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Influences on the activity and lying behavior of lactating dairy cows with particular attention to lameness

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Meinem Bruder

Abstract

Consumers often believe that their farmers pay particular attention to each individual animal and have a close, personal relationship with each of them. This is certainly an idyllic hyperbole, but the concept of animal welfare is gaining more and more importance in the course of social change towards a more conscious handling of food. The consumers' purchasing decisions can indirectly influence the housing conditions of animals. On a modern, future-orientated dairy cattle breeding farm however, herd sizes are continuously growing, which means that without the use of modern sensor systems, farmers can no longer live up to society's expectations of animal welfare.

Lameness, which is usually the cause of a painful claw disease, continues to be the third most common reason for culling on dairy-producing farms in Germany. Claw diseases are not only painful, affecting both health and well-being of the animals, they are also often diagnosed too late. Performance losses and associated financial losses are the result. In order to counteract such losses and additionally increase animal welfare, the earliest possible detection of lameness and subsequent treatment of the cause of lameness are essential. Despite more than 70% of all farmers being willing to eliminate this malady and improve hoof health, lameness prevalence is often underestimated. In order to support the farmer as good as possible and at the same time meet the requirements of ever-advancing herd management, sensor-assisted lameness detection should be ensured, because the earliest possible detection and treatment of lameness can significantly reduce the costs of a dairy farm and benefit individual animal welfare.

In the first presented study data on the lying behavior of dairy cows with regard to animal-physiological, environmental and management-based influences were analyzed in order to make it available for further lameness research. It was found that above all the daily lying time was influenced by the lactation number, the lactation status, the oestrus and the milking frequency. Therefore, these factors should be taken into account in future models as well.

The aim of the second study was to investigate the causal relationship between the walking speed of dairy cows and hoof health. A standard stopwatch was used to measure the time taken by the cows to cover a defined distance. At the same time, the locomotion score of the animals was used to determine the degree of lameness. Lame animals showed a significantly slower walking speed than non-lame animals. Also, the longer the period of time, for which an animal had already been lame, the slower its walking speeds across the test track.

Numerous sensor systems enable an accurate and continuous monitoring of the health status of the dairy cows. Accelerometer systems are standard on most farms already. The time measurement and subsequent walking speed measurement can be implemented in modern animal tracking systems. The combination of data from different sensor systems enables the farmer to accurately monitor the health status of each individual animal in real time. In this way, the farmer is able to meet the demands of society for increased animal welfare in modern dairy farms.

Zusammenfassung

Der Aspekt des Tierwohls gewinnt im Zuge des gesellschaftlichen Wandels hin zu einem bewussteren Umgang mit Lebensmitteln immer mehr an Bedeutung. Durch sein Kaufverhalten kann der Konsument die Haltungsbedinungen indirekt mitbestimmen. Der Verbraucher geht davon aus, dass Landwirte jedem einzelnen Tier besondere Aufmerksamkeit zukommen lassen und darüber hinaus zu jedem Tier eine persönliche Beziehung haben. In der zukunftsorientierten Milchviehhaltung mit steigenden Herdengrößen ist dies nicht mehr möglich. Der Einsatz von modernen Sensorsystemen unterstützt den Landwirt dabei, den Erwartungen der Gesellschaft hinsichtlich einer tiergerechten Haltung gerecht zu werden.

Lahmheiten, die meist eine schmerzhafte Klauenerkrankung als Ursache haben, stellen nach wie vor den dritthäufigsten Abgangsgrund auf milcherzeugenden Betrieben in Deutschland dar. Klauenerkrankungen sind nicht nur schmerzhaft und beeinträchtigen damit sowohl die Gesundheit als auch das Wohlergehen der Tiere, sondern werden darüber hinaus auch oft zu spät erkannt. Leistungseinbußen und damit verbundene finanzielle Verluste sind die Folge. Um derartigen Verlusten entgegenzuwirken und zusätzlich das Tierwohl zu steigern, ist eine frühestmögliche Lahmheitsdetektion und anschließende Behandlung der Lahmheitsursache essentiell. Auf den Betrieben jedoch unterschätzen die Landwirte Studien zufolge die Lahmheitsprävalenz oft. Dennoch sind mehr als 70 % bereit diesen Missstand zu beseitigen und die Klauengesundheit zu verbessern. Um den Landwirt dabei so gut wie möglich zu unterstützen und gleichzeitig der immer weiter fortschreitenden Technisierung des Herdenmanagements - bedingt durch steigende Herdengrößen - gerecht zu werden, sollte eine sensor-gestützte Lahmheitsdetektion gewährleistet werden. So kann eine möglichst frühzeitige Erkennung und Behandlung von Lahmheiten die Kosten für den Milchviehbetrieb deutlich reduzieren. Des Weiteren kommen diese Systeme durch die Früherkennung dem Tierwohl zu Gute, da Kühe mit schmerzhaften Gliedmaßenerkrankungen weniger lang Schmerzen erleiden müssen.

Im Rahmen der vorliegenden Arbeit wurden zunächst Daten zum Liegeverhalten von Milchkühen hinsichtlich tier-physiologischer, umweltbedingter und Management basierter Einflüsse analysiert, um diese für weiterführende Lahmheitsbetrachtungen verfügbar zu machen. Dabei zeigte sich, dass vor allem die tägliche Gesamtliegedauer durch die Laktationszahl, den Laktationsstatus, den Östrus und die Milchfrequenz beeinflusst wurde. Eine Berücksichtigung dieser Faktoren in zukünftigen Modellen ist daher sinnvoll.

Ziel der zweiten Studie war es zu untersuchen, ob ein kausaler Zusammenhang zwischen der Laufgeschwindigkeit von Milchkühen und der Klauengesundheit besteht. Dabei wurde mithilfe einer handelsüblichen Stoppuhr die Zeit gemessen, die die Kühe benötigen, um eine definierte Wegstrecke zurückzulegen. Zeitgleich wurde der Locomotion Score der Tiere bestimmt, um den Grad einer Lahmheit festzustellen. Lahme Tiere zeigten dabei eine signifikant langsamere Laufgeschwindigkeit als nicht lahme Tiere. Je länger ein Tier lahmt, desto langsamer legte es die Teststrecke zurück.

Zahlreiche Sensorsysteme ermöglichen eine genaue und kontinuierliche Überwachung des Gesundheitszustandes der Milchkühe. Accelerometersysteme zählen auf den meisten Betrieben zur Standardausstattung. Die Zeitmessung und anschließende Laufgeschwindigkeitsmessung lässt sich gut, einfach und kostengünstig in moderne Tierortungssysteme implementieren. Die Kombination von Daten aus verschiedenen Sensorsystemen ermöglicht es dem Landwirt, den Gesundheitszustand jedes einzelnen Tieres in Echtzeit genau zu überwachen. Auf diese Weise kann der Landwirt den Forderungen der Gesellschaft nach mehr Tierschutz in modernen Milchviehbetrieben gerecht werden.

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Abbreviations

AGRF	Average Ground Reaction Force
AMS	Automated Milking System
ANOVA	Analysis of Variance
DD	Dermatitis Digitalis
DIM	Days in milk
DPP	Differential-precision-pedometer
FOA	Food and Agriculture Organization of the United Nations
GRF	Ground reaction force
HE	Heel horn erosion
L	Lactation
LMS	Locomotion Score
LKV	Landeskuratorium der Erzeugerringe für tierische Veredelung in Bayern e.V.
LWR	Leg weight ratio
M	Mean
MANOVA	Multiple analysis of Variance
MF	Milking frequency
MS	Milking system
MY	Daily milk yield
NRS	Numerical rating system

PGRF	Peak Ground Reaction Force
PLF	Precision Livestock Farming
RH	Relative humidity
SD	Standard deviation
SF	Symmetry factor
SU	Sole ulcer
THI	Temperature humidity index
WLD	White line disease
Vit	Vereinigte Informationssysteme Tierhaltung w.V.

1 General Introduction

1.1 Lameness in dairy cows

Lameness is one of the most important diseases in modern dairy production affecting not only the health, but also the well-being of an animal (Flower et al., 2005; Whay 2002; Bicalho et al., 2007a). According to Mülling et al. (2006), lameness is a symptom that accounts for 90% of a painful claw disorder. Animals suffering from this painful limb disease change their gait. This change of gait results from a relieving posture taken by the cows in order to avoid pain (Scott, 1989). Lameness also leads to other behavioral changes: Lame animals are less active (Thorup et al., 2015), show longer lying times (Chapinal et al., 2010) and are less likely to visit grooming devices such as the cow brush (Mandel et al., 2018) than non-lame cows.

However, it does not need severe cases of lameness to observe behavioral change in dairy cows; even moderately lame cows deviate from “normal” behavior (Weigele et al., 2018).

From the behavior of an animal, conclusions about its well-being can be drawn (Mattachini et al., 2013). Animal welfare is a factor, which is becoming increasingly important in today's society. Therefore, it is important to identify and treat anything affecting the well-being of an animal as early as possible.

1.1.1 Claw diseases in dairy cows

Claw diseases often derive from interdependent risk factors. External factors include the housing system (cubicle type, floor design), barn management and hygiene (Charlton et al., 2014; Krawczel et al., 2012; DeVries and von Keyserlingk, 2005); animal-specific factors include genetic disposition (Barker et al., 2010) or parity (Stone et al., 2017). Inappropriate feeding and an improper and poor claw care can also have a negative impact on claw health (Becker et al., 2014).

Claw diseases in dairy cattle may affect both the horn shoe and the underlying tissue as well as the skin of the coronary band and the interdigital space. They can generally be divided into two categories: infectious and non-infectious claw diseases.

The most common infectious claw diseases include Dermatitis Digitalis (DD) and heel horn erosion (HE). Sole ulcers (SU) and white line diseases (WLD) were shown to be predominant non-infectious claw disorders. (Manske et al., 2002; Barker et al., 2010; Becker et al., 2014)

1.1.1.1 Digital Dermatits (Papillomatous Digital Dermatits, Footwarts)

Cheli and Mortellaro first discovered Digital Dermatitis in cattle in 1974 in Italy (Cheli and Mortellaro, 1974). DD is a highly contagious infection of the skin with a combination of bacteria (Vink et al., 2009). The most common bacteria present in lesions are spirochetes of the genus Treponema spp. (Clegg et al., 2015). The painful round lesions mainly affect the hind feet of dairy cattle and occur along the coronary band, above the interdigital cleft below the dew claws (Walker et al., 1995). These lesions may bleed, develop filiform papillae and lead to the formation of hyperkeratotic skin areas with longer hairs (Read and Walker, 1998).

Döpfer et al. (1997) developed a standardized method that was further developed by Berry et al. (2012), to classify DD lesions into six stages (table 1).

Table 1: Classification of the different DD stages according to Berry et al., 2012

Stage	Appearance of the lesion
M0	Healthy skin
M1	Small limited red or gray granulomatous areas of the skin of 0-2cm
M2	Ulcerative lesion of > 2cm
M3	Ulcerative lesion covered by a scab
M4	Alteration of the skin with hyperkeratotic lesions, occurrence of proliferative events
M4.1	Altered skin with a small granulomatous area of skin; combination of M4 and M1

Especially the classes M1, M2 and M4.1 are painful, are often prone to bleeding (Berry et al., 2012) and are associated with lameness. Cows that are severely affected by DD try not to strain the affected limb or nip their limbs for as little time as possible (Bassett et al., 1990; Read and Walker, 1998). In addition, the animals are reluctant to move (Read and Walker, 1998).

1.1.1.2 Heel horn erosion (Dermatitis ungulae)

Heel horn erosion (HE) is one of the most prevalent hoof lesions in dairy herds (Sogstadt et al., 2015; Manske et al., 2002b). The pathogenesis is still not fully understood, but a wet and unhygienic environment plays a major role in its development (Borderas et al., 2004). If the heel comes into contact with manure slurry (Bergsten and Petterson, 1992), then various bacteria, for example Bacteroides nodosus or Dichelobacter nodosus, attack the horn and reduce the hardness of the claws (Borderas et al., 2004; Knappe-Poindecker et al., 2013). In addition, studies show that heel horn erosions have the same causative factors as digital and interdigital dermatitis (Manske et al., 2002b; Knappe-Poindecker et al., 2013). In addition to associations between the diseases, some studies suggest that dermatitis and heel horn erosion are part of the same disease process (Frankena et al., 2009; Manske et al., 2002b).

According to Frankena et al. (2009) there is a higher risk of lameness in cows with severe cases of heel horn erosion, because the heel should act like a shock absorber during movement. Severe erosions may reduce shock absorbance and predispose the claw to horn lesions (Greenough and Weaver, 1997).

