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Recording group and area-specific activity of fattening pigs by using Passive Infrared Detectors on farm

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Animal activity in pigs can be a direct indicator of animal welfare. Passive infrared detectors (PID) provide one method of measuring animal activity on the pen level as a cost-effective and easy-to-use sensor technique. The study aimed to test PIDs on different commercial farms with fattening pigs. On each farm, a focus pen was selected and group activity, and activity in the feeding and exploration area was measured by using three PIDs. For data evaluation, three continuous 24h time periods were selected for each farm. Additionally, animal behavior was recorded by video cameras for visual scan sampling. To compare the PID outcome with the recorded behaviors, an ethogram was used to categorize active and inactive behaviors. Using scan sampling, the validation of the PID data was based on still frames at 10 min intervals. In addition, barn climate such as temperature, relative humidity, and ammonia concentration were measured. The analysis of seven farms showed a strong correlation between PID data and visual assessment for group activity from 0.67 - 0.91 ($p < 0.001$; $n = 432$). For the activity in the feeding area, medium to strong correlations between 0.44 - 0.65 ($p < 0.001$; $n = 327$) could be found. The PID data for the exploration area reached correlations with a smaller effect strength. Based on the activity data measured by PIDs, a typical diurnal rhythm for pigs could be found for all farms. Moreover, the PID data indicated different activity patterns depending on, e.g., feeding times and sex group composition. The results demonstrated that PIDs can also be used in different housing conditions for measuring animal activity. In combination with barn climate data, the PIDs can provide useful information for the farmer and also characterize farm-specific management.

KEYWORDS

animal activity, animal behavior, PID, infrared sensor, welfare, ammonia, barn climate

1 Introduction

Today more than ever, modern and conventional livestock farming is caught between the conflicting priorities of animal welfare, environmental protection, and economics. Animal welfare in livestock farming has recently become increasingly important to society and might now be a decisive purchasing criterion (Sonoda et al., 2018; Sødring et al., 2020; Derstappen and Christoph-Schulz, 2022). Many consumers expect issues such as animal welfare to be recorded and observed along the value chain. Pig farming has potential conflicts due to animal welfare concerns about housing conditions, mutilations such as tail docking (Pedersen, 2017; Sødring et al., 2020), and medical treatments for diseases (Martínez-Avilés et al., 2017). In addition, animal production has been undergoing structural changes for years. As a result, the number of farms has declined, and the number of animals per farm and farmer has risen in recent years (Neuenfeldt et al., 2019). This ratio impacts tradeoff, since more animal welfare goes along with improved animal monitoring, but this is made more difficult by an increasing number of animals (Chapa et al., 2020).

In response to the increased interest in improving animal welfare, several animal health and welfare assessment protocols have been developed (Pfeifer et al., 2019). A common animal welfare assessment is provided by scoring guides such as the Welfare Quality[®] Assessment protocol for pigs (Welfare Quality[®], 2009). Based on defined indicators for animal-, management- and resource-based measures, the animal welfare level can be assessed by means of a point system (Welfare Quality[®], 2009). It must be considered that the evaluation could be influenced by the subjective decision of the observer (Blatchford, 2017). Moreover, welfare assessment protocols provide discontinuous information based on a snapshot during the whole production period taken by the farmer or competent authority. As a consequence, this method of animal welfare assessment may only be applied as health monitoring with limitations (Pfeifer et al., 2019; Chapa et al., 2020).

Precision Livestock Farming (PLF) supports on-farm self-monitoring (Berckmans, 2017). Among other things, PLF includes the recording, processing, and provision of data in agriculture. By integrating various technologies such as sensors, data analytics, and automation, it aims to improve herd management and animal welfare (Berckmans, 2017; Werkheiser, 2020). In pig farming, the most widely used sensors measure the environmental conditions in the barn, such as temperature and relative humidity (Huynh et al., 2005a; Vermeer and Hopster, 2018). The use of sensors for continuous health monitoring at group or individual animal level is not as widely used in pig farming as in, e.g., dairy farming. Concerning the increasing number of animals per farm and per caretaker, and the increase in animal welfare requirements, the possibilities for sensor-based recording of animal data are advantageous.

In pig farming, continuous measurement of animal activity behavior could support health monitoring and may serve as a direct animal-based indicator of animal welfare (Gómez et al., 2021). Especially in intensive housing systems, the activity behavior can be influenced by several factors such as the quality of the

environmental enrichment (Zwicker et al., 2012), health constraints due to diseases (Martínez-Avilés et al., 2017), and lameness (Heinonen et al., 2013). By quantifying the pigs' activity patterns, deviations from normal behavior can be identified and timely action be taken to ensure optimal animal welfare (Statham et al., 2009; Martínez-Avilés et al., 2017). For example, in an attempt to predict outbreaks of tail biting, Statham et al. (2009) found that activity was significantly higher four days before a severe outbreak compared to the control group. In addition, the barn climate influences the activity of the pigs, as the animals react to temperature fluctuations (Ngwabie et al., 2011) and relative humidity (Huynh et al., 2005b) with altered behavior. Ngwabie et al. (2011) verified that an increase in indoor temperature led to a decrease in animal activity.

Different technologies for measuring animal behavior have been tested in scientific studies and are already available on the market. Kapun et al. (2020) were able to use RFID (radio-frequency identification) technology to measure activity in the feeding and exploration area with a sensitivity of 80%. RFID requires tags attached to the individual animal, whereas video-based activity detection is often performed at the group level in pigs. Image processing techniques, in which foreground and background objects can be distinguished based on pixels and deep learning techniques, can be used to measure feeding activity (Alameer et al., 2020), lying positions (Riekert et al., 2020), and activity related to climate variations in the barn (Costa et al., 2014). Currently, RFID technology for measuring activity is only used in scientific research (Kapun et al., 2020) and camera technology is often a cost-intensive investment (Arulmozhi et al., 2021).

Passive Infrared Detectors (PIDs) provide another possibility to measure animal activity on a group level as a cost-effective (Ni et al., 2017) and easy-to-use technology. PIDs were first tested by Pedersen and Pedersen (1995) to measure activity under laboratory conditions. Since then, several researchers have used PIDs under laboratory conditions with simulated pigs (Cai et al., 2019), in piglet rearing (Besteiro et al., 2018b; Besteiro et al., 2021), and fattening pigs under trial conditions (Jasmund et al., 2020). As far as the authors were aware, no study has yet focused on whether PIDs also provide reliable activity data for specific focus areas, e.g., feeding and enrichment, in pen with fattening pigs, on-farm, and what challenges could potentially arise. Therefore, in this study, PIDs were tested on seven different commercial farms, with a focus on the following research questions:

1. Do PIDs provide reliable activity data for group activity, activity in the feeding, and the exploration area in fattening pigs?
2. What valuable information can be derived from the data of the PIDs about the activity patterns of pigs?
3. Is there a relationship between PID-measured activity data and barn climate characteristics?

