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Review article

Alterations in sick dairy cows' daily behavioural patterns

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ABSTRACT

The recent development of dairy production is characterised by increasing herd sizes and therefore increasingly complicated visual observation of cow behaviour, which is traditionally the basis for diagnoses of production diseases. The limitation of the direct visual behavioural observation due to the increasing number of individual cows implies a growing need for an automated detection of changes within behavioural patterns to identify cows that show sickness behaviour. Sensor systems can be used to measure behavioural patterns such as activity, resting, feeding and rumination. Behavioural patterns change with the occurrence of sickness but also interact with external factors. Changes such as prolonged lying duration or shortened feeding duration caused by metabolic disorders or infections, respectively, then serve as a detection tool for sick individuals. The aim of the present review is to outline the impact of production diseases on the daily behavioural patterns of dairy cows by referring to sickness behaviour.

1. Introduction

In recent years, the identification of sick dairy cows in an early state of disease by observing the individual cow's behaviour has become more and more important. The standard approach for this task is direct visual observation, which traditionally serves as a diagnostic tool for farmers and veterinarians (Huzzey et al., 2007; Broom and Fraser, 2015). Dairy cows thereby exhibit distinctive behavioural patterns such as resting, feeding, physical activity and social behaviour, which are usually altered by many external factors, e.g. climatic changes, oestrus and emerging sickness. That is, deviations can be observed, measured and used to identify individual cows at risk of developing health issues, but other external influences have to be taken into account as well to avoid distortions of identified patterns (Weary et al., 2009). In general, health issues are accompanied by so-called sickness behaviour, which is defined as an adaptive behavioural response to infection or injury that shows stereotypical characteristics and is caused by the immune and central nervous system (Johnson, 2002; Tizard, 2008). According to Tizard (2008), most of these adaptive behavioural changes are associated with depression, loss of appetite and unexplained weight loss and, furthermore, with pain. Thus, early detection of sickness is also a welfare issue (Broom and Fraser, 2015).

This review focusses on sickness-induced changes in the behavioural patterns of dairy cows, illustrating resting, physical activity, feeding and rumination in combination with the impact of the most frequently occurring production diseases (hypocalcaemia, ketosis, metritis, mastitis and lameness).

2. Physiological background of sickness behaviour

As mentioned above, the identification of sick farm animals is based on sickness-related alterations in the animals' daily behavioural patterns. These behavioural changes are collectively called "sickness behaviour", which summarises inter alia behavioural symptoms such as anorexia, fatigue, loss of interest in usual daily activities, social withdrawal, listlessness or malaise (Harden et al., 2015). Furthermore, sickness behaviour is defined as a stereotypical behavioural response to infection or injury, whereby the behavioural adjustments are results of an active process and not a passive consequence caused by upcoming sickness. The invading pathogens activate the immune system and particularly sentinel cells, which release inflammatory cytokines and thus trigger the behavioural changes. In the case of a tissue damage, so-called alarmins are released which activate the immune system as pathogens do; inflammatory cytokines are released as well (Tizard, 2008). So, the upcoming infection or rather inflammation effects the immune system to release mediators, which propagate an inflammatory response to the central nervous system shortly after the peripheral activation of the innate immune system (Harden et al., 2015). Hence, sickness related changes in daily behavioural patterns of any kind are provoked by physiological processes and inflammatory cytokines in particular (Tizard, 2008; Hart

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and Hart, 2019). In this context, three inflammatory cytokines (Interleukin-1, Interleukin-6 and Tumour necrosis factor-α) are mainly associated with the genesis of fever and sickness behaviour (Table 1) (Konsman et al., 2002; Broom, 2006; Tizard, 2008; Hart and Hart, 2019).

