Aus der
Tierklinik für Fortpflanzung
des Fachbereichs Veterinärmedizin
der Freien Universität Berlin

Activity monitoring in dairy cattle: Evaluation of a technical estrus detection device

Inaugural-Dissertation
Zur Erlangung des Grades eines
Doktors der Veterinärmedizin
an der
Freien Universität Berlin

Vorgelegt von
Ina Michaelis
Tierärztin aus Bergisch Gladbach

Berlin 2015
Journal-Nr.: 3841

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Für

Finley

Margrit & Günter

Mein Mädchen wann dürfen wir dich endlich Frau Doktor nennen? Das würde ich so gern noch miterleben... (Opa Michaelis 91 Jahre)

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1. Introduction

1.1 Estrus in dairy cows

In mammals, estrus is a behavioral symptom and strategy to ensure that a female is mated close to the time of ovulation. Estrus in cows is an external and visible sign of ovulation, an internal and invisible event (Roelofs 2010). During estrus the uterus is swollen, the vagina is hyperemic and swollen, mucus vaginal discharge and cows behavior changes due to hormonal influence of gonadotropin releasing hormone (GnRH) and estrogen. Typical signs of estrus in dairy cows include cajoling (flehmen), restlessness, sniffing the vagina of other cows, chin resting, mounting but not standing, mounting (or attempt) other cows and mounting other cows head side. However the most pronounced sign of estrus is the standing heat which is characterized by standing immobile when being mounted by other cows (Van Eerdenburg 2002). Furthermore a drop of milk yield has been demonstrated to be a good indicator for estrus (Schofield et al., 1991).
The correct identification of cows in estrus is essential to provide an artificial insemination at the correct time. However, estrus detection is time consuming and difficult to implement on modern dairy farms. Poor estrus detection is one of the most important problems, is limiting high reproductive performance in dairy cows (Senger, 1994). Estrus detection efficiency is defined as the probability of a cow being detected when in estrus (Heuwieser et al., 1997). Poor efficiency of estrus detection not only increases the time from calving to first AI but also the average interval between AI services (Stevenson and Call, 1983) limiting the rate at which cows may become pregnant (Valenza et al., 2012). The most important factor affecting the efficiency of estrus detection is that farm staff responsible for estrus detection should fully understand the signs and be committed to estrus detection (Diskin and Sreenan, 2000). Estrus signs in pregnant cows make the situation even more difficult. Pregnant cows will sometimes even show standing behavior when being mounted (Dijkhuizen 1997). Achieving efficient estrus detection by visual observation requires experience, diligent attention, and time (Harris et al., 2010). Several risk factors such as milk yield, lameness, poor nutrition, and herd size have been identified to affect reproductive performance (Roelofs et al., 2010). For example, milk production increases steadily and the metabolic clearance of steroid hormone related to high milk production (Sangsritavong 2002) probably reduces behavioral manifestation of estrus (Roelofs 2010). A bull in the same barn can have positive effects on estrus behavior since the interactions of a fenceline-housed bull to the cows are higher during estrus. On the other hand the interactions with a bull may inhibt the cow to cow mounting (Kilgour 1977). Recently, it has been demonstrated that today's cows show fewer signs of estrus and for shorter duration. Therefore it is more challenging for farmers to identify estrus (Dobson et al., 2007). It has been demonstrated that the average estrus period lasts for about 9.5 h during which the cow mounts other cows on average 10.1 times. Only 6 mounts lasted more than 2 s (Walker et al., 1996). Some cows express signs of estrus for less than 3 h (Roelofs et al., 2005). These data illustrate that on average the opportunity to identify a cow in estrus is relatively short (i.e. 24.1 s per 21 d cycle).

1.2 Estrus detection methods

Traditionally, estrus detection was performed by visual observation for signs of mounting behavior, which is accurate, but larger herd sizes and less labor per cow reduce opportunities for visual observation. As a result estrus detection efficiency is often below 50% (Homer et al., 2013, Van Eerdenburg et al., 2002, Roelofs et al. 2006). It is well documented that activity of cows increase considerably during estrus (Kiddy, 1977, Schofield, 1991, Wendl, 1995). Highest conception or pregnancy rates were reported when the artificial insemination was performed between 5-17 h after the increase of activity (Maajte 1997, Roelofs 2008). The observation of increasing activity has been utilized in different applications. Automated systems have been developed to detect cows standing to be mounted or to determine increased activity (Nebel et al., 2000, Firk et al., 2002). Different technologies such as heat mount detectors and activity monitoring systems have been commercialized and validated (At-Taras and Spahr, 2001, Cavalieri et al., 2003a, Cavalieri et al., 2003b). Activity meters such as pedometers or accelerometers for automated estrus detection have been reported as useful (Kamphuis et al., 2012) achieving estrus detection efficiencies from 81.4% to 91.3% (Cavalieri et al., 2003a). However, the error rate is variable and reported to range between 17 and 55% (Firk et al., 2002).
Recently, a direct comparison between different commercially available estrus detection aids, i.e. pedometers (SAE Afikim, Kibbutz Afikim, Israel), accelerometers (Heatime, SCR Engineers Ltd., Netanya, Israel) and 2 heat mount detectors (Scratchcard Dairymac, Hampshire, UK; KaMaR, Zionsville, USA) was conducted with the objective to determine test characteristics of these different technological approaches (Holman et al., 2011). Sensitivity expressed as estrus events coinciding with periods of low milk progesterone was 63.3%, for the pedometer, 58.9%, for the accelerometers attached to neck collars, 56.7% for the KaMaR heat mount detectors and 35.9% for the Scratchcard heat mount detectors. A further automated estrus detection device, which is detecting mounting behavior, is a system named HeatWatch (CowChips LLC, Manalapan, NJ). It uses digital radio transmitters incorporating a pressure switch that are glued onto the tailhead and have a reported accuracy of 87.5% (Rorie et al., 2002). Although several studies have described the use of commercially available activity monitoring systems and the factors that influence their success (Yaniz et al., 2003, Lopez-Gatius et al., 2005) only few studies measured their performance on commercial dairy farms or in direct comparison with other reproductive management tools.
More recently an automated activity monitoring (**AAM**) system (Heatime, SCR Engineers Ltd., Netanya, Israel) has become commercially available that provides data for individual cow activity levels. According to information provided by the manufacturer and German AI companies, about 1,700,000 AAM tags have been sold worldwide and approximately 100,000 tags are currently used on dairy farms in Germany, respectively. Science-based information about the efficiency of the AAM system in comparison of a traditional estrus detection protocol is not available.
Therefore a the overall objective of my studies was to determine the usefulness of this device to detect cows in estrus. In a first study we surveyed estrus detection practices in Germany and the experiences of farmers who used the AAM Heatime. Secondly, conducted a large scale study to evaluate an automated activity monitoring system to detect estruses in dairy cows in comparison to visual observation.
The results of the studies were published in Reproduction in Domestic Animals (impact factor 1.515) and Tierärztliche Praxis Grosstiere (impact factor 0.528):

Evaluation of oestrous detection in dairy cattle comparing an automated activity monitoring system to visual observation
Michaelis I, Burfeind O, Heuwieser W.
Reprodution in Domestic Animals, 2014, ;49:621-628

Estrus detection in dairy cattle: changes after the introduction of an automated activity monitoring system?
Michaelis I, Hasenpusch E, Heuwieser W.
Tierärztliche Praxis Ausgabe Grosstiere/ Nutztiere, 2013, 41:159-165.

Addtionally the results were presented on the Phd symposium 2013 in Berlin :

Evaluation of an automated activity monitoring system to detect estruses in dairy cows in comparison to visual observation (Doktorandensymposium 2013/ DRS Präsentationsseminar)

2. Publication I:

Estrus detection in dairy cattle: Changes after the introduction of an automated activity monitoring system?

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Brunsterkennung bei Milchkühen: Veränderungen nach der Einführung eines automatisierten, aktivitätsmessenden Brunsterkennungssystems?

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2.1 Summary

Objective: In context of the study farmers using an automated activity monitoring (AAM) system called Heatime were surveyed on estrus detection practices. The aim of the study was to gain an overview of the usual estrus detection methods and especially to learn about the practical aspects of that system. Material and methods: Items addressing farm and animal environment, estrus detection before and after installation of Heatime, reproduction, Heatime management and the farmer's perception of efficiency were asked. Results: A total of 232 survey forms were returned (58.3% response rate) and 219 surveys could be used for final analysis. Visual observation was the most common practice to detect estrus. After installation of the Heatime system the farmers assessed that the application of hormones for re-production management decreased. The majority of the responding dairy farmers (93.1%) strongly agreed or agreed that heat detection was higher after the installation of Heatime. Most of them (92.3%) strongly agreed or agreed with the statement that the reproduction management became easier with Heatime. Conclusion: Overall, 94.1% of the responding farm managers were satisfied with the Heatime system and almost all of them (94.5%) would install the system again. Clinical relevance: The results show that the Heatime system is a well accepted estrus detection aid and has the potential to reduce the time needed for estrus detection and might potentially reduce the use of hormones.

2.2 Key words

Activity monitoring, dairy cattle, accelerometer, estrus detection

2.3 Introduction

Reproductive efficiency remains of major importance for the dairy industry (17, 26). Senger (29) described the poor detection of estrus as the most important problem, which is limiting high reproductive efficiency. Several risk factors such as milk yield, lameness, poor nutrition, and herd size have been identified to affect reproductive performance (22). Estrus detection efficiency has the highest correlation with the calving to conception interval and the greatest impact on reproductive performance (2, 8). The average estrus detection rate in dairy herds ranges widely from approximately 50% to 92% (9, 18). Recently, it has been demonstrated that today's cows show fewer signs of estrus and for shorter duration. Mainly the durations and intensities of behavioral signs are decreased in terms of reduced sniffing of the vulva and less mounting activity. Therefore it is more difficult for farmers to identify estrus (7). Some cows express signs of estrus for less than 3 hours (24). It has been demonstrated that the average estrus period lasts for about 9.5 hours during which the cow mounts other cows 10.1 times on average. Only six mounts lasted more than 2 seconds (31). These data illustrate that the opportunity to identify a cow in estrus is relatively short (i. e., 24.1 seconds per 21 day cycle).