This study aimed to provide valuable information on the practical use of PIDs in pig farming, focusing on measuring group-, feeding- and exploration activity to support and improve management and animal welfare.

2 Materials and methods

2.1 Description of farms, focus pens and animals

The results of the present study are based on the data collection from seven fattening pig farms in Germany, where PIDs were tested under on-farm conditions. All farms were conventionally managed and housed fattening pigs with typical breeding lines, kept on a fully slatted concrete floor. In each of the seven farms, a compartment representative of the corresponding farm was selected. In this compartment, a so-called focus pen was chosen and the activity of the fattening pigs as well as important environmental parameters within this pen were recorded. For further data evaluation, three continuous 24 h time periods were selected for each farm, in which no technical disturbances, changes in the typical farm routine, or other similar events impacted the recording or the behavior of the animals.

The compartments and pens of the farms differed in design. In general, pens differed in size, position of functional areas, and provision of enrichment materials. On average, the space allowance was 0.8 m² per animal. Enrichment materials were offered, e.g., chains, plastic balls, seesaws of different materials and organic substrates such as straws (from rack) or wooden sticks. Depending on the pen design, the functional areas of feeding (in the feeding area) and exploration (in the exploration area) were more or less well separated. For example, Figure 1 shows pens with non-separated, overlapping functional areas in Farm 1 (A) with separate, clearly distinguishable functional areas in Farm 2 (B).

In particular, the corresponding farm-specific focus pens differed in the number of animals, group composition, fattening phase, and estimated average animal weight (see Table 1).

On a total of 6 of the 7 farms, the animals were fed restrictively by a liquid feeding system with a sensor. The frequency of the feeding phases and dosing intervals during the course of the day

significantly differed from two to ten. Farm 4 differed from the other farms as feed was available to the animal's *ad libitum* via a mash feeder. The light and dark periods differed depending on the farm-specific light management and the corresponding season. All selected compartments had natural daylight (via windows) and artificial lighting.

2.2 Activity measurement by PIDs and visual assessment as reference method

The activity of the animals was recorded in each focus pen with a total of three PIDs (item no.1362922, Renkforce, Conrad Electronic SE, Hirschau, Germany), as indicated in Figure 1. One sensor recorded the activity of the entire group of animals in the focus pen to provide general information on periods of resting and periods of activity. A second sensor documented activity in the feeding area and thus recorded, for example, the activity during the feeding phases throughout the day. A third sensor recorded the activity in the exploration area based on the interaction with the enrichment material. If different enrichment materials were available to the animals in the pen, the PID was focused on the area most often occupied by the pigs. For this purpose, the interaction with the materials was observed before the placing the PID. The sensor's signal output depended on both the temperature difference between the moving body and the floor, as well as the velocity of the moving body (Pedersen and Pedersen, 1995; Ni et al., 2017). More technical details of the PIDs such as output, installation of a signal light, and covering of the lens to limit the area recorded, are described by Jasmund et al. (2020). The data were stored every minute using a data logger (ALMEMO[®], Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, Germany).

Depending on the housing conditions, 2 - 3 infrared cameras (König Electronic SEC-CAM35B, Nedis B.V., 's-Hertogenbosch,

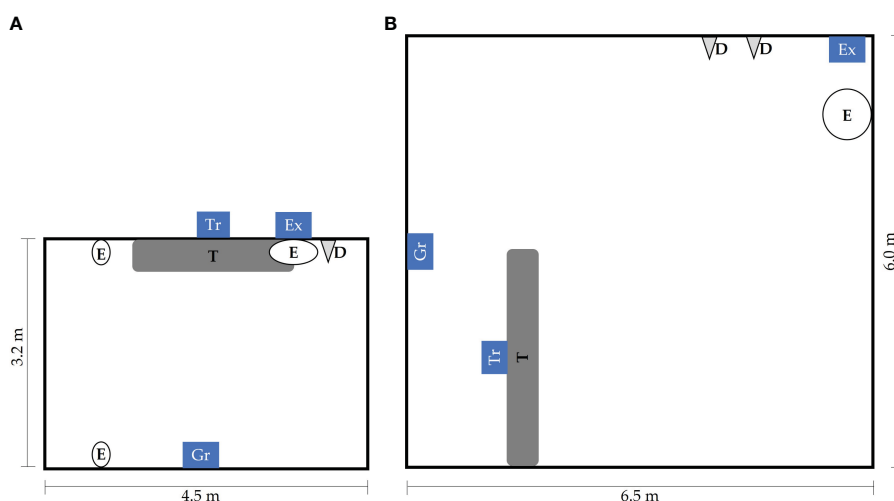


FIGURE 1

Pen with non-separated, overlapping functional areas for feeding (T = trough area) and exploring (E = exploration area) in Farm 1 (A) as well as pen with separated, clearly distinguishable functional areas in Farm 2 (B). Also shown in both are the drinkers (D) and the position of the three PIDs used for the measurement of activity of the group of animals (Gr), in the feeding area (Tr) and in the exploration area (Ex).

TABLE 1 Overview of farms.

Farm	Fattening phase	Live weight (kg)	Group composition	Group size per pen	Stocking density (m ² per animal)
1	Finishing period	>80 – 110	Sows + castrated males	18	0,80
2	Starting period	28 – 50	Castrated males	48	0,81
3	Middle period	>50 – 80	Sows + castrated males	16	0,86
4	Starting period	28 – 50	Sows + castrated males	61	0,75
5	Middle period	>50 – 80	Sows + castrated males	42	0,84
6	Starting period	28 – 50	Boars	26	0,69
7	Finishing period	>80 – 110	Sows + castrated males	39	0,88

Netherlands) were installed in each focus pen to validate PID using video recordings. To validate the group-related PID data, scan sampling was used at 10-minute intervals (144 frames per day and 432 frames per farm). For the evaluation of the PID data of the activity in the feeding and exploration area, it was previously investigated if the animals also showed activity such as eating or exploring at night. Because in the vast majority of cases, there was no activity at all, the night hours were excluded from further evaluation of the still frames, so that still frames from 5.00 – 23.00 h were evaluated at 10-min intervals (109 frames per day or 327 still frames per farm).

In addition, frames were assessed one second before and one second after to better judge whether animals were moving. To be able to make decisions in borderline cases, video frames were also viewed ten seconds before and ten seconds after the frame under discussion. The evaluation of the frames, regarding the activity and behavior of the animals, was run based on a previously determined ethogram (Table 2).