1.1.1.3 Sole ulcers

Sole ulcers are one of the common causes of lameness and arise when the natural horn formation is disrupted (O'Driscoll et al., 2015). Mostly the lateral claw of the hind limbs is affected (Greenough, 1987). Housing conditions, nutrition, parturition and claw care are among the predisposing factors. These factors lead to mechanical and / or metabolic changes. Changes in the hormone level especially during parturition leads to increased vascular permeability, which results in a higher risk of ischemia (Knott et al., 2007). Consequently, the cellular proliferation and differentiation in the basal layer of the sole is disturbed and a sole ulcer occurs. In addition, hormones such as relaxin and estrogen, which mainly occur in the peripartal period, weaken the suspension system of the pedal bone. In combination with an enzyme-induced degeneration of the collagen fibers of the laminar corium, the pedal bone is hence lowered and rotated, damaging the underlying corium and thus facilitating the development of ulcers. (Lischer et al., 2002)

In addition to hormonal changes during the parturition, rumen acidosis and laminitis also play an important role in predisposing claw lesions through metabolic conditions (Enevoldsen et al., 1991; Vermunt and Greenough, 1994). Endotoxins lead to the release of vasoactive cytokines that cause changes in the vascular system and activation of metalloproteinases, responsible for dissolving the collagen crosslinking (Lischer et al., 2002).

Sole ulcers may also have mechanical causes, such as hard walking surfaces. Due to the abrasive function of the soil, the sole becomes very thin and the development of sole ulcers is fostered. (Van Amstel and Shearer, 2008)

1.1.1.4 White line disease

The white line is visible as a light streak on the sole between the hard wall horn and the softer sole horn. It consists of leaflet horn, which is composed of keratinized squamous cells, called intertubular horn (Budras et al., 1996). Horn production in the white line is faster than in other structures, resulting in incomplete keratinization and consequently reduced horn quality with lower hardness. The white line is therefore more susceptible to damage. If foreign material gets into the white line, it will damage the corium. Ascending germs can lead to infections and the emergence of white line disease (Budras et al., 1998). Lameness is occurring (Hedges et al., 2001).

1.1.2 Effect of lameness on animal behavior

A painful limb disease has an effect on the behavior of animals. However, not all claw diseases are associated with behavioral changes (Tadich et al., 2010; Thorup et al., 2014). In a study by Tadich et al. (2010) cows with sole ulcers showed signs of lameness, while cows with heel horn erosion and sole bleeding showed no signs of impaired movement. Similarly, Dyer et al. (2007) found that pain-sensitive claws also occurred in non-lame cows. Furthermore, the authors suspect that cows can get used to mild, long-lasting claw pain and therefore do not recognize any limitations in their natural movement.

According to O'Callaghan et al. (2003), the pain perception of animals varies greatly. In particular, cows often conceal pain instinctively because of their characteristics as escape and herd animals. Therefore, it is difficult to recognize lame animals early and safely. In some studies, the investigation of physical properties of lame cows (e.g. weight bearing) was used for lameness detection (Pastell and Kujala, 2007), whereas in other studies changes in production (e.g. milk yield) were used for lameness assessment (Bach et al., 2007). Many studies also focused on the general behavior (e.g. activity, lying behavior) of lame animals (O'Callaghan et al., 2003; Blackie et al., 2011; Alsaaod et al., 2012). Chapinal et al. (2010) observed that lame cows (5-point Numerical Rating System, NRS ≥ 3) had longer lying bouts than non-lame cows. This is consistent with the findings of a study by Blackie et al. (2011), who found that lame cows have longer lying times as well and spend less time standing than non-lame animals. In addition, the average duration of a lying bout increased with increasing lameness. Furthermore, Ito et al. (2010) postulated that animals showing an increase in daily lying time (> 14.5 h d^{-1}) are 16 times more likely to develop severely lameness. As the lying time increases during lameness, the activity of an animal decreases. Mazrier et al. (2006) showed that 92% of cows that develop lameness had a reduction in activity by at least 15% a few days before lameness became evident. O'Callaghan et al. (2003) also showed that lame cows had a decline in activity compared to healthy cows.

Lameness in addition to the lying behavior and activity also affects the feeding behavior. The daily feeding time decreases to minimize the painful movement as much as possible (González et al., 2008). Although the number of feeding trough visits and the total feeding time is decreasing, the dry matter intake does not change

(Thorup et al., 2015). Instead, lame animals take in more food in less time, thereby shortening feed intake time and reducing the burden on the painful limb.

1.1.3 Importance of lameness in livestock farming

Lameness is the third most frequent reason for early culling behind udder infections and infertility (Juarez et al., 2003). The lameness prevalence, however, varies among farms, regions, countries and housing systems although it is generally higher in freestall barns compared with tiestalls (Sogstadt et al., 2005).

In Europe freestall diaries had an overall lameness prevalence of 18 %, whereas herd prevalence in France, Germany, Spain and Sweden was estimated to be 25 %, 20 %, 10 % and 5 % respectively (Sjöström et al., 2018). British studies describe a prevalence of lame cows of 36.8 % (Barker et al., 2010). Espejo et al. (2006) reported a mean lameness prevalence of 25 % in Minnesota, whereas overall lameness prevalence in California and northeastern United States was assessed to be 34 and 63% (von Keyserlingk et al., 2012). Studies have shown that farmers underestimate the proportion of lame animals on their farms (Bennett et al., 2014; Leach et al., 2010). Higginson Cutler et al. (2017) found that farmers assessed the mean herd-level prevalence to be 9 %, whereas researchers estimated it to be 22 %. Despite lameness leading to economic and thus financial losses, 90 % of farmers do not consider the disease to be a major problem (Leach et al., 2010). Bruijnis et al. (2010) calculated the economic costs of subclinical (before diagnosis) and clinically lame (with diagnosed claw disease) cows: their study calculated the total costs of claw diseases to average a total of 3,474 € per year within a herd. The costs were subdivided as follows (figure 1):

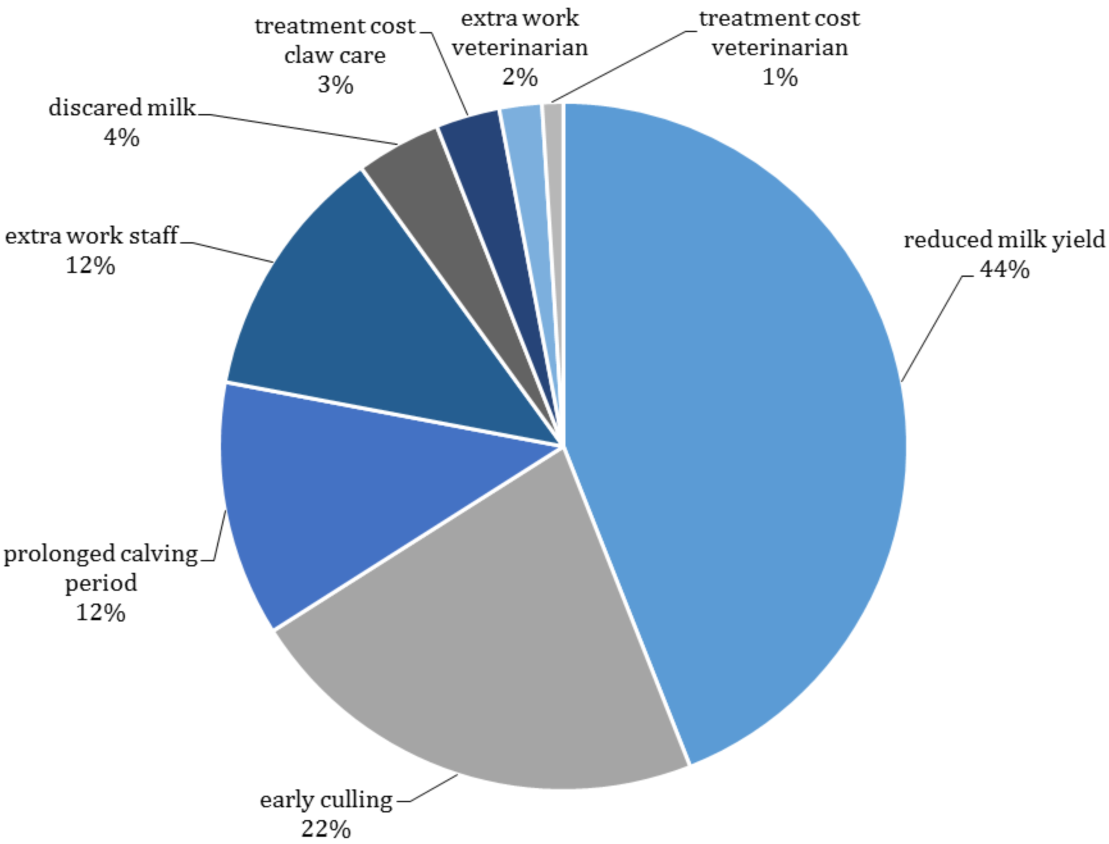

Figure 1: Distribution of the total costs of claw diseases according to Bruijnis et al., 2010

Amory et al. (2008) also found a connection between claw diseases in dairy cows and milk yield losses. According to the authors, cows with WLD deliver 369 kg less milk per lactation. In cows with SU a reduction in milk yield by lactation of up to 573 kg was noticed. Furthermore, Green et al. (2002) found that milk yield from clinically lame cows might be reduced from four months before the diagnosis of lameness up to five months after treatment.

According to Scott (1989), diagnosis and treatment of claw diseases and lameness in dairy cattle husbandry should be established in the interest of economic management. Many farmers are still unaware of the economic consequences of lameness. Nonetheless, a total of 70 % of them are willing to improve claw health on their farms (Bruijnis et al., 2013).

1.2 Visual methods of lameness detection

The most common method used to identify lame animals is the assessment of motion using a numerical rating system (Sprecher et al., 1997; Manson and Leaver, 1988; Flower and Weary, 2006). Thereby each animal is individually inspected while standing and during movement. There are several variants of locomotion scoring, which differ in the assessment of gait patterns while standing and during movement and in the number of degrees of lameness. A total of twenty five manual locomotion scoring systems can be distinguished. These systems differ in terms of which scales are to be used for locomotion scoring and which gait and posture characteristics are to be considered (Schlageter-Tello et al., 2014). Most commonly, the gait pattern of an animal is assessed using the locomotion score according to Sprecher et al. (1997). The focus of this method is put on a potentially asymmetrical gait, reluctance to bear weight and the curvature of the back line. The gait pattern of the animals is divided into five categories as can be seen in figure 2. Flower and Weary, (2006) as well as Manson and Leaver (1988), described a nine-stage locomotion scoring system. Combinations of these different locomotion scoring systems have also been used for lameness detection (Amory et al., 2008). The EU project Welfare Quality (2000) tried to standardize the locomotion scoring system and developed a three-stage locomotion score, which was described by Winckler and Willen (2001). However, there is no consistent protocol on how to perform locomotion scoring.

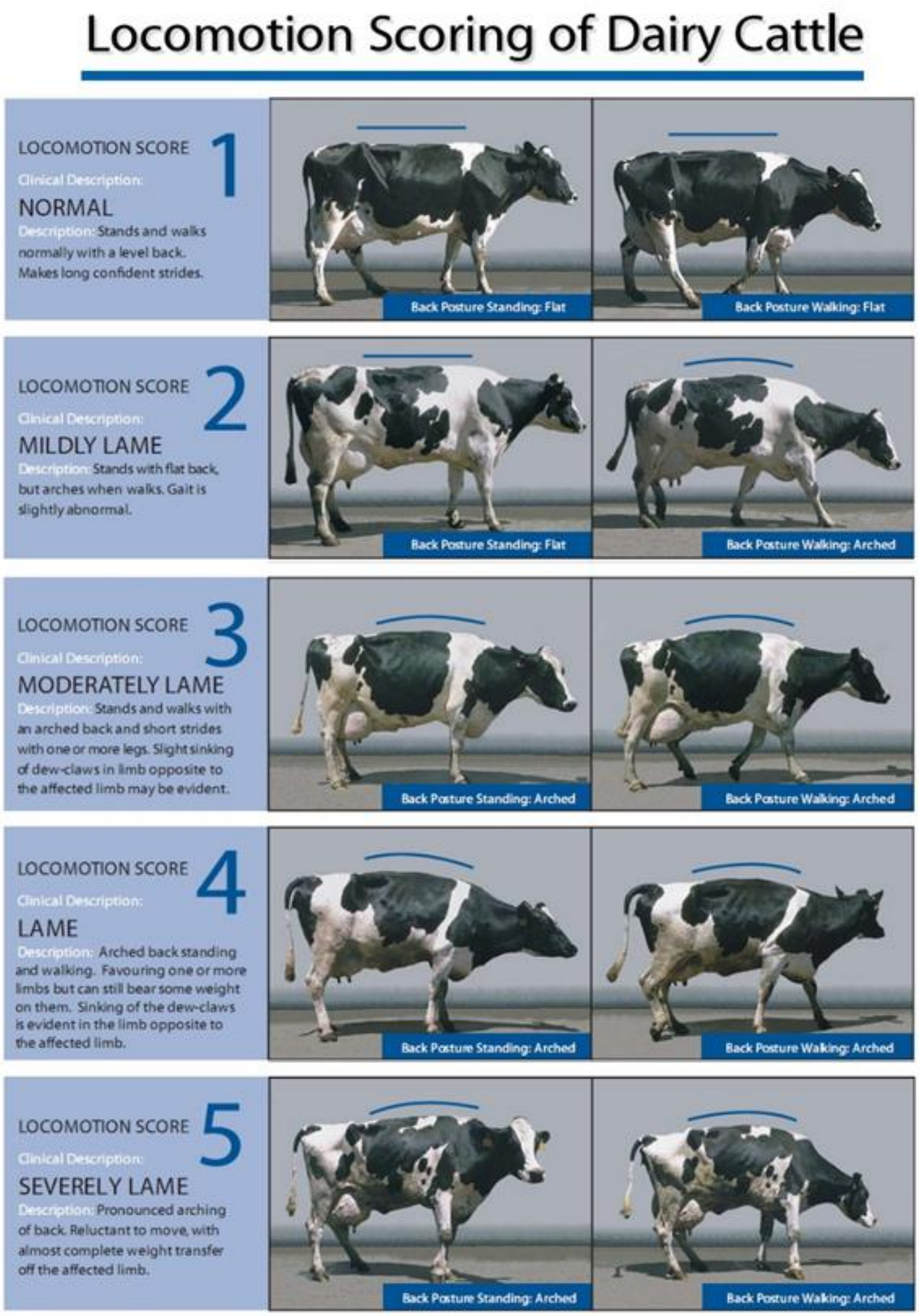

Figure 2: Locomotion Scoring according to Sprecher et al., 1997

Nevertheless, any locomotion scoring should be performed while the animals are walking "(...) on a flat, firm, and non-slippery surface" (Schlageter-Tello et al., 2014).

