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Evaluation of video-based determination of the respiratory rate in calves

Diploma Thesis

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submitted by

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Declaration of Independence:

I hereby declare that I have written the submitted work independently and have not used any sources or aids other than those stated. All text passages taken from external sources have been marked as such. I have carried out the decisive work myself and have named all those who have provided assistance with their contribution to the work. The present work has not been submitted or published elsewhere.

Vienna, December 2024 Gina Flachowsky

Abstract

This work aims to evaluate whether it is possible to assess the respiratory rate of calves retrospectively using camera recordings. Respiratory rate is a parameter for detecting heat stress. Heat stress in livestock is an increasing problem due to global warming, affecting both animal welfare and the profitability of farms. By default, respiratory rate is measured by direct observation by staff. This method is both time-consuming and labour-intensive, does not allow continuous monitoring and can additionally stress the animals.

As part of the experiment, ten Simmental calves aged three to ten weeks were filmed with surveillance cameras installed in the calf barn. Respiratory rates were determined both by direct observation by two observers and retrospectively from the video recordings by the same observers. A total of 330 respiratory rate sequences were analysed for agreement between live observations and video-based counts. A statistical analysis was performed, including Spearman correlation and Bland-Altman plots, to evaluate the accuracy and reliability of the video-based method. The results indicated a significant correlation between live counts and video recordings, with video-based counts tending to underestimate respiratory rates, especially at higher levels.

The study concludes that video recordings are generally suitable for monitoring the respiratory rate of calves, but that improvements in image quality, camera positioning, and lighting are needed to ensure reliable detection. In the future, artificial intelligence (AI) could be used for automated monitoring to detect heat stress in calves more efficiently and improve animal welfare. Studies, like the present one, are a first step in developing such AI-based approaches.

Zusammenfassung

In dieser Arbeit soll evaluiert werden, ob es möglich ist die Atemfrequenz von Kälbern retrospektiv mithilfe von Kameraaufnahmen zu beurteilen. Die Atemfrequenz ist ein Parameter zur Erkennung von Hitzestress. Hitzestress bei Nutztieren, ist aufgrund der globalen Erwärmung ein zunehmendes Problem, das sich sowohl auf das Tierwohl als auch auf die

Wirtschaftlichkeit der Betriebe auswirkt. Standardmäßig wird die Atemfrequenz durch direkte Beobachtung am Tier, meist durch Stallpersonal erhoben. Diese Methode ist sowohl zeit- als auch arbeitsintensiv, ermöglicht keine kontinuierliche Überwachung und kann die Tiere zusätzlich unter Stress setzen.

Im Rahmen des Versuches wurden zehn Fleckvieh Kälber im Alter von drei bis zehn Wochen mit Überwachungskameras gefilmt, die im Kälberstall installiert waren. Die Atemfrequenz wurde sowohl durch direkte Beobachtung im Stall von zwei Beobachtern als auch retrospektiv mithilfe einer Software durch die gleichen Beobachter aus dem Videomaterial ermittelt. Insgesamt wurden 330 Sequenzen der Atemfrequenz auf Übereinstimmung zwischen Live-Beobachtungen und videobasierten Zählungen analysiert. Es wurde eine statistische Analyse durchgeführt, einschließlich Spearman-Korrelation und Bland-Altman-Diagramme, um die Genauigkeit und Zuverlässigkeit der videobasierten Methode zu bewerten. Die Ergebnisse ergaben eine signifikante Korrelation zwischen Live-Zählungen und Videoaufzeichnungen, wobei bei den videobasierten Zählungen die Atemfrequenz tendenziell unterschätzt wurde, insbesondere bei höheren Atemfrequenzen.

Die Studie kommt zu dem Schluss, dass Videoaufnahmen grundsätzlich zur Überwachung der Atemfrequenz von Kälbern geeignet sind, jedoch Verbesserungen in der Bildqualität, Positionierung der Kameras und Beleuchtung erforderlich sind, um eine zuverlässige Erkennung zu gewährleisten. In Zukunft könnte künstliche Intelligenz (KI) zur automatisierten Überwachung eingesetzt werden, um den Hitzestress bei Kälbern effizienter zu erkennen und das Tierwohl zu verbessern. Studien, wie die vorliegende können dabei als Grundlage für die KI-basierten Verfahren dienen.

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AUC	Area under the curve
Fig.	Figure
FPR	False Positive Rate
p	Significance level
p_c	Lin's Concordance Correlation Coefficient
r	Correlation coefficient
R^2	Linear regression
RH	Relative humidity
ROC	Receiver operating characteristic
THI	Temperature-Humidity-Index
TPR	True Positive Rate

1. Introduction

Due to global warming, the issue of heat stress in livestock is becoming more and more present. Heat stress occurs when the heat gain from the environment and metabolism surpasses the heat loss by radiation, convection, evaporation, and conduction. Neurons located throughout the body transmit information to the hypothalamus. The hypothalamus then reacts with physiological, anatomical, and behavioural changes to maintain temperature equilibrium. During heat stress the body cannot dissipate the excess heat because the body temperature is elevated (1, 2).

Generally, it is believed that calves are more heat tolerant than adult cows, because they have less metabolic heat production and have a greater body surface area relative to internal body mass, which allows them to more successfully maintain thermal homeostasis. Therefore, they are more likely to suffer less (3, 23, 25).There are already numerous studies on the effects of heat stress on lactating and adult cattle. Unfortunately, little is known about this topic in calves, even though heat stress causes high economic losses to the cattle industry every year e.g. due to delayed weight gain of calves (4).

The most widely used index for quantifying heat stress is the THI (Temperature-Humidity Index). This was first developed by Thom in 1958 and adapted for cattle by Berry et al. (1964) (5). For dairy cattle, thresholds are described by >68 (6) or >72. (7) Other authors defined four THI ranges for cattle: threshold (Temperature (T) 22-24 °C, Relative Humidity (RH): 60 %, THI = 68 to 70), mild (T: 26-28 °C, RH: 60 %, THI = 74 to 76), moderate (T: 29-31 °C, RH:80 %, THI = 81 to 83), and severe (32-34 °C, RH: 80 %, THI = 88 to 90) (8, 9). The problem when using THI is that radiant heat and wind speed are not taken into account.

The thermoneutral zone of calves is assumed to be within a range of 13-25 °C for a one-month-old calf (10). Confirmed THI thresholds for calves remain unknown (3) and it is thought that thresholds for adults are only applicable to a limited extent. Some authors described changes in parameters like heart rate, body temperature, and respiration rate within a wide range of THI-levels of 65 to 88 in calves (11–13). Neuwirth et al. (14), gives a threshold value for ambient

temperature at 32 °C and RH of 60 %, which corresponds to a THI of 80.6 for calves. Kovacs et al. (13) describes a risk to welfare from a THI of 78 and serious heat stress from 88.

Different effects of heat stress are described in calves, depending on the time of exposure. Heat stress during the prenatal phase is decisive. So-called foetal programming occurs via the uterus. The growth of the foetus is impaired by hyperthermia-induced placental insufficiency, which is caused by a reduced inflow of oxygen and nutrients. In addition, the gestation period can be shortened and the weaning weight lowered (15). It is generally observed that calves born in summer have a lower average daily weight gain (3). As the foetus has twice the metabolic rate of the mother, foetal hyperthermia occurs, which in turn leads to increased catabolic hormone release and increased insulin levels (16).

Prenatal heat stress leads to a prolonged postnatal standing time in the calves (17). In addition, the Immunoglobulin G (IgG) concentration in colostrum and absorption of IgG decrease possibly leading to failure in transfer of passive immunity. This may result in long-lasting effects on immunity and disease resistance (15).