These proinflammatory cytokines affect each other and are responsible for the exceedance of the thermoregulatory set-point in the case of fever, so the body temperature is stabilised at a higher normal temperature (Tizard, 2008). Fever and sickness behaviour are simultaneously occurring phenomena, which influence each other. Febrile infections generally cause reductions in physical activities and promote resting hence they are triggering characteristics of sickness behaviour like depression and lethargy. These behavioural alterations caused by illness are necessary to protect the individual's energetic resources, which are needed to fight infection (Tizard, 2008; Hart, 2010; Hart and Hart, 2019). Thereby, decreasing physical activity is the most outstanding behavioural response to disease. While resting behaviour increases, the physical activity is minimised by three different reasons or mechanisms respectively. The first activity is reduced by inflammatory cytokines as mentioned above, the second activity decreases because of an injury and the associated pain and the third mechanism is the social isolation of a sick individual to avoid the spreading of pathogens (Broom, 2006). Another slightly contrary function of the cytokines mentioned is a loss of appetite, which seems disadvantageous due to increasing requirements for energy while dealing with infection or injury. Reductions in feed intake caused by loss of appetite, reserve energy consumption due to gut activity and feeding itself (Broom, 2006). The phenomenon sickness behaviour is an opportunity to detect sick animals in an early state of disease by keeping in mind that not all aspects of the sickness behaviour phenomenon have been completely investigated and explained (Tizard, 2008).

3. Sickness-related changes in behavioural patterns

3.1. Activity and feeding behaviour pattern

Activity and feeding behaviour pattern play major roles in cows' health, productivity and welfare (Weary et al., 2009). These patterns consist of various characteristics, which interact closely with each other. Thus, they are often part of behaviour-based health monitoring. The main parts of activity behaviour patterns are resting and physical activity. Resting can be subdivided into lying and standing; physical activity is divided into daily walking activity, increased activity during oestrous and restlessness at milking.

The feeding behaviour pattern is subdivided into feed intake, total feeding duration and feeding bouts (number and duration) as well as rumination. The pattern of feed intake is generally regulated by diurnal rhythms of increasing and decreasing daylight, respectively, thus the main feed intake is observable in the morning and evenings (D'Mello, 2000).The different behavioural patterns account for different time-budgets and cow-specific priorities. Thereby the daily behavioural routine of a dairy cow is dominated by resting behaviour and lying in particular, due to its fundamentality for rumination. Hence, prevention of lying causes a reduction in productivity and increases the number of health issues (Munksgaard et al., 2005; Schirmann et al., 2012).

Table 1
Three major cytokines associated with the genesis of sickness behaviour (Konsman et al., 2002; Broom, 2006; Tizard, 2008; Hart and Hart, 2019).

Cytokine	Origin	Impact
Tumour necrosis factor-α (TNF-α)	Macrophages, monocytes, T-lymphocytes	Inflammation, sickness behaviour and fever
Interleukin-1 (α, β; IL-1)	Macrophages, fibroblasts, endothelial cells, monocytes	Immune regulation, inflammation and fever
Interleukin-6 (IL-6)	Fibroblasts, tumour cells, macrophages, endothelial cells	Inflammation, acquired immunity and fever

The monitoring of activity and feeding behaviour therefore provides specific information about aspects of the dairy cows' health and welfare. Monitoring physical activity for instance is already one of the most frequently used methods to identify cows that are in oestrous, so it is straightforward to use these observations for the identification of sick cows (Roelofs et al., 2010).

Proudfoot et al. (2014) reported a link between appearance of disease and lying. They detected increasing lying duration for ill cows in comparison with healthy cows in the early post partum period. This link shows the adaptive behavioural changes by any disease as part of so-called sickness behaviour (Tizard, 2008). The sickness-induced behavioural changes described in the following are summarised in Table 2.