A variety of estrus detection aids such as heat mount detectors, activity monitoring systems, and tail paint were developed and validated (1, 4, 5). It is well documented that activity of cows in- creases considerably during estrus (16, 28, 34). This observation has been utilized in different applications. Activity meters such as pedometers or accelerometers for automated estrus detection have been reported as

useful (15). A further approach were milk progesterone tests, which were commercialized to detect non-luteal periods and to indicate estrus detection errors (19). While high concentrations of progesterone indicate interestrus low concentrations are not necessarily indicative of estrus. Furthermore, the progesterone concentration in milk is highly correlated with the milk fat content (i. e. low before milking, high after milking) which makes the assessment of the concentration more difficult (10, 13). In the past years one AAM system (Heatime, SCR Engineers Ltd., Netanya, Israel) has been promoted by several AI companies and is increasingly used by the dairy industry. According to information provided by the manufacturer and German artificial insemination companies, about 1,700,000 Heatime tags have been sold worldwide and approximately 100,000 tags are currently used on more than 1000 dairy farms in Germany, respectively. The Heatime system consists of animal tags, a small control terminal and an identification (ID) transceiver. The animal tags monitor individual cow activity levels and 24 hour cumulated activity. Every animal movement and movement intensity is provided using a three-dimensional accelerometer. The data is analyzed and filtered by using an algorithm in an on-board processing unit. The result is a dimensionless activity index that is stored in 12 2-hour memory cells. The neck collar positions the logger on the left side of the neck. The ID transceiver should be located at a place were each cow passes trough at least twice a day. Suggestible locations are, for example, above the exit from the milking parlor or over drinking stations. When a cow passes the ID transceiver data is sent via infrared communication from the tag to the control terminal and over a possible connection to the farm computer (Heatime for PC, SCR Engineering Ltd., Netanya, Israel).
Most recently a direct comparison between pedometers (SAE Afikim, Kibbutz Afikim, Israel), accelerometers (Heatime) and heat mount detectors (Scratchcard, Dairymac, Hampshire, UK or KaMaR, Zionsville, USA) was conducted on one commercial UK dairy farm (14). The results based on 67 Holstein Friesian cows demonstrated a sensitivity of 58.9% for the accelerometers, 63.3% for the pedometers, 56.7% (KaMaR) and 35.9% for the heat mount detectors (Scratchcard) compared to the concentration of milk progesterone as the reference method. A true estrus was defined as any event identified as estrus by a given detection method that coincided with a period of milk progesterone less than 0.3 ng/ml followed by a period of milk progesterone more than 0.3 ng/ml. When two of these methods were combined the sensitivity in- creased up to 75.9% and the positive predictive value was 60.3%. Data on specificity were not provided.
Current information about long term experiences and practices how the Heatime system is being used on commercial dairy farms is not available. Therefore, the objective of this study was to identify current management practices related to estrus detection in Germany via a survey of dairy managers using the Heatime system particularly considering factors that could influence estrus detection efficiency.

2.4 Material and methods

A comprehensive survey form was developed to obtain information about common management practices related to estrus detection from farmers using the Heatime AAM system. The survey was conducted in cooperation with two German semen sales companies (Rinderproduktion Berlin-Brandenburg, Groß Kreutz; Rinderzucht Schleswig-Holstein eG, Neumünster), which also support the purchase of the Heatime system to their customers. The survey form was delivered to the herd managers in

March and April 2011 by mail and was returned anonymously.
The questionnaire included a total of 49 questions related to four sections; i.e. farm and animal environment (7 questions), estrus detection before and after installation of Heatime (14 questions), aspects about reproduction and Heatime management (10 questions), and the farmer's perception of efficiency (18 questions). The questions were open (10 questions), closed-ended (11 questions) or coded on a 5-point Likert scale (18 questions). Questions were analyzed by herd size, with herds categorized as small (< 100 cows; n = 136), medium (100 to 199 cows; n = 71), or large (_ 200 cows; n = 12) based on the number of cows. Percentages were rounded to the nearest whole percentage point. The data were analyzed using IBM SPSS Statistics for Windows (Version 20.0, IBM Deutschland GmbH, Ehningen, Germany).

2.5 Results and discussion

A total of 232 survey forms were returned in May and June 2011. That implies a 58.3% response rate, which is considerably high regarding other mail surveys (12, 33). Due to incomplete information 13 forms (5.6%) were excluded. In the remaining 219 survey forms most questions had been answered and these were used for final analysis.
Table 1 provides the information from the first survey section regarding the farm and animal environment. Most of the responding farms (99.5%) had box stalls whereas 60.3% and 55.3% used straw and rubber mats as bedding material for the stalls, respectively. Access to pasture was provided by 79.0% of the farmers.
In the second section of the survey, questions about estrus detection before and after the installation of Heatime were asked (Table 2). Before and after the Heatime system was installed al- most every farm used visual observation to detect or to support detection of cows in estrus, respectively. The time spent on visual estrus detection decreased after the installation. It is well known that the efficiency of estrus detection by visual observation requires experience, diligent attention and time (11). Furthermore, the increasing herd size as well as the increasing reliance on unskilled labor turn estrus detection into a challenge (6). Our survey data show that an automated system for estrus detection can help alleviate these problems.
Estrus detection in heifers through visual observation was less common. Some of the farm managers (18.7%) answered that they used other aids to detect heifers in estrus. Almost all of them (92.7%) stated the use of a bull to service the heifers.
Heat mount detectors were used in only 7.3% and 1.4% of the farms before and after Heatime installation, respectively. Pedometers (0.5%) and other devices (4.6%) were not commonly applied. In a similar survey with 153 large commercial dairy farms located in the United States Caraviello et al. (3) showed that only few herd managers used pedometers or pressure-activated rump- mounted patches to detect estrus. The reason might be a relatively low efficiency of those systems or a high loss rate. In a French study efficiency and accuracy of an electronic device detecting cows standing to be mounted (DEC system, IMV Technologies, France) was evaluated (25). The study utilized 30 Holstein cows and demonstrated efficiencies of 35.4% (DEC system) and 68.8% (visual observation), respectively.
Regarding pedometry, Wangler et al. (32) described sensitivities between 73% and 95% depending on threshold values. In order to have high sensitivities error rates between 54% and 80% had to be accepted. The results indicated that using pedometer data alone did not produce optimal results (32).

The application of hormones for reproductive management decreased after the Heatime system was installed. About 6.8% of the responding dairy farmers completely stopped the use of hormones to induce estrus and 38.8% indicated that the hormone usage was reduced since the installation of Heatime. Even though the proper use of hormones does not have any known negative effect on animal welfare or public health, consumers are concerned about food safety and have a growing interest in animal health and welfare issues especially ethical concerns regarding the use of hormones and antibiotics (21). We speculate that such concerns will become increasingly important for the dairy industry and technical aids besides hormones to assure proper reproductive performance are beneficial and valuable to address those negative perceptions. As most recently demonstrated (20) overall reproductive performance was similar between management based on the automatic activity monitoring (AAM) system and a synchronization program for timed artificial insemination (TAI). In some instances times to pregnancy was shorter with the AAM system. This comparison demonstrates that AAM systems might be an efficacious approach to reduce hormone use.

Responses by herd managers to questions related to reproduction and Heatime management are summarized in Table 3. On average the responding farms had used the system for 9.8 ± 6.6 (mean ± SD) months. Only 49.3% answered that they had a sufficient number of tags for their cows. The farms defined as small had 67.9 ± 15.4 cows and used 31.7 ± 11.7 tags, which was considered to be not enough by 53.7% of the farmers. The manufacturer recommends tags for only 40% of the herd if breeding is not seasonal. More than 70.0% of the farmers checked the animals for signs of estrus after an alert. The average interval from calving until first insemination was 64.3 ± 13.8 days. In 82.2% of the farms an artificial insemination (AI) technician conducted the inseminations.

In the fourth section the farmer's perception about the Heatime system was surveyed (Table 4 and Table 5). The majority (93.1%) strongly agreed or agreed that estrus detection was higher after the installation of Heatime. On their website the manufacturers advertise that the Heatime system improves fertility rates and calving cycles, reduces days open and reduces expenses on semen. More than half of the farmers (57.1%) strongly agreed or agreed that the success of the insemination was better. However, only 36.1% had the impression that reproduction performance improved in general. These perceptions are in line with observations that estrus detection aids can help to improve estrus detection rates; but it will take some time to see an improvement in fertility parameters such as calving interval and insemination number (22). It is important to point out that these findings are based on a survey investigating personal perceptions. Further research is warranted to validate our survey results with actual reproductive performance data. Most of the responding dairy farmers (92.3%) strongly agreed or agreed with the statement that the reproductive management became easier with the Heatime system. Also 82.2% of the farmers strongly agreed or agreed that they saved time utilizing the Heatime system but only 53.5% confirmed a financial benefit.

2.6 Conclusion and relevance

The results of this survey demonstrated that the Heatime system is a well-accepted estrus detection aid, which has the potential to reduce the time needed for estrus detection and might potentially reduce the use of hormones. The data is based on a

survey and therefore on personal perceptions of the participating farmers. Since science- based information on the validity of the Heatime system is scarce more research is required to determine the efficiency.
Overall, 94.1% of the responding farm managers were satisfied with the Heatime system and almost all of them (94.5%) would in- stall it again. It is noteworthy that 55.7% would not have bought the system without financial support of the semen sale companies. As previously stated it is important that purchase and maintenance costs of an estrus detection system pay off (29). The majority of the respondents strongly agreed or agreed with the statement that the Heatime system was easy to handle (81.2%) and technical problems were uncommon (86.3%). Heatime can be purchased as a stand-alone unit, which does not require a computer or previous computer knowledge as the manufacturer describes. This might be advantageous for small farms without a computer. We speculate that a missing integration into an existing herd management soft- ware, however, could also be considered as a major drawback.
The last three questions focused on further interest to timely identify diseased animals, detect rumination activity and monitor animal health. In a recent study a system for monitoring rumination in dairy cows (Hi-Tag, SCR Engineers Ltd., Netanya, Israel) which incorporates not only an identical accelerometer but also a rumination monitoring device was validated in dairy cows (27). However, to detect cows close to parturition or sick cows by means of daily rumination time further research is required (27). Identification of sick cows in the postpartum period has been recognized as important for a swift return of the animals back to a healthy state (30). About 54.8% of the responding farmers were interested in such a system. These survey data demonstrate that maintaining a dairy cow's health during the periparturient period is a major challenge for dairy producers as mentioned by Smith and Risco (30).

2.7 Acknowledgement

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Conflict of interest
The authors confirm that they do not have any conflict of interest.