The area within one animal length around the trough and the corresponding enrichment material was defined as the feeding and exploration area, respectively. Figure 2, for example, shows the spatial outline of the focus areas for the visual observation based on the videos.

To compare the PID data (output in %) with the visual observation, the level of activity was determined (ratio of number of pigs per behavior and total number of animals in the specific focus area). The total activity of the group was determined based on the sum of all behaviors, except lying. The activity in the feeding and exploration area was calculated by comparing the number of animals eating or exploring with the general number of animals in the specific focus area. Live weight was calculated by multiplying the number of animals by their average weight and used to determine if the live weight per pen affected the group activity measurement of the PIDs.

2.3 NH₃ concentration and Temperature Humidity Index (THI)

NH₃ concentration (Polytron C300 equipped with DrägerSensor[®] NH3 AL, Dräger, Lübeck, Germany), as well as air temperature and relative humidity (FHAD 46-C2, ALMEMO[®],

Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, Germany), were also measured every minute in the focus pens and stored on the same data logger as the activity data of the PIDs.

Based on the data on temperature and relative humidity, the THI_{NOAA} was calculated according to Vitt et al. (2017):

$$\text{THI}_{\text{NOAA}} = 0.81 T_{\text{DB}} + 46.3 + R/100 (T_{\text{DB}} - 14.3)$$

whereby dry bulb temperature is given by T_{DB} (= air temperature T, °C), and relative humidity by R (%). A THI_{NOAA}-

TABLE 2 Definition and assignment of behaviors.

Category	Subtype	Description	Place-bound behavior?
Inactive	Lying	Pig lying in prone or lateral position without performing any activity	No
Active	Standing	Pig standing on front and hind legs, the floor is only touched with the feet and possibly the snout	No
	Sitting	Forefeet and hindquarters of the pig have ground contact at the same time	No
	Eating in feeding area	Pig is in standing or sitting position at the feeding area keeping its snout in the trough and/or showing the typical head posture and movement of chewing	Yes, feeding area
	(only) Staying in feeding area	Pig staying with at least half of its body or the entire head in the respective defined feeding area	Yes, feeding area
	Exploration of enrichment material	Pig chews, bites, licks, drags or works with its snout on the enrichment material or the hay rack (regardless of body position)	Yes, enrichment material/exploration area
	(only) Staying in exploration area	Pig staying with at least half of its body or the entire head in the respective defined exploration area	Yes, enrichment material/exploration area



value of ≥ 72 was assumed as a threshold with a negative economic impact on fattening pigs (St-Pierre et al., 2003; Vitt et al., 2017).

2.4 Processing of data and statistical analysis

Due to technical problems and an obstructed field of view, a visual assessment of activity in the exploration area could not be conducted for Farm 6.

IBM SPSS Statistics version 29 (IBM, New York, NY, USA, 2022) was used for the statistical analysis of the data. Since the data were not normally distributed (checked by the Kolmogorov-Smirnov test), the quality of the linear relationship between the PID data and the visual assessment was calculated using Spearman-Rho. The strength of the effect size of the determined correlations was assessed using the classification by Cohen (1988). Nonparametric tests (Mann-Whitney-U and Kruskal-Wallis test) were used to check for significant differences (α -level set at $p \leq 0.05$). The further analysis of the PID data is descriptive. To present the data graphically or to adapt the data to the respective question, data were averaged and summarized for specific phases or periods.

3 Results

3.1 Comparison between PID data and visual assessment

To assess if the PIDs are suitable for measuring group activity and activity in specific focus areas on the farm, the activity recorded by PID and activity determined by video recording were correlated for each farm individually. The correlations between the general group activity and activity in the feeding and exploration areas measured by PIDs and visual assessment are given in Table 3.

A strongly significant correlation between group activity measured by PID and visual assessment was found for all farms

($r = 0.76$; $p < 0.001$; $n = 3024$). The strongest correlation was on Farm 6 ($r = 0.91$; $p < 0.001$; $n = 432$). The other farms also showed strong significant correlations between 0.61 - 0.86 ($p < 0.001$; $n = 432$). Figure 3 shows an example of the daily course of group activity measured by PID compared to the visual assessment for Farm 5 ($r = 0.83$; $p < 0.001$; $n = 432$). The figure demonstrates that activity peaks differ in intensity but are the same in their progression.

Significant correlations between the feeding activity measured by PID and visual assessment were found with medium or large effect strength from 0.44 - 0.65 and with Farm 7 showing the strongest correlation ($p < 0.001$; $n = 327$). Only Farm 4 showed a significant correlation with a small effect strength of 0.18 ($p < 0.001$; $n = 327$).

Significant correlations with a rather small effect strength were found overall for activity measurement in the exploration area. A medium effect strength, out of the 0.36 maximum, was detected for Farm 2.

3.2 Activity patterns assessed by using PIDs and group behavior

Pigs on all farms show a diurnal rhythm with regard to the activity of the respective animal group in the focus pen. This is characterized by active phases interrupted by one or more rest phases in the course of the day as well as reduced activity or rather inactivity during the night hours. The individual farm activity patterns are decisively influenced by the different feeding regimes or feeding times and light hours (depending on seasonal differences and artificial lighting), shown as examples in Figures 4–6 for farms 2, 4, and 6.

Depending on the light hours and the feeding times, rest and activity phases alternate during the day. Farm 2 showed a multiphasic daily rhythm in their group activity with four activity peaks (Figure 4). In addition, the data indicate that, especially for the first two feeding phases of the day, the increase in activity relates to the start of feeding. A biphasic activity pattern, typical for pigs, was found for Farm 4, where pigs were fed *ad libitum* (Figure 5).

TABLE 3 Correlations between animal activity using PIDs and visual assessment based on still-frames (n) for group activity, activity in the feeding and exploration area for all farms.