Heat stress can affect the development and function of the immune system in calves. The development of the immune system begins prenatally and is mature around weaning. Serotonin acts as a neurotransmitter and stress-response mediator with immunomodulatory effects. Chronic heat stress results in lower red blood cell count, serotonin, IgG, and B-Lymphocyte levels. Serotonin receptors, on the other hand, are formed more frequently. Chronic heat stress dysregulates peripheral serotonin signalling and thus impairs the development of the humoral immune response. Short-term adaptations involve cellular homeostasis. Long-term adaptations, on the other hand, involve reprogramming of gene expression and endocrine changes. Heat stress thus permanently suppresses the development and differentiation of the calves' adapted immune system (18).

The reproductive tract can also be impaired affected because heat stress slows down follicular development. This can lead to long term problems in fertility (19).

First signs of heat stress may be seeking for shaded areas, frequent postural changes, reluctance to move, or bunking to provide shade for each other (18). Physiological reactions follow (20).

Signs of acute heat stress are an increase in heart rate, respiratory rate, and rectal temperature (20) as well as endocrinological changes such as an increase in cortisol concentrations in saliva and plasma (21) and a decrease in thyroid hormones T3 and T4 (22). An increased blood cortisol level and blood urea nitrogen level are together associated with a prolonged standing time close to long term heat stress conditions in calves (23).

After some time, heat shock protein genes (HSP70 and HSP90) can also be detected in the hair follicles of calves (8). These heat shock protein expression in peripheral blood mononuclear cells can be used as an indicator of heat stress (8, 9). Other biomarkers that can be used to detect heat stress are the metabolic parameters e.g. carbohydrates (ribose, myo-inositol, galactose, and lactose), fatty acids (oleic acid), and amino acids (asparagine and lysine) as these are significantly affected (4).

An important physiological mechanism is the increase in respiratory rate by up to 50 % to enhance cooling by evaporation (25). In cattle, panting can be observed with the mouth closed or open. It is concluded that temperature exchange takes place via the mucous membranes of the upper respiratory tract. When panting, the respiratory rate is increased. However, the tidal volume decreases at the same time (26). In cows, it is known that the increased respiratory rate leads to increased carbon dioxide exhalation, which can lead to respiratory alkalosis, which in turn impairs gastrointestinal activity. Although not yet proven in calves, this problem is likely to occur in all age groups (3).

Different sources describe different physiological limits of the respiration rate for calves, varying between 20 and 60 movements/minute (24, 27).

Monitoring respiration rates is usually be done by visual observation. This nevertheless is time consuming and can only be done during short time periods during the day.

Digital technologies, summarised under precision livestock farming (28) could be promising in increasing the detection of elevated respiration rates e.g. during heat stress.

Some research has already been done to allow for a constant monitoring of the respiration rate for the use in the field and for research purposes (28–30).

One possibility might be the monitoring via cameras and use of computer vision. This has so far been tested in adult cows and revealed promising results (31). To my best knowledge this was not tested in calves so far.

Consequently, the aim of my work was to determine whether the evaluation of the respiratory rate in calves is possible using recordings from surveillance cameras in comparison to direct visual observation in the barn.

The hypothesis was, that video recordings allow a reproducible evaluation of the respiration rate in calves, which can in future be used in computer vision for automated monitoring of the respiration in calves.

2. Material and Methods

The study was performed at the calf barn of the Vetfarm of the University of Veterinary Medicine Vienna (Kremesberg, Lower Austria). In this work, ten preweaned Simmental calves aged three to ten weeks were included. These calves were group-housed in a free stall barn with two pens of five animals each. Each pen included a nest and an open area.

After identification of the calf by the ear tag number, an optical signal was set for clear calf identification on the cameras later on (flashing of a light on the collar). This was done because the ear tags were not recognizable on the cameras.

The visual observation of the respiration rate was performed first. At the same time, the calves were filmed by the cameras. However, the camera recordings were analysed at a later date. To test the inter-observer reliability of the frequence counted under live conditions, two observers (including me) independently observed one calf at the same time. It was ensured that the results were neither exchanged verbally nor written down for the other person to see.

Counting was done both from inside and outside the pen, depending on the position of the calves, to provide the best possible view. If possible, a position diagonally behind the calf was chosen. If this was not possible, we positioned ourselves diagonally in front of or at right angles to the calf. Every observer chose the position that was best for them.

The observers started simultaneously following a hand signal. Time was measured using a smartphone stopwatch app. Only whole breaths were counted, starting with the beginning of inspiration. The rate was counted for 60s (= one sequence) (32). The end was marked verbally and by lowering the arm. For sample size calculation a variance of 5 % between the methods was suggest as tolerable. Consequently, using a type-I-error of $\alpha = 0.05$ and a power of $(1-\beta) = 0.95$ revealed that 285 sequences would be necessary. Taking losses into account, we overall measured 330 sequences (60s each). Measurements were performed on all calves. Calves were evaluated when standing or lying, what was recorded and taken into account.

We used six cameras (IR Bullet Network Camera Version DS-2CD2632F-I(S), Hikvision, Hangzhou, China) per pen. Below each of the two nests a fisheye camera was used. In the

middle above each pen was a top view camera. The remaining four cameras, attached right under the ceiling, recorded from different angles (Fig. 1). The non-fisheye cameras were installed at a height of approximately 4 m.

After about four weeks, the respiratory rates were assessed again by both observers separately, using recordings from the cameras on the laptop. The professional software for video analyses (Mangold Interact, Mangold International GmbH, Arnstorf, Germany) was used for this purpose.

At the end all results from both observers were collected in an Excel file.

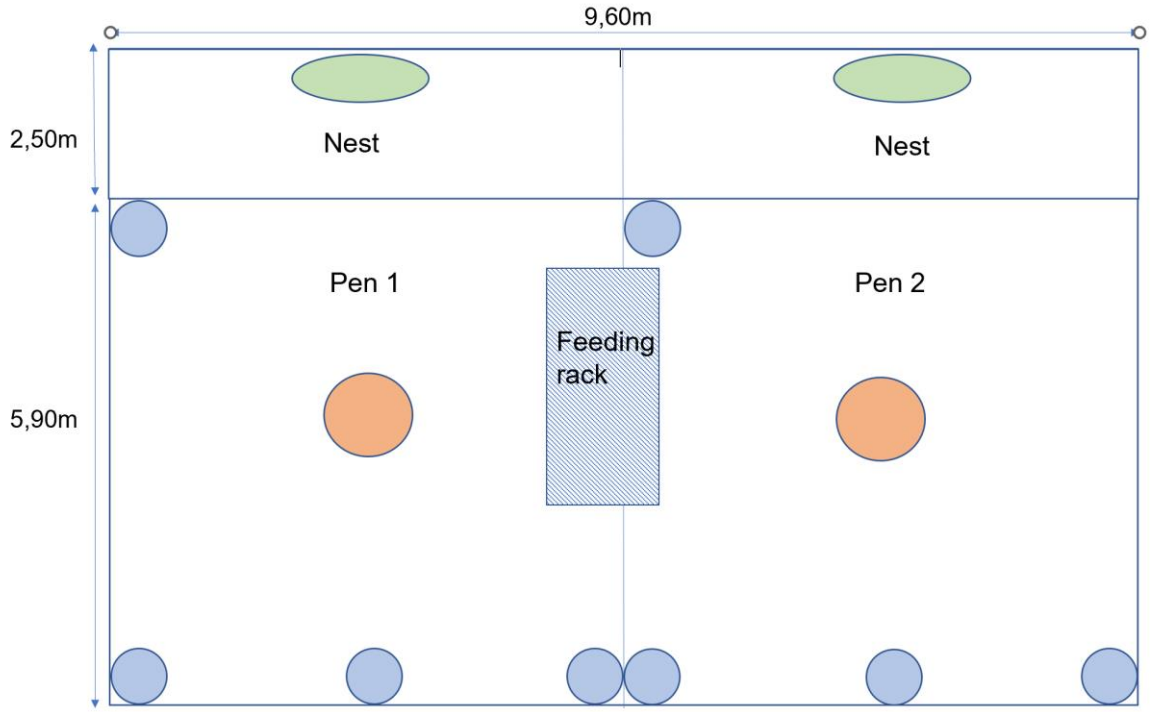


Fig. 1 Arrangements of the cameras: free stall barn with two pens. Every pen was equipped with one fisheye camera (green) with a height of 1.20 m, one top view camera (orange) in a height of approximately 5.0 m and four cameras in different angles in a height of approximately 3.0 m (blue).