In addition, each locomotion scoring should follow the same procedure (Whay, 2002) and trained evaluators should judge the gait patterns (Engel et al., 2003). Flower et al. (2006) recommended gait assessment to be performed after milking when cows returning to the barn. This path is part of the cows' daily routine, therefore purposefully crossed and the gait is not influenced by a filled udder (Flower et al., 2006). Although locomotion scoring is the gold standard for lameness detection in many studies (Whay, 2002; Schlageter-Tello et al., 2014), it is a time-consuming - especially for large herds - and subjective assessment method (Liu et al., 2009).

According to Flower and Weary (2006) it may occur that one observer rates the same cow differently in two successive locomotion scorings. Furthermore, if the observer is not adequately trained to recognize and assess posture and gait of the cows, he will not adequately cope with the task of locomotion scoring and possibly overlook mildly or moderately lame cows (Whay, 2002; Leach et al., 2010). In this case, a first lameness diagnosis is only made at an advanced stage where treatment is often no longer an option (Bicalho et al 2007a; Liu et al 2009).

1.3 Sensor based methods of lameness detection

Increased mechanization of herd management and workflow automation due to growing herd sizes should ensure sensor-assisted lameness detection (Neveux et al., 2006). Dairy farms can strongly benefit from sensor-assisted lameness detection methods: On the one hand animal welfare increases, since lame cows have to suffer less pain and restrictions of movement due to early stage detection and treatment of the illness. On the other hand the increased health of the herd subsequently leads to a reduction of costs. According to Bicalho et al. (2007a), animal welfare is gaining importance due to an increasing social awareness for livestock-friendly means of production and a more conscious demand of food by consumers, which can indirectly influence the housing conditions to a certain extent.

1.3.1 Weighing systems

Reliable information about leg health can be obtained by using weighing systems. As a result, lameness can be assessed (Pastell et al., 2006; Chapinal and Tucker, 2012). With four independently mounted weighing plates (e.g.: four-foot balance, Figure 3), the limbs of a cow can be weighed individually. By using this method, it can be determined whether individual affected limbs are relieved of the cow in restraint and therefore have a lower weight. Relieving a limb may be an indication of existing lameness (Pastell et al., 2006; Pastell et al., 2010; Chapinal and Tucker, 2012). Pastell et al. (2010) calculated the leg weight ratio (LWR) to describe the relative amount of weight put on each limb. It was used not only to differentiate between lame and non-lame animals but also between healthy cows and cows with sole ulcers. Following the same principle, Chapinal et al. (2010) found a significant ($p = 0.003$) weight asymmetry between the hind legs of lame cows with a LWR of 78 % ± 2 % and the hind legs of non-lame cows with an LWR of 87 % ± 2 %. Lameness can therefore be detected automatically using weighing systems. It should be noted, however, that the technique of the four-foot balance is designed for lameness detection on the basis of one diseased limb. Cows having claw disorders on both adjacent claws may be less likely to be identified as lame when standing on the scale (Kujala et al., 2008).

1.3.2 Ground reaction force (GRF)

The force exerted from the ground to the claw while a cow is standing and walking is called Ground Reaction Force (GRF) and can be measured by reaction force detection systems (van der Tol et al., 2003; Tasch and Rajkondawar, 2004). This measuring technology has its origins in human medicine and is used in animal husbandry to investigate pressure distribution underneath the claws (van der Tool et al., 2002). Because the pressure is not evenly distributed between the claws and some regions are more heavily stressed than others, the risk of injury increases in these areas (van der Tol et al., 2002). If the normal pressure load of a claw changes, it is possible to draw conclusions about pathological processes and, as a result, potential lameness. BouMatic's Stepmetrix is an automatic lameness detection system that uses GRF to detect lame cows (Bicalho et al., 2007a). Exceeding the GRF system both the body weight of the animal and the vertical GRF on each limb are recorded via load cells. With the aid of light barriers, the position of the cow and its speed are also determined. Based on the measurement data, a limb movement variable can now be assigned to each individual limb. According to Tasch et al. (2004), there are differences in lame animals compared to non-lame cows when it comes to the duration of stance phases, as well as the size of normalized PGRF and AGRF (table 2).

Table 2: Limb movement variables of a sound and a lame cow (according to Tasch et al., 2004)

Limb movement variable	**Sound cow**				**Lame cow**			
	Left front	Right front	Left rear	Right rear	Left front	Right front	Left rear	Right rear
Stance time	2,30	1,95	1,70	1,65	1,20	1,20	1,45	0,75
Normalized PGRF	0,54	0,55	0,41	0,39	0,53	0,47	0,50	0,12
Normalized AGRF	0,38	0,37	0,31	0,27	0,33	0,32	0,35	0,07

With the aid of a so-called symmetry factor (SF), additional statements about the severity of a lameness can be made (Tasch et al., 2004). This factor indicates how much the neighboring limb pairs differ from each other. Negative SF indicate a significant deviation in the motion symmetry of the affected limb. But since not all lame animals also show a relief of the limb, lameness detection can be improved by means of a three-dimensional force measurement (Dunthorn et al., 2015).

1.3.3 Measurement of walking speed

The measurement of walking speed is a good way to detect lame animals (Flower et al., 2006; Beer et al., 2016). As animals with a painful limb disease change their gait in order to avoid pain, walking speed also changes. Lameness causes the animals to take shorter strides with less stride height, a longer stride duration and a longer stance phase, which results in a slower overall walking speed (Flower et al., 2006; table 3).

Table 3: Least square means + SEM of kinematic stride variables before and after milking for sound (without sole ulcer) and lame (with sole ulcer) cows (according to Flower et al., 2006)

Variable	Sound cows (without SU)		Lame cows (with SU)	
	Before	After	Before	After
Stride length [cm]	126.3 ± 1.7	139.1 ± 1.7	120.5 ± 3.6	127.8 ± 3.6
Stride height [cm]	8.6 ± 0.2	9.5 ± 0.2	7.9 ± 0.3	8.2 ± 0.3
Stride duration [s]	1.42 ± 0.03	0.86 ± 0.02	1.55 ± 0.06	1.52 ± 0.06
Stance duration [s]	0.97 ± 0.02	0.86 ± 0.02	1.12 ± 0.05	1.07 ± 0.05
Speed [m s-1]	0.89 ± 0.02	1.08 ± 0.02	0.80 ± 0.05	0.87 ± 0.05

Since a filled udder influences the gait pattern of a dairy cow, the best time to detect lameness by means of timekeeping is, according to a study by Flower et al., 2006, after the milking process (table 3). Differences between lame and non-lame animals are most evident at this time, according to the authors. In addition, care must be taken that the animals walk over a paved, non-slippery floor to exclude gait deviations due to the nature of the soil (Flower et al., 2007). The animals should also pass the test track as far as possible without moving, as additional moving leads to an increase in lameness incidence (Bran et al., 2018).

Although measuring walking speed is a good indicator of lameness, an improvement in lameness detection can be achieved by combining with lying time and weight distribution (Chapinal et al., 2010a).

1.3.4 Use of accelerometers

With the help of accelerometer systems, attached to the limbs of the animals, the acceleration of the limbs during movement can be measured continuously (Pastell et al., 2009). Originally, accelerometers were used in sports medicine to detect physical activity in humans that enabled them to make statements about chronic and cardiovascular diseases (Chen et al., 2005). In livestock farming, accelerometer systems were initially used to detect estrus events in dairy cows in order to improve insemination rate (Fricke et al., 2014; LeRoy et al., 2018). Increased activity is considered a secondary sign of estrus in cattle. This is detected by means of accelerometers and is subsequently associated with estrus behavior (Fricke et al., 2014). Furthermore, activity changes can not only be used for estrus determination, but also for lameness detection (Pastell et al., 2009; Alsaaod et al., 2012). Accelerometers can be mounted above the metatarsal joint as well as in the collar for this purpose.

Pastell (2009) and Alsaaod (2012) used changes in activity in their studies to draw conclusions about lameness events. In order to measure activity wireless three-dimensional acceleration measurement devices were attached above the metatarsophalangeal joint. Alsaaod (2012) used an ALT pedometer, which consist of a piezoelectric sensor for measuring the activity, a digital position sensor for detecting lying time and a thermal sensor for temperature recordings. Pastel et al. (2009) used a wireless three-dimensional acceleration sensor to determine movement and inclination. The data obtained will be stored over certain periods of time in the pedometer and transmitted via radio waves manually or automatically (for example, readout unit at the milking parlor) to a PC and are converted into activity patterns using different models (wavelet filters, support vector machines) (Pastell et al., 2009; Alsaaod et al., 2012).

To detect lame animals based on activity data, lame phases should be compared with non-lame phases within the animal, according to Alsaaod et al. (2012), because the animal-specific activity fluctuations are greater than the differences between lame and non-lame animals.

The effect of lameness on pedometric activity seems to be bidirectional. If some animals show reduced activity for several days before recognizable lameness (Mazrier et al., 2006), the activity on others increases (Flower et al., 2005). Reason for low activity may be that painful limb disorders cause lame animals put on the painful limb more cautiously, causing them to walk more carefully (Pastell et al., 2009). On the other hand, lame cows try to put as much strain on painful limbs as possible, so they take shorter steps and need more steps to cover the same distance (Flower et al., 2005; Alsaaod et al., 2012). In consideration of the lying behavior, lame animals show prolonged lying periods and a prolonged daily lying time (Ito et al., 2010; Chapinal et al., 2010). In addition, Ito et al. (2010) found that cows with long lying times (>14.5 h d^{-1}) had a 16.2 times higher risk of being severely lame (5-point NRS = 4). As the limbs are particularly stressed when rising up, lame cows often avoid rising up, which probably explains the increased lying times.

Automated detection of lame animals based on their activity and lying behavior is possible with accelerometers. However, as animal behavior is not only affected by lameness, but also, for example, the way in which it is kept (DeVries and von Keyserlingk, 2005; Charlton et al., 2014) the design of the cubicles (Calamari et al., 2009), and milk yield (Stone et al., 2017) a combination of accelerometer data and other parameters is promising in order to improve lameness detection in dairy cows.

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2 Thesis outline

Based on the outset described above the goal of the project was to develop an inter-farm support tool as an early warning system for monitoring and improving claw health on dairy farms. Above all, the focus was on linking accelerometer data with data from the herd management system to make statements about lameness as early as possible.

The aim of the main study (paper I) was to identify and evaluate different influencing factors on the lying behavior of lactating dairy cows and thus make pedometric data applicable for lameness analysis.

The aim of the second study (paper II) was to determine, whether there is a close causal relationship between walking speed and lameness, respectively lameness degree, so that walking speed could be integrated as a feature into a prediction model.

3 Published Trials

3.1 Paper I

Environmental, management, and animal physiological influences on the lying behavior of dairy cows

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ABSTRACT

The eligibility using pedometers to identify and observe lameness in dairy cows has been justified by several previous studies. Monitoring individual lying behavior has proven to be a suitable instrument for lameness detection. However, pedometric sensors measure activity, neglecting environmental, management-based and animal-physiological influences. These influences must be taken into account to gain truly reliable data, based on pedometers, about detectable diseases such as lameness.