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Table 1 Summary of responses by herd managers (n = 219) to questions related to farm and animal environment

Tab. 1 Antworten von 219 Milcherzeugern zum Betrieb und der Tierhaltung

Survey question and answer categories	**Herd size**			
	Small (n = 136)	**Medium (n = 71)**	**Large (n = 12)**	**All herds (n = 219)**
How many cows do you have?	67.9 ± 15.4	124.3 ± 23.6	256.7 ± 87.1	96.5 ± 53.7
How many heifers do you have?	29.5 ± 8.7	49.0 ± 14.5	105.8 ± 68.6	39.9 ± 26.2
How many employees do you have?	1.8 ± 0.6	2.7 ± 0.8	4.1 ± 2.8	2.2 ± 1.1
How are your cows housed?				
Box stall	99.3%	100%	100%	99.5%
Deep straw bedding	5.1%	4.2%	8.3%	5.0%
What kind of material is used for the stall?				
Straw	57.4%	60.6%	91.7%	60.3%
Sawdust	5.1%	5.6%	8.3%	5.5%
Sand	0.7%	0.0%	0.0%	0.5%
Rubber mats	59.6%	59.3%	50%	55.3%
Other	11.8%	5.6%	8.3%	9.6%
Do the cows have access to pasture?				
Yes	89.0%	63.4%	58.3%	79.0%
If yes, which cows for how long (h/day)?				
Early lactation cows	7.8 ± 5.2	5.4 ± 4.2	0.7 ± 1.2	7.1 ± 5.1
Late lactation cows	7.8 ± 5.2	4.8 ± 4.0	0 ± 0	7.0 ± 5.11
Dry cows	21.2 ± 6.7	20.4 ± 7.3	24 ± 0	21.1 ± 6.7
Heifers	21.0 ± 7.0	20.9 ± 7.5	19.2 ± 10.7	20.9 ± 7.2

Table 2 Summary of responses by herd managers (n = 219) to questions related to estrus detection before and after installation of Heatime system

Tab. 2 Antworten von 219 Milcherzeugern zur Brunsterkennung vor und nach der Installation von Heatime

Survey question and answer categories	**Herd size**							
	Small (n=136)		**Medium (n=71)**		**Large (n=12)**		**All herds (n=219)**	
	before	after	before	after	before	after	before	after
Cows								
Visual observation	97.8%	92.7%	100%	91.5 %	91.7%	75.0%	98.2%	91.3%
Time needed (min/day)	42.3	29.8	57.5	43.6	97.0	61.7	50.3	35.5
No. of employees	1.6	1.5	1.7	1.7	2.5	2.4	1.7	1.6
Heat mount detectors	6.6%	0.7%	5.6%	1.4%	25.0%	8.3%	7.3%	1.4%
Hormone protocols	28.7%	21.3%	38.0%	32.4 %	41.7%	33.3%	32.4%	25.6%
Pedometers	0.0%		1.4%		0.0%		0.5%	
Other	4.4%	2.2%	2.8%	1.4%	16.7%	8.3%	4.6%	2.3%
Heifers								
Visual observation	80.9%	64.0%	71.8%	60.6 %	75%	58.3%	77.6%	62.6%
Time needed (min/day)	27.0	26.9	37.0	23.0	66.3	44.0	32.3	26.6
No. of employees	1.5	1.5	1.7	1.7	2.1	1.9	1.6	1.6
Heat mount detectors	2.9%	0.7%	0.0%	0.0%	0.0%	0.0%	1.8%	0.5%
Hormone protocols	13.2%	10.3%	14.1%	11.3 %	8.3%	0.0%	13.3%	10.0%
Pedometers	0.0%		0.0%		0.0%		0.0%	
Other	17.6%	23.5%	19.7%	22.6 %	25.0%	16.7%	18.7%	22.8%

Table 3 Summary of responses by herd managers (n = 219) to questions related to reproduction and management practices of Heatime system

Tab. 3 Antworten von 219 Milcherzeugern zur Fruchtbarkeit und zur Anwendung von Heatime

Survey question and answer categories	**Herd size**			
	Small	**Medium**	**Large**	**All herds**
How many months have you used Heatime?	9.8 ± 6.3	9.7 ± 7.2	11.7 ± 7.2	9.8 ± 6.6
How many tags do you have?	31.5 ± 11.7	50.7 ± 15.5	102.9 ± 43.5	41.7 ± 23.6
The amount of tags is sufficient	46.3%	52.1%	66.7%	49.3%
When do you attach the tags onto the cows?				
At calving	23.5%	19.7%	25.0%	22.4%
Days after calving	24.9 ± 15.7	31.6 ± 19.6	27.2 ± 15.8	27.2 ± 27.3
When do you remove the tags?				
When confirmed pregnant	86.8%	91.5%	100%	89.0%
After the first AI	1.5%	0.0%	0.0%	0.9%
After the second AI	0.7%	0.0%	0.0%	0.5%
Whenever I need the tag for another cow	17.7%	11.3%	0.0%	14.6%
Never	2.2%	0.0%	0.0%	1.7%
Other	5.1%	4.2%	16.7%	5.5%
The data will be deleted after removing the tag	74.3%	81.7%	91.7%	77.6%
Every cow has the same tag	5.9%	2.8%	0.0%	4.6%
How many hours after Heatime alert are the cows inseminated?	10.7 ± 4.4	10.4 ± 3.9	9.9 ± 2.5	10.6 ± 4.1
Cows are checked for signs of estrus after Heatime alert	75.7%	63.4%	91.7%	72.6%
How many cows are treated with PG for heat induction?	1.4 ± 1.9	2.4 ± 2.5	3.6 ± 4.7	1.8 ± 2.4
How many days after calving are the cows inseminated?	63.9 ± 14.5	64.1 ± 12.3	70.8 ± 14.2	64.3 ± 13.8
Who performs the artifcial insemination(AI)?				
Veterinarian	4.4%	8.5%	0.0%	5.5%
AI technician	86.0%	73.2%	91.7%	82.2%
Herdsman	4.4%	14.1%	16.7%	8.2%
Detected heats which are not used are documented	72.1%	69.0%	75%	71.2%
A herd management program is used	20.6%	36.6%	83.3%	29.2%
SMS service is used to notice cows in heat	0.0%	2.8%	0.0%	0.9%

Table 4 Summary of responses by herd managers (n = 219) to questions related to the efficiency of Heatime system

Tab. 4 Antworten von 219 Milcherzeugern zur Effizienz von Heatime

Survey question and answer categories	**Level of agreement (%)**					**Missing answer**
After the installation of Heatime …	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	
The heat detection rate increased	58.4	34.7	0.4	0.1	0.0	1.8
The insemination results improved	15.1	42.0	27.4	11.4	0.5	3.7
The reproductive performance in general is better	5.5	30.6	42.5	15.1	1.4	5.0
The reproduction management is easier	42.5	49.8	4.6	2.3	0.0	0.9
Number of hormone application decreased	9.1	29.7	26.0	26.0	1.8	7.3
The veterinary costs are lower	3.2	14.6	42.9	31.1	3.2	4.6
I save time	34.7	47.5	8.2	6.8	0.0	2.7
I save money	11.9	41.6	25.1	16.9	0.9	3.7

Table 5 Summary of responses by herd managers (n = 219) to questions related to satisfaction with the Heatime system

Tab. 5 Antworten von 219 Milcherzeugern zur Zufriedenheit mit Heatime

Survey question and answer categories	**Level of agreement (%)**					**Missing answer**
Statement (n = 219)	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	
I am satisfied with the Heatime system	43.4	50.7	4.6	0.9	0.0	0.0
I would install the system again	47.0	47.5	2.7	1.4	0.0	1.4
I recommend the Heatime system	43.8	48.0	5.5	0.9	0.0	1.8
I would have bought the system even without support from the RSH	27.4	10.5	27.9	45.2	10.5	0.5
I have enough information about Heatime	11.0	58.0	14.2	13.2	2.2	1.4
Heatime is easy to handle	23.7	57.5	13.2	4.6	0.9	0.0
Technical problems are common	0.5	3.7	6.4	56.6	29.7	3.2
I would like to use the system to early detect health issues	10.0	37.4	28.3	19.1	3.2	1.8
I am interested in a technical device to detect rumination activity	5.5	27.9	31.5	24.7	9.1	13.7
I would like to use the system to monitor animal health	11.0	43.8	25.1	12.8	5.5	1.8
RSH = German semen sales company Rinderzucht Schleswig-Holstein eG						

3. Publication II:

Evaluation of estrus detection in dairy cattle comparing an automated activity monitoring system to visual observation

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3.1 Abstracts

The objective of the study was to evaluate an automated activity monitoring (AAM) system for estrus detection in dairy cows. Specifically, we set out to determine the estrus detection efficiency and accuracy of the AAM system and to compare reproductive performance of cows detected either by AAM, by visual observation (VO) or at least 1 of the 2 methods (EOM). A total of 1,004 potential cow-periods from 348 cows were analyzed. Estrus detection rates (EDR) were calculated for 21 d (VWP+21), 42 d (VWP+42), and 63 d (VWP+63) after VWP. Estrus detection rate did not differ between AAM (42.1%) and VO (37.3%) during VWP+21 ($P > 0.05$) but was significantly higher in EOM (56.3%, $P < 0.05$). Estrus detection by AAM achieved an efficiency (number of correctly detected estruses / total number of cow-periods*100) of 35.6% and an accuracy (number of correctly detected estruses/ (number of true+ false estruses)*100) of 83.8%. Visual observation resulted in an efficiency of 34.3% and accuracy of 75.1%. Pregnancy rate at 200 DIM was higher in AAM (66.8%) and EOM (68.8%) than in VO (57.1%, $P < 0.05$). Cows detected by AAM ($P < 0.05$) showed a 1.37 times greater risk to conceive than cows detected by VO as the reference ($P < 0.05$). The results show that an automated activity monitoring system can support estrus detection in dairy cattle. The exclusive use of such a system, however, cannot be recommended.

3.2 Key words:

Estrus detection, automated activity monitoring, dairy cattle

3.3 Introduction

Poor estrus detection is one of the most important problems, which is limiting high reproductive efficiency in dairy cows (Senger 1994). Estrus detection efficiency is defined as the probability of a cow being detected when in estrus (Heuwieser et al. 1997). Poor efficiency of estrus detection not only increases the time from calving to first AI but also the average interval between AI services (Stevenson and Call 1983) limiting the rate at which cows may become pregnant (Valenza et al. 2012). The most important factor affecting the efficiency of estrus detection using visual observation is that farm staff responsible for estrus detection should fully understand the signs and be committed to estrus detection (Diskin and Sreenan 2000). Achieving efficient estrus detection by visual observation requires experience, diligent attention, and time (Harris et al. 2010). Several risk factors such as milk yield, lameness, poor nutrition, and herd size have been identified to affect reproductive performance (Roelofs et al. 2010). Recently, it has been demonstrated that today's cows show fewer signs of estrus and for shorter duration. Therefore it is more difficult for farmers to identify estrus (Dobson et al. 2007). It has been demonstrated that the average estrus period lasts for about 9.5 h during which the cow mounts other cows on average 10.1 times. Only 6 mounts lasted more than 2 s (Walker et al. 1996). Some cows express signs of estrus for less than 3 h (Roelofs et al. 2005). These data illustrate that on average the opportunity to identify a cow in estrus is relatively short (i.e. 24.1 s per 21 d cycle).