2.1.Data analysis

All data sets were tested for normal distribution using the Shapiro-Wilk test. To examine the evaluation of the respiration rate via camera recordings in comparison to the reference method -visual observation in the barn- precision was calculated (Spearman correlation and linear regression R^2). A correlation of ≤ 0.35 was considered as weak, 0.36 to 0.67 as moderate, 0.68 to 0.90 as strong, and > 0.90 as very strong (33). Additionally, Bland-Altman plots were created to assess agreement.

Heat stress was assumed if the breathing rate per minute exceeded a value of 40 (34).

The agreement of the data sets of the live and the camera-based counts were verified using the Lin's Concordance Correlation Coefficient (p_c). The live counts of observer 1 were used as gold standard.

A receiver operating characteristic curve (ROC) analysis with calculation of the Area under the curve (AUC) was performed to verify the quality of the camera-based detection of the respiration rate with the live count of observer 1 as reference method.

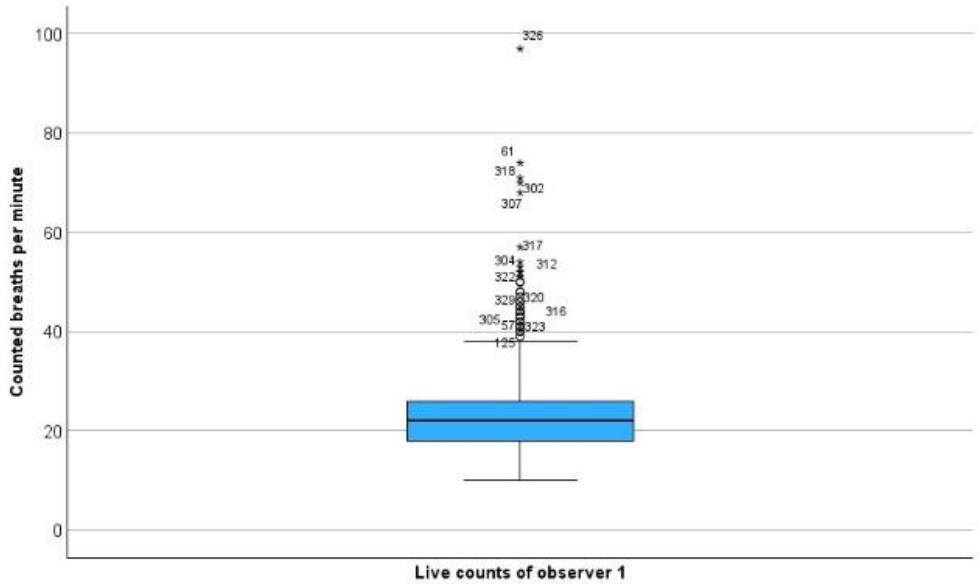
3. Results

3.1. Recording the respiration rate by direct observation in the barn

A total of 330 breathing sequences (= minutes) were counted during the live count in the barn. Two-hundred and thirty counts were performed, when the calf was lying and 99 when standing; during one count the calf changed position, so during standing and lying. The individual values of these counts are shown in table S1 in the supplements. The mean respiratory rate of all calves was 25 breaths per minute for observer 1. The minimum value was 10 and the maximum value was 97. The standard deviation was 11. The mean respiratory rate for observer 2 was 25 breaths per minute. The minimum value was also 10, the maximum value was 96 and the standard deviation was 11.

The data recorded by both observers are shown in Fig. 2 a. The median for observer 1 is centred between the two quartiles 1 and 3. The lower whisker is shorter than the upper whisker. The variance in the lower range is slightly smaller than in the upper range. There are only outliers in the upper range. These are both slight and extreme outliers. These outliers are not due to measurement errors but represent natural deviations from the mean value. For this reason, they were not excluded from further analysis.

a



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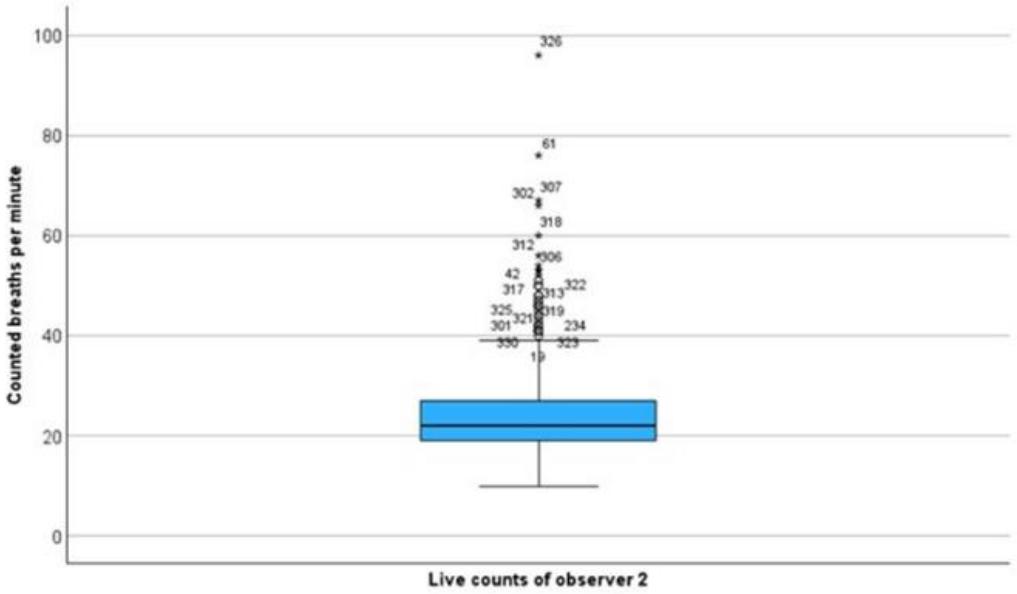


Fig. 2a Data from the live count of observer 1 and Fig. 2b for observer 2.

For the values recorded by observer 2, the median tends to be at the lower end of the box (Fig. 2 b). The lower whisker is also shorter than the upper whisker. In this data set, too, the variance in the lower range is smaller than in the upper range. There are also slight and extreme outliers, but exclusively in the upper range. These outliers are also not due to measurement errors. They represent natural deviations from the mean value.

As the outliers in both data sets could not be excluded, a non-parametric test was used to test for normal distribution with the Shapiro-Wilk test. The significance values determined were <0.001 for both observer 1 and 2. As both significance values are well below 0.05, a normal distribution of the data can be ruled out. This can also be seen in Fig's. 3 and 4. Both data sets show a clearly left-skewed distribution.

