KTBL, Darmstadt, 2013, (978-3-941583-80-1), 142-147.

9 Acknowledgements

Ich bedanke mich sehr bei Herrn Professor Dr. Brunsch und Frau Dr. Hoffmann für die Unterstützung bei der Arbeit am Leibniz-Institut für Agrartechnik und die Überlassung des Themas. Mein weiterer besonderer Dank gilt meinem Doktorvater, Herrn Professor Dr. Lahrmann, für die gute Betreuung an der Freien Universität Berlin und die stets konstruktive Zusammenarbeit. Den Projektpartnern Dr. Anne Elkmann (Big Dutchman) und Dr. Peter Schön sowie Christian Manteuffel (Leibniz-Institut für Nutztierbiologie) gilt mein großer Dank für die tolle Zusammenarbeit und Hilfe in dem Verbundprojekt. Der BLE danke ich für die Möglichkeit der Anfertigung dieser Arbeit durch die Bewilligung und finanzielle Unterstützung des MultiExpert-Verbundprojekts.

Frau Dr. med. vet. Gundula Hoffmann möchte ich noch einmal ganz Besonders erwähnen. Ohne Ihr Vertrauen in meine Arbeit, die tolle Anleitung bei der Anfertigung der Veröffentlichungen und der Dissertation und die immerwährenden Aufmunterungen und den unermüdlichen Einsatz für mich wäre ich wohl das ein oder andere Mal verzweifelt! Während der drei Jahre hat sich auch eine tolle Freundschaft entwickelt über die ich sehr dankbar bin.

Mein besonderer Dank gilt Dr. Christian Ammon und PD Dr. habil. Sandra Rose-Meierhöfer sowie der gesamten Abteilung 5 des ATB für den technischen support und die stets geduldige Hilfe, die aufmunternden Worte und konstruktive Kritik. Die Zusammenarbeit hat mir stets sehr viel Freude bereitet und ich bin dankbar dafür in so einem tollen Team gearbeitet zu haben.

Meiner Kollegin und besten Freundin Carolin Riedel, meinen Freunden Stefanie Hromek, Natalie Lange, Juljane Huckstorf und Sabrina Elsholz danke ich für all die netten und stets sehr amüsanten Stunden die ich mit euch hatte und auch hoffentlich noch lange haben werde!

Meiner Mama Ines Schmidt und meinem Vati Michael Schmidt, meinem Bruder Toni sowie meinen Großeltern Anni und Paul Werner danke ich für die Unterstützung auf dem langen Weg hierher.

Meinen Partner Markus Luft und unsere Kinder möchte ich ganz speziell erwähnen. Euch gilt mein ganz besonderer Dank. Markus, mit dir wird das Schwere leicht, das Trübe klar und das Enge weit. Ich liebe Euch!

10 Declaration of independence

This is to declare that I conducted all of the studies described herein, and the manuscripts were produced independently. I confirm that I have used only the specified resources and tools to complete this thesis. My personal contributions to the research projects presented under this cumulative doctoral thesis are summarised in the following table.

Contribution	Research project 1/ Publication 1	Research project 2/ Publication 2	Research project 3/ Publication 3
Study design	+++[1]	+++	+++
Data collection	+++	+++	+++
Data analyses	++	++	++
Manuscript writing	+++	+++	+++
Manuscript editing	++	++	++

[1]Score: + ≤ 50%; ++ = 50-70%; +++ ≥70%

Mariana Schmidt Potsdam, 01.03.2014