The aim of this study was therefore to identify and evaluate the different influencing factors in order to make pedometric data applicable for lameness analysis. Electronic data loggers recorded the lying behavior (average lying bout duration per hour in minutes, number of lying bouts per day) of 2,538 lactating dairy cows from six German dairy farms for 14 months (June 2015 until August 2016). A pedometric data set of 505,800 days with observations was available for evaluation. A linear mixed model with animal - lactation nested in farm as a random effect and the herd mean as a covariate was used to investigate various influential factors. Breed (Holstein Friesian or Simmental), age at first calving, localization of pedometer (hind or fore leg), and milking system (AMS = Automated Milking System or milking parlor) had no significant influence on dairy cows' lying behavior. Daily lying time was particularly influenced by milking frequency, DIM, number of lactation and oestrus. Compared to the mean the daily lying time was significantly ($p < 0.0001$) increased in animals with increasing number of lactation and DIM up to 200. In addition, an increase in daily lying time was found at a milking frequency of two and three times a day, respectively. The average number of lying bouts per day and the average lying time for each lying bout was significantly but only slightly affected.

Our results confirm the assumption that certain factors influence the lying behavior, especially the daily lying time, of dairy cows. Therefore, these factors should be taken into account in future studies with regard to a meaningful lameness analysis using pedometer data.

Key Words: dairy cow, lying behavior, influence, accelerometer

INTRODUCTION

On dairy farms lameness is currently at the center of both economic and animal welfare interests. Unrecognized and untreated claw and limb diseases are painful and affect the health as well as the well-being of dairy cows (Scott, 1989; Whay, 2002; Flower et al., 2005; Bicalho et al., 2007a). As a result, dairy farms experience losses in performance and associated financial losses (Bruijnis et al., 2010). According to Neveux (2006), a sensor-supported lameness detection system should be ensured in order to keep such losses as low as possible and to give dairy farmers a practical, technological tool to support their herd management. Several studies have proven the eligibility of pedometer usage for lameness detection and evaluation (O' Callaghan et al., 2003; Mazrier et al., 2006; Alsaaod et al., 2012). Pedometers deliver valuable data which allow a close consideration of an individual cow`s lying behavior. Therefore, these devices are especially suitable for early lameness detection. Chapinal (2010) observed in a study that lame cows (5-point Numerical Rating System, **NRS** ≥ 3) had longer lying bouts than non-lame cows. Furthermore, Ito et al. (2010) found that cows with long lying times (>14.5 h d^{-1}) had a 16.2 times higher risk of being severely lame (5-point NRS = 4).

Activity in general is affected by different factors including heat stress (Cook et al., 2007; Allen at al., 2015), production (Deming et al., 2013; Stone et al., 2017), barn management (Charlton et al., 2014; Krawczel et al., 2012; DeVries and von Keyserlingk, 2005), parity (Westin et al., 2016; Stone et al., 2017), cubicle bedding (Calamari et al., 2009) and health status (Stone et al., 2017; Westin et al., 2016). The sensors, however, which are generally used to determine animal activity, collect data without taking any of these extrinsic or intrinsic influences into account. If these data are used to assess the state of health of an animal, misinterpretations may occur because (besides lameness) changes in activity may also indicate an incipient birth, estrus or other diseases. Hence, in order to gain reliable information about lameness based on pedometers, their data must be corrected by taking management, environmental and animal physiological influences into account.

The aim of this study was therefore to identify and evaluate the different influencing factors and thus make pedometric data applicable for lameness analysis.

MATERIALS AND METHODS

1.1 Farm Selection and Description

Activity data (average number of motion impulses per hour; average number of lying bouts per day; average lying time for each lying bout) was collected over a period of 14 months (June 2015 until August 2016) from 4,646 lactating dairy cows from six different dairy farms in Germany. Three farms were located in eastern Germany (Panel East), three farms in southern Germany (Panel South). All of the cows were free in stall housing without access to pasture. Detailed information on the individual farms is given in table 1.

Table 1: Detailed farm characteristics

panel	farm	feeding frequency [d-1]	frequency of feed submission [d-1]	milking frequency [d-1]	cubicle design	floor type	herd size (M ± SD)[1]
East	1	1	4-6	2	deep-bedded stalls (chopped straw and lime as bedding)	concrete floor with different rubber coating	480 ± 14
	2	2	3	2	mattress stalls (rubber mat with minimal bedding)	Barn 1: fully slatted floor with rubber coating Barn 2: fully slatted floor	729 ± 17
	3	2	automatically (at hourly intervals)	AMS[2]	deep-bedded stalls (chopped straw and lime as bedding)	concrete floor with rubber mats in the feeding area	524 ± 114
South	5	1	4-5	2	mattress stalls (rubber mat with minimal bedding)	concrete floor with rubber mats in the feeding area	77 ± 16
	6	1	3-4	3	deep-bedded stalls (chopped straw and lime as bedding)	concrete floor	715 ± 51
	7	1	automatically (at two-hourly intervals)	AMS	mattress stalls (rubber mat with minimal bedding)	concrete floor	72 ± 3

[1]: Herd size shown here as mean (M) ± standard deviation (SD)

[2]: Automated milking system

1.2 Data Collection

Daily activity was recorded using electronic data loggers (differential-precision-pedometer, DPP; Lemmer-Fullwood GmbH, Lohmar, Germany), which were attached to one of the cow's hind or fore legs. The pedometers used provided accumulated daily values. For each lactating animal, three values were available per day: average number of motion impulses, average number of lying bouts and the average lying time for each lying bout (recorded in minutes).

Furthermore, daily lying time (in minutes) for each cow was calculated according to the following formula:

$$Daily\ lying\ time = average\ number\ of\ lying\ bouts \times lying\ time\ for\ each\ lying\ bout$$

The day with the highest number of motion impulses within a three-day interval, the period of one day before artificial insemination until one day afterwards was designated as a heat event. Days of insemination were taken from each farm's herd management program.

Temperature-Humidity Index (THI) was calculated daily according to the National Research Council formula (NRC 1971):

$$THI = (1.8 \times T_{db} + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26)]$$

with T_{db}: dry bulb temperature (°C) and RH: relative humidity (%).

T_{db} and RH were retrieved from the weather station closest to each farm. These can be downloaded directly via the German weather service. Following Heidenreich et al. (2004), the THI was subdivided into categories to be considered as an extrinsic factor in our study. THI < 68 was defined as category one, in which no sign of heat stress can be observed. THI between 68 and 71 represent category two; here mild heat stress may occur. THI between 72 and 79 constitute moderate heat stress and were named as category three. Category four was defined as THI between 80 and 89. THI > 90 was declared as category five in which death can occur. Due to the temperate climate in Germany, no data above 78 occurred during the data collection

phase, so only categories one to three were available to be taken into account.

The milking system (MS) and milking frequency (MF) were taken directly from the individual farms. The daily milk yield (MY) was taken from farm records generated directly by the milking technology (Lemmer-Fullwood GmbH, Lohmar, Germany) and afterwards transferred in ADIS data format. Lactation (L), and DIM were obtained from the milk performance test. These tests are carried out monthly in the panel east by **vit** (Vereinigte Informationssysteme Tierhaltung w.V, Verden / Aller, Germany) and in the panel south by **LKV Bayern** (Landeskuratorium der Erzeugerringe für tierische Veredelung in Bayern e.V, Munich, Germany). MS was divided into two groups: cows milked in a milking parlor and cows milked by an automated milking system (AMS). Cows were milked once, twice or three times a day. In order to prevent the model from recognizing an AMS, MF was also set at three in the case of an AMS. The daily milk yield was calculated from the sum of the individual milkings per cow within 24 hours, starting at 0:01 a.m. in the case of a milking parlor. If there was an AMS, the daily milk yield was calculated according to the following formula:

$$MY = \frac{MY\ (today) + MY\ (yesterday)}{Mi(today) + Mi\ (yesterday)} \times 1440\ min$$

with Mi: length of milking intervals [min] and MY: milk yield [kg]. MY, L and DIM were divided into classes, which can be taken from table 2.

Table 2: Classification of influence factor Milk Yield, Lactation and DIM

Influence factor	Classes
MY [kg]	< 25
	25-30
	30-35
	35-40
	> 40
L	1
	2
	3
	> 3
DIM [d]	< 100
	100-200
	> 200

Statistical Analyses

The data was compiled and prepared using SAS ® Proprietary Software 9.4 (TS1M2) (SAS Institute Inc., Cary, NC, USA); data analysis was performed using R 3.4.0 (R Foundation for Statistical Computing, Vienna, Austria).

Non sense data were removed before any statistical evaluations took place. Data above and below the level of mean ± 2-fold standard deviation were excluded. The following principle was used in order to generate a largest possible data set make meaningful evaluations. For each animal 30 observations were required within a lactation. If one day with observations was missing, this was replaced by the mean value of the adjoining days.

MANOVA was used to determine correlations. In order to be able to calculate correlations with respect to milk parameters, MANOVA only took days into account on which a sample was taken. Analysis of variance (ANOVA, table 3) was performed. Effects with a p value of ≤ 0.0001 were considered significant. This level was chosen because of the large number of records. ANOVA was performed with type III errors to account for a possible interaction between fixed effects. Including interactions results in a rank-deficient design matrix of the model. Therefore, no interactions were directly investigated.

Table 3: Significances for the linear mixed model with animal lactation nested in farm as a random effect and farm as a covariate

Influence factor	p value of average number of lying bouts	p value of lying time for each lying bout	p value of daily lying time
Breed	0.9939	0.562	0.3442
Age at first calving	0.2386	0.0096	0.0519
Number of lactation	< 0.0001	< 0.0001	< 0.0001
Days in milk	< 0.0001	< 0.0001	< 0.0001
Heat event	< 0.0001	< 0.0001	< 0.0001
Daily milk yield	< 0.0001	< 0.0001	< 0.0001
Milking frequency	< 0.0001	< 0.0001	< 0.0001
Performance	0.2504	0.0002	< 0.0001
Content of fat	< 0.0001	< 0.0001	< 0.0001
Content of protein	< 0.0001	< 0.0001	< 0.0001
Content of urea	< 0.0001	< 0.0001	0.0049
Somatic cell count	< 0.0001	< 0.0001	< 0.0001
Season	< 0.0001	< 0.0001	< 0.0001
Localization of pedometer	0.051	0.0515	0.81
Milking system	0.1758	0.2744	0.2024
Temperature- Humidity Index	0.5699	< 0.0001	< 0.0001
Herd mean	< 0.0001	< 0.0001	< 0.0001

With the help of the residual sum of squares, the suitability of various models for the investigation of the influence factors on lying behavior was examined. If animal is taken into account as a random effect in the model, 42% of variance of the number of lying bouts, 38% of variance of the average lying time for each lying bout, and 36% of variance of the daily lying time can be explained. If, in addition to animal, the lactation effect within the farm is also considered, 44%, 38% and 38% of the variance of the number of lying events, lying time for each lying bout, and daily lying time can be described. The rolling average, however, describes only 0.14%, 0.17%, and 0.01% of the lying parameters. This suggests that the difference between animals is greater than between farms. A linear mixed model with animal- lactation nested in farm as a random effect proved to be most suitable and was therefore used to calculate the influential impact of each individual factor. Breed, age at first calving, number of lactation, DIM, heat event, daily milk yield, milking frequency, performance, content of fat, protein and urea, somatic cell count, season, localization of pedometer (hind or front leg), milking system and THI were defined as fixed effects. The rolling average entered the model as a covariate, and animal-lactation nested in farm entered the model as a random effect.

Breed, age at first calving, localization of pedometer, and milking system had no significant influence on the lying behavior and are therefore not mentioned further. Since the impact of performance, fat, protein and urea content of the milk, somatic cell count and season was significant, but very low, these parameters are not mentioned in this study.

Results are only mentioned, if the significant influence is numerical greater than one lying bout per day and one minute in case of lying time for each lying bout and daily lying time respectively.

RESULTS AND DISCUSSION

The evaluation of a pedometer data set of 505,800 records including 2,538 animals with 3,302 lactations produced the following results: Cows had an average daily lying time of 682.8 ± 136.7 minutes (348 min d^{-1} to 1001 min d^{-1}) with an average number of lying bouts of 9.8 ± 2.8 (3 to 17). The average lying duration for each lying bout was 74.3 ± 20.6 minutes (22 min to 129 min). These results are consistent with results from a study by Ito et al. (2009) in which the lying behavior of 2033 cows on 43 Canadian farms was investigated. There cows lay down 11.0 ±2.1 h/d within 9±3 bouts/d, which ranged between 7 to 10 bouts/d. The mean bout duration was 88±30min.

MANOVA showed weak correlations, as can be seen in table 4. Thus, a mutual interdependence of the factors considered can be excluded.