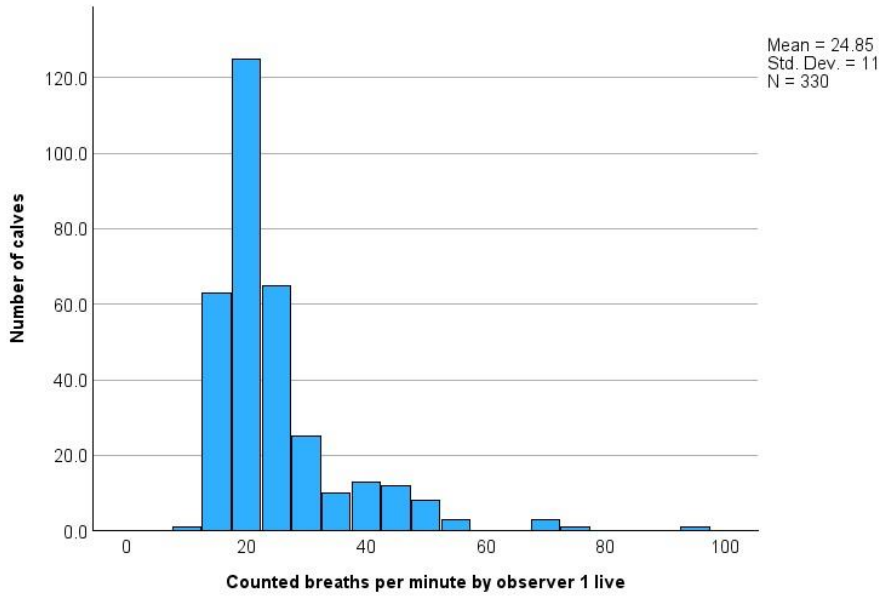


Fig. 3 Histogram of the count values of observer 1 under live conditions. Mean- mean number of calves with a given number of counted breaths per minute; Std. Dev.- standard deviation; N- total number of calves counted.

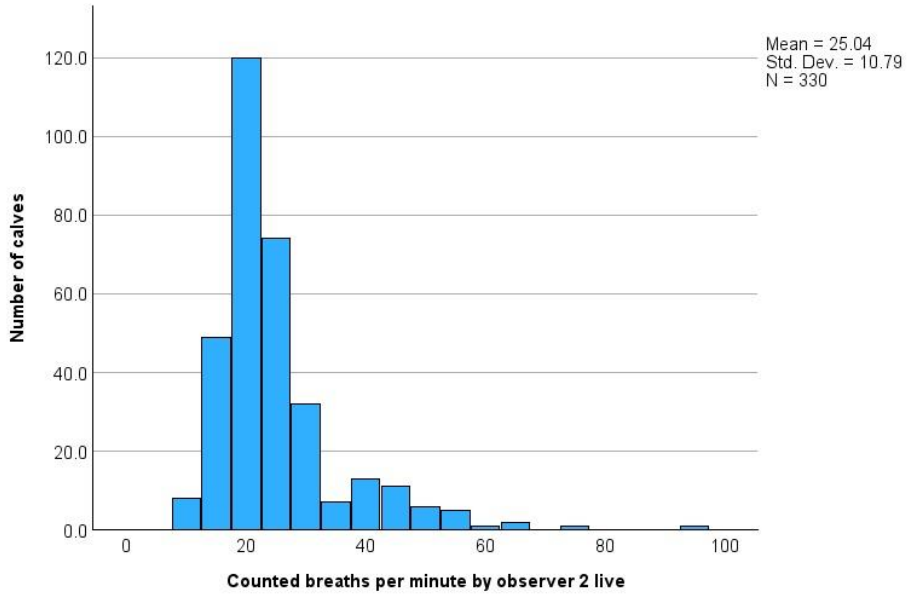


Fig. 4 Histogram of the count values of observer 2 under live conditions. Mean- mean number of calves with a given number of counted breaths per minute; Std. Dev.- standard deviation; N- total number of calves counted.

The difference between the count values determined by the observers for each calf are shown as a Bland-Altmann-plot in Fig. 5. The deviations between the counts of both observers are evenly distributed in the positive and negative range. No general trend can be recognised.

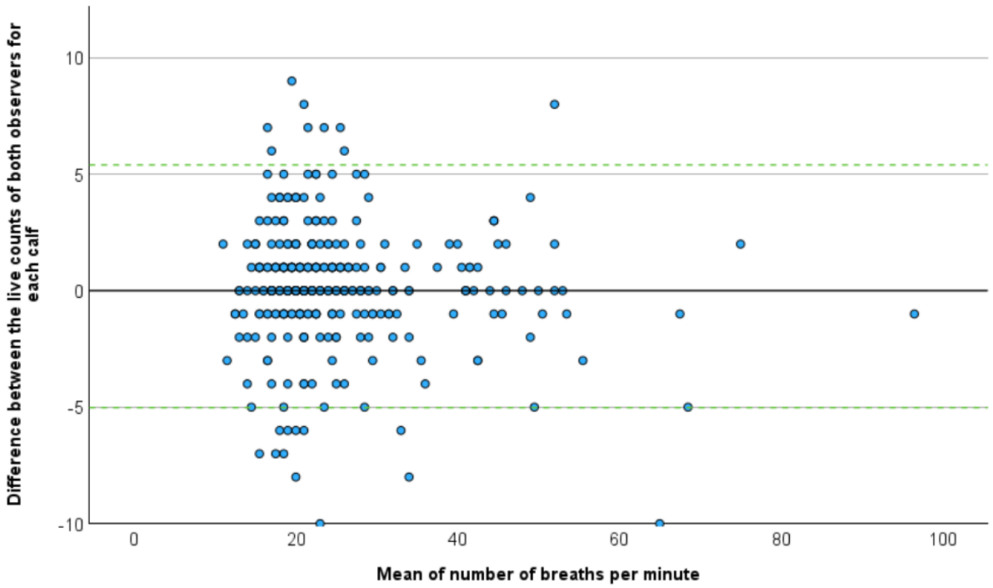


Fig. 5 Difference of the live counts.

The live counts of observer 1 were subtracted by the live counts of observer 2. The black line marks the zero value on the y-axis, which means that there is no difference between the counts of both observers. The dashed green lines show the standard deviation multiplied by the confidence interval.

The data sets determined by both observers under live conditions were then tested for correlation using the Spearman test. Both data sets showed a high statistically significant correlation with a correlation coefficient of r=0.89 at a significance level of p=0.001. The live count values of both observers showed a high linear regression coefficient of R^2=0.9 (Fig. 6).

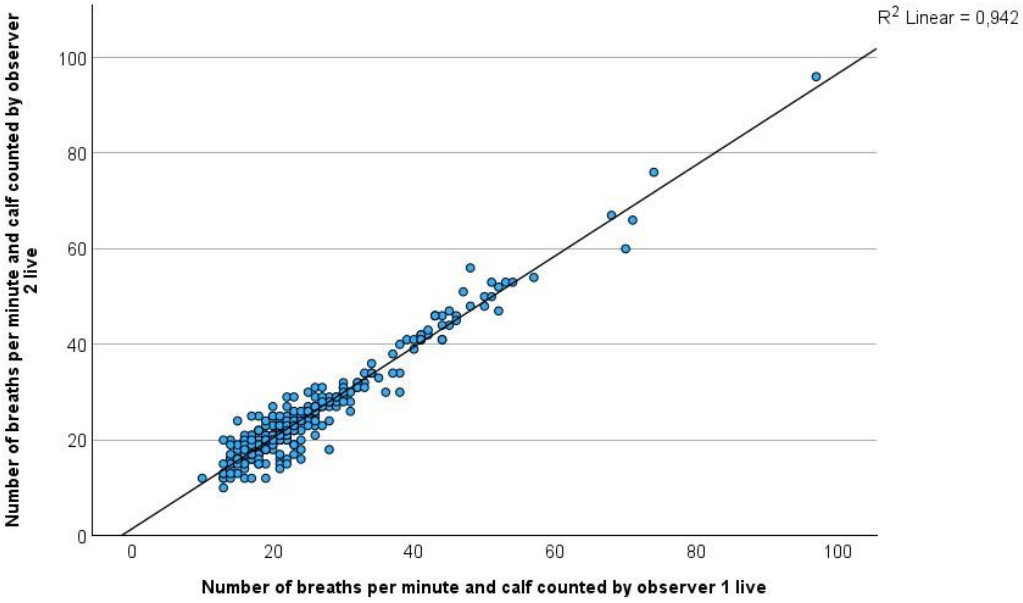


Fig. 6 Linear regression of the live count values.