Farm	Group activity in focus pen (n = 432)	Activity in the feeding area (n = 327)	Activity in the exploration area (n = 327)
1	0.84**	0.59**	0.16**
2	0.85**	0.61**	0.36**
3	0.72**	0.57**	0.20**
4	0.67**	0.18**	0.18**
5	0.82**	0.44**	0.29**
6	0.91**	0.61**	–
7	0.86**	0.65**	0.17**

** $p \leq 0.01$.

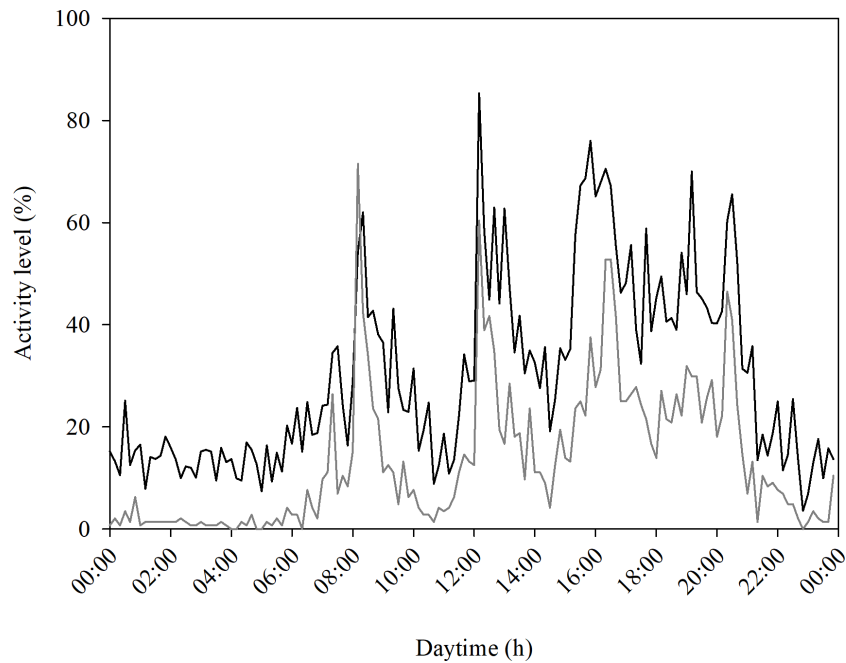


FIGURE 3
Comparison of the course of group activity measured by PID (black line) and visual assessment (gray line) shown for Farm 5 ($r = 0.83$; $p < 0.001$; $n = 432$). The figure shows the averaged data over the entire three focus days based on still frames at 10-min intervals.

Both farms showed a clear day-night rhythm. In contrast, Farm 6, with ten feeding times a day, showed a less clear rhythm in group activity (Figure 6). As shown in Figure 6, an increase in activity is partially but not necessarily triggered by the start of feeding and

reached an activity level of 100% several times, especially between midday and afternoon.

However, the animal activity of the three exemplary farms was not only collated with feeding times. The animal activity of the farms was

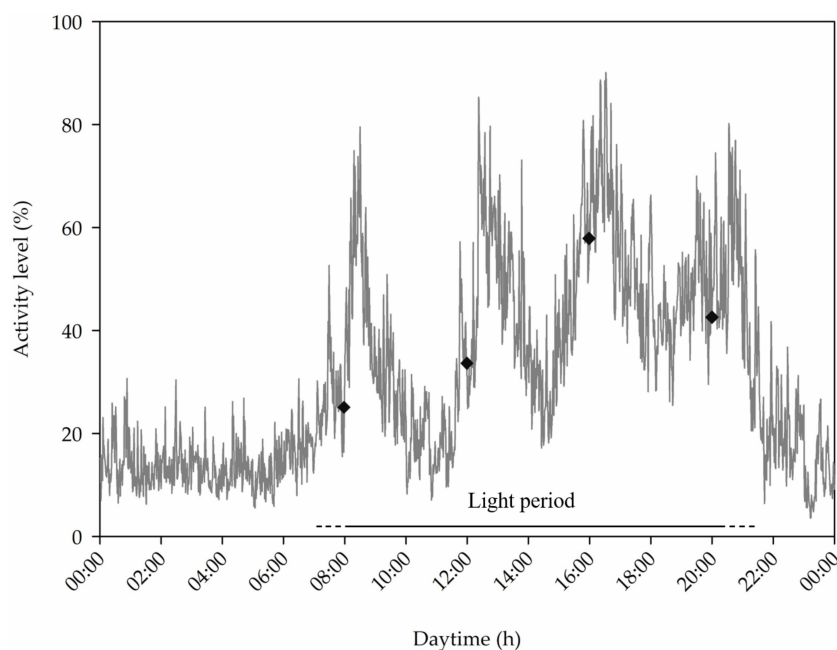


FIGURE 4
Diurnal rhythm of the animal activity on Farm 2 (line) and the respective start times of the total of four feeding phases during the course of the day (squares). The approximate length of the light period based on natural light incidence and artificial lighting is also presented. The figure shows the averaged data in 1-min intervals over the entire three focus days.

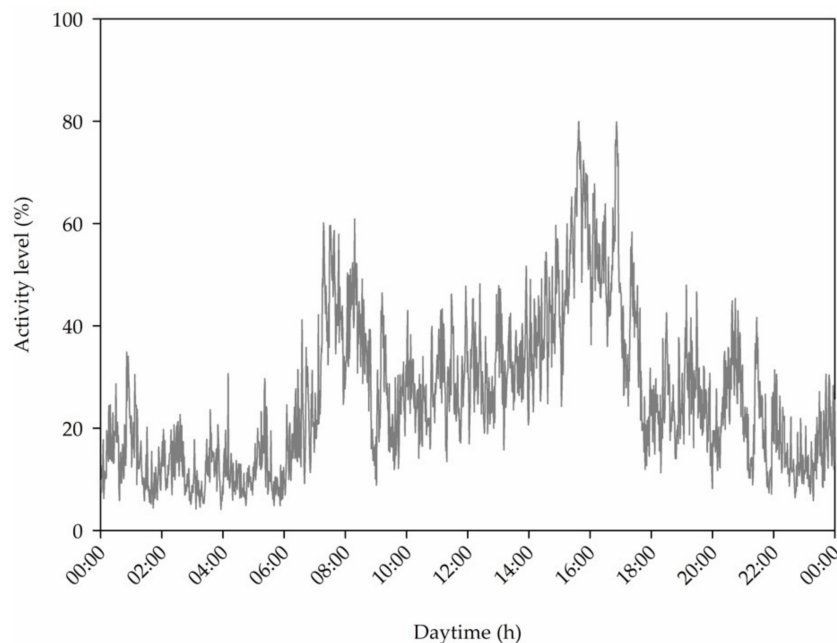


FIGURE 5
Diurnal rhythm of the animal activity on Farm 4 (line) with *ad libitum* feeding. The approximate length of the light period based on natural light incidence and artificial lighting is also presented. The figure shows the averaged data in 1-min intervals over the entire three focus days.

also compared with each other, considering the respective group composition. The other farms were excluded because only the three exemplary farms were in the same fattening period with different group compositions. Thus, the activity of a group of castrated males (Farm 2), a mixed-sex group (Farm 4), and boars (Farm 6) were compared.