Table 4: Correlations (investigated by MANOVA) between considered influence factors

Influence factor	Ø number of lying bouts per day	Ø lying time for each lying bout	Daily lying time	MY	THI
Ø number of lying bouts per day	**1**	**-0.69**	**0.37**	**0.02**	**0.08**
Ø lying time for each lying bout	**-0.69**	**1**	**0.22**	**-0.06**	**-0.09**
Daily lying time	**0.37**	**0.22**	**1**	**-0.01**	**0**
MY	**0.02**	**-0.06**	**-0.01**	**1**	**0.04**
THI	**0.08**	**-0.09**	**0**	**0.04**	**1**

Looking at the significances (table 2), it is striking that the influence of MS with p = 0.1758, p = 0.2744 and p = 0.2024 was not significant with respect to the number of lying bouts, the average duration of each lying bout and the daily lying time, respectively. Rumination is one of the basic needs of cows and mainly occurs when the animals are lying down (Schirmann et al., 2012). Duration and frequency depend on the number of feed table visits and the amount of feed intake (Schirmann et al., 2012). As a result, the number of lying bouts and the duration of each lying bout are predominantly influenced by feeding behavior rather than the milking system. Feed intake behavior was not documented in the present study and should be considered an important influencing factor in future studies on lying behavior. Furthermore, according to Munksgaard (2005), lying behavior is referred to as a high-priority behavior for dairy cows. Animals therefore try to reach a daily lying time of 12h regardless of time constraints, such as milking times or feeding times (Munksgaard et al., 2005). The animals in our study do not change their lying behavior significantly depending on the milking system. Deming et al. (2013), also showed in a study that cows have the same lying behavior, regardless of whether they are milked in a milking parlor or an automatic milking system. They suspected that the AMS waiting area has similar effects on cows' retention time as pre-waiting areas of conventional milking parlors. Jacobs et al. (2012) described some factors that could cause animals to wait in front of AMS units before they enter.

Cows in estrus had 3.7 minutes shorter lying time for each lying bout than animals without any symptoms of estrus. Overall, daily lying time during estrus was reduced by 88.8 minutes. Similar results were also obtained by Dolecheck et al. (2015). To detect behavioral changes around estrus events, lying time and number of lying bouts were measured by IceQube accelerometers, which are as reliable as our ones (Higginson et al., 2010). By comparing lying behavior during estrus with lying behavior during non estrus, lying time as well as number of lying bouts decreased due to increasing activity and restlessness (Jonsson et al., 2011).

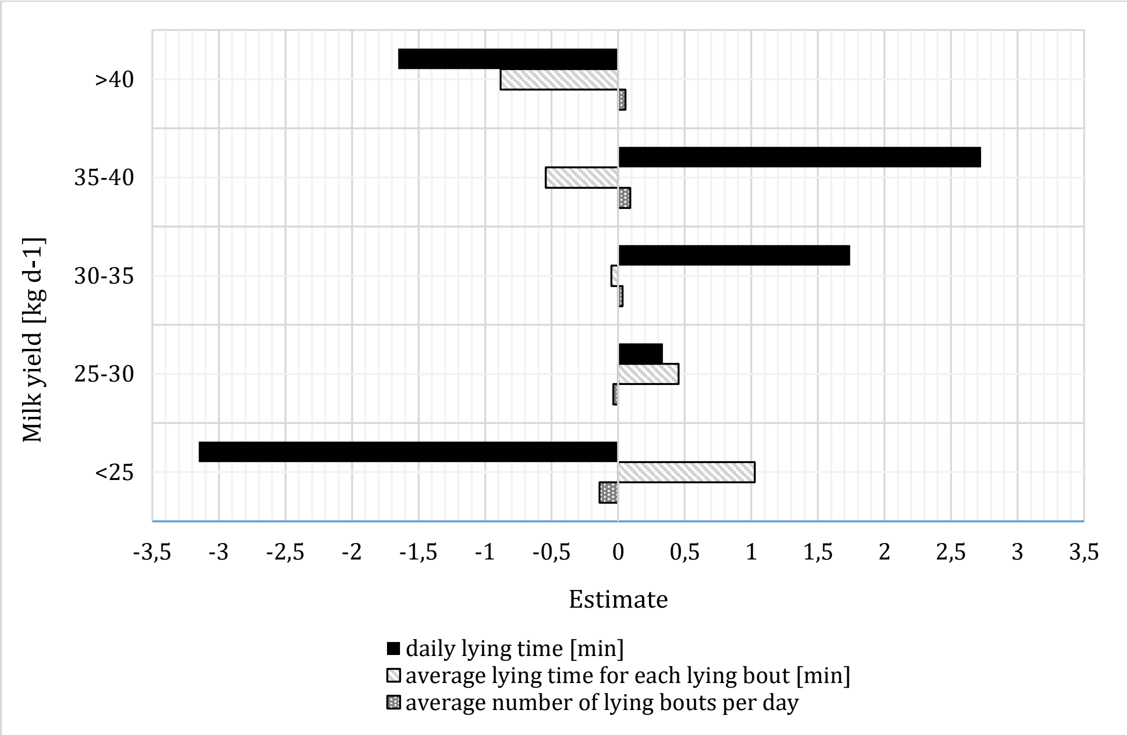

Figure 1: Daily lying time was reduced in animals with a daily milk yield of < 25 kg and > 40 kg; average lying time for each lying bout decreased with increasing milk yield; average number of lying bouts per day increased up to a milk yield of 35 - 40 kg and decreased again with a milk yield > 40 kg

Similar to the results of a previous study by Deming et al. (2013), our study also proved that cows with increasing amounts of milk had shorter lying bouts (Figure 1). This result supports the thesis of DeVries et al. (2011) that animals with shorter lying bouts have longer standing times resulting from longer feeding periods and larger meals. In order to cope with increasing milk production, the animals have to increase their food intake and therefore spend more time standing at the feed bunk (Bewley et al., 2010).

Surprisingly, daily lying time did not fluctuate according to the lying bout duration, as can be seen in figure 1. Only animals with a milk yield higher than 40 kg d^{-1} behaved as described in previous studies (Stone et al., 2017; Deming et al., 2013) and consequently showed a 1.7-minute decrease in the length of daily lying time when compared to the average cow. In animals with a daily milk amount between 25 and 40 kg, daily lying time even increased, while animals with a milk yield of less than 25 kg showed a reduction of 3.2 minutes in the daily lying time compared to the average. The reason for a lower daily lying time might be that these animals have a lower food intake due to their lower milk yield and therefore have to spend less time ruminating, which mainly occurs when they are lying down (Schirmann et al., 2012). They can therefore use the rest of the time for their social and comfort behavior. In addition, animals with a high milk yield have a larger udder and thus a higher udder filling capacity (Maselyne et al., 2017). This in turn leads to higher pressure loads of the already filled udder during lying periods. Cows with high milk performance could therefore try to minimize udder pressure by reducing their lying times (Norring et al., 2012).

Consideration of the lying frequency shows that the number of lying bouts still corresponded to the herd average if the milk yield increased. In a previous study about the influence of the milk yield of dairy cows on time management, Norrington et al. (2012) found that the amount of milk was not correlated with the number of lying bouts. Lying behavior would change, but not the frequency of lying bouts. These findings were supported by our own results.

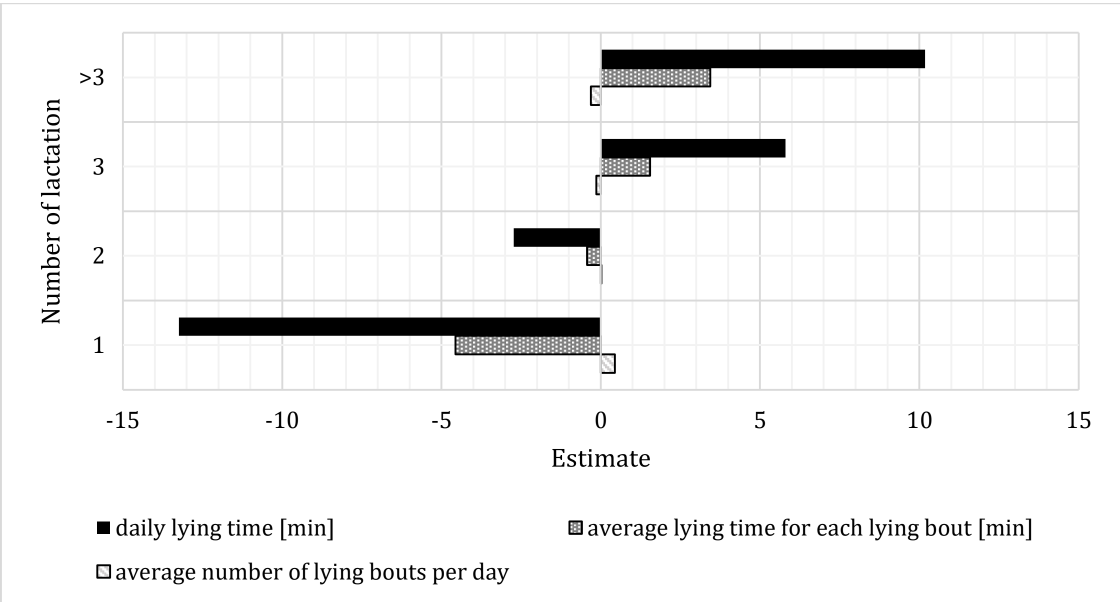

Figure 2: Daily lying time was decreased in primiparous animals and animals in lactation exceeding the third lactation; it was increased in animals in the second and third lactation

Although the number of lactation had a significant influence on all lying parameters, debatable differences could only be seen in relation to the daily lying time and the lying time for each lying bout (figure 2). Daily lying time in primiparous animals was shortened by 13.2 minutes, which corresponds to the results of Norring et al. (2008). In that study, they were able to show that daily lying time increased with increasing parity because multiparous animals spend more time ruminating than primiparous ones (Norring et al., 2012). In addition, primiparous animals were even more restless due to their considerably younger age and therefore showed a shorter daily lying time. (Jonsson et al., 2011). Multiparous animals, however, are higher in rank (Hohenbrink and Menecke-Tillmann, 2012), have a higher body mass and milk production and thus a higher metabolic performance (Norring et al., 2012, Charlton et al., 2016). The increase of the daily lying time in the third and later lactation by 5.8 and 10.2 minutes confirmed this assumption. Since the lactation number has a clear influence on the lying behavior, this should be considered in future studies.

The stage of lactation, however, had a significant effect on all lying parameters, but the number of lying events was only minimally affected (figure 3).

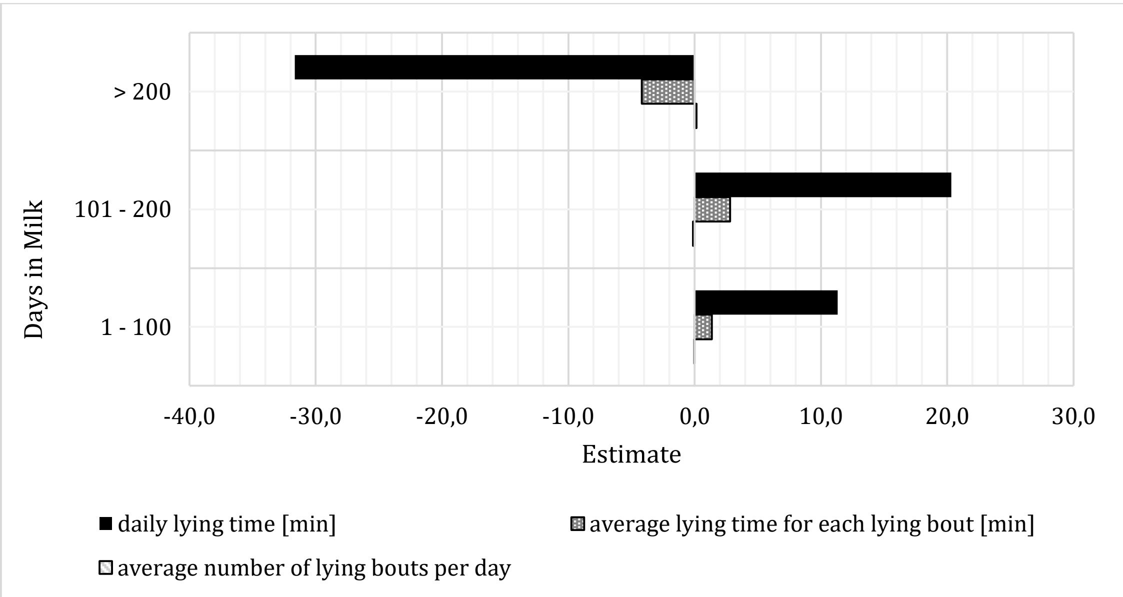

Figure 3: Daily lying time increased up to DIM 200, then decreased with DIM > 200. The average lying time for each lying bout increased up to DIM 200, decreased with DIM > 200.

Although the number of lying events remains nearly the same throughout lactation, lying time for each lying bout as well as daily lying time increase with increasing lactation up to DIM 200. During the first 100 days of lactation, the animals lay down more than the average of 1.4 minutes per lying bout and 11.3 minutes per day. Animals within DIM between 100 and 200 lay down 2.8 minutes longer for each lying bout and therefore had a 20.3 minute longer daily lying time. Animals in the last third of lactation and DIM > 200 showed a decrease in lying time (estimate for lying time for each lying bout = -4.2 minutes, estimate for daily lying time = -31.7 minutes).