3.2. Counting the respiration rate from camera recordings

Each of the two observers separately counted the respiration rate on the according (to the frequence in direct observation) camera recordings. The individual counting values are shown in table S1 in the supplements. A total of 30 (9 %) of the 330 recordings could not be analysed due to poor video quality.

The camera counts determined by both observers were tested for correlation using the Spearman correlation. Both data sets showed a significant correlation with a Spearman correlation coefficient of r=0.7 and a significance level of p=0.001. The camera counted values of both observers showed a high linear regression coefficient of R^2=0.8 (Fig. 7).

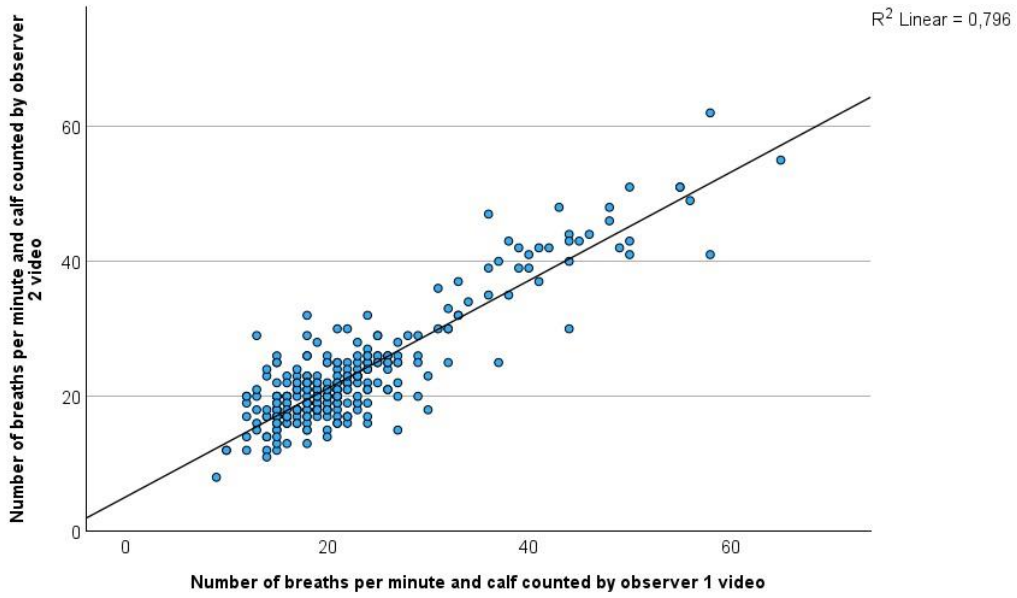


Fig. 7 Linear regression of the camera counted values of both observers.

The mean respiratory rate of all calves was 22.5 breaths per minute for observer 1. The minimum value was 9 and the maximum value was 65. The standard deviation was 9.4. The mean respiratory rate for observer 2 was 23 breaths per minute. The minimum value was also 8, the maximum value was 62 and the standard deviation was 8.4. The data recorded by observer 1 are displayed graphically in Fig. 8 a. The median is slightly shifted to the lower range. Both whiskers have more or less the same size. The variance is rather evenly distributed. There are numerous outliers, which appear only in the upper range. Among them, there are slight, but also extreme outliers. This is in agreement with the counts recorded under live conditions. As these outliers are not due to measurement errors, they were not excluded from further analysis.

For the values recorded by observer 2, the median tends to be slightly shifted to the lower end of the box (Fig. 8 b). This is different compared to the live data of this observer. Both whiskers have more or less the same size. The variance is rather evenly distributed. There are numerous outliers, which appear only in the upper range. Among them, there are slight, but also extreme outliers. This is in agreement with the counts recorded under live conditions. As these outliers are not due to measurement errors, they were not excluded from further analysis. Consequently, a non-parametric test was used to test for normal distribution.

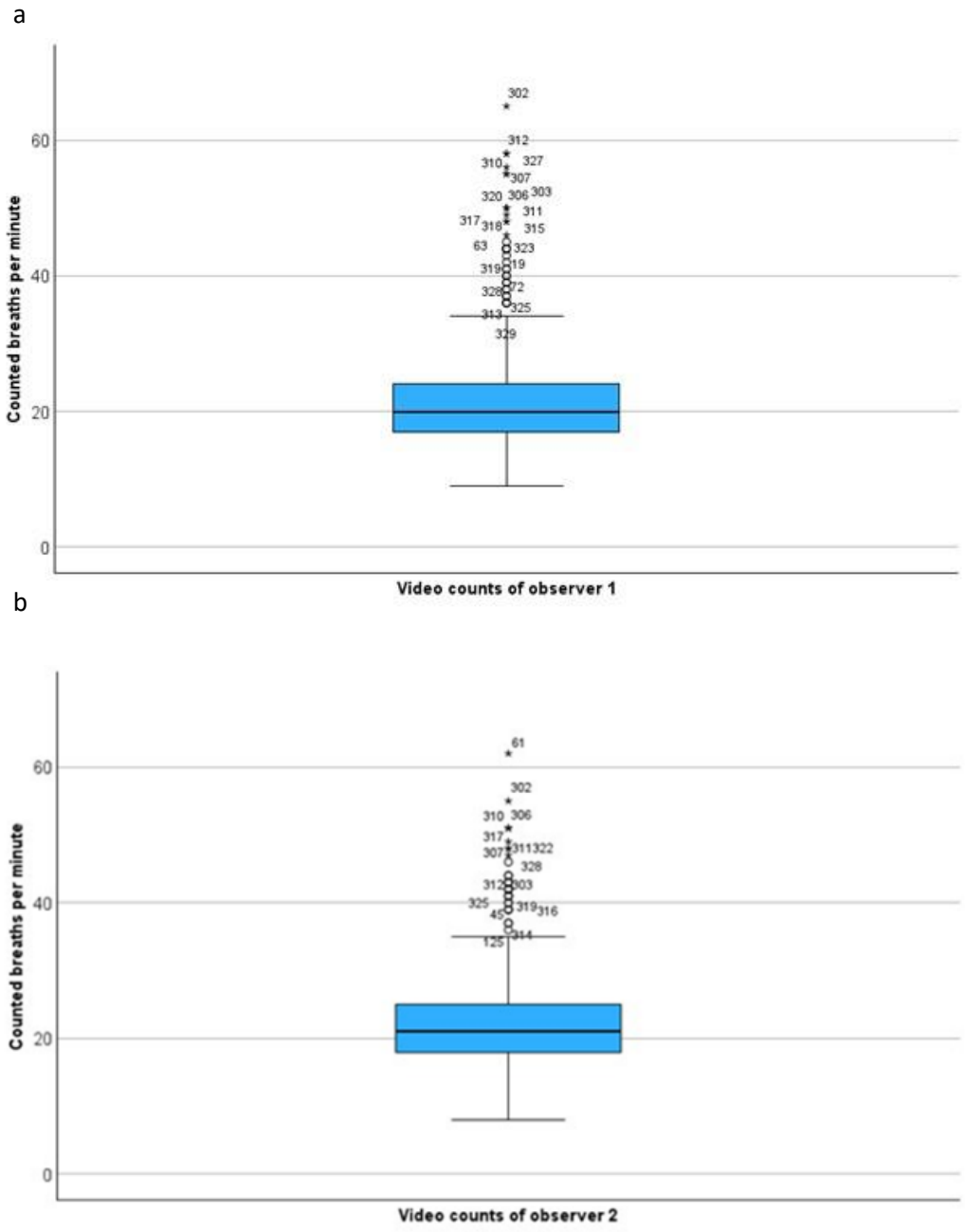
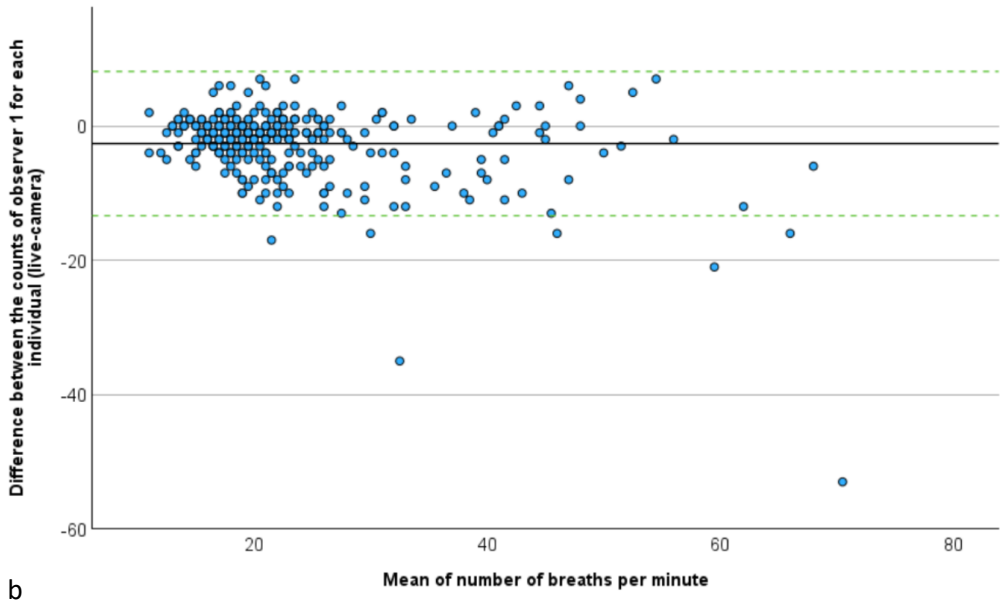