As shown in [Figure 7](#), the PID data for group activity on Farm 2 and Farm 4 were significantly different from Farm 6 ($p < 0.001$; $n = 135$). On average, the PID data showed higher activity on Farm 6 ($M = 52.16\%$; $SE = 1.73$) compared to Farm 2 ($M = 30.17\%$; $SE = 1.05$) and Farm 4 ($M = 26.25\%$; $SE = 0.98$). Compared to the two

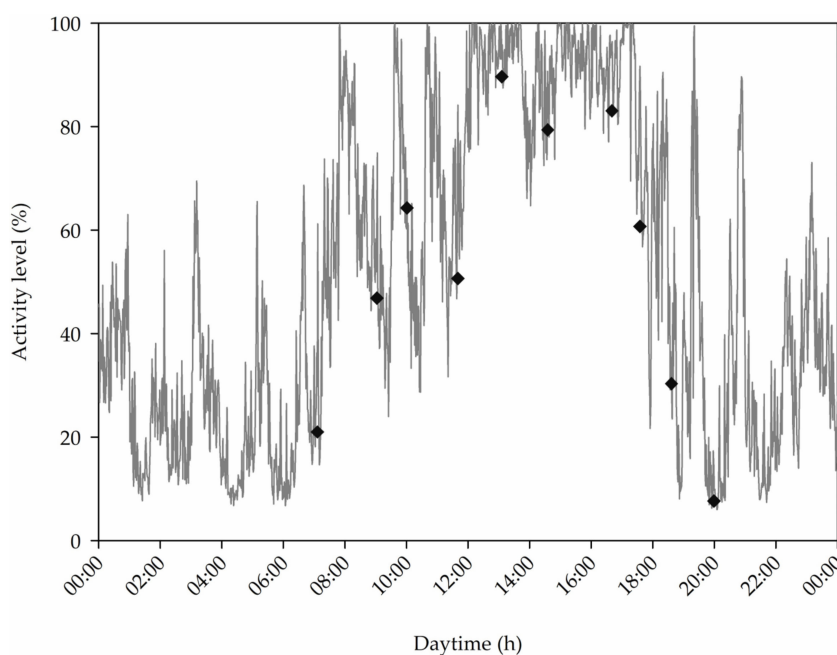


FIGURE 6
Diurnal rhythm of the animal activity on Farm 6 (line) and the respective start times of the total of ten feeding phases during the course of the day (squares). The approximate length of the light period based on natural light incidence and artificial lighting is also presented. The figure shows the averaged data in 1-min intervals over the entire three focus days.

other farms, the animals on Farm 6 showed activity peaks of up to 90%, especially in the afternoon, while the other groups showed activity peaks of 60%. In contrast, no significant differences were found between Farm 2 and Farm 4.

3.3 Activity measurements with PID and barn climate

The barn climate data differs between farms and correlates with the corresponding fattening phase, season, and generally with the respective ventilation technology and management. On average, the temperature in the focus pens was $26.72^{\circ}\text{C} \pm 2.05^{\circ}\text{C}$ with a range of $23.76^{\circ}\text{C} - 29.53^{\circ}\text{C}$. The average relative humidity was $64.27\% \pm 7.20\%$ with a range of $58.61\% - 71.14\%$ across farms. The average calculated THI_{NOAA} was 75.95 ± 3.21 with a range of $72.28 - 80.80$ across farms. Across all farms, the average temperature range between minimum and maximum values on the three focus days was 3.14°C , while the average relative humidity range was 23.20% . Due to different seasonal trial periods affecting ammonia concentration (Ivanova-Peneva et al., 2008), a general consideration across all farms is not meaningful.

Concerning the correlation between the group activity of the animals and THI_{NOAA} , as well as the NH_3 concentration, a different picture emerged based on the statistical evaluation. Table 4 shows an overview of the correlations per farm.

Except for Farm 1, significant negative correlations with small or medium effect strength between group activity and NH_3 concentration were found for all farms. The graphical representation shows a pronounced decrease in the NH_3 concentration during the day with increasing activity and increased NH_3 concentrations at night, as seen in Figure 8 for Farm 5.

NH_3 concentration peaks with the first increase in group activity in the morning. Subsequently, the NH_3 concentration decreases during the day to 2 ppm before increasing again toward evening.

During the day, THI_{NOAA} values increase with increasing animal activity. Except for Farm 7 ($r = -0.151$; $p < 0.001$; $n = 4320$), moderate ($r = 0.313$; $p < 0.001$) to strong positive correlation ($r = 0.585$; $p < 0.001$; $n = 4320$) were found for all farms between group activity and THI_{NOAA} . As shown in Figure 9, the THI_{NOAA} increases during the day and reaches peak values with the activity peaks and decreases again in the evening or night hours.

4 Discussion

4.1 Comparison of PID data and visual assessment

In modern pig farming, the use of sensor systems to monitor and control feeding and housing conditions is well established. Measuring activity at the individual animal or group level in real-time can be another complementary method to improve animal health and welfare in pigs. In this study, a low-cost and easy-to-use technology was tested to measure group activity and activity in the feeding and exploration area. Even though the conditions varied within the seven test farms, the PIDs measured realistic values.

4.1.1 PID performance for measuring group activity

Strong correlations were found between group activity using PIDs and visual assessment for all farms. These findings are comparable to the results of the previous study by von Jasmund et al. (2020), where strong correlations were obtained between group activity as measured by PID and visual assessment. Similarly, other studies, such as Besteiro et al. (2018b), found strong correlations between group activity and visual assessment using PIDs. Also, Drexler et al. (2023) examined the relationship between different methods of measuring animal activity in piglet rearing. Strong correlations were observed between visual assessment and PID, as well as between dynamic background

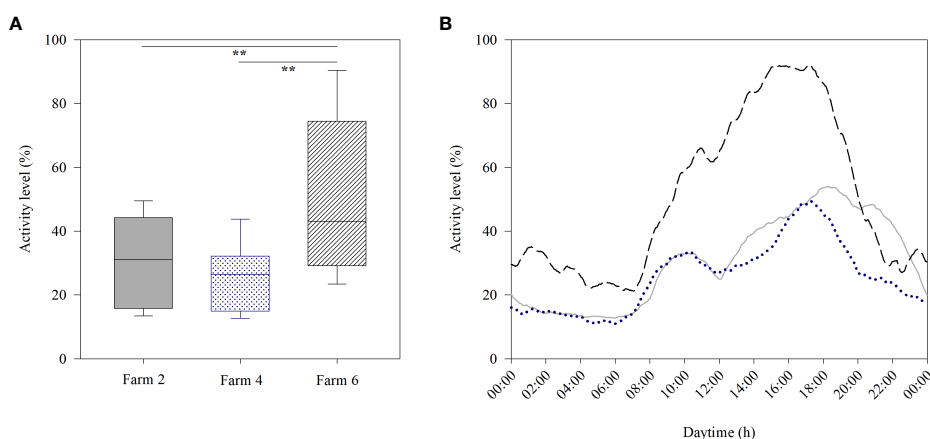


FIGURE 7

Group activity (A) and the activity pattern (B) of the individual farms for the entire three days. Activity is shown for Farm 2 (grey; castrated males), for Farm 4 (blue dots; mixed-sex group), and for Farm 6 (black lines; boars). Significant difference in group activity between farms are indicated ** with $p \leq 0.01$.