3.2. Metabolic disorders

The occurrence of metabolic disorders causes diverse variations in activity and feeding behaviour patterns. Thereby a metabolic challenge or a poor metabolic status without a definite diagnosis is sufficient to change the cows' standing and lying behaviour (Müller et al., 2018; van Hoeij et al., 2018). The interacting parts of the feeding behaviour pattern, feeding and rumination, are alternated by the occurrence of a metabolic disorder, however, rumination is influenced by the occurrence of any clinical disease (Calamari et al., 2014). In general, metabolic disorders influence activity behaviour as total lying time is increased and physical activity is decreased such as for instance in the case of hypocalcaemia (Jawor et al., 2012; Sepúlveda-Varas et al., 2014; Itle et al., 2015). Additionally, Jawor et al. (2012) described reduced feeding duration and less visits to the feeder post partum, when cows were diagnosed with hypocalcaemia. In contrast to hypocalcaemia, several studies have found prolonged standing time and again decreased feeding duration in the week ante partum and thus prior to clinical diagnosis of ketosis (Goldhawk et al., 2009). However, Rodriguez-Jimenez et al. (2018) found decreased standing duration pre partum in cows diagnosed with ketosis post partum. With a developing disorder, ketotic cows have shown reduced physical activity of up to three weeks post partum (Itle et al., 2015; Liboreiro et al., 2015; Steensels et al., 2017).

3.3. Infectious diseases

The critical phase around parturition and the onset of lactation are accompanied by a negative energy balance, due to an inadequate energy intake. A reduction in feeding duration caused by metabolic disorders thereby increases the risk of secondary diseases such as infections due to an additional nutritional imbalance (D'Mello, 2000). Behavioural deviations are especially likely to occur within the transition period as it is characterised by a suppressed immune system, which increases the risk of infectious diseases. Although this period is particularly dangerous, infections of the udder or the uterine system may occur during the whole lactation (Ingvartsen et al., 2003). Metritic infections for instance influence the lying behaviour of grazing dairy cows within the first week post partum by increasing the total daily lying time and simultaneously reducing physical activity as well as reduced feeding in the three weeks prior to diagnosis (Ingvartsen et al., 2003; Urton et al., 2005; Hammon et al., 2006; Huzzey et al., 2007; Sepúlveda-Varas et al., 2014; Neave et al., 2018). In combination with the reduced feeding duration, a shortened rumination duration is expectable and has been observed in metritic cows within three weeks post partum and again prior to clinical diagnosis (Stangaferro et al., 2016b; Steensels et al., 2017). Metritic cows show measurable deviations in feeding behaviour patterns prior to clinical diagnosis, which could recommend the observation of feeding behaviour patterns as an early-warning indicator for these infections and metabolic disorders as well (Goldhawk et al., 2009; Stangaferro et al., 2016b; Steensels et al., 2017). Barragan et al. (2018) found similar variations in lying behaviour for primiparous cows, the multiparous cows however did not differ in their lying behaviour due to metritis.

Table 2
Summary of changes in activity and feeding behaviour patterns caused by different health issues including the total number of cows (n) used for the studies mentioned.