It is well documented that activity of cows increase considerably during estrus (Kiddy 1977; Schofield 1991; Wendl 1995). This observation has been utilized in different applications. Automated systems have been developed to detect cows standing to be mounted or to determine increased activity (Nebel et al. 2000; Firk et al. 2002).

Different technologies such as heat mount detectors and activity monitoring systems have been commercialized and validated (At-Taras and Spahr 2001; Cavalieri et al. 2003a; Cavalieri et al. 2003b). Activity meters such as pedometers or accelerometers for automated estrus detection have been reported as useful (Kamphuis et al. 2012) achieving estrus detection efficiencies from 81.4% to 91.3% (Cavalieri et al. 2003a). Recently, a direct comparison between different commercially available estrus detection aids, i.e. pedometers (SAE Afikim, Kibbutz Afikim, Israel), accelerometers (Heatime, SCR Engineers Ltd., Netanya, Israel) and 2 heat mount detectors (Scratchcard Dairymac, Hampshire, UK; KaMaR, Zionsville, USA) was conducted on 1 commercial UK dairy farm on 67 Holstein Frisian cows with the objective to determine test characteristics of these different technological approaches (Holman et al. 2011). Sensitivity expressed as estrus events coinciding with periods of low milk progesterone was 63.3% (100 of 158) for the pedometer, 58.9% (86 of 146) for the accelerometers attached to neck collars, 56.7% (38 of 67) for the KaMaR heat mount detectors and 35.9% (23 of 64) for the Scratchcard heat mount detectors compared to the concentration of milk progesterone as the reference method. When 2 of these methods were combined the sensitivity and the positive predictive value increased up to 75.9% and 60.3%, respectively. Data on specificity were not provided. Although several studies have described the use of commercially available activity monitoring systems and the factors that influence their success (Yaniz et al. 2003; Lopez-Gatius et al. 2005) only few studies measured their performance on commercial dairy farms or in direct comparison with other reproductive management tools.

Some years ago an automated activity monitoring (**AAM**) system (Heatime, SCR Engineers Ltd., Netanya, Israel) has become commercially available that provides data for individual cow activity levels. According to information provided by the manufacturer and German AI companies, about 1,700,000 AAM tags have been sold worldwide and approximately 100,000 tags are currently used on dairy farms in Germany, respectively. Science-based information about the efficiency of the AAM system in comparison of a traditional estrus detection protocol is not available. In one study, mean annual herd 21d pregnancy risk and mean conception risk were comparable (P = 0.25; P = 0.43) in a group of cows managed solely with an automated activity system (14.6%; 31%) to a group of cows that underwent a timed AI program (15.9%; 30%). Managers continued to use visual observation for detection of estrus in both groups (Neves et al., 2012). Therefore, the objective of this study was to validate the AAM system and to compare its efficiency to estrus detection by visual observation. Specifically, we set out 1) to evaluate if the AAM system achieves an estrus detection efficiency of 80% as advertised by the manufacturer, 2) to determine sensitivity and specificity of the AAM system, respectively and 3) to compare reproductive performance of cows detected by the AAM, by visual observation (**VO**) or by either one of the two methods (**EOM**).

3.4 Materials and Methods

3.4.1 Animals and housing

The study was conducted between September 2011 and November 2012 on a commercial dairy farm in Brandenburg (N 52° 15′ 03″, E 013° 22′ 48″), Germany, with a total of 676 dairy cows and one breeding bull in a separate barn. Cows were housed indoors in a free-stall barn with concrete floor and straw bedding in the cubicles. During the first 54 to 60 DIM cows were housed in groups of approximately 60 cows. After the voluntary waiting period (**VWP**) of 54 to 60 DIM cows were moved to the breeding group consisting of 160 cows. The group composition was dynamic with cows entering at DIM 54 to 60 and leaving the group after pregnancy confirmation. Most cows were purebred Holstein-Friesian cows (85.8%). Cows were milked twice daily (0500 and 1600 h). The herd had an annual average milk yield of 9,699 kg per cow (3.99% fat and 3.44% protein). Cows were fed a partial mixed ration (**PMR**) twice daily at 0800 and 1700 h. They received 54.3% corn silage, 25.4% haylage and 20.3% concentrate mineral mix on a DM basis. Feed was pushed up 3 times during the day. Cows with a milk yield > 33 kg/d had additional access to concentrate (35% wheat, 35% rye, 24% rapeseed extract, 5% soy and 1% oil mix on a DM basis) via an automatic feeder based on their individual milk yield.

3.4.2. Reproductive management and study design

The day of calving was defined as day 0. The time until the observation period started was used to conduct the following examinations (1-3). Once a week all cows between 21 and 27 DIM were examined (Examination 1). Cows were equipped with AAM collars (Heatime, SCR HR-Tag; SCR Engineers Ltd., Netanya, Israel) and checked for signs of endometritis using a Metricheck device (Simcro, Hamilton, New Zealand) as previously described (McDougall et al. 2007; Pleticha et al. 2009). According to the method of Williams et al. (2005) vaginal discharge was classified on a 4-point scoring system (0 = clear mucus, 1 = mucus containing flecks of pus, 2 = discharge containing less than 50% pus, 3 = discharge containing more than 50% pus). Cows diagnosed with a vaginal discharge score of 2 and 3 were treated with 2 injections of cloprostenol i.m. 14 d apart (526 µg, alfaCloprost forte, Alfavet, Neumünster, Germany).

Every Tuesday cows between 47 and 53 DIM were examined again (Examination 2). The uterus and ovarian structures were examined by rectal palpation and ultrasonography. Uterine consistency and contractility was scored using a 3-point scale (1 = uterus slack and not very contractile, 2 = moderate contractility, 3 = strong contractility) (Rosenberger 1979). Ultrasonography was performed using a portable ultrasound scanner (Easi-scan bovine, BCF Technology, Livingston, Scotland) equipped with a 4.5 to 8.5 MHz rectal transducer. Existing corpora lutea were measured, the image was frozen and the largest diameter measured with the electronic caliper function (Kastelic et al. 1990). Body condition was scored using a 5-point scale with 0.5 increments (**BCS**) (Edmonson et al. 1989) and locomotion was scored using a 5-point scale (Sprecher et al. 1997).

The following inclusion criteria were set: presence of a corpus luteum greater than 10 mm on at least 1 ovary, no pathological findings of the uterus (e.g. purulent discharge, adhesions) by rectal palpation and rectal ultrasonography, a locomotion score ≤ 3 and a BCS ≥ 2,5. If these criteria were not fulfilled the cow could not be included except for the presence of a corpus luteum. A second chance to detect a present corpus luteum was given in a third examination (Examination 3) 7 d later by rectal ultrasonography. If there was still no corpus luteum present, the cow was defined as acyclic and excluded from the study. All examinations were conducted by a veterinarian. Cows with luteal and follicular cysts were treated with cloprostenol i.m. (526 µg, alfaCloprost forte, Alfavet, Neumünster, Germany) or gonadorelin i.m. (100

µg, Ovarelin, Ceva, Düsseldorf, Germany), respectively. All cows treated with cloprostenol or gonadorelin were excluded from the study and the data was not used for analysis.
The observation period for estrus detection of all cows enrolled started between 54 and 60 DIM. A total of 414 cows were enrolled into the study. Cows with missing data or other reasons for missing the protocol were excluded (n = 66) from final analysis. The most common reasons for missing the protocol were: lameness, ovarian cysts and missing data due to failure of transferring data from tag to computer. The observation period of each cow was split into 21d cow-periods according to the cycle length. Therefore, after the VWP every cow started into a first 21d cow-period. The study animals were observed for a maximum of 7 cow-periods unless a cow became pregnant earlier. The remaining 348 cows had a total of 1,004 potential cow-periods based on a 21 d estrus cycle length. The distribution of cow-periods was: cow-period 1 (**P1**) = 316 cows (31.5%), cow-period 2 (**P2**) = 203 cows (20.2%), cow-period 3 (**P3**) = 152 cows (15.1%), cow-period 4 (**P4**) = 122 cows (12.2%), cow-period 5 (**P5**) = 85 (8.5%), cow-period 6 (**P6**) = 70 cows (7.0%) and cow-period 7 (**P7**) = 56 cows (5.6%).

3.4.3 Estrus detection

The AAM system consists of animal tags **(**Heat and Rumination Tags, **HR-tags)**, a small control terminal and an identification **(ID)** transceiver. The HR-tags monitor individual cow activity level and intensity as well as rumination characteristics (Schirmann et al. 2009; Burfeind et al. 2011). The HR-tag detects every animal movement and movement intensity using an accelerometer. An onboard data processing unit analyzes the movements of the cow using a complex algorithm. Data are calculated and summarized in 2-h intervals and stored in the memory of the logger for up to 22 h. The technology allows for the collection of 11 2-h intervals (22 h), after which the first interval recorded is overwritten (Schirmann et al. 2009). A neck collar positions the logger on the left side of the neck. The ID transceiver was located above the exit from the milking parlor. When a cow left the milking parlor (i.e. twice a day) the data was sent via infrared communication from the collar to the control terminal which was located beside the ID transceiver and connected to the on farm computer equipped with a special software (Heatime for PC, SCR Engineering Ltd., Netanya, Israel). A specially developed algorithm is used to calculate a weighted activity index. The resulting activity index expresses a current deviation of the average activity from the previous 7 d. The weighted activity index is used to generate activity alerts based on a threshold according to the manufacture recommendation (activity index 35). In estrus, this weighted activity index gradually increases reaching the heat alert level usually 4 h after the start of activity increase. It reaches a peak and typically 4 to 6 h after this peak, the weighted activity index decreases under the estrus alert level (Bar 2010). Because the AI technician visited the farm daily between 1100 to 1200 h, the AAM system was checked after every morning milking between 0900 to 1000 h using the on farm computer by the investigators.

3.4.4 Visual Observation

The herd manager performed visual estrus detection twice a day between 0900 to 1000 h for 30 min and between 1600 to 1700 h for about 30 min daily. The herd manager defined a cow in estrus based on primary (i.e. cows standing to be mounted) and secondary signs of estrus (i.e. high activity by visual observation, mounting other cows, transparent vaginal discharge, cows sniffing, licking or resting the chin on the rump of other cows). The herd manager did not have access to the data from the AAM system at any time.