TABLE 4 Correlations between group activity measured by PID and barn climate (n = 432 per farm).

Farm	Correlation between group activity and measured/calculated values for			
	NH ₃ (ppm)	THI _{NOAA}	Temp. (°C)	Relative humidity (%)
1	0.021	0.54**	0.35**	0.60**
2	-0.44**	0.63**	0.53**	0.52**
3	-0.33**	0.32**	0.33**	0.10
4	-0.28**	0.45**	0.43**	0.03
5	-0.34**	0.27**	0.50**	-0.25**
6	-0.06**	0.68**	0.56**	0.62**
7	-0.22**	0.60**	-0.11*	0.66**

**p ≤ 0.01 and *p ≤ 0.05.

subtraction and PID for an activity area (Drexler et al., 2023). Other researchers have investigated camera techniques for activity measurements and posture detection, which showed comparable correlations to the PID technique. Thus, Ott et al. (2014) were able to use automated video analysis to measure group activity at the pen level, which also correlated strongly with visual assessment. Also, lateral and sternal lying postures in pigs could be successfully distinguished with high accuracy and sensitivity (Nasirahmadi et al., 2019). When detecting locomotion patterns within groups of piglets, Kashiha et al. (2014) were able to achieve also accuracy using automated image processing methods. In addition to image-based detection and analysis techniques, other simple sensors can measure animal activity too. Compared to PIDs, accelerometers in the ear tag provide information about the activity pattern of animals individually (Liu et al., 2018; Oczak et al., 2022). Liu et al. (2018) found a biphasic activity pattern with two main periods in sows with accelerometers. However, this technique for measuring activity

has only been used in sows, as ear tags are easily ripped out by fighting or playing (Liu et al., 2018; Kapun et al., 2020). However, Arulmozhi et al. (2021) mention that on-farm lighting conditions, variations in lighting, obstacles, and airborne objects lead to limitations in the use of camera technology. In contrast, activity measurement with PIDs is not affected by these factors, which is advantageous for pig farms where an unfavorable environment for sensitive sensor technology often exists (Basteiro, 2018).

Group activity and PID data showed strong correlations. However, the data also showed that the PIDs tend to overestimate animal activity during the day and rest periods at night. Peaks of activity measured by PID could occur at night because individual animals sometimes rise to take in water or to change their lying position. Thus, the PIDs are limited in their ability to measure fluctuations in the number of animals observed during video analysis, and single small peaks in activity at rest periods indicate short-term and individual pig activity (Ni et al., 2017). While other

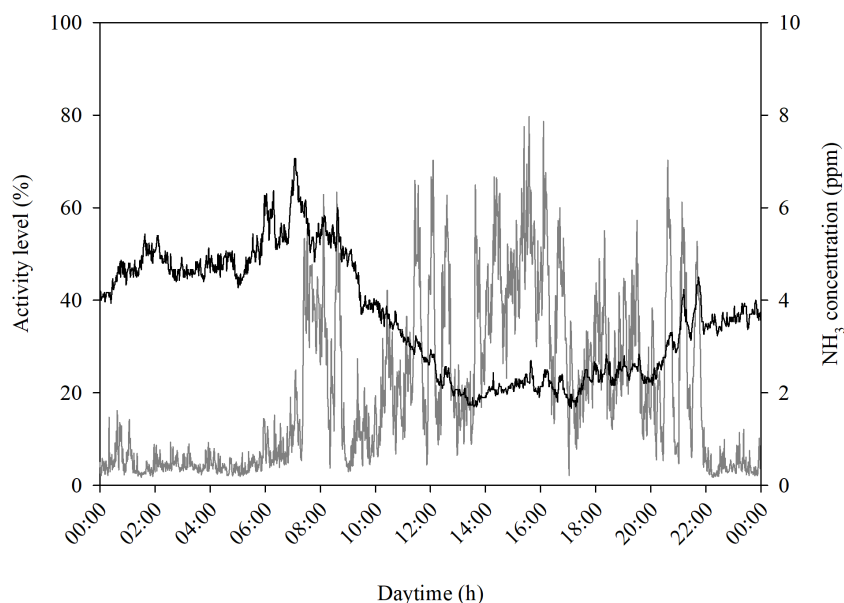


FIGURE 8

Group activity measured by PID (grey line) and NH₃ concentration (black line) over the course of the day shown for Farm 5. The figure shows the averaged data in 1-min intervals over the entire three focus days.

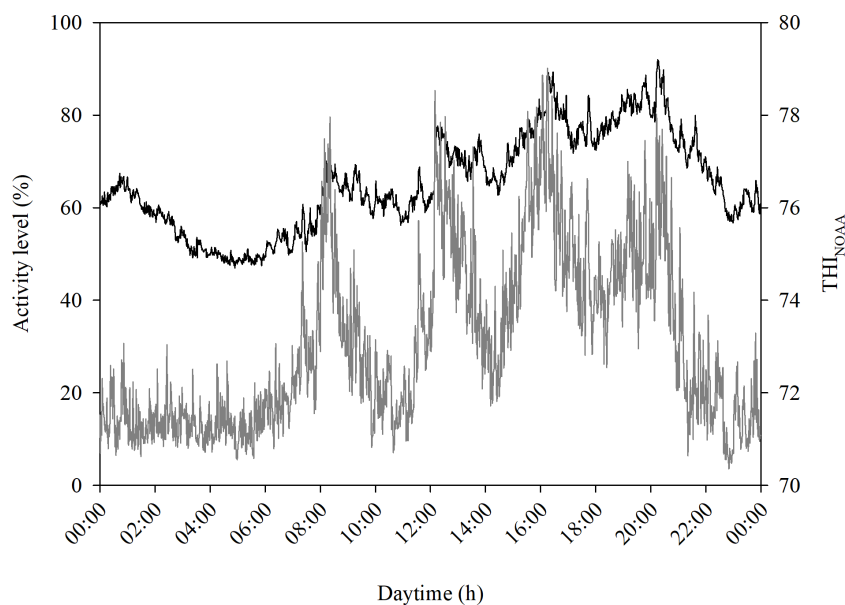


FIGURE 9

Group activity measured by PID (grey line) and THI_{NOAA} (black line) over the course of the day exemplary shown for Farm 2. The figure shows the averaged data in 1-min intervals over the entire three focus days.