Maselyne et al. (2017) also found that, with increasing DIM, lying time increases, too. During early lactation, lying time decreased down to a minimum of 4 weeks after calving, whereupon it increased again until the end of lactation. For this reason, Maselyne et al., (2017) suggested that animals with large amounts of milk (especially at the beginning of lactation) suffered from increased udder pressure. In addition, according to DeVries et al. (2012), animals with a higher milk yield have longer visits to the feeding trough and consequently longer standing and shorter lying times. These results are supported by other studies (Vasseur et al., 2012; Westin et al., 2016). In contrast to these studies, the lying time in our study did not show a decrease during early lactation. Daily lying time even increased during the first 100 days of lactation. Grant (2009) found a positive correlation between performance and lying time. Each extra hour of lying time results in 2 to 3.5 pounds more milk. Since milk production increases especially at the beginning of lactation, this could be the reason for the increased lying time in our study. At the end of lactation cows are more active and make more steps per minute (Maselyne et al., 2017). The lying time is therefore significantly reduced from DIM > 200.

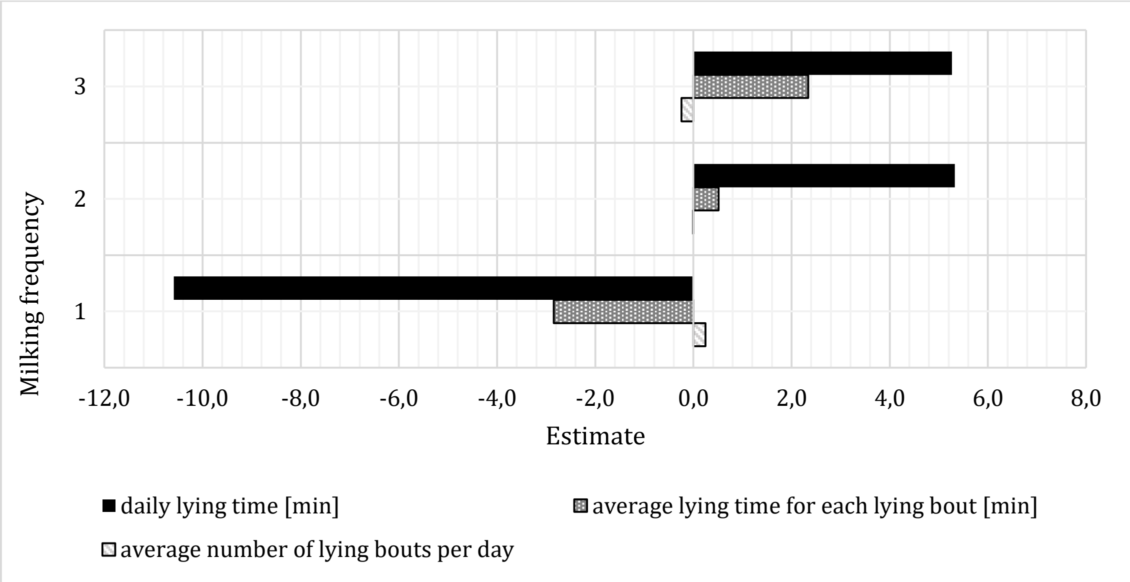

Figure 4: Daily lying time was reduced if animals are milked once a day; it increased with increasing milking frequency. Average lying time for each lying bout was reduced if animals are milked once a day; it increased with increasing milking frequency.

On looking at lying behavior in relation to milking frequency, it is evident that the lying bout duration of animals that are only milked once a day was 2.8 minutes below the average. Accordingly, the total daily lying time was reduced by 10.6 minutes. As the milking frequency increased, both the lying bout duration and the daily lying time rose up to a maximum of 2.3 minutes and 5.3 minutes compared to the average in terms of MF = 3 (figure 4). The influence of milking frequency on lying frequency is of considerably significance, but moves largely according to the average. These results were surprising, as we would have expected the lying time to drop due to a higher milking frequency and associated longer standing times. Hart et al. (2013) also found that animals milked 3 times a day lay 19 minutes less a day. This result was not significant, but can be confirmed by the current study.

In addition, Hart et al. (2013) found that lying times for animals tend to increase the longer they are away for milking. This study and our results confirmed the assumption that management-based factors such as a higher milking frequency do not necessarily have a negative effect on lying behavior. On the contrary, daily lying time can be extended by controlling those factors.

The temperature-humidity-index played an important role with regard to the lying behavior of cows (Cook et al., 2007; Stone et al., 2017; Allen et al., 2015). Also in the current study, daily lying time and lying bout duration were significantly influenced by the THI. Daily lying time would be shortened by 1.6 minutes if animals were exposed to moderate heat stress (THI = 71-79), which, according to Allen et al. (2015), results in prolonged standing times. Animals try to give off heat by standing and taking advantage of the airflow. If THI ≤ 68, the animals showed an extended daily lying time of 2.2 minutes. THI was calculated using temperature and humidity values delivered by the weather stations closest to the farms. This means there were no data loggers in the barn. Since the THI in the barn can differ from the THI outside the barn, this could be a reason for the small influence on lying behavior. The mild climate in Germany with changes between days with high temperatures and colder days is another explanation for the low influence of the THI on lying behavior. Days with high temperature change with colder days. Before animal behavior changes due to high temperatures, cooler days have already arrived, making it difficult to detect heat-induced behavioral changes.

CONCLUSIONS

Daily lying time was influenced by numerous considered factors. Especially the number of lactation, the stage of lactation, estrus, and milking frequency had great influences. Those factors should be taken into account in lameness evaluation in future research. The number of lying bouts, however, turned out to be hardly influenced by environmental, management based, and animal physiological factors.

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https://www.landtechnik.uni-bonn.de/research/livestock-technology/folder_projects/2015_07_02_klauenfitnet?set_language=en

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3.2 Paper II

Using walking speed for lameness detection in lactating dairy cows

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ABSTRACT

Lameness detection is performed based on deviations from the normal gait pattern of cows. Thereby each cow must be individually considered and thoroughly assessed. This process makes lameness detection a time-consuming job for the farmer, especially since herd sizes keep increasing. A sensor-based lameness detection could save the farmer time and complies simultaneously with advancing technological developments. The goal of this study was therefore to determine, whether there is a close causal relationship between walking speed and lameness, respectively lameness degree, so that walking speed could be integrated as a feature into a prediction model.

To survey walking speed, we performed repeated time measurements on 53 lactating dairy cows of the Holstein Friesian breed while, passing through a 8.40 m long, straight test track. After morning and evening milking, the run time and the current locomotion score (LMS) were recorded for each cow.

We found that lameness was significantly ($p < 0.05$) associated with walking speed. Lame cows (LMS ≥ 3) covered the test track at a significantly slower walking speed than non-lame cows (LMS ≤ 2). Also, the longer cows had suffered from lameness before, the slower the cows cover the distance.

We conclude that such simple walking speed measurements can efficiently support lameness detection and thus contribute to the well-being of cows as well as the farmers' benefit in time.

Keywords:

Lameness detection, Walking speed, Dairy cow, Locomotion score

INTRODUCTION

Lameness affects both health and well-being of dairy cows and is usually caused by painful limb disorders (Mülling et al., 2010). According to Scott (1989), cows with a painful limb disease change their gait as they choose a relieving posture in order to avoid pain. Lameness in dairy cows becomes evident by deviations from a normal gait, which include a slower walking speed (Flower et al., 2005; Chapinal et al., 2010; Maertens et al., 2011), shorter steps (Flower et al., 2005), an irregular stride, a curved back, and a lowered head (Maertens et al., 2011). Based on these features lame cows can be identified and then selectively examined and treated if necessary. The most common method used to identify lame cows is the assessment of locomotion using a numerical rating system (Sprecher et al., 1997; Flower and Weary, 2006; Manson and Leaver, 1988). An exact gait assessment requires each animal to be individually inspected, which makes locomotion analysis a time-consuming (Leach et al., 2010) task. Winckler and Willen (2001) showed that using several different observants for the as-sessment of gait patterns caused a troubling differentiation between healthy and slightly lame cows. This resulted in an inter-observer repeatability of only 63-74%. Accordingly, Way et al. (2002) recommend to have the locomotion scoring performed by a single, previously trained person. The necessity of in depth training of personnel to ensure a most accurate detection of lame cows and the time-consuming locomotion assessment by a single person along with increasing herd sizes turn lameness detection into a real challenge for farmers.

Studies have shown that farmers underestimate the proportion of lame cows on their farms (Bennett et al., 2014; Leach et al., 2010). Higginson Cutler et al. (2017) found that farmers assessed the mean lameness herd-level prevalence to be 9%, whereas researchers estimated it to be 22%. Especially cattle with incipient lameness should be given special attention in order to treat claw diseases as early as possible and thereby prevent any further progression of the disease (Miguel-Pacheco et al., 2017). In addition, Leach et al. (2010) showed that 90% of farmers do not consider lameness as a major problem. However, claw diseases are the third most frequent reason for culling, runner-up to mastitis and infertility. Nevertheless, Bruijnis et al. (2013) found that 70% of farmers are willing to improve claw health on their farms, but time and labor-saving play a crucial role in the implementation of neccessary measures (Leach et al., 2010). In order to meet the farmer’s needs regarding lameness detection, a sensor-assisted approach should be ensured (Neveux et al., 2006). The use of accelerometers (Alsaaod et al., 2012), weight distribution measurement (Van De Gucht et al., 2017; Pastell et al., 2010), and the use of video image analysis (Jabbar et al., 2017) are the most common sensor-based detection systems. However, these systems are usually expensive and difficult to use (Chapinal et al., 2010) and therefore not in practice yet. An objective, simple and time-saving way to detect lame cows as early as possible is the measurement of walking speed. The aim of this study was therefore to review the following hypotheses:

1) Walking speed can be used to detect lame cows.
2) Walking speed depends on the severity of lameness.

MATERIAL AND METHODS

Study animals and experimental procedure

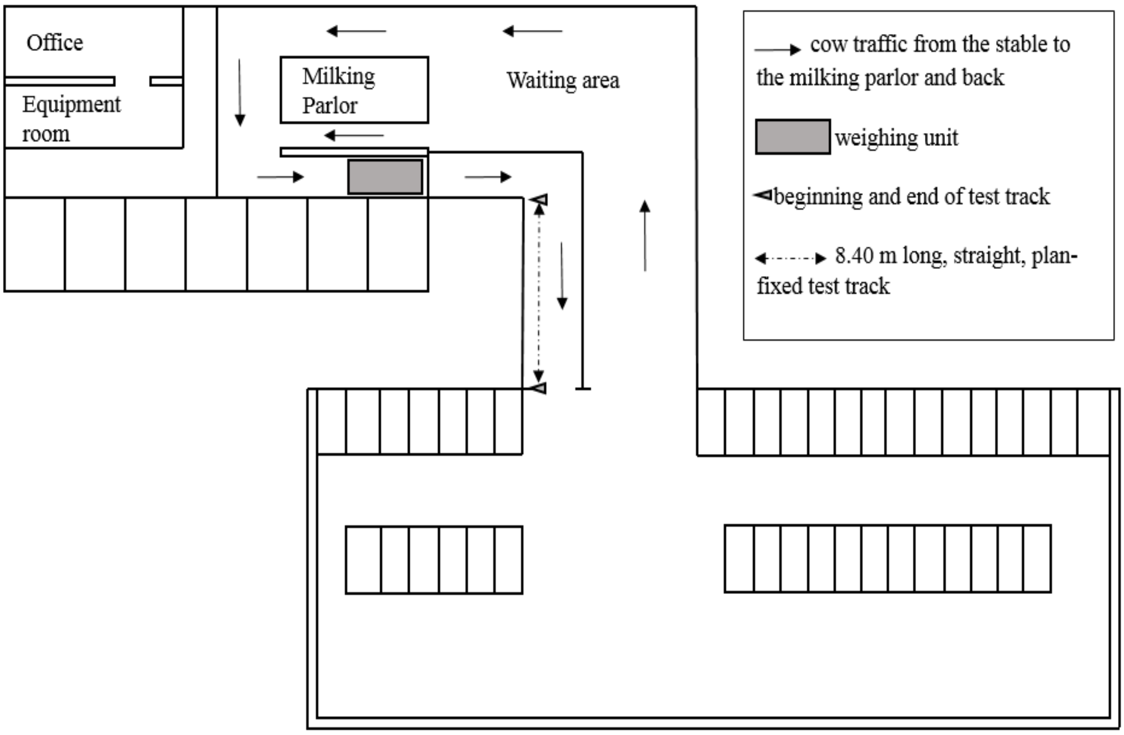

Figure 1: Overview of Frankenforst teaching and research station of Bonn University at Königswinter (Germany)

A three-week trial was conducted from mid-July to early August 2016 at the Frankenforst teaching and research station of Bonn University at Königswinter (Germany) (Figure 1). The trial included 53 lactating dairy cows of the Holstein Friesian breed with an average useful life of 2.4 lactations and an average milk yield of 10,353 kg per animal and year. All cows were free stall housed without access to

pasture. Twice a day after milking the cows were fed a total mixed ration (TMR) consisting of the following components: 38.1% grass silage, 31.1% corn silage, 8.9% lucerne silage, 4.1% rapeseed meal, 13.7% pressed chip silage, 3.7% wheat kernels and 0.2% mineral feed (Blattimin® M 46 ADE; Höveler Spezialfutterwerke GmbH & Co. KG, Dormagen, Germany). The cows were fed via permanently installed weighing troughs (RIC Management, Hokofarm Group, Marknesse, the Netherlands). In addition, animal-specific concentrate feed was offered by two automatic feeders. Twice a day, the cows were milked in a separate double 4-in-line milking parlor. Subsequently, the weight of the cows was recorded by an electronic balance (Hokofarm Group, Marknesse, the Netherlands), installed in the reverse drive.
Returning from the milking parlor the cows were separated at the weighing unit. After weighing, cows walked into a straight 8.40 m long plan fixed section of track which was narrowed with a chain allowing cows walk in line for a proper locomotion scoring and time measurement. This arrangement allowed an unobstructed view at the gait pattern of each individual animal, which was necessary to enable the determination of the locomotion score and the execution of the time measurements. All visual changes were installed one week before the actual measurements took place in order to allow the cows to get accustomed to these modifications. Errors within the data collection such as prolonged running times due to cows stopping on the test track and exploring the changes described earlier, were thereby minimized.