Fig. 8a Data from the camera count of observer 1 and Fig. 8b of observer 2.

Normal distribution was tested using the Shapiro-Wilk test. The significance values determined were <0.001 for both observer 1 and 2.

The differences between the live count and camera count values determined by both observers for each calf are shown in Bland-Altmann-Plots in Fig. 9.

a



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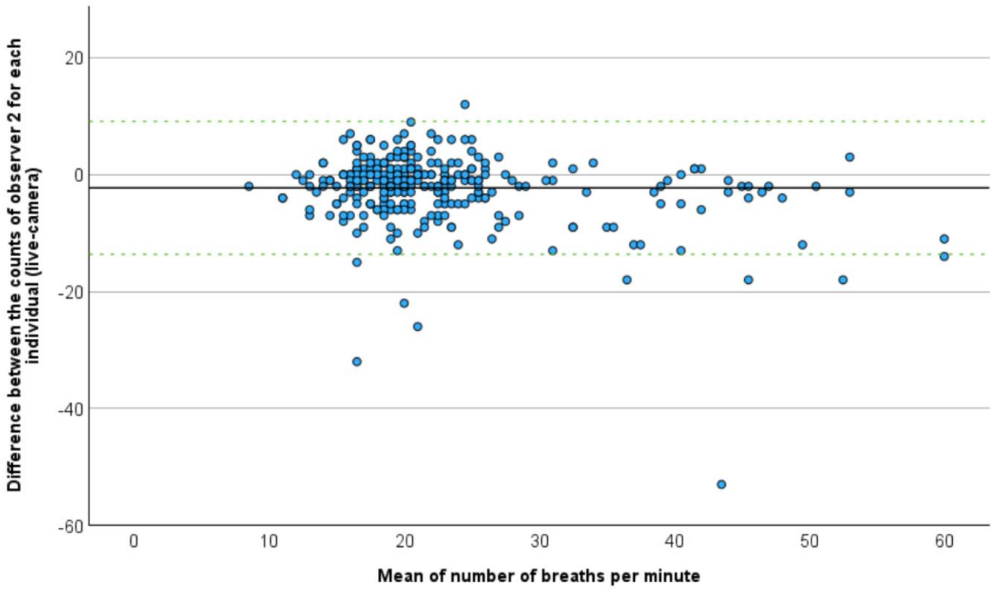


Fig. 9a Differences between the camera and live counts of observer 1 and Fig. 9b of observer 2.

The deviations between the counts are more or less evenly distributed in the positive and negative range. No general trend can be recognised. In the negative range, however, there were more data points with a deviation that exceeded the standard deviation.

The live counts were subtracted by the camera counts. The black line marks the zero value on the y-axis, which means that there is no difference between the live and camera counts, respectively. The dashed green lines show the standard deviation multiplied by the confidence interval.

There were a total of 10 calves for which the difference between the live-counted values and those determined by camera was greater than the standard deviation (Table 1). Seven of these outliers occurred in the data collected by observer 1. Eight outliers occurred in the data obtained by observer 2. In five calves, both observers counted significantly higher respiratory rates under live conditions than with the camera.

Tab. 1. Difference between the respiratory rates recorded by camera and those counted under live conditions for both observers.

Count	Diff. Observer 1	Diff. Observer 2	Reason
36	-16		white calf in direct sunlight
42	-35	-32	chain is in the view, biggest possible distance from calf to camera
57		-26	chain is in the view, biggest possible distance from calf to camera
61	-16	-14	white calf in the sun, scratched camera, biggest possible distance from calf to camera, just one view because lying under the nest
112	-17		dark brown calf in the shadow
251		-15	dark brown calf in the shadow, lying on the very edge of the field of vision
307		-15	Scratched camera, lying on the edge of the field vision, high frequency
318	-21	-18	Lots of calves, walking during counting, high frequency

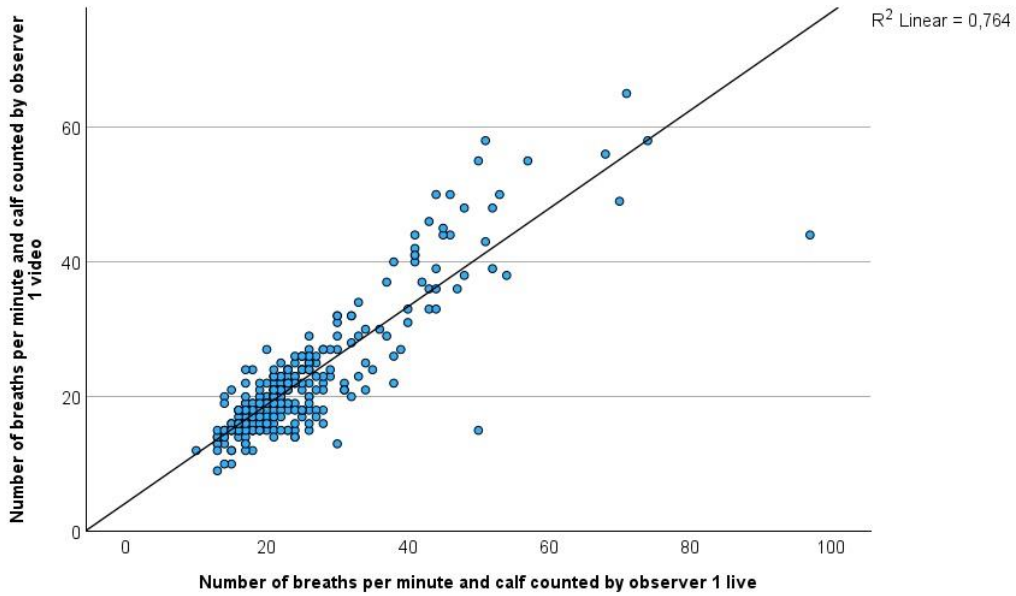
324	-16	-18	white calf in direct light, high frequency
326	-53	-53	walking, moving a lot, sniffing, high frequency

3.3. Comparison of the respiration rates counted under live conditions and from the camera recordings

The respiration rates counted under live condition were compared to those counted from the camera recordings. The live counts and the camera recorded values of observer 1 showed a significant Spearman correlation of r=0.8 at a significance level of p=0.001. The linear regression coefficient of both data sets was high with R^2=0.8 (Fig. 10 a).