researchers also indicate that PID data overestimate animal activity (Ni et al., 2017; Besteiro et al., 2018b; Besteiro et al., 2021; Drexler et al., 2023), the scan-sampling method in 10 min intervals used in this study could have limitations in accurately capturing animal activity, resulting in a tendency to underestimate activity. In addition, a slight negative correlation was found between live weight per pen and accuracy for measuring group activity. Stocking density does not seem to have an impact on the measurement of group activity, as strong correlations were obtained both at low stocking density (Farm 6) and at higher stocking density (Farm 7). In the study by Besteiro et al. (2018b) the correlation between visual assessment and daily activity decreased over the fattening period when using PIDs. This decrease is due to the technical functionality of PIDs, as the measurement depends on the temperature difference between the environment and the animal surface. Higher live weight creates a higher and more homogenous temperature range (Pedersen and Pedersen, 1995; Besteiro et al., 2018b). Another factor affecting the activity measurement is the velocity of the object. That, however, was unable to be included in this research. Thus, Cai et al. (2019) found that the PID signal increases in proportion to velocity. Therefore, important factors, such as surface temperature and animal velocity, should be recorded in further studies.

4.1.2 PID performance for measuring activity in specific focus areas

Regarding measuring animal activity in specific focus areas of a pen, correlations between PID and visual assessment were stronger for the feeding area than for the exploration area. The results seem to depend on the feeding regime (number of feeding phases) and the supply (*ad libitum* or restricted). Except for Farm 4, strong correlations were obtained for the activity in the feeding area. In

contrast, correlations for the exploration area activity were low to moderate.

The lack of spatial distance between the different functional areas within the pen may have affected the PID data and, thus, the interpretation concerning the focus areas. The correlations for the feeding activity are strong, even if the focus areas cannot be differentiated, resulting in an overlapping exploration and other functional areas, e.g., the drinking area. The strong correlations between feeding activity and visual assessment were an unexpected result, as several studies define a clear spatial separation of the functional areas as one of the most important prerequisites for good performance of the applied techniques (Besteiro et al., 2018b; Jasmund et al., 2020). Nevertheless, the strongest correlation was on Farm 7, with the feeding area clearly differentiated from all other areas.

Data suggest that despite the difference between farms in animal age and weight, PIDs generate similar results. Compared to Besteiro et al. (2018b) in which the correlation between the PID and human observation for feeding behavior decreased with the growth of weaners, similar correlations were found in our study in the pre-fattening (Farm 2 and 6) and finishing period (Farm 7). Cai et al. (2019) found stronger correlations in post-weaning piglets around day 30 than around day 50, showing lower correlations.

Continuous measurements of activity in the exploration area are not yet well-established. The results of the present study indicate that for the exploration area, separation from other functional areas of the pen seems to play a significant role in the focusability and interpretability of the PID data, compared to the feeding area. Farm 1 shows that an unclear structuring of the exploration area leads to a low correlation between PID and visual assessment. On Farm 7, also showing a low correlation, the exploration area was next to a scouring area applied as a comfort enrichment to the pigs in the

pen. Furthermore, the exploration area was used frequently as a transit area, which also impacted the recording of the PID data. Instead, a comparatively stronger correlation was found for Farm 2, which had a clearly structured pen. With different performance parameters, Veldkamp et al. (2023) found a similar low correlation between exploration activity using PIDs and visual assessment. Their results also showed that the PIDs are limited in detecting specific behaviors, such as exploring. In general, PIDs are a low-cost and easy-to-use technology that perform equally as well as the accelerometer and the neural network model algorithms based on video images when analyzing the interaction with enrichment material. In contrast, the previous study by von Jasmund et al. (2020) found strong correlations for the exploration area as reported here.

The validity for measurements of group activity might be stronger than measurements in the feeding and exploration area because the observation area included the whole focus pen. Another reason for the different correlations found for different farms could be due to the variability in PID location caused by specifics of the housing conditions applied. According to Cai et al. (2019), who tested PIDs under laboratory conditions with simulated pigs, different angles, distances to the object, and the object's moving speed (m/s) affected the results.

Data cannot explain the low correlation between Farm 4's feeding and exploration areas. Since the functional areas were clearly separated and the PID was placed directly above the feeding area, other behaviors could not be measured. *Ad libitum* feeding might have resulted in more short-duration animal visits to the feeding area (Angermann, 2021), leading to higher activity measurements by the PID. The video recordings show fewer animals in comparison.

4.2 Activity data by using PIDs and animals' behavior

Pigs show a diurnal rhythm in their natural behavior (Hardin and Panda, 2013), which was also shown by each group of fattening pigs in this study. Active phases alternate with one or more rest phases during daytime, and reduced activity or rather inactivity during night hours. These findings are supported by a wide range of studies (Rijnen et al., 2003; Blanes-Vidal et al., 2008; Ni et al., 2017; Besteiro et al., 2018a; Besteiro et al., 2021). During the day, the animals show different activity patterns depending on the farm, which should be interpreted individually, as this can be influenced by a variety of factors such as feeding management (Pedersen et al., 2015), enrichment material (Nasirahmadi et al., 2017), and barn climate (Huynh et al., 2005a; Godyń et al., 2020; Jasmund et al., 2020).

A typical biphasic activity pattern, characterized by alternating feeding and activity peaks in the morning and at the end of the day (Ni et al., 2017), was observed only for Farm 4 with *ad libitum* feeding. This finding is consistent with results from other researchers, who also found a low activity peak in the morning and a higher one in the afternoon in pre-fattening pigs with *ad libitum* feeding (Ni et al., 2017; Besteiro et al., 2018a). However, the

biphasic activity pattern typically develops later during fattening periods (Ni et al., 2017; Besteiro et al., 2018a). Ni et al. (2017) found different activity patterns during the fattening period, with pigs showing multiple activity peaks in the first month and a pattern with two activity peaks in the second month. The activity pattern of Farm 4 also differs from the activity pattern of the same-age pigs on Farm 2 and Farm 6. The present data suggest that this difference between group activity, especially in the daily activity pattern, is due to differences in feeding management. Farm 6 fed restrictively, with feed given ten times per day. Therefore, feeding times could have influenced the activity pattern resulting in many activity peaks. The multiphasic daily rhythm of the Farm 2 with activity peaks on Farm 4 also coincides with four feeding times. These results are consistent with Pedersen et al. (2015), who also found increased activity using PIDs when feed was dispensed. In Cai et al. (2019), the feeding times also coincided with the maximum daily activity of the pigs.