Locomotion scoring

Locomotion scoring was conducted using a five point lameness scoring system (Sprecher et al., 1997) once weekly on day zero, seven and 14 by the same, previously trained observer. Cows with an Locomotion Score (LMS) ≥ 3 were classified as lame, cows with a LMS ≤ 2 as non-lame. In order to exclude the influence of a filled udder on gait patterns, the assignment of locomotion score was carried out after the morning milking process. If the cows showed lameness on any of the days the LMS was performed, this was defined as a lameness incidence.

Measurement of time

Based on the common motivational background of the cows to quickly get back to the stable to start with the feed and water intake or to lie down in a clean cubicle, the time was measured after the morning and evening milking process. The time each animal required for its way back from the milking parlor to the stable was taken by a standard stopwatch (Junior stopwatch, Kasper & Richter GmbH, Uttenreuth, Germany) on days zero to seven and fourteen. The markers needed for the timekeeping were red and white rods positioned at the beginning and end of the track An additional person unlike the one who did the locomotion scoring started the time-keeping process as soon as the animal passed a predetermined marking with its muzzle. Time keeping ended as soon as the animal reached a second marking with its muzzle. In order to prevent the cows from stop-walking while being timed, an animal keeper known to the cows walked next to the cows in order to motivate them. Walking speed was subsequently calculated according to the following formula:

$$v_{WS} = \frac{s}{t}$$

with v_{ws} as the walking speed in m s^{-1}, s as the length of the test track in m and t as time needed for covering the test track in s.

Statistical Analyses

Statistical data analysis was carried out using SPSS Version 23. The Kolmogorov-Smirnoff test was used to test data for normality. Analysis of variance (ANOVA) was used to determine significances. Sensitivity (SN) and specificity (SP) were calculated as follows:

$$SN = \frac{n\ (lame\ cows_{corr.})}{n\ (lame\ cows_{truly})}$$

with “n (lame cows $_{corr.}$)” as the number of correctly recognized lame cows and “n (lame cows $_{truly}$)” as the number of all lame cows.

$$SP = \frac{n\ (non\ lame\ cows_{corr.})}{n\ (non\ lame\ cows\ _{truly})}$$

with “n (non lame cows $_{corr}$).” As the number of correctly recognized non lame cows and “n (non lame cows $_{truly}$)” as the number of all non lame cows.

RESULTS AND DISCUSSION

Locomotion scoring

Table 1: Distribution of LMS on the individual test days

Test day	Locomotion score (LMS) (n = 53 cows)					Mean LMS of the herd	Lameness prevalence* [%]
	1	2	3	4	5		
0	21	19	7	6	0	1.96	25
7	16	16	12	9	0	2.26	40
14	17	11	10	14	1	2.45	47

* Cows with LMS ≥ 3 were classified as lame. Cows with LMS ≤ 2 were classified as non lame.

Locomotion score (LMS) was recorded on a total of 53 cows on study days 0, 7 and 14. Table 1 shows the number of cows in each LMS class, the associated mean and lameness prevalence for each trial day.

Solano et al. (2015) found lameness prevalences between 0 and 69% on 141 dairy farms in Québec, Ontario, and Alberta. The results were related to management conditions on the farms, especially to the floor condition and the lying surface. In our trial, lameness prevalence of the herd was determined at 36%. An abrupt increase in lameness prevalence from 25 to 40% could be seen between study day 0 and 7 (Table 1). However, a claw trimming was performed on individual cows on day 5 of the experiment. Van Hertem et al. (2014) found that the proportion of lame cows (LMS ≥ 3) increased from previously 14% to 34% immediately after claw trimming. Claw care can be a reason for discomfort and even pain, causing the gait of cows to change. Van Hertem et et al. (2014) also suggested that after claw trimming cows have to find their balance again, due to changes of the claw conformation as a result of the trimming process. These conformational changes eventually lead to a decrease in walking speed (Chapinal et al., 2010). Garcia-Munoz et al. (2017) reached similar results with locomotion scores initially deteriorating right after claw trimming and then improving over time. All these findings indicate that cows need some time to get used to changes concerning their claws and provide a sufficient reason for the sudden increase in lameness prevalence in our study.

Walking Speed

The cows covered the track at a speed of 0.84 ± 0.13 m s^{-1} in the morning and 0.93 ± 0.16 m s^{-1} in the evening. Thus it took them an average of 9.71 ± 1.07 s to cover the distance of 8.40 m, which corresponds to a walking speed of 0.87 m s^{-1}. Assuming an average walking speed of 0.97 m s^{-1} on slatted or concrete floor (Telezhenko and Bergsten, 2005) a cow would cover the test route within 8.15 s In contrast to the results of Telezhenko and Bergsten (2005), the cows in our study generally needed more time to cover the test track, whether in the morning or in the evening, and thus had a lower walking speed. This could mainly be due to the fact that the cows walked on a solid concrete floor. According to Flower et al. (2007), a solid concrete floor results in a slow walking speed, even though it has the highest friction coefficient (Telezhenko and Bergsten, 2005). The slower walking speed results from the fact that the claws on concrete floor have less contact to the ground surface, since they can not sink into the ground (Flower et al., 2007). Furthermore, a certain amount of residue of the cows' excrements remained on the test track, despite it has regularly being cleaned. The excrements made the surface slightly slippery and which could have made it difficult for the cows to safely walk the measured distance. As a result, walking speed decreased.

Due to the significant difference ($p < 0.05$) between the morning walking speed and the evening walking speed (Figure 2), either one (the morning OR the evening walking speed) should be used for lameness detection.

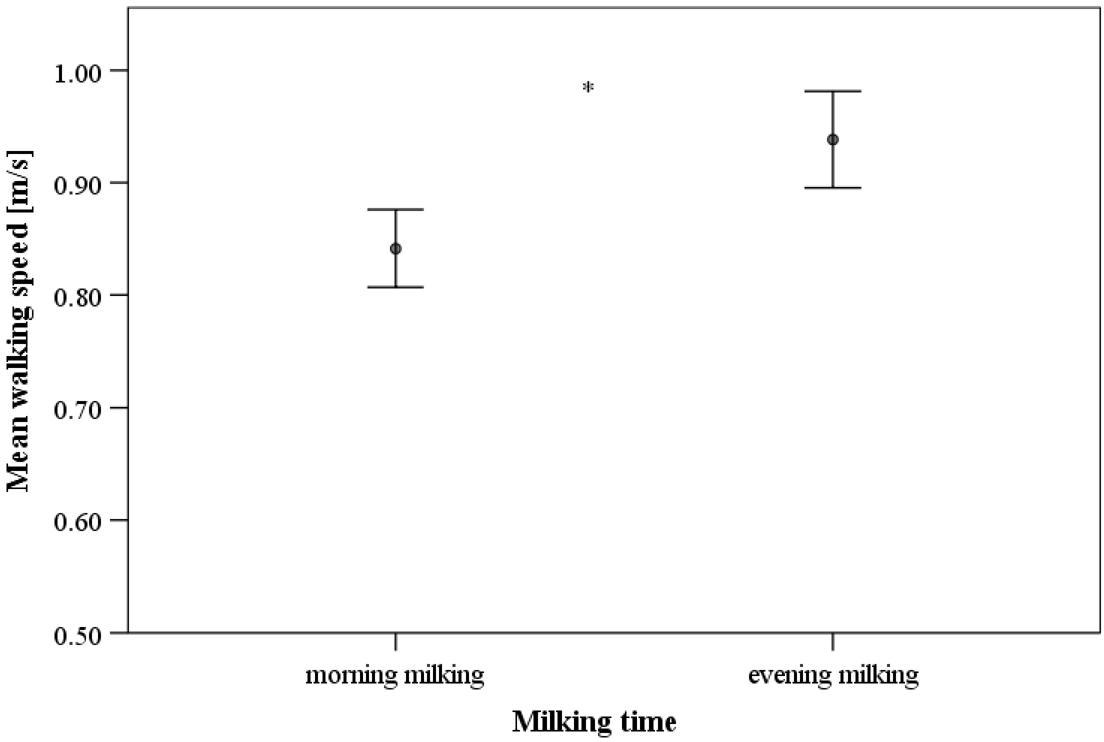

Figure 2: Mean walking speed while covering the test track after morning and evening milking, with standard error (bars), n = 53, * $p < 0.05$

The primary objective of this study was to test the potential of simple run time measurements and consequently walking speed calculation as an indicator for early lameness detection. Regardless of morning and evening differences, lameness was significant associated with walking speed. Lame cows covered the track at 0.77 ± 0.11 m s^{-1} in the morning and 0.87 ± 0.16 m s^{-1} in the evening. In contrast, non-lame cows returned significantly ($p < 0.05$) faster with 0.92 ± 0.09 m s^{-1} and 1.01 ± 0.12 m s^{-1}, both in the morning and in the evening. These findings confirm the results of other studies (Thorup et al., 2014; Flower et al., 2005; Telezhenko and Bergsten, 2005).

The higher the locomotion score and thus the worse the lameness progression, the slower did the cows proceed over the 8.40 m track distance (Figure 3). The speed of the cows in the four LMS categories differed significantly after morning milking. After evening milking, there was a significant difference only between cows with LMS 3 and LMS 4.

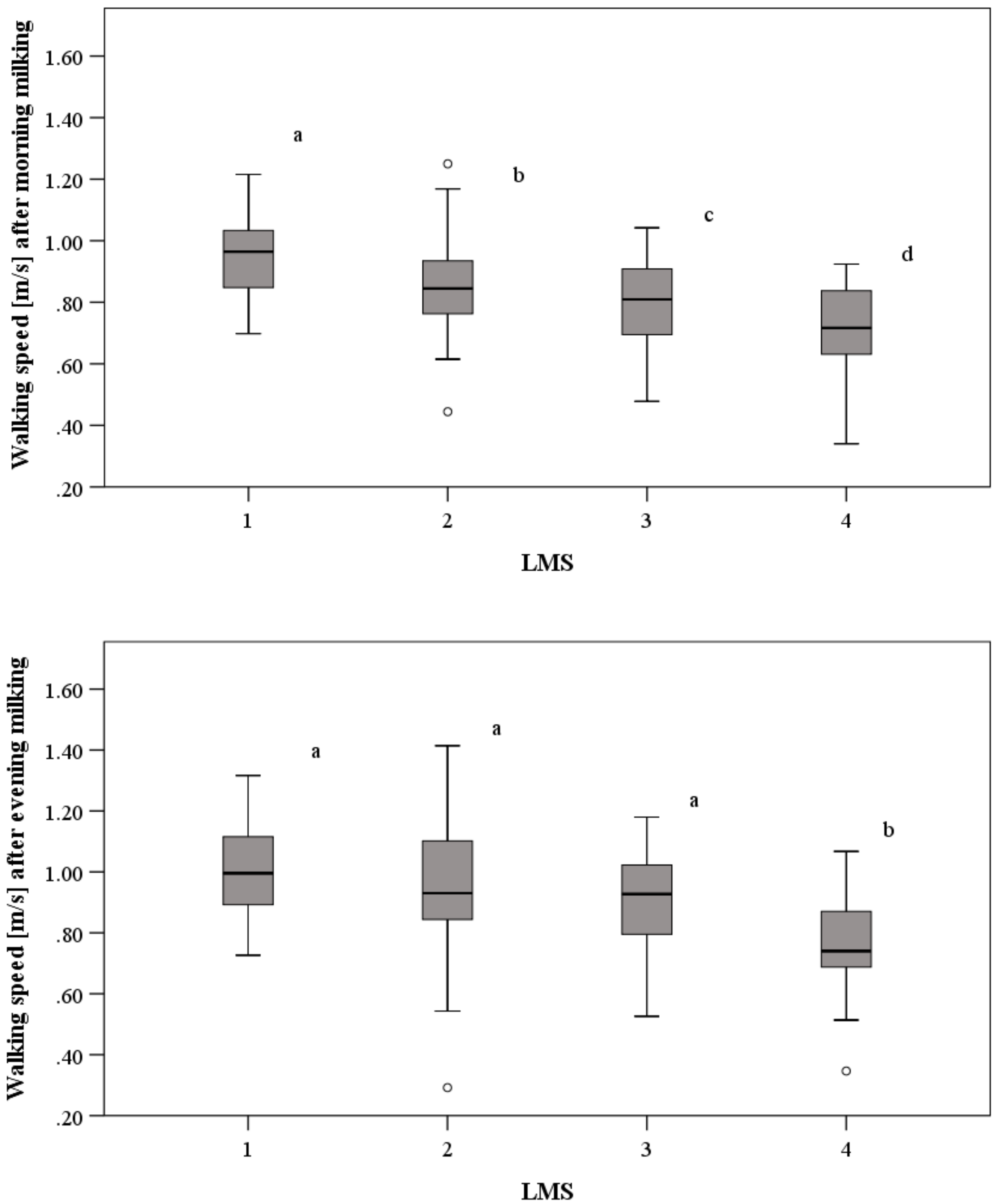

Figure 3: Mean walking speed of cows after morning and evening milking, divided according to the degree of lameness (LMS 1-4), different letters indicate significant ($p<0.05$) differences, ○ marks outliers

Instead of calculating an average, we separately considered the walking speed after morning and evening milking. This precise time analysis could be the reason that the speed of the cows differ significantly in the morning according to their LMS, but in the evening no significant differences could be detected. Beer et al. (2016) considered 24 h averages and noted that even though lame cows differ from non-lame cows, lame cows with varying degrees of lameness do not exhibit significantly different walking speeds.