3.4.5 Day of estrus

When a cow was reported to be in estrus (i.e. by the AAM system or by the herd manager) one of the authors visited the farm on the same day (between 1000 and 1100 h) to establish the reference standard (i.e. estrus vs diestrus) by transrectal palpation and ultrasonography. In addition blood samples were obtained by puncture of the vena coccygea mediana using a vacutainer system (Venoject II, Terumo Europe N.V., Leuven, Belgium). Samples were centrifuged (10 min, 1,000 × g) and serum was stored in 3 aliquots at −20°C until progesterone analysis.

3.4.6 Definition of estrus

For statistical analysis the reference standard for true estrus was retrospectively defined using the following criteria: 1) A corpus luteum was not detectable by ultrasound or < 10 mm in diameter, 2) presence of a follicle with diameter of 12 to 25 mm (Lopez-Gatius and Camon-Urgel 1991) serum progesterone concentration was ≤ 1 ng/ml (Walker et al. 1996). A true estrus was also assumed if the AI resulted in a positive pregnancy outcome and progesterone was not analyzed for these samples.

3.4.7 Statistical Analysis

Data were analysed using IBM SPSS Statistics for Windows (Version 20.0, IBM Deutschland GmbH, Ehningen, Germany). Depending on the method to detect estrus in a given cow-period (21 d), 3 groups were considered based on a total of 1,004 cow-periods: group 1 (AAM) all estrus events were detected by AAM, group 2 (VO) estrus events detected by VO, and group 3 (EOM) estrus events detected by either one of the two methods. Estrus detection efficiency and reproductive performance among the 3 groups were compared using Chi²-Test. A binary logistic regression model was used to calculate the risk of conception. Therefore, method (1 = VO, 2 = AAM, 3 = EOM), parity class (1 = primiparous, 2 = multiparous), season of AI (1 = March to May; 2 = June to August; 3 = September to November; 4 = December to February) and number of AI (1 = first AI, 2 = all other AI) were first tested in a univariate analysis and only variables with $P < 0.20$ included in the final model. In the final model, parity was not included ($P = 0.96$). Survival analysis for the probability of pregnancy within 200 DIM was performed using Cox regression, censoring cows that were not pregnant. Therefore, method (1 = VO, 2 = AAM, 3 = EOM), parity class (1 = primiparous, 2 = multiparous), season of AI (1 = March to May, 2 = June to August, 3 = September to November, 4 = December to February) and number of AI (1 = first AI, 2 = all other AI) were included as factors in the model. Group VO was chosen as reference in both models. Adjusted odds ratios, confidence intervals and *P*-values are reported. For logistic regression and survival analysis, CI was set at 95%. For all statistical analyses level of significance was set at α = 0.05.

Estrus detection rates (**EDR**) were calculated for 21 d (**VWP+21**), 42 d (**VWP+42**), and 63 d (**VWP+63**), respectively (Table 1). Estrus detection rate did not differ between AAM (42.1%) and VO (37.3%) during VWP+21 ($P > 0.05$). It was higher in EOM (56.3%, $P < 0.05$). Estrus detection rate during VWP+42 was different in VO (47.6%), AAM (56.0%) and EOM (84.8%, $P < 0.05$). Estrus detection rate during VWP+63 was different in VO (53.8%), AAM (63.1%) and EOM (99.5%, $P < 0.05$).
Further efficiency (number of correctly detected estruses/ total number of cow-periods*100) and accuracy (number of correctly detected estruses/ number of true + false estruses*100) were calculated (Table 1).

3.5 Results

According to the ultrasound examinations (E2 and E3) and the associated appearance of a corpus luteum in one of these examinations, the included cows had resumed cyclicity at the beginning of the study. Therefore 1,004 predicted cow-periods were determined according to a 21-d cycle length. Estrus detection by AAM achieved an efficiency of 35.6% and an accuracy of 83.8%. Visual observation resulted in an efficiency of 34.3% and accuracy of 75.1%. If estrus was detected by at least 1 method (EOM) the efficiency was 48.2% and accuracy 75.0%. Accuracy did not differ among the 3 methods ($P > 0.05$), whereas efficiency was higher in EOM ($P < 0.05$)
Descriptive data of reproductive performance is summarized in Table 2. Median days to first AI after calving, median days open, first AI conception rate and overall conception rate did not differ between AAM, VO and EOM ($P > 0.05$). Pregnancy rate at 200 DIM was higher in AAM (66.8%) and EOM (68.8%) than in VO (57.1%, $P < 0.05$, Figure 2).
A binary logistic regression analysis was conducted for the risk of conception including all inseminations (Table 3). Method, season of AI and number of AI were included as factors. Although overall the method of estrus detection used did not have an influence ($P = 0.13$), cows detected by AAM ($P < 0.05$) showed a 1.37 times greater risk to conceive than cows detected by VO as the reference ($P < 0.05$). Season of AI had an influence on the risk of conception ($P < 0.01$). Cows bred from June to August had a 0.69 lower risk to conceive ($P = 0.03$) than cows that were bred from March to May. Cows that were bred from September to November or from December to February had a similar risk of conception than cows bred from March to May ($P = 0.18$ and $P = 0.68$). No influence of number of AI was observed ($P = 0.81$).
In Table 4 the results of the survival analysis (Cox regression) for the probability of pregnancy within 200 DIM are summarized. Cows detected by the AAM or EOM had a 1.41 and 1.45 higher probability of pregnancy at 200 DIM than cow detected by VO ($P < 0.01$, Figure 1). Considering the season of AI, cows which were bred from June to August had a 0.74 less probability of being pregnant at 200 DIM than cows bred from March to May ($P = 0.02$), whereas cows bred from September to November and from December to February had a similar probability ($P = 0.24$ and $P = 0.11$). The number of AI had an effect on the probability of pregnancy at 200 DIM. Second or further AI led to a 0.39 lower risk of pregnancy at 200 DIM than the first AI, which was used as the reference ($P < 0.01$). Parity class had no influence on the probability of pregnancy at 200 DIM ($P = 0.24$).

3.6 Discussion

The present study demonstrated the efficiency of AAM and VO and the benefits of using the methods combined (EOM). The efficiency which was achieved by using AAM (Table 1) does not confirm our first hypothesis of 80% efficiency as advertised by the manufacturer. Most recently, a study reported a sensitivity and specificity for estrus detection of 76.9% and 99.4% for the same AAM (Heatime) and 91.3% and 99.4% for VO, respectively, using individual milk progesterone patterns for each cow sampled twice a week as a gold standard for estrus detection (Kamphuis et al. 2012). The higher sensitivities reported herein could be due to several factors. Most importantly the study was conducted on a pasture-based dairy farm with 670 cows (predominantly Jersey × Friesian crossbred), which were observed for a breeding period of only 37 d. Those cows not inseminated within this period received a natural service. Furthermore, the visual observation was assisted by tail paint and heat patch, which has been shown to increase estrus detection efficiency and accuracy. Sensitivity and specificity were calculated as the proportion of estruses correctly detected by the 2 methods based on the gold standard (milk progesterone) or the proportion of cows that were correctly predicted not being in estrus referring to the gold standard (Kamphuis et al. 2012), respectively. It remains speculative why sensitivities and specificity of VO were so high in that study. In a recent study, Holman et al. (2011) described a comparison of different estrus detection methods including the direct comparison between VO and AAM (Heatime). The results showed a sensitivity of 56.5% and 58.9% for VO and AAM, respectively, and when both methods where combined a sensitivity of 75.0% compared to milk progesterone as gold standard. These results are based on 67 cows, which were synchronized with a modified Ovsynch protocol. A true estrus event was defined as any event identified as positive by any of the detection methods that coincided with a period of low milk progesterone (less than 0.3 ng/ml) and followed by a period of increasing progesterone (more than 0.3 ng/ml). The reference criteria used in our study were more stringent and thus might help explain the discrepancy. Another difference of the study design was that visual observation was performed 6 times a day compared to our herd manager who only observed twice a day.

The efficiency of VO in our study was slightly lower (34.3%) than the efficiency usually reported in the literature (38 to 56%) (Saumande 2002). If AAM and VO were combined efficiency significantly increased to 48.2%. The main reason for this low detection rate is probably related to our strict criteria for the definition of the reference standard. When comparing estrus detection variables between studies, it is important to know what was used as 'golden standard', because this can influence the results (Roelofs 2010). The criteria we chose to set a gold standard for a positive estrus event included the size of a corpus luteum by ultrasound (< 10 mm in diameter), the presence of a follicle with diameter of 12 to 25 mm (Lopez-Gatius and Camon-Urgel 1991), and serum progesterone concentration ≤ 1 ng/ml (Walker et al. 1996). These were more stringent compared to the concentration of progesterone in milk alone as used in other studies (Holman et al. 2011; Kamphuis et al. 2012). Another reason that contributed to different estrus detection efficiency is the personnel conducting VO. Visual observation was conducted by 1 herd manager twice a day. Not only the behaviors that are observed, but also the time of day, frequency, and duration of observation have an effect on estrus detection. The estrus detection rates vary with the method of visual observation that is used. Therefore, it is possible to compare estrus detection rates between different studies only when timing, duration, and frequency of visual observations, as well as which behaviors are included, are described in detail (Roelofs et al. 2010).

Furthermore, the definition of estrus detection rate is crucial when making comparisons between trials. In previous studies, Holman et al. (2011) and Kamphuis et al. (2012), did not report the estrus detection rate defined as the proportions of cows bred from the cows eligible to be bred on a 21 d basis (LeBlanc et al. 2006), although this measure not only includes the proportion of cows detected to be in estrus but also the proportion of eligible cows that was not detected in estrus. Furthermore, increasing estrus detection rate most often results in an increasing pregnancy rate, which is considered to be the key reproductive performance indicator (Vries 2011) and the measure of interest for the producer (LeBlanc 2005; Iwersen et al. 2012). Pregnancy rate measures the speed at which open cows become pregnant. Average pregnancy rate in the USA (Fetrow et al. 2007) and Canada (LeBlanc 2005) is between 12% and 13%. Therefore, we reported estrus detection rate calculated as the proportion of cows detected in estrus in a 21 d time frame, which is most important for the producer.

Estrus detection rates for VWP+21, VWP+42 and VWP+63 were higher when combining both methods compared to AAM or VO alone (Table 1). This observation confirms findings of a previous study (Peralta et al. 2005), which compared 3 different estrus detection methods (i.e. visual observation, automated detection of being mounted, and activity monitoring). The results of a recent survey conducted among 219 German dairy farmers using the same AAM provides evidence that even after the installation of the AAM almost every farm used VO to support the detection of cows in estrus. The time spent on visual estrus detection, however, decreased after the installation (Michaelis et al. 2013).