Health issue	Behavioural change	Type of change	Reference [n]
Hypocalcaemia	Standing duration	↑	Jawor et al. (2012) [101]
	Lying duration	↑	Sepúlveda-Varas et al. (2014) [274]
	Feeding duration	↓	Jawor et al. (2012) [101]
Ketosis	Standing duration	↑	Itle et al. (2015) [184]
		↓	Rodriguez-Jimenez et al. (2018) [24]
	Physical activity	↓	Liboreiro et al. (2015) [296], Steensels et al. (2017) [703]
	Feed intake	↓	Rodriguez-Jimenez et al. (2018) [24]
	Feeding bouts	↓	Goldhawk et al. (2009) [10]
	Feeding duration	↓	Goldhawk et al. (2009) [10]
	Rumination duration	↓	Steensels et al. (2017) [70], King et al. (2018) [60]
Metritis	Lying duration	↑	Sepúlveda-Varas et al. (2014) [274], Barragan et al. (2018) [200]
	Lying bout duration	↑	Neave et al. (2018) [74]
	Physical Activity	↓	Liboreiro et al. (2015) [184], Stangaferro et al. (2016b) [1121], Steensels et al. (2017) [703]
	Feed intake	↓	Huzzey et al. (2007) [10], Neave et al. (2018) [74]
	Feeding duration	↓	Urton et al. (2005) [26]
	Rumination duration	↓	Stangaferro et al. (2016b) [11], Steensels et al. (2017) [70]
Mastitis	Standing duration	↑	Siivonen et al. (2011) [6], Fogsgaard et al. (2012) [20]
	Lying duration	↓	Cyples et al. (2012) [21], Fogsgaard et al. (2015) [60]
		↑	Sepúlveda-Varas et al. (2014) [274]
	Physical activity	↑	Siivonen et al. (2011) [6]
		↓	Stangaferro et al. (2016a) [1121]
	Restlessness	↑	Medrano-Galarza et al. (2012) [42], Fogsgaard et al. (2015) [60]
	Feed intake	↓	Fogsgaard et al. (2015) [60]
	Feeding duration	↑	Siivonen et al. (2011) [6]
		↓	Fogsgaard et al. (2012) [20]
	Rumination duration	↓	Fogsgaard et al. (2012) [20], Stangaferro et al. (2016a) [11], King et al. (2018) [60]
Lameness	Lying duration	↑	Chapinal et al. (2009) [53], Ito et al. (2010) [1319], Thorup et al. (2015) [348], Weigele et al. (2018) [389], Solano et al. (2016) [5135]
	Lying bout duration	↑	Beer et al. (2016) [53]
	Physical activity	↓	Chapinal et al. (2010) [57], Beer et al. (2016) [53], Nechanitzky et al. (2016) [42], Weigele et al. (2018) [389]
	Feed intake	↑	Palmer et al. (2012) [45]
	Feeding bouts	↓	Palmer et al. (2012) [45], Miguel-Pacheco et al. (2014) [24]
	Feeding duration	↓	Miguel-Pacheco et al. (2014) [24], Palmer et al. (2012) [45], Norring et al. (2014) [50], Beer et al. (2016) [53], Thorup et al. (2016) [16], Weigele et al. (2018) [38], Barker et al. (2018) [19],
	Rumination duration	↓	Miguel-Pacheco et al. (2014) [24], Beer et al. (2016) [53], King et al. (2018) [60]

Furthermore, Lomb et al. (2018) found that a single pain treatment did not have an effect an all treated cows, whereby multiparous cows with metritis reduced their lying time after the treatment compared to non-treated cows.

Apart from metritis, intramammary infections often appear in the early post partum period but are not exclusively related to this early phase of lactation. The changes caused by mastitic infections are various, but deliver indications of a current infection as well, even if the cows spend more time at the feeder in some cases (Siivonen et al., 2011; Fogsgaard et al., 2012).

However, it is necessary to differentiate between artificially induced and naturally occurring mastitis infections. Induced infections are used to provoke strong physiological reactions, which potentially change the cows' behaviour. These mastitic infections are induced to trigger sickness behaviour, so the tendency and extent of behavioural changes can be observed (Siivonen et al., 2011). As expected, the induced mastitis causes changes in behaviour such as prolonged standing time and shortened total lying time on the day of infection (Siivonen et al., 2011; Cyples et al., 2012; Fogsgaard et al., 2012). Comparable contrasts have been found for feeding and rumination duration, whereby prolonged feeding duration, but shortened rumination duration have been described at the day of infection (Siivonen et al., 2011; Fogsgaard et al., 2012).

Similarly, Medrano-Galarza et al. (2012) and Fogsgaard et al. (2015) found that total lying time and feeding duration were shortened by naturally occurring mastitis. In contrast to these results, Sepúlveda-Varas et al. (2014) detected increasing lying time and reduced feeding duration for mastitic cows on pasture within the first week post partum.