The live counts and the camera recorded values of observer 2 showed a significant correlation of r=0.7 at a significance level of p=0.001. The linear regression coefficient of both data sets was high with R^2=0.7 (Fig. 10 b).

a



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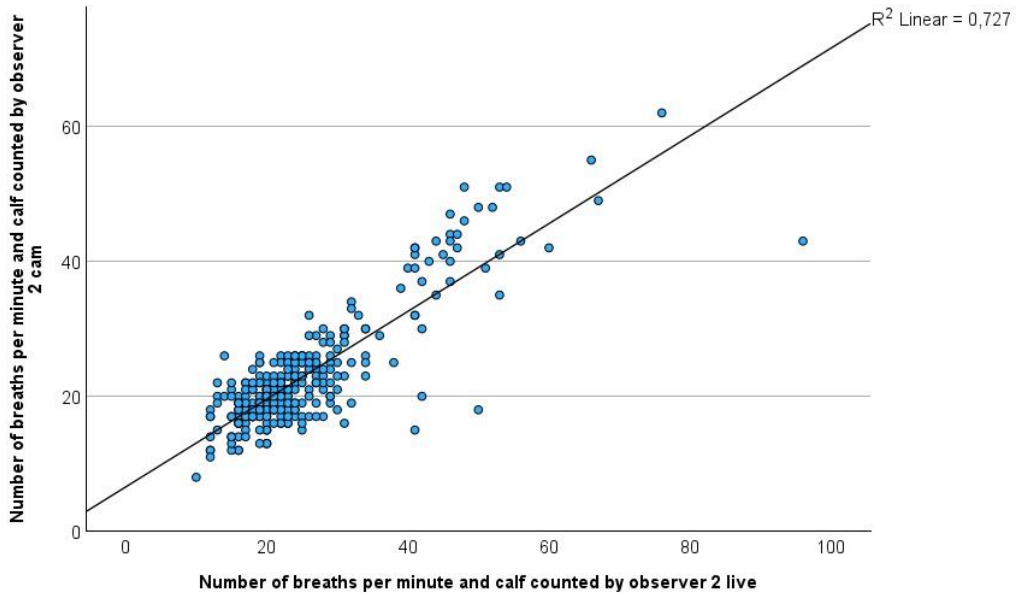

Fig. 7a Linear regression of the live counts and the camera counts of observer 1 and Fig. 10b of observer 2.

3.4. Verifying the accuracy of the camera-based detection of the respiration rate

A substantial p_c value of 0.97 was observed for the live counts of observer 2 compared to the gold standard (live counts of observer 1). Only poor p_c values were observed for the camera-based detection of the respiration rate. The p_c value of both observers was p_c= 0.8.

A receiver operating characteristic curve (ROC) with live counts of observer 1 as reference is presented in Figure 11. The live counts of observer 2 showed very high values in terms of sensitivity and specificity. The area under the curve (AUC) was 1. The AUC of both observers for the camera counts was 0.8. The True Positive Rate (TPR) was 0.65 for observer 1 and 0.66 for observer 2. The False Positive Rate (FPR) was 0. The specificity was 0.62 for observer 1 and 0.65 for observer 2.

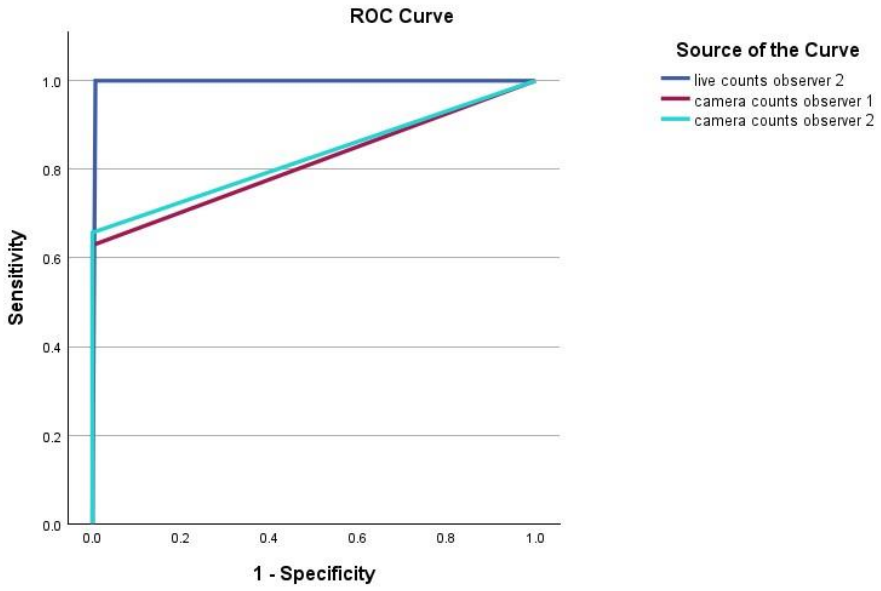

Fig. 8 Receiver operating characteristic (ROC) analysis for verifying the camera-based detection of the respiration rate of observer 1 and 2 with the live counts of observer 1 as reference.

4. Discussion

Heat stress is a problem in calf rearing that will continue to increase in the future due to the current climate change (7). To avoid heat stress, farmers have permanent, semi-flexible and flexible options to choose from. In addition to the selection of a suitable housing system (35, 36) and its orientation (37), the permanent options also include shading structures of various kinds (38–40). Semi-flexible options include, for example, reflective covers (41, 42), while flexible methods are based, for example, on the use of fans to increase air circulation (43, 12) and nutritional management (44–46).

In order to optimise the use of such semi-flexible and flexible methods in response to an existing stress situation, the farmer needs reliable decision-making aids. The basis for every decision is the reliability of recognising stress symptoms. One stress symptom that is often used in practice as a basis for decision-making is an increase in respiratory rate. This is usually determined by a trained observer counting the respiration rate (frequency) of the animals by direct observation in the barn (47, 32). However, as this procedure is time-consuming and labour-intensive (48–50), only allows to determine the respiration rate during short time periods during the day, and also causes stress for the animals (30), there is a desire to develop automated measurement methods. So far infrared thermography (IRT), based on thermal fluctuations around the nostrils during inhalation and exhalation (51, 52), respiration rate sensors using the pressure difference between inhaled and exhaled breath (30, 48), spirometry and impulse oscillometry systems (ios) have been described (53). All these methods work sufficiently but are only suitable for routine use in practice to a limited extent for various reasons.

For example, the infrared thermography method has the disadvantage that the changes in environmental conditions over recording periods must be taken into account. In addition, the sensors are sensitive to sunlight and in hot conditions the ambient temperatures can be similar to the exhaled air, which makes it difficult to recognise the temperature fluctuations (51). The method of assessing respiratory frequency by measuring the pressure difference between inhalation and exhalation has the disadvantage that equipment on the animals' head (halter and a nose ring) are required, for which the calves must be at least one week old to ensure a good fit. The calves also experience stress caused by the unfamiliar equipment, which may affect the

sensor. This can make it difficult to distinguish physiologically relevant values from artefacts (30). This method also requires closely timed monitoring, as the power bank has to be replaced regularly (e.g. every 6 hours) depending on the device (48). The method of spirometry and impulse oscillometry systems (ios) consists of a balloon catheter in the oesophagus, a pneumotachograph and a tight-fitting face mask and is therefore more labour-intensive and not suitable for continuous monitoring (53).

A method that is simple, requires little technical effort, and works reliable under on farm conditions does not yet exist.

There is currently great hope in the development of computer vision methods in which the calves are camera observed. There are also promising computer vision algorithms with regard to evaluation of respiration rates in cattle (31). However, there is still no methodology that is sufficiently developed for routine use on farm. This requires further development.