Performing the binary logistic regression (Table 3) and survival analysis (Table 4) all estrus events were used and split into 3 different groups being aware that these groups were not independent as the same cows were used. In our experimental approach, however, each method had the same chance to detect a cow in estrus and the information obtained by one method was blinded for the other one. Furthermore, the two methods were based on different methodological approaches i.e. a technical device which measured activity, visual observation of the cows conducted by one person. Thus, we consider that this blinding allowed a direct comparison of the methods. Implementing a study design with 3 different independent groups in different pens would have resulted in different environmental conditions and different cows assigned to different methods, which might have biased the results.

Conception rate did not differ between the 3 different groups and ranged from 35.8% to 42.9%. This is in accordance with other studies describing conception rates for Holstein dairy cows (Lucy 2001). The results of the binary logistic regression analysis for the risk of conception revealed a significant influence of the season. It is well documented that heat stress is one important factor for decreasing reproductive performance in dairy cows (Lucy 2002; García-Ispierto et al. 2007).

Our results show that the risk to conceive was 0.69 times less from June to August compared to the referent (March to May). In the survival analysis, a similar effect was present. The probability of pregnancy at 200 DIM was 0.74 times less from June to August compared to the referent. These effects might be due to the heat stress in the

summer months, which is known to affect conception rates in Holstein dairy cows both in tropical (Morton et al. 2007) and moderate climates (Schüller et al. 2013a). Most recently our study site was part of a trial that compared climate conditions measured on site in comparison to official meteorological stations nearby. Interestingly, the number of days with a temperature humidity index above 72 which is indicative of heat stress was greater compared to other farms in the surrounding area (Schüller et al. 2013b). Further research is warranted to study estrus activity in relation to climate and to investigate if decreasing the threshold for the activity alert in the summer months might increase estrus detection rate. The most probable cause of a decrease in estrus detection could be attributed to a reduction in the expression of estrus behavior (i.e. activity) due to the physical lethargy caused by heat stress (Peralta et al. 2005).
It ist well documented that lameness has a negative effect on the fertility of dairy cows (Sprecher et al. 1997; Garbarino et al. 2004). In lame cows the ovarian activity can be delayed (Gabriano et al. 2004) and an negative effect on the follicle growth and the prevalence of cyctic ovarian disease increased (Morris et al. 2011). Since every cow was defined as cyclic by ultrasound investigation before entering the study we are able to neglect this aspect. Furthermore, we had the intention to test the AAM in a real situation, including cows with slight forms of lamness that are often undetected by farm personnel. Therefore we decided to exclude only cows with a locomotion score of 4 and 5 indicative of severe lamness. Our results have to be interpreted with caution, because the trial was performed on a single farm only.

3.7 Conclusion

Overall, estrus detection efficiency of the AAM system was 35.6% and considerably lower than the value of 80% advertised by the manufacturer. The results show, however, that the AAM system can support estrus detection in dairy cattle. The exclusive use of the AAM system cannot be recommended because estrus detection rates of 42% in the 21 d after the VWP are insufficient. This is one of the first trials that reports estrus detection rate based on 21 d cow-periods, which is the variable of interest for producers. Further research is necessary to validate the findings on multiple dairy farms.

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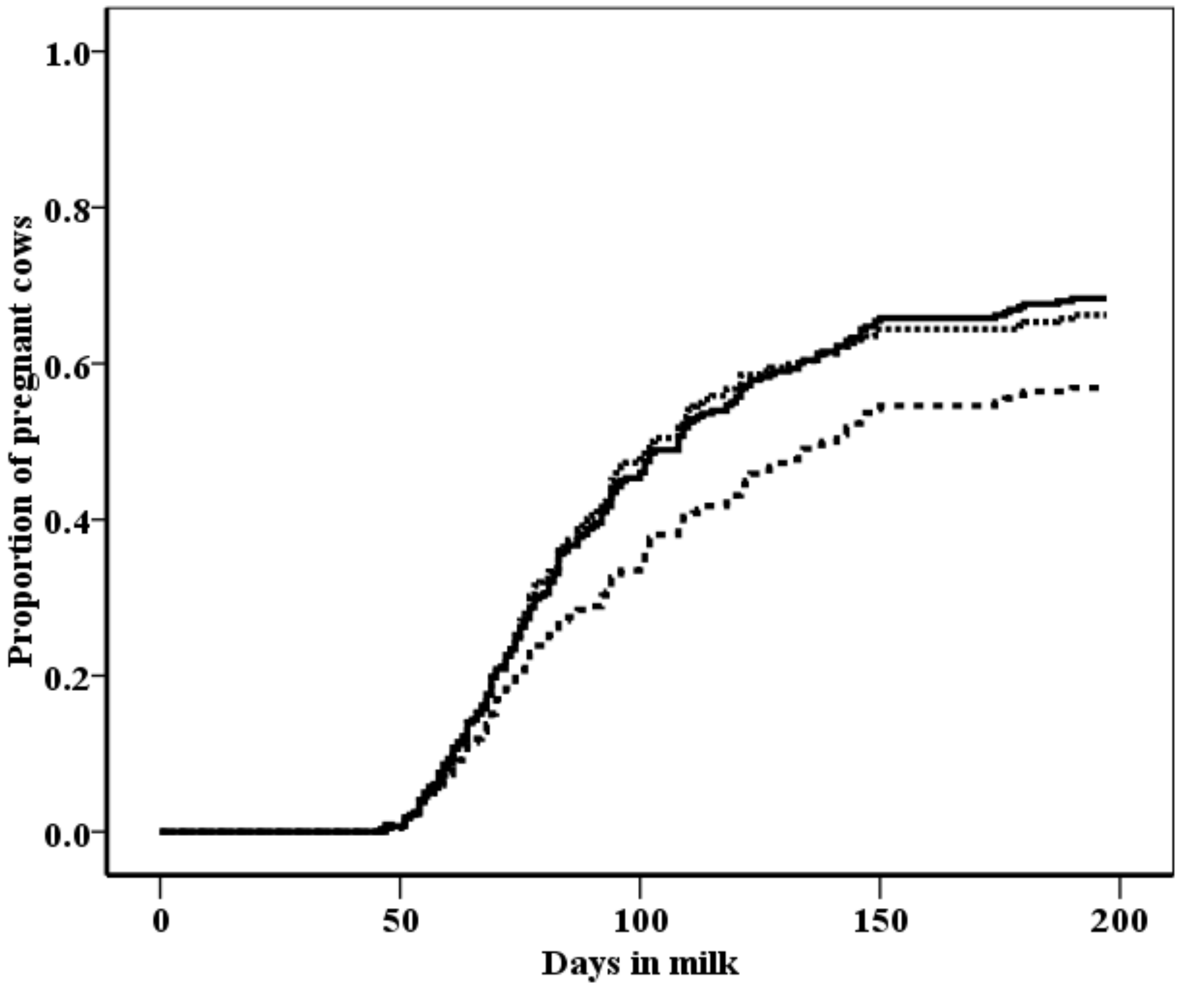


Figure 1. Proportion of pregnant cows at 200 days in milk detected in estrus by visual observation (----), the automated activity monitoring system (····) or either one of the two methods (—).

Table 1. Descriptive statistics of estrus detection conducted with the automated activity monitoring system (AAM), by visual observation (VO) or either one of the two methods (EOM)

	Method of estrus detection		
Parameter	AAM	VO	EOM
Total cycles[1]	1,004	1,004	1,004
Correctly detected estruses	357[a]	344[a]	484[b]
False detected estruses	69[a]	114[b]	161[c]
Efficiency[2] (%)	35.6[a]	34.3[a]	48.2[b]
Accuracy[3] (%)	83.8	75.1	75.0
Estrus detection rate			
first 21 days after VWP (%)	42.1[a]	37.3[a]	56.3[b]
first 42 days after VWP (%)	56.0[a]	47.6[b]	84.8[c]
first 63 days after VWP (%)	63.1[a]	53.8[b]	99.5[c]

[a,b,c] Values with different superscripts in the same row differ ($P < 0.05$)
[1] Predicted estrus cycles based on a 21d cycle length
[2] Number of correctly detected estruses/ total number of cow-periods*100
[3] Number of correctly detected estruses/ number of true + false estruses*100

Table 2. Descriptive statistics of reproductive performance parameters for cows detected by the automated activity monitoring system (AAM), by visual observation (VO) or either one of the two methods (EOM)
[a,b,c] Values with different superscripts in the same row differ ($P < 0.05$)
[1]IR = interquartile range
Conception rate = number of pregnant cows/ total number of inseminated cows

	Estrus detected by		
Parameter	AAM	VO	EOM
Number of cows	175	173	253
Median days to first AI (IR[1])	70 (61-80)	69 (61-83)	69 (61-81)
Median days open (IR)	81 (68-102)	88 (69-120)	83 (68-109)
First AI conception rate (%)	46.8	36.6	41.8
Overall conception rate (%)	42.9	35.8	39.6
Pregnancy rate at 200 days (%)	66.8[a]	57.1[b]	68.8[a]

Table 3. Results of binary logistic regression analysis for the risk of conception of all inseminations observed with the automated activity monitoring system, visual observation or either one of the two methods including method, season and number of AI.

	Conceiving after AI		
Parameter	Odds ratio	95% CL	P-Value
Method			0.13
Visual observation		Reference	
Automated activity monitoring	1.37	1.01-1.87	<0.05
Either one of the two methods	1.18	0.88-1.57	0.26
Season of AI			<0.01
March to May		Reference	
June to August	0.69	0.49-0.96	0.03
September to November	1.27	0.90-1.80	0.18
December to February	0.94	0.68-1.29	0.68
Number of AI			
First AI		Reference	
Second and further AI	0.08	0.64-1.03	0.81

Table 4. Results of the survival analysis (Cox regression) for the odds of pregnancy within 200 DIM in cows detected by the automated activity monitoring system, by visual observation or either one of the two methods

	Probability of Pregnancy		
Parameter	Hazard ratio	95% CL	P-Value
Method			<0.01
Visual observation		Referent	
Automated activity monitoring	1.41	1.11-1.79	<0.01
Either one of the two methods	1.45	1.16-1.83	<0.01
Season of AI			<0.01
March to May		Referent	
June to August	0.74	0.57-0.96	0.02
September to November	1.17	0.90-1.53	0.24
December to February	1.22	0.96-1.56	0.11
Number of AI			
First AI		Referent	
Second and further AI	0.39	0.32-0.47	<0.01
Parity class			
Primiparous		Referent	
Multiparous	1.13	0.93-1.37	0.24

4. Discussion

The overall objective of my studies was to determine the usefulness of an electronic device to detect cows in estrus. In a first study we surveyed estrus detection practices in Germany and the experiences of farmers who used the automated activity monitoring (AAM) system (Heatime, SCR, Netanya, Israel). Secondly, I conducted a large scale study to evaluate an automated activity monitoring system to detect estruses in dairy cows in comparison to visual observation. Specifically for the second study, we set out 1) to evaluate if the AAM system achieves an estrus detection efficiency of 80% as advertised by the manufacturer, 2) to determine sensitivity and specificity of the AAM system, respectively and 3) to compare reproductive performance of cows detected by the AAM, by VO or EOM.