Contrary results were also found for physical activity, as the step count increased in cases of induced mastitis and the overall activity decreased due to mastitis of natural origin (Fogsgaard et al., 2012; Stangaferro et al., 2016a). The increasing step count can be explained by the stride length, which was shortened by the infected cows to avoid contact of the leg and the painful udder quarter (Siivonen et al., 2011). Veissier et al. (2017) found furthermore, that the circadian rhythm of activity was changed due to an intramammary infection, as the sick cows tended to be more active. Additionally, mastitic challenges were found to have a great impact on variations of restlessness at milking due to the infection-induced pain in combination with milk withdrawal (Medrano-Galarza et al., 2012; Fogsgaard et al., 2015).

3.4. Lameness

In modern dairy herds, lameness is a highly prevalent disease pattern, which is usually guided by painful injuries or infections of either the claw or other parts of cows' limbs. The causes of the lameness are manifold, injuries accompanied by tissue damage or other mechanical reasons are not directly classifiable as sickness, but change the cows' behaviour as the definition of sickness behaviour implies. Generally, lame cows differ in their behaviour as the definition of sickness behaviour implies, but also show avoidance behaviour against pain (Johnson, 2002; Juarez et al., 2003; Tizard, 2008). Additionally, lameness is predominantly independent from the transition period and delivers important information for the assessment of the cows' welfare (Von Keyserlingk et al., 2009; Barkema et al., 2015). Insufficient claw health, e.g. claw horn lesions, is often a trigger for lameness. This leads lame cows to increase their total daily lying time and decrease their total standing time while spending less time feeding and ruminating without lowering the mean feed intake (Chapinal et al., 2009; Ito et al., 2010; Proudfoot et al., 2010; Thorup et al., 2015, 2016; Weigele et al., 2018; Miguel-Pacheco et al., 2014; Norring et al., 2014; Beer et al., 2016; Barker et al., 2018; King et al., 2018). Furthermore, Sepúlveda-Varas et al. (2014) detected a decreasing number of lying bouts, but in contrast to this, Solano et al. (2016) found the numbers of lying bouts to be increased while the duration of lying bouts decreased. Then again, prolonged lying bout duration has been determined for lame cows as well (Beer et al., 2016). Additionally, Palmer et al. (2012) found an increased meal size per visit together with less frequent visits at the feeder.

Further, there is the impact of lameness on physical activity, which appears as a reduction in daily physical activity and walking in particular. This reduction is apparent in all grades of lameness and even in cows that are in oestrous and thus are supposed to be more active (Walker et al., 2008; Chapinal et al., 2010; Beer et al., 2016; Nechanitzky et al., 2016; Weigele et al., 2018). Then again Veissier et al. (2017) found the nocturnal activity to be increased in cases of lameness.

4. Discussion

Dairy cows are challenged by different production diseases, which are sufficient to alternate the daily behavioural routine of the sick individual. The physiological base for these behavioural changes is given by so-called "sickness behaviour", which includes the release and effect of different inflammatory cytokines (Tizard, 2008). Other reasons for sickness-related behavioural changes are for instance the transition period, as it is accompanied by an immune deficiency and a negative energy balance. Furthermore, injuries as a mechanical reason for lameness or other non-inflammatory reasons for lameness or discomfort lead the cows to change their behaviour independently from inflammatory cytokines. Metabolic disorders for instance show a severe impact on the behavioural patterns of dairy cows, as resting generally increases and feed intake or rather feeding duration decreases (Goldhawk et al., 2009; Itle et al., 2015; Rodriguez-Jimenez et al., 2018). These behavioural changes are comparable to the definitions of sickness behaviour relating to the proposal that inflammatory mediators are directly linked to the pathobiology of metabolic disorders (Esposito et al., 2014). As the deviations of feeding behaviour are already observable in the week ante partum, a detailed observation of this phase could indicate a prevalence for metabolic disorders, especially for ketosis in the early post partum period (Goldhawk et al., 2009).