Furthermore, the farms differed not only in terms of activity pattern but also in the intensity of activity. For instance, the boars on Farm 6 were significantly more active than those on Farm 2 (castrated males) and Farm 4 (mixed-sex group). One reason for the increased activity of the boars could have been general restlessness before and after feeding times (Zoric et al., 2015). In some studies, boars were more aggressive than the castrated males and mixed-sex groups. In Holinger et al. (2015), the percentage of animals fighting was significantly higher in sole male groups compared to mixed-sex groups of sows and castrated males. In a similar study, Cronin et al. (2003) found that male pigs aged 21 weeks displayed higher levels of aggressive behavior than castrated males. However, contrary to the current results, Büniger et al. (2015) could not demonstrate any differences in activity between the sexes. The authors argue that the absence of a significant difference might be due to a low stocking density of 12 animals per pen and *ad libitum* feeding. In this study, the stocking density of 26 animals was higher than in Büniger et al. (2015). Nevertheless, animals should have sufficient periods of activity and rest, which can be measured using PIDs.

4.3 Activity data by using PIDs and barn climate

During the day and with increasing animal activity, there was a general decrease in NH₃ concentration. An increase in concentration was measured in night hours. A negative relationship between NH₃ concentration and pig activity was also shown by Kim et al. (2008). Here, we focused on air quality in the barn and, thus, NH₃ concentration. In contrast, other studies often investigate NH₃ emissions (Aarnink et al., 1995; Aarnink et al., 1996; Jeppsson, 2002; de Sousa and Pedersen, 2004; Blanes-Vidal et al., 2008). Therefore, a direct comparison of the values of this study to those from other studies is not possible. The decrease in NH₃ concentration during the day and its increase during the night may be due to ventilation management. Typically the ventilation rate is higher during the day than at night, also seen in Aarnink et al. (1995); de Sousa and Pedersen (2004) and Blanes-Vidal et al. (2008). Thus, more air in the barn compartment and, consequently, more NH₃ being transported out via ventilation.

Data on the airflow and ventilation rate were not collected, therefore, no emission data could be calculated and compared with other studies. In addition, there was an observed rise in the concentration of NH_3 during the morning hours. This increase might be due to the close relationship between the elimination behavior after resting and the activity of the pigs (Aarnink et al., 1996), which increases again after the nocturnal rest period and affect the ammonia level in the compartment. In Guo et al. (2015), elimination behavior also increased in the morning after nighttime and with the first feeding.

With regard to the THI_{NOAA} values, the relationship to activity was contrary to NH_3 across all farms. As animal activity increases during the day, the THI_{NOAA} also increases and decreases again in the evening or night hours. In most cases, as activity increases, so do temperature and relative humidity in the focus pens. The average range between minimum and maximum values for temperature on the three focus days was 3.14°C across all focus farms. However, the average relative humidity range across farms is 23.20% and thus varies much more over the course of the day than temperature. Heat production of the animals influences the ambient temperature (Aarnink et al., 1996), which is, among other things, related to the activity of the animals (Aarnink et al., 1996; CIGR, 1999). The temperature in the barn, in turn, influences respiration, among other things (Olczak et al., 2015). And by respiration, more water vapor is released into the environment through evaporation via the exhaled air (Loeffler and Gäbel, 2009). Jeppsson (2002) also showed a positive correlation between water vapor emission and animal activity. So, if animal activity increases during the day, the temperature and the relative humidity of the ambient air also increase, which increases the THI_{NOAA} .

4.4 Outlook

Activity measurement in fattening pigs is not yet widely used in practice. PIDs are an easy, cost-effective (Ni et al., 2017), and non-invasive technique that allows continuous activity measurement. Compared to cameras, PIDs are robust, and their accuracy is not affected by light conditions or other environmental factors in the barn. Due to the comparatively low costs, activity can also be measured in several pens. The PIDs are particularly suitable for measuring group activity within a pen. To measure activity in individual focus areas, it is important to fulfill certain requirements: firstly, the PIDs must focus on specific areas. Secondly, the interpretative value of the data depends on the structuring of the pen, as the focus area should be separated from the other functional areas in the pen. However, this separation is not always guaranteed on-farm. The third point is the validation of activity tracking and behavior shown by the animals since the PID cannot distinguish between behaviors. In addition, there are many validation methods to investigate different techniques. Care should be taken to ensure that the validation technique best reflects the activity measurement of the PIDs and still capture the actual activity of the animals. Nevertheless, the possibility of simple activity measurement should

be used, since daily rhythms as well as active and resting phases are recognizable and differ depending on the housing conditions. Similar to Basteiro (2018), we also conclude that the PID data show that each farm should also be considered individually and that standardization or general thresholds are not useful. Artificial intelligence could be used to display individual activity patterns of animal groups over days or weeks. This could allow the detection of deviations in activity behavior due to disease (Hart, 1988), cannibalism (Statham et al., 2009; Ursinus et al., 2014; Larsen et al., 2016; Larsen et al., 2019), or heat stress (Huynh et al., 2005b; Jasmund et al., 2020), for example. In this way, the recording of activity behavior using PIDs provide the farmer with useful information on animal welfare and could be implemented in a decision-support system.

5 Conclusion

This paper compared PID data with the visual assessment to assess group activity and activity in the feeding and exploration area in focus pens with fattening pigs on different farms under practical conditions. Furthermore, the activity behavior of the animals was examined in relation to feeding management and barn climate. Results showed that PIDs measuring group activity performed best, followed by activity measurement in the feeding area. Only moderate correlations were reached in measuring activity in the exploration area. Fattening pigs showed different diurnal activity patterns depending on housing conditions and management, leading to the assumption that farms should be considered individually. In summary, activity measurement in functional focus areas of the pen is a challenge, especially due to the necessity of pen structuring on-farm. Nevertheless, PIDs are a useful tool for activity measurement in groups of animals. They have the potential, in combination with other sensor systems and supported by algorithms and/or artificial intelligence in the context of evaluation, to provide animal and husbandry-related information to the farmer leading to substantial support for management decisions and well-being confirmation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

No ethical approval was required because no animal procedures were performed. The animals were observed only by sensor and camera. This study involved sensor technology for the barn, which did not need to be attached to the animal. The animals were not disturbed in their daily routine.

Author contributions

EW: Formal Analysis, Methodology, Validation, Visualization, Writing – original draft. NJ: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft. IT: Writing – review & editing. KS: Data curation, Investigation, Writing – review & editing. WB: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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