The results of the first study indicated that the AAM is a well-accepted activity monitoring system. The data was based on a survey with a response rate of 58.3%. However, the data is based on personal perceptions of the participating farmers. Before and after the AAM system was installed almost every farm used visual observation to detect or to support detection of cows in estrus, respectively. The time spent on visual estrus detection decreased after the installation. It is well known that the efficiency of estrus detection by visual observation requires experience, diligent attention and time (Harris et al., 2010). Furthermore, the increasing herd size as well as the increasing reliance on unskilled labor turn estrus detection into a challenge (Cuthbert 2008). The estrus detection rate could be improved without increased labor input by using sensors for automated estrus detection (Rutten et al., 2014). Our survey data also show that an automated system for estrus detection can help alleviate these problems. However, information on the economic consequences of using activity meters is lacking (Rutten et al., 2014). In a recent study Rutten et al. analysed if the use of activity meters for automated estrus detection is profitable. The study was conducted with a stochastic dynamic simulation model to stimulate the reproductive performance. The dutch working team showed that longer calving intervals led to lower milk production and fewer calvings the prolonged calving interval is associated with economic losses. Improving estrus detection increases the likelihood that a cow in estrus becomes pregnant and thereby shortens the calving interval, which is economically beneficial. Although benefits of automated estrus detection are expected, farmers need to invest in such a system. The results of this study indicate that investment in activity meters for estrus detection is likely to be profitable for most dairy farms. (Rutten et al., 2014).

The application of hormones for reproductive management decreased after the Heatime system was installed. About 6.8% of the responding dairy farmers completely stopped the use of hormones to induce estrus and 38.8% indicated that the hormone usage was reduced since the installation of Heatime. Even though the proper use of hormones does not have any known negative effect on animal welfare or public health, consumers are concerned about food safety and have a growing interest in animal health and welfare issues especially ethical concerns regarding the use of hormones and antibiotics (Refsdal 2000). We speculate that such concerns will become increasingly important for the dairy industry. Technical aids besides hormones to assure proper reproductive performance are beneficial and valuable to address those negative perceptions. As most recently demonstrated (Neves et al., 2012) overall reproductive performance was similar between management based on the AAM system and a synchronization program for timed artificial insemination (TAI). In some instances times to pregnancy was shorter with the AAM system. This comparison demonstrates that AAM systems might be an efficacious approach to reduce hormone use. In a recent study Neves et al. (2015) accomplished a questionnaire in Canada similar to our survey in Germany. Overall, the reproductive performance in that study was not different between herds managing reproduction with AAM- or TAI-based programs. On average, herds that adopted an AAM system had an increase in pregnancy rate and insemination rate, whereas the conception rate was unchanged when compared with the reproductive performance from the previous year. These results support the findings from randomized trials that AAM-based programs can yield comparable reproductive performance to TAI-based programs (Neves et al., 2015)

The majority of respondents (93.1%) strongly agreed or agreed that estrus detection was higher after the installation of the AAM. On their website the manufacturers advertise that the AAM system improves fertility rates and calving cycles, reduces days open and reduces expenses on semen. More than half of the farmers (57.1%) strongly agreed or agreed that the success of the insemination was better. However, only 36.1% had the impression that reproduction performance improved in general. These perceptions are in line with observations that estrus detection aids can help to improve estrus detection rates, but it will take some time to see an improvement in fertility parameters such as calving interval and insemination number (Roelofs et al., 2010). In this regard the Canadian questionnaire figured that herds which implemented an AAM system had a significant increase in annual pregnancy risk, from 15 to 17%, and insemination risk increased from 42 to 50%, whereas conception risk was unchanged (37 and 35%) following adoption of the system (Neves et al., 2015).

In our second study I comprehensively researched the AAM and demonstrated the efficiency of AAM and visual observation (VO) and the benefits of using the methods combined (EOM). The efficiency, which was achieved by using AAM, does not confirm our first hypothesis of 80% efficiency as advertised by the manufacturer.

The efficiency of VO in our study was slightly lower (34.3%) than the efficiency usually reported in the literature (38 to 56%) (Saumande 2002). If AAM and VO were combined efficiency significantly increased to 48.2%. The main reason for this low detection rate is probably related to our strict criteria for the definition of the reference standard. When comparing estrus detection variables between studies, it is important to know what was used as ‘golden standard’, because this can influence the results (Roelofs 2010). Most recently Reith et al., (2014) investigated a study concerning activity and rumination time measured by the same AAM (Heatime) of dairy cows over the peri-estrus period. To ensure a true estrus event only cows with artificial insemination leading to conception were included in the study. The results showed that during estrus, daily activity measured by collar-mounted acceleration technology (Heatime) was increased, whereas daily ruminaton time was reduced. One of the most important results was that some cows were only detected in estrus by observing rumination time data. These observations provide the idea of combining activity and rumination time for detection of estrus. It is plausible to speculate that rumination time may be used to indicate cows with silent estrus. This may be another important issue for future studies (Reith et al., 2014).

The estrus detection rates vary with the method of visual observation that is used. Therefore, it is possible to compare estrus detection rates between different studies only when timing, duration, and frequency of visual observations, as well as which behaviors are included, are described in detail (Roelofs et al. 2010).

Estrus detection rates for VWP+21, VWP+42 and VWP+63 were higher when combining both methods compared to AAM or VO alone. This observation confirms findings of a previous study (Peralta et al. 2005), which compared 3 different estrus detection methods (i.e. visual observation, automated detection of being mounted, and activity monitoring). This reflects the results of the first study survey were the farmers

used the same AAM and that even after the installation of the AAM almost every farm used VO to support the detection of cows in estrus. The time spent on visual estrus detection, however, decreased after the installation.
Conception rate did not differ between the 3 different groups and ranged from 35.8% to 42.9%. This is in accordance with other studies describing conception rates for Holstein dairy cows (Lucy 2001). The results of the binary logistic regression analysis for the risk of conception revealed a significant influence of the season. It is well documented that heat stress is one important factor for decreasing reproductive performance in dairy cows (Lucy 2002; García-Ispierto et al. 2007). Further research is warranted to study estrus activity in relation to climate and to investigate if decreasing the threshold for the activity alert in the summer months might increase estrus detection rate.
It ist well documented that lameness has a negative effect on the fertility of dairy cows (Sprecher et al. 1997; Garbarino et al. 2004). Since every cow was defined as cyclic by ultrasound investigation before entering the study we are able to neglect this bias. Furthermore, we had the intention to test the AAM in a real situation, including cows with slight forms of lameness that are often undetected by farm personnel. Therefore we decided to exclude only cows with a locomotion score of 4 and 5 indicative of severe lameness. However, our results have to be interpreted with caution, because the trial was performed on a single farm only.
Overall, the results show, that the AAM system can support estrus detection in dairy cattle. The results of the survey demonstrated that the Heatime system is a well-accepted estrus detection aid, which has the potential to reduce the time needed for estrus detection and might potentially reduce the use of hormones.

5. Additional Data

5.1 Introduction

The thermal environment is a major factor that can negatively affect milk production of dairy cows, especially in animals of high genetic merit. Dairy cattle research has tended to concentrate on genetic improvements to increase milk production and on nutrient supply to the cow during early lactation. Little attention has been paid to the thermoregulatory ability of the modern cow as her capacity to produce milk has increased (Kadzere et al., 2002). Lactating dairy cows create a large quantity of metabolic heat and accumulate additional heat from radiant energy. Heat production and accumulation, coupled with compromised cooling capability because of environmental conditions, causes heat load in the cow to increase to the point that body temperature rises, intake declines and ultimately the cow’s productivity declines (West 2003). As milk yield of dairy cows is expected to further increase, the negative impact of heat stress will become more important (Schüller et al., 2014). Heat stress can have major effects on fertility and embryonic survival in lactating dairy cows (Hansen 2000). Therefore, we collected, climate data parallel to the estrus detection data. The objective of the study was to compare the climate conditions of the barn to the climate data from the closest official meteorological station and examine heat stress.

5.2. Methods and Material

The study was conducted between September 2011 and November 2012 on a commercial dairy farm in Brandenburg (N 52° 15′ 03″, E 013° 22′ 48″), Germany, with a total of 676 dairy cows and one breeding bull in a separate barn. The barn had mechanical fan-systems and open ventilation and was positioned in North-East to South-West orientation.

Cows were housed indoors in a free-stall barn with concrete floor and straw bedding in the cubicles. During the first 54 to 60 DIM cows were housed in groups of approximately 60 cows. After the voluntary waiting period of 54 to 60 DIM cows were moved to the breeding group consisting of 160 cows. The group composition was dynamic with cows entering at DIM 54 to 60 and leaving the group after pregnancy confirmation. Most cows were purebred Holstein-Friesian cows (85.8%). Cows were milked twice daily (0500 and 1600 h). The herd had an annual average milk yield of 9,699 kg per cow (3.99% fat and 3.44% protein). Cows were fed a partial mixed ration twice daily at 0800 and 1700 h. They received 54.3% corn silage, 25.4% haylage and 20.3% concentrate mineral mix on a DM basis. Feed was pushed up 3 times during the day. Cows with a milk yield > 33 kg/d had additional access to concentrate (35% wheat, 35% rye, 24% rapeseed extract, 5% soy and 1% oil mix on a DM basis) via an automatic feeder based on their individual milk yield.

The ambient temperature (AT) and relative humidity (RH) within the barn were recorded using 3 Tinytag Plus II logger (Germini Loggers Ltd., Chichester, UK). The logger were attached in the middle alley of the barn in about 3 meter height at 3 different locations (high-yielding pen, fresh cow pen and holding area).