The here presented work is intended to function as a bases for the development of computer vision to automatically determine respiration rate in calves. A prerequisite, therefore, is that the results generated by camera recordings correspond sufficiently with the reference method, counting the respiration frequency by direct observation of each individual under live conditions in the barn. Consequently, the aim of the present study was to compare whether the respiration rates determined for calves using permanently installed cameras match the ones counted by trained personnel under live conditions.

The interobserver reliability (Spearman correlation, linear regression coefficient, Lin's concordance correlation coefficient and AUC) between the two observers in the assessment of respiration rates by direct observation of the animals was nearly perfect. This was an important prerequisite to use this as a reference method for the video-based observations. Slight deviations in the results between the two observers can be explained by different viewing angles or activities like chewing in calves that made counting difficult.

Another important finding was, that in the used setting and camera positions, 9 % of the camera sequences could not be evaluated. This was due to:

- scratches in the camera caused by the calves, when cameras had to be installed in the reach of calves (under the roof in the nest area).
- too superficial breathing (sniffing).
- lack in contrast (dark calf in the shade, light calf in the light).
- too dark surroundings.
- too much movement of calves during the evaluation (running, jumping).
- behaviour that influenced flank movement (chewing, suckling).
- calves (partly) covered by other calves or barn equipment.

Some of these problems could be overcome by changes in camera settings. Protection of cameras from calves without impairment of the video quality is challenging and currently tested. Other factors will always interfere with camera observations like covering by other animals, excessive movement, high frequency and superficial breathing.

In contrast to the finding in direct observations, the agreement between the two observers in counting the respiration rates in video recordings was lower with a Spearman correlation of $r=0.7$ ($p=0.001$) and a regression coefficient of $R^2=0.8$.

There were a total of ten calves for which the difference between the live-counted values and those determined by camera was greater than the standard deviation. In five calves, both observers counted significantly higher respiratory rates under live conditions than with the camera. It is noticeable that the difference in these sequences were comparable between both observers. This suggests that these camera recordings were difficult to analyse.

Overall, when counting the respiration rate via direct observation in the barn both observers regularly counted (in 65 and 60 % of cases) higher frequencies than on the recorded videos. A possible explanation could be, that on the recordings it cannot be clearly distinguished between the single breaths, especially when the respiration rate is high. In addition, unlike counting on video recordings, it is possible to continuously adjust the position of the observer during live counting to ensure an optimum viewing angle. This can be of importance, when using video observations or computer vision for classifying calves as heat stressed.

Problems that made it difficult to reliably evaluate the respiratory rate of camera recordings have also been described in other studies. For this reason, Strutzke et al., (48) filmed the cattle for 5 minutes and then only used 1-minute film sequences in which the cattle could be assessed perfectly. Continuous monitoring like in computer vision could overcome this problem.

4.1.Summary and outlook

To summarise, it can be said that the respiration rates of calves can be assessed by video recordings. The comparability with data gained by direct observation in the present study have however, been too low for an assessment of stress symptoms. Changes in the settings have to be done to improve this. Such an improvement can be achieved by using high-quality cameras, optimal positioning of the cameras, good illumination of the barn, and improving the contrast in camera settings. For continuous evaluation or taking sequences for video observation only good quality sequences could be chosen, as it is not necessary to count every minute to detect heat stress associated increase in respiration rate.

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Supplements

S1

number	Live counts Observer 1	Live counts Observer 2	Camera counts Observer 1	Camera counts Observer 2
1	13	10	9	8
2	22	23	23	23
3	20	20	15	17
4	17	18	15	19
5	17	17	15	17
6	18	18	12	17
7	33	32	34	34
8	15	16	10	12
9	19	20	16	13
10	19	19	19	19
11	17	17	13	16
12	14	16	10	12
13	17	16	19	17
14	20	21	19	21
15	20	20	19	19
16	16	12	14	12
17	19	19	15	20
18	21	16	16	19
19	38	40	40	39
20	20	20	20	20
21	36	30	30	18
22	18	19	15	
23	26	26	18	32
24	25	24	24	24

25	32	31	32	30
26	26	25	26	26
27	20	19	18	26
28	19	19	19	19
29	35	33	24	32
30	31	26	22	25
31	26	24	15	17
32	17	17	15	22
33	17	18	17	
34	17	17	14	17
35	22	22	21	21
36	38	34	22	30
37	18	20	15	18
38	26	31	22	23
39	18	22	17	20
40	25	26	21	24
41	22	23	20	20
42	50	50	15	18
43	22	20	21	21
44	25	24	24	22
45	46	46	44	40
46	19	15	18	21
47	23	19	21	23
48	16	16	16	17
49	18	15	15	12
50	14	16	13	20
51	24	25	14	17
52	10	12	12	12
53	26	23	20	25
54	22	29	23	19
55	24	25	22	

56	19	20	19	18
57	39	41	27	15
58	18	18	17	17
59	22	22	22	22
60	23	24	22	22
61	74	76	58	62
62	17	18	17	18
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69	31	30	21	25
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72	41	41	40	41
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74	19	18	18	18
75	32	32	32	33
76	13	12	14	11
77	22	23	25	26
78	18	19	19	19
79	27	27	25	26
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81	19	21	19	20
82	13	12	13	18
83	34	36	25	29
84	18	19	16	20
85	21	20	19	22
86	25	25	17	

87	22	22	22	22
88	23	23	19	23
89	16	16	15	16
90	16	15		
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94	26	21	29	20
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96	22	20	20	18
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115	34	34	21	30
116	26	26	20	26
117	21	20	20	19

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119	14	12	14	14
120	23	19	24	25
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123	32	32	20	19
124	23	23	22	21
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146	19	19	18	17
147	22	20	20	15
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153	24	20	18	13
154	25	25	24	25
155	19	21	20	18
156	14	14		
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162	29	29	27	25
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176	18	19		
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178	19	20	17	21
179	21	22	21	16

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209	19	21	20	20
210	30	32	32	25

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215	25	24	18	26
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233	27	23	21	16
234	42	42		20
235	26	29	19	28
236	13	15	15	13
237	20	21	19	19
238	18	16	17	18
239	20	20	16	20
240	26	27	24	19
241	19	18	17	22

242	22	16	23	19
243	26	24	24	21
244	30	30		23
245	16	20	18	21
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260	15	24	21	19
261	19	24	21	25
262	17	12	16	17
263	22	23	17	24
264	22	15	21	20
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267	23	22	24	16
268	20	20	19	20
269	22	27	15	25
270	22	22	19	18
271	21	21	19	18
272	21	14	23	26

273	15	13	16	19
274	14	13	19	22
275	23	23	22	21
276	18	15	18	22
277	16	15	16	17
278	18	22		20
279	27	28	26	24
280	16	19	16	18
281	15	16	15	16
282	17	19	18	15
283	25	26		
284	34	34	30	23
285	16	17	18	
286	16	18	16	17
287	21	21	17	16
288	15	15	15	14
289	21	25	24	26
290	19	20	19	20
291	26	27	26	25
292	19	18	22	17
293	17	17	20	14
294	15	16	15	19
295	24	24	26	26
296	21	21	21	20
297	30	28	32	30
298	17	20	24	17
299	25	26	26	25
300	23	23	22	17
301	41	42	44	30
302	71	66	65	55
303	46	45	50	41

304	52	47	39	42
305	40	41	33	32
306	53	53	50	51
307	68	67	56	49
308	48	56	38	43
309	45	47	44	44
310	57	54	55	51
311	48	48	48	46
312	51	53	58	41
313	47	51	36	39
314	43	46	33	37
315	45	44	45	43
316	44	41	39	39
317	52	52	48	48
318	70	60	49	42
319	41	42	41	37
320	44	46	50	43
321	41	41	42	42
322	51	50	43	48
323	41	41	41	42
324	54	53	38	35
325	42	43	37	40
326	97	96	44	43
327	50	48	55	51
328	43	46	36	47
329	44	44	36	35
330	44	41	33	32