If one considers the number of lameness incidences in the group of lame cows (LMS ≥ 3), the time required to cover the track increased in accordance with the number of lameness incidences (Table 2).

Table 2: Average durations of running times (Mean and standard deviations) after morning and evening milking depending on the number of lameness incidences

	Number of lameness incidences			
	0 (n=25)	**1 (n=9)**	**2 (n=7)**	**3 (n=12)**
RtM † [s]	9.25^{a}±1.00	10.72^{b}±1.97	$10.39^{a,b}$±0.89	11.79^{b}±1.73
RtE ‡ [s]	8.42^{c}±1.00	$9.93^{c,d}$±2.93	9.36^{d}±1.46	10.34^{d}±1.66

† running time after morning milking, ‡ running time after evening milking , a,b,c,d considering the results in one data row, different letters indicate significance $p < 0.05$

The slower walking speed of lame cattle is mainly due to the use of protective postures to avoid further strain on the hurting limbs (Flower et al., 2005, Chapinal et al., 2010; Maertens et al., 2011), which can be caused by various claw diseases, such as sole ulcers or digital dermatitis (Chapinal et al., 2009; Flower et al., 2006). The further lameness has progressed, the slower the cow moves, because its normal motion range is disturbed (Scott, 1989). Investigations concerning the exact cause of lameness, e.g. a claw disease, did not take place in our study. However, such investigations could provide information about the development of lameness and help developing solutions for the farms in order to detect lameness as early as possible and to carry out prophylactic measures.

By applying an iterative comparison of the run time of each cow (with separate consideration of the run times in the morning and in the evening), limit values for lameness detection have been determined. If the cows covered the track slower than 0.84 m s^{-1} in the morning and slower than 0.93 m s^{-1} in the evening, lameness was clearly indicated. With this approach, 20 cows from a total of 28 lame cows were correctly identified as lame giving 71.43 % sensitivity. From a total of 28 non-lame cows, 6 were erroneously identified to be lame which is equal to 78.57 % specificity. Despite the method used being simple, it delivered results, which are comparable to previous studies (Jabbar et al., 2017, Alsaaod et al., 2012). When interpreting the results of our study, it should be noted that so far only one data set has been examined using the method of mean comparison. For the purpose of validation further data sets are necessary. A combination of parameters including walking speed, number of standing bouts and eating time, for example, could further improve the evaluation in terms of lameness detection (Beer et al., 2016). In the analysis of our data it should also be taken into account that in order to prevent the cows from stopping on the track, a trusted person pursued them within a few meters of distance in the course of our study. If this had not been the case, the cows would have generally walked more slowly. The timing of the cows covering the test track and consequently lameness detection should be automated in the future. In order to make an animal-specific walking speed evaluation possible, it would be useful to implement wavelet filters or machine learning methods, for example (Miekley et al., 2012). Furthermore, we detected large differences between individual cows in terms of walking speed (minimum in the morning: 0.59 m s^{-1} vs. maximum in the morning: 1.10 m s^{-1} and minimum in the evening: 0.49 m s^{-1} vs. maximum in the evening: 1.26 m s^{-1}). Therefore, a data pool at animal-specific level should be generated in order to improve statements regarding run times related to lameness incidences.

CONCLUSION

The measurement of run time and the subsequent calculation of the walking speed served as a simple and efficient way to detect lameness in dairy cows. With a sensitivity and specificity of 71.43 % and 78.57 %, respectively, lame cows can be identified and subsequently treated. The hypotheses that walking speed can be used to detect lame cows was confirmed in our study. Concerning differences in the severity of lameness, our study was able to identify variations of slower walking speeds amongst lame cows after the morning milking correlating with an increasing degree of lameness. These findings however could not be observed after the evening milking.

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4 General Discussion and Conclusions

According to the FOA - Food and Agriculture Organization of the United Nations (2017) - the world population is growing steadily. By the year 2050, up to 9.15 billion people will be living on earth; a development, which will directly result in an increase in global demand for animal products (Van Hertem et al., 2017). At the same time the number of dairy farms decreases while the remaining farms are growing larger in terms of size, herds and production output (European Commission, 2017a, 2017b). However, even though macroeconomic requirements have to be met, farmers are expected to pay attention to and have a personal relationship with each individual animal (Broom, 2017), especially since animal welfare is becoming a more and more important topic in society (Van Hertem et al., 2017). Using modern technology, farmers are able to monitor each animal individually in order to assess their welfare situation in real time (Hemeryck and Berckmans, 2015).

Additional sensor systems can help to reduce labor requirements even further and improve the management of large herds (Bewley 2010; Eastwood et al., 2012, 2016a). The continuous automated monitoring of an animal and its environment with regards to animal health, animal behavior and animal performance is known as Precision Livestock Farming (PLF) (Berckmans, 2008). PLF can improve the welfare of animals (Rushen et al., 2012) by e.g. using automated early warning systems (Dawkins et al., 2017). Data about an individual animal is collected by a variety of sensor systems and subsequently evaluated for various diseases including lameness (Ito et al., 2010; Alsaaod et al., 2012). The early detection of lame cows and consequently immediate treatment reduces the severity of claw horn diseases (Leach et al. 2012) and thus the duration of pain for the cow as well as the cost of treatment. Thereby the automated sensor systems not only enhance animal welfare, but also meets the farmers' need for cost efficiency, timesaving and earliest possible detection of lameness (Barker et al. 2018).

Lameness is associated with detectable changes in activity and in lying behavior. For reliable lameness detection, Alsaaod et al. (2012) used the deviation in activity and lying time from individual behavior. They discovered that deviations from individual “normal” behavior of a cow in the case of lameness are greater than the difference between lame and non-lame cows. Thus, "healthy" phases should be compared to "lame" phases of the individual cow and used for lameness detection.

With regards to the lying behavior in lame cows, several studies on the topic have delivered contradicting results: Blackie et al. (2011) as well as Beer et al. (2016) found that lame cows show increased lying times. In contrast, Ito et al. (2010) found no differences in the lying behavior of lame and non-lame animals. Cook et al. (2008) even noted decreased lying times in lame cows.

Activity and lying behavior are generally influenced by different extrinsic and intrinsic factors, including heat stress (Cook et al., 2007; Allen at al., 2015), production (Deming et al., 2013; Stone et al., 2017), barn management (DeVries and von Keyserlingk, 2005; Krawczel et al., 2012; Charlton et al., 2014), parity (Westin et al., 2016; Stone et al., 2017), cubicle bedding (Calamari et al., 2009) and health status (Westin et al., 2016; Stone et al., 2017). These should be taken into account in lameness evaluations as they have a major influence on dairy cow behavior. A sensor-based collection of data for each of the parameters mentioned above would happen independently. However, misinterpretations during data evaluations can occur. Therefore in the first study presented (paper I), a model was developed to identify and evaluate possible factors influencing cow behavior. This model mainly took factors with an influence on lying behavior into account, which were further analyzed to make data available for lameness evaluation. All of the factors examined (apart from breed, age at first calving, localization of pedometer, and milking system) had a highly significant influence on the lying behavior. The reason for that can be found in the large data set. According to Khalilzadeh and Tasci (2017) studies with a large number of cases often lead to highly significant results due to the high selectivity of a test. In that case, the effects found are often small. In our study, however, number of lactation, the stage of lactation, estrus, and milking frequency had a major influence on lying behavior and should be taken into account with regard to lameness evaluations based on accelerometer data.

In modern farms, a large amount of data is produced (Braun et al., 2018). Accelerometers are currently used primarily for detecting heat events in dairy cows (Shahriar et al., 2016). Automated milk yield measurement and ingredient determination are used in automatic milking systems as well as in milking parlors. The herd management system records all data of the health status of the individual animal. Data loggers constantly monitor temperature and humidity. All of this data can be used for lameness assessments, but most farmers do not have the skills to effectively use the collected data (Van Hertem et al., 2017). The combination and interpretation is difficult, because the data comes from different sensors and is only available in different formats (Van Hertem et al., 2017). To solve this problem, the data from paper I was put into a uniform adis-format to simplify and accelerate the evaluation. In a further step, the results would have to be visualized. This would ultimately enable the farmer to make fast, data-based decisions concerning his management and lead to a wide-spread establishment of PLF sensor systems (Van Hertem et al., 2017) on dairy farms.

The combination of different PLF sensors and thus different individual data sets, improves the early detection of diseases, e.g. lameness (Beer et al., 2016). For this purpose, Barker et al. (2018) linked a local positioning sensor with a neck-mounted accelerometer. Network Sensors were positioned at defined positions across the stable. With the help of mobile sensors fixed to the neck collar, the position of an animal could be determined by interaction between the mobile and the network sensors. In addition, each cow-mounted mobile sensor contained a triaxial accelerometer to determine activity. Subsequently, different behaviors were defined (feeding, not feeding, milking). Analysis showed, that lame cows had a significantly lower daily feeding time than non-lame cows (Barker et al., 2018). According to the authors, combined sensor systems are suited for detecting differences in feeding behavior, which may be associated with lameness. This is also confirmed by the results of a study by Beer et al. (2016). They linked the number of standing bouts with the walking speed and were able to identify lame cows with 90.2 % sensitivity and 91.7 % specificity. In addition, Chapinal et al. (2010a) postulated, that linking of walking speed measurements with automatic lying time and weight distribution measurements improves lameness detection. The results of the second study (paper II) also show that walking speed is suitable for being implemented in a predictive model. In contrast, the results of a study by Chapinal et al. (2009) for using walking speed to detect claw lesions showed no difference in walking speed between cows with and without sole ulcers. According to the authors it is difficult to say if slow walking speeds are due to deviations from the normal gait or obvious gait changes are the result of a slow gait. Since walking speed is easy and cost effective to register, this feature should be included in future research. It should be noted here, however, that due to the large animal-specific differences, each animal should be compared to itself.

Positioning system data is used to investigate the effects of lameness and claw lesions on animal behavior (Homer et al., 2013; Frondelius et al., 2015; Veissier et al., 2017). CowView by GEA (GEA Farm Technologies, Bönen, Germany) for example is an automated tracking system for dairy cows, which provides location data and creates a virtual map of the barn, depicting all areas where an individual animal has been (Tullo et al., 2016). Based on the collected data, animal behavior can thereby be monitored and evaluate (Tullo et al., 2016). Adding further sensors to CowView or any other tracking system could improve their accuracy (Pastell et al., 2018) and the problem of data incompatibility would no longer be an issue. However, any additional sensors by a rival company of GEA depend on the associated evaluation software and cannot simply be linked with CowView. At the moment there is no system on the market, which would enable farmers to collectively view and analyze data collected by sensors from multiple manufacturers. By establishing a tracking system, which allows the involvement of sensors from different companies, individual animal positioning in the barn could be monitored as well as conclusions be drawn about that particular animal’s health status. Thereby, animal welfare could be enhanced and herd management simplified.

With PLF, different information technologies can be linked into an automated online tool to control and monitor animal behavior (Tullo et al., 2013). Animal tracking systems as such are particularly suitable.

By incorporating other data (e.g. activity, weight distribution, milk yield), lameness detection can be improved. This increases animal welfare (Braun et al., 2018) and the acceptance of precision technologies among farmers (Gargiulo et al., 2018). PLF is able to monitor, manage and control many aspects of livestock production in real-time and in an automated way (Wathes et al., 2008). Especially for farmers with large herd sizes, the PLF technology improves farm management. Thereby farmers' acceptance of PLF technologies grows as well (Gargiulo et al., 2018). The use of precision technologies alone does not increase animal welfare. Training farmers in dealing with and interpreting the collected data is also crucial (Van Hertem et al., 2017; Braun et al., 2018;) to generate a sustainable animal husbandry. Altogether, livestock farming in the age of Industry 4.0 is made possible by the use of PLF (Braun et al., 2018).

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