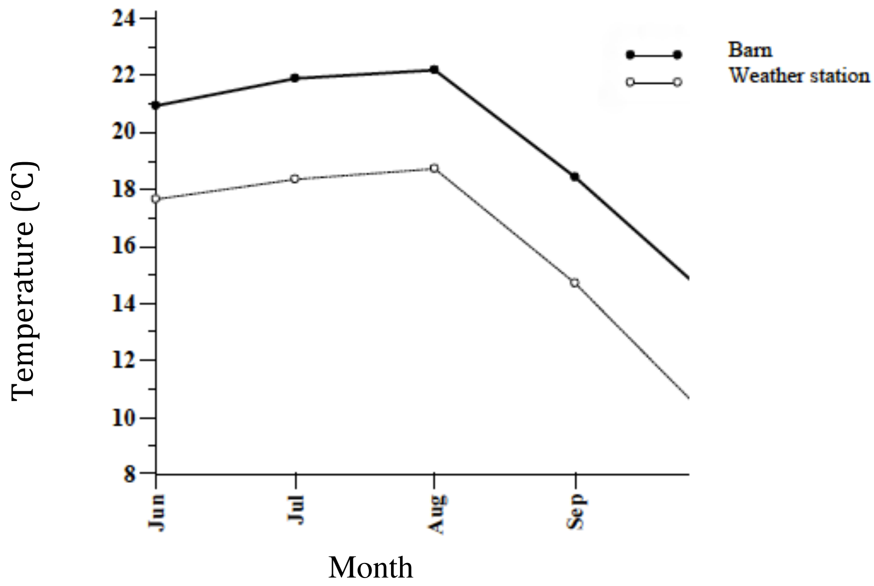
These loggers measured AT from - 25 to + 85 °C with an accuracy of ± 0.3 °C and a resolution of 0.01 °C and RH from 0 to 100% with an accuracy of ± 3% and a resolution of 0.3%. These data were recorded hourly and loggers were calibrated by the manufacturer at the beginning and the end of the study and accuracy was checked. Additionally, AT and RH recorded at the same times were obtained from a meteorological station located 18 km north-east from the barn. Using the equation reported by Kendall et al. (2009) the THI was calculated with the recorded AT and RH.

$$THI = (1.8 \times AT + 32) - ((0.55 - 0.0055 \times RH) \times (1.8 \times AT - 26)).$$

5.3. Results and Discussion

On farm measurements are significantly different to the data from the official meteorological station as previously demonstrated (Schüller et al. 2013). Measurement of AT and relative humidity index (THI) were significantly higher on farm measurements compared to the closest meteorological station. The results indicate that in studies, which obtained data from meteorological station, heat stress is underestimated.

Figure 1. Temperature profile in the barn and at the weather station



Morton, et al. (2007) estimated that heat stress defined as a daily maximum THI of 72 or more from Day 35 before to Day 6 after the day of breeding decreases conception rate of lactating dairy cows by around 30% points relative to days of breeding in which there was no heat load from Day 35 before to Day 6 after the day of breeding. The average THI in the moderate climates in the temperate latitudes (e.g., Central Europe, Northern US, and Canada) can reach the threshold of 72 during summer months. Most recently, it was demonstrated that the THI threshold of 72 was reached on 162 of 756 experimental days inside a commercial dairy barn in Germany (Schüller et al. 2014). This observation highlighted the importance of heat stress even in the moderate climates and underlines the fact that heat stress is underestimated in non tropical regions. Furthermore, our data show that the temperature between June to October was on average 20±3.7° degree in the barn. The relative humidity was 78.6± 7.5 %. The average THI was 67.1± 6.1. Within the trial the THI exceeded the limit for 72 on 26 out of 123 study days. The study showed that heat stress was present and underestimated. We concluded that more research is requested to see the influence on estrus behaviour and related activity patterns. The results of our second study, show that the risk to conceive was 0.69 times less from June to August compared to the referent (March to May). In the survival analysis, a similar effect was present. The probability of pregnancy at 200 DIM was 0.74 times less from June to August compared to the referent. These effects might be due to the heat stress in the summer months, which is known to affect conception rates in Holstein dairy cows both in tropical (Morton et al. 2007) and moderate climates (Schüller et al. 2013).

Table 1. Summary of mean ambient temperature, humidity and temperature-humidity index of climate conditions from June to October

Climate data	
Temperature (°C)	
In the barn	20.0± 3.7
At the Weather station	16.4± 4.1
Difference	3.6± 0.9
Humidity (%)	
In the barn	78.6± 7.5
At the Weather station	77.3± 9.7
Difference	0.9± 4.9
Temperature-humidity-index	
In the Barn	67.1± 6.1
At the Weather station	60.5± 6.3
Difference	6.5± 0.1

5.4 Conclusion

We concluded that further research is warranted to study estrus activity in relation to on farm climate and to investigate if decreasing the threshold for the activity alert in the summer months might increase estrus detection rate. The most probable cause of a decrease in estrus detection could be attributed to a reduction in the expression of estrus behavior (i.e. activity) due to the physical lethargy caused by heat stress (Peralta et al. 2005).

5.5 References

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Activity monitoring in dairy cattle:
Evaluation of a technical estrus detection device

6. Summary

In my first study farmers were surveyed, who use an automated activity monitoring (AAM) system for the detection of estrus. The objective of this study was to gain an overview of current management practices for of estrus detection and to learn more about the practical aspects. The farmers were surveyed about the influences on animal environment, business processes, methods of estrus detection before and after installing the AAM, handling and overall impression of efficiency. Overall, 94.1% of surveyed managers were satisfied with the AAM and almost all of them (94.5%) would install the system again. The results show that the AAM represents a well accepted system with the potential to reduce the time required for estrus detection and the administration of hormones. In the second trial the objective was to validate the AAM and compare its efficiency to estrus detection by visual observation (VO). More specifically the efficiency and accuracy of AAM Systems were identified and the reproductive performance of cows by AAM or VO or one of the two methods (EOM) compared. In total 1,004 potential cycles were analyzed from 348 cows. Estrus detection rate (EDR) were calculated for 21 d after the voluntary waiting period (VWP + 21), 42 d (VWP + 42), and 63 d (VWP + 63). In the time period VWP + 21 ($P > 0.05$) the EDR differed barely between AAM (42.1%) and VO (37.3%) – but the EDR of EOM differed (56.3%, $p < 0.05$) significantly. The estrus detection by AAM achieved an efficiency (number of correctly recognized estrues / total number of cycles * 100) of 35.6% and an accuracy (number of the estruses / (number of true + false the estruses correctly identified) * 100) of 83.8%, Visual observation (VO) led to an efficiency of 34.3% and an accuracy of 75.1%. The pregnancy rate was 200 DIM with AAM (66.8%) and EOM (68.8%) and with VO (57.1%, $p < 0.05$). From AAM system recognized cows ($P < 0.05$) showed a 1.37 times higher Risk to conceive than cows that were detected by VO ($P < 0.05$). The results show that an automated activity monitoring system can support estrus detection in dairy cows. However, the exclusive use of such a system can not be recommended.

Aktivitätsüberwachung bei Milchkühen: Die Evaluierung eines technischen Brunsterkennungssystems

7. Zusammenfassung

In der ersten Studie wurden Landwirte befragt, die für zur Erkennung der Brunst das auf automatisierte Aktivitätsbeobachtung (AAM) basierende System „Heatime“ nutzen. Das Ziel dieser Studie war es, einen Überblick über die üblichen Methoden der Brunsterkennung zu gewinnen und mehr über die praktischen Aspekte des Systems zu erfahren. Hierbei wurden die Landwirte nach den Einflüssen auf Tierumgebung, betriebliche Abläufe, Methoden der Brunsterkennung vor und nach der Installation von AAM, Handhabung und Gesamteindruck zur Effizienz befragt. Insgesamt waren 94,1% der befragten Betriebsleiter mit AAM zufrieden und fast alle von ihnen (94,5%) würden das System erneut installieren. Die Ergebnisse zeigen, dass AAM eine gut akzeptierte Hilfe bei der Brunsterkennung darstellt mit dem Potenzial, die benötigte Zeit für die Brunsterkennung sowie möglicherweise die Verabreichung von Hormonen zu reduzieren. In unserer zweiten Studie war es das Ziel, AAM in Bezug auf die Brunsterkennung bei Milchkühen zu bewerten. Genauer gesagt wurde Effizienz und Genauigkeit des AAM-Systems ermittelt und die Reproduktionsleistung der Kühe durch AAM oder visuelle Beobachtung (VO) oder eine der beiden Methoden (EOM) miteinander verglichen. Insgesamt wurden 1.004 potenzielle Zyklen von 348 Kühen analysiert. Brunsterkennungsraten (EDR) wurden für 21 d nach der freiwilligen Wartezeit (VWP + 21), 42 d (VWP + 42), und 63 d (VWP + 63) berechnet. Die Brunsterkennungsraten haben sich im Zeitraum VWP + 21 (P> 0,05) kaum zwischen AAM (42,1%) und VO (37,3%) unterschieden – jedoch wurde bei der Kombination beider Methoden ein deutlich höherer Wert festgestellt: EOM (56,3%, p <0,05). Die Brunsterkennung durch AAM erreichte einen Wirkungsgrad (Zahl der richtig erkannten Brunsten / Gesamtzahl der Zyklen * 100) von 35,6% und eine Genauigkeit (Anzahl der Brunsten / (Anzahl echte + falsche Brunsten richtig erkannt) * 100) von 83,8%. Die visuelle Beobachtung (VO) führte zu einem Wirkungsgrad von 34,3% und einer Genauigkeit von 75,1%. Die Trächtigkeitsrate bei 200 DIM war mit AAM (66,8%) und EOM (68,8%) höher als mit VO (57,1%, p <0,05). Vom AAM-System erkannte Kühe (P<0,05) zeigten eine 1,37 mal höhere Trächtigkeitswahrscheinlichkeit als Kühe die durch VO festgestellt wurden (P <0,05). Die Ergebnisse zeigen, dass ein automatisiertes Aktivitätsbeobachtung-System die Brunsterkennung bei Milchkühen unterstützen kann. Die ausschließliche Verwendung eines solchen Systems kann jedoch nicht empfohlen werden.

8. References for Introduction and Discussion

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10. Declaration of independence

Hiermit bestätige ich, Ina Michaelis, dass ich die vorliegende Dissertation selbständig angefertigt habe. Ich versichere, dass ich ausschließlich die angegebenen Quellen und Hilfen in Anspruch genommen habe.

Table 2. Eigener Anteil[1] an den Forschungsprojekten der vorliegenden Dissertation.

Aktivität	Studie 1[a]	Studie 2[b]	Studie 3[c]
Studienplanung	+++	++	++
Datenerhebung	+++	+++	+++
Datenanalyse	+++	++	++
Verfassen des Manuskripts	+++	+++	+++
Editieren des Manuskripts	++	++	++

Legende[1]: +++: > 70 %
++: 50- 70 %
+: < 50%

[a] Estrus detection in dairy cattle: Changes after the introduction of an automated activity monitoring system?
[b] Evaluation of estrus detection in dairy cattle comparing an automated activity monitoring system to visual observation
[c] Climate conditions in the barn and at the weather station and examination of heat stress