The sickness behavioural pattern is most likely to occur, when an inflammation or infection develops. Metritis and mastitis are common infectious disease patterns in dairy cattle and cause various behavioural changes according to the definitions of sickness behaviour. Generally, these infections reduce the physical activity and promote resting behaviour in order to facilitate recovery (Tizard, 2008). Metritic cows show thereby early variation in their feeding patterns by reducing the feed intake three weeks prior to diagnosis (Huzzey et al., 2007). In comparison to other disease patterns, metritis and metabolic disorders cause behavioural variations that could have a predictive value for cows being at risk for these health issues.

Intramammary infections on the other hand show a different timeline of behavioural variation. Most studies describe enhanced lying duration, but some induced mastitic infections cause a reduction in lying duration and prolonged standing duration at the day of infection (Siivonen et al., 2011; Cyples et al., 2012; Fogsgaard et al., 2012). These slight contradictions can be explained by the pain occurring in the infected udder quarter, which impairs the animals ability to lie on the painful udder quarter, therefore, they prefer to rest in a standing position. As these infections are induced, the behavioural differences are clearly classifiable as early signs of sickness and because of inflammatory processes. However, other studies have found the lying duration to be increased four days prior to diagnosis and therefore have shown the potential to derive a risk of disease from behavioural deviations. However, this potential could be dependent on the invading pathogen and the phase of infection (Sepúlveda-Varas et al., 2016; Des Roches et al., 2017).

Lameness as a highly prevalent disease pattern in modern dairy herds results from various causes. Injuries of the claws or the limbs cause painful bruises, which lead the cow to change its locomotion due to pain avoidance. Tissue damage or infections of the claw are sufficient to induce sickness behaviour as inflammatory cytokines are released, but even if the immune reaction is not present, lame cows differ their behaviour due to pain (Juarez et al., 2003; Tizard, 2008). These behavioural deviations are potentially different from those caused by other diseases due to the gradual characteristics of lameness and therewith an expectable gradual behavioural change. Observing these gradual changes would help to identify lame cows early, so the lameness-causing injury or inflammation could be treated to prevent severe lameness. To some extent, behavioural deviations in the transition period provide guidance for insufficient claw health in mid lactation (Proudfoot et al., 2010).

In general, the determination of a linkage between behavioural deviations and a specific diagnosis is potentially one of the major challenges, when interpreting the changes described. As the direction of the deviation is mostly similar for all described disease patterns, it is necessary to include other information such as the phase of lactation or productivity parameters to diagnose a disease. Generally, the observation of feeding patterns within the critical phase around parturition seems to show whether there is a risk of metabolic disorders or metritis (Huzzey et al., 2007; Goldhawk et al., 2009).

5. Conclusion

Dairy cows show behaviour alterations according to the definition of sickness behaviour when challenged by any kind of common production disease. Even if some contradictories are present, resting behaviour is generally prolonged, while physical activity and general feeding behaviour is impaired. Regarding the disease patterns described, it is obvious, that not each disease changes the behaviour through the release and effect of inflammatory cytokines. Metabolic disorders for instance affect the daily behavioural routine of dairy cows as expected, but the inflammatory response is not necessarily given as with infectious diseases. These infections affect the dairy cows according to the definition of sickness behaviour, but some contradictions were described with reduced lying duration. Contradictory observations for cows with mastitis do not necessarily indicate that the diseased animal is not lethargic as the sickness behavioural pattern assumes, because dairy cows rest in a standing position as well. The lameness-associated behavioural deviations are partly contradictory but show characteristics of pain avoidance. Considering that sick cows are more sensitive to pain, it is likely to classify these behavioural deviations as a kind of sickness behaviour, although the previously mentioned definition assumes an inflammatory process. Generally, the behavioural observations are valuable for the automated monitoring of dairy cows' health and welfare. To some extent it, is even possible to use behavioural changes to predict particular production diseases.

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Additional information

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