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Using sensors to monitor calves in a cow-calf rearing system

Master Thesis in Animal Sciences (45 ECTS)

Picture by Moritz Pfeiffer, February 2024.

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Preface

The thesis was written as the final step of my master's degree in Animal Sciences at the University of Copenhagen. The whole process of writing this thesis has not only been the most challenging but also the most instructive part of my life yet. Going into this thesis I honestly didn't fully know what to expect.

Starting in November 2023, I took large parts in planning the study and learned all the factors that have to be taken into account. And when you think you have finally thought of every possible influence, something new peeks around the corner. In my case that was the question of how to finance such a project. The answer was to apply for funding. An application had to be written and most importantly be accepted. Luckily this was the case and the monetary question was solved. When arriving at the farm to observe the calves and measure all factors, more "disturbing factors" came to mind. In the first days before the calves move from the calving box into the group pen and also when they move out of the group pen the dams/ foster cows were not separated. And of course many of them don't really appreciate the fact that some random man checks up on their babies. The task of getting out there uninjured was luckily successful. The data collection period was in general a period I really enjoyed. Although having 12 hour days twice a week was quite draining as well.

To be able to receive results that I can then use I also needed to learn how to use "R". What in the beginning seemed like a unsolvable problem, in the end actually became something I found lots of joy in. Producing all results after being sure that it would never be possible to get anything out of this program was a great satisfaction.

It continued with question marks when the decision which results to include in the thesis and which to drop needed to be done. But also this task was completed after all. The process of writing this thesis was a lot of work, but worth it after all.

In the end I can just say, that this whole period really let me grow as a person and I'm very thankful to have experienced it.

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Ethics

The project has been approved by the Animal Ethics Institutional Review Board of the Department of Veterinary and Animal Sciences in the Faculty of Health and Medical Sciences.

Declaration of Interest

The author declares no conflict of interest.

List of Abbreviations

IgG	Immunoglobulin G
FPI	Failed passive immunity
SPI	Successful passive immunity
NCD	Neonatal calf diarrhea
E.coli	*Escherichia coli*
ETEC	*Enterotoxigenic Escherichia coli*
C.parvum	*Cryptosporidium parvum*
S.dublin	*Salmonella Dublin*
BRD	Bovine respiratory disease
CCC-System	Cow-Calf-Contact Systems
differenceMean	difference from the group mean value
dHA	difference from the group mean value of High Active behavior
dNA	difference from the group mean value of Not Active behavior
lsmean	least square mean

Contents

Abstract

The neonatal period is the most critical period of a calf's life. The performance and health throughout this period are decisive for their lifetime productivity. An insufficient healthcare can therefore have major impacts on the longevity in later years. One way of ensuring health is the use of sensors. In the last decade sensors had a major impact in dairy cow surveillance. For calves however a widespread use is lacking. The aim was therefore to investigate if calves that have been found sick by clinical observation can be detected by using activity sensor data.

52 calves, housed in a cow-calf-contact system were clinically observed twice a week throughout the first 28 days of their life. Multiple factors like the body weight, 'feces consistency' and the 'level of sickness' were investigated.

Shortly after birth they were equipped with an Ear-Tag sensor that measured five different activities. The activity data was analyzed for the different 'levels of sickness'. Lastly Shewhart Control Charts were made to receive alerts for sick calves by comparing the difference of the group mean of their 'High Active' behavior with the average of apparently healthy calves.

A drop in 'High Active' behavior could be seen in all calves between days 7-12 which is very likely correlated to the occurrence of disease. In this period the amount of sick calves was the highest and no weight gain could be observed.

Sick calves showed a consistently higher difference from the group mean in 'High Active' behavior when compared to apparently healthy calves. With Shewhart Control Charts the majority of clinically sick calves could be identified as sick by receiving an alert, when they were observed as sick. Due to a limited frequency of clinical observations, alerts outside the observation period could neither be verified nor falsified. Further research is needed to continuously and with a higher certainty detect sick calves in a herd.

1. Introduction

The neonatal period being the first month of a calf's life, is the most critical period in an animals life (Mee, 2023). Most calf mortality occurs in the perinatal period, which is referred to as the first 48 hours after birth (Mee, 2008). Calf rearing has therefore received more and more attention over the past decades. The performance as well as health and welfare throughout the first months of a calf's life are decisive for their productivity in later years (Brown et al., 2021; Heinrichs et al., 2005). To ensure this, calves need to be provided with an appropriate diet, fulfilling all nutritional needs, as well as an adequate healthcare (Brown et al., 2021).

An insufficient healthcare can have major impacts on the calf's longevity (Brown et al., 2021) and therefore lead to significant economic loss (Wang et al., 2018; Yazdanbakhsh et al., 2017) due to a need for treatment (Schaefer et al., 2012) or an impaired growth and a higher mortality (Windeyer et al., 2017). A well-functioning immune system is therefore crucial to ensure a calf's wellbeing.

1.1 Colostrum supply

Throughout the cows gestation period there is no *in utero* transfer of immune factors because of a separation of maternal and fetal blood supplies (McGuirk & Collins, 2004). Newborn calves therefore depend on Colostrum (McGuirk & Collins, 2004). Colostrum is produced in a process called colostrogenesis during the late pregnancy period of a cow (Baumrucker & Bruckmaier, 2014). Calves are dependent on components in the colostrum like immunoglobulins, most importantly Immunoglobulin G (IgG). IgG1 being more prominent than IgG2 (Brandon et al., 1971), or immune cells and cytokines right after birth to be able to develop a sufficient immune system (Barrington & Parish, 2001). Additionally a sufficient colostrum uptake helps the calf in maturing their intestine and develop organs (Hammon et al., 2020). The Colostrum provides the calf with proteins, nonprotein nitrogen, fat, vitamins and minerals (Charles Crowther & Raistrick, 1916) as well as sugars like glucose, fructose, glucosamine and galactosamine and oligosaccharides (Gopal & Gill, 2000).

However, the timeframe in which calves are able to uptake colostrum is not unlimited. The calf's ability to absorb immunoglobulins from the colostrum through their small intestine decreases rapidly after birth. 12 hours after birth the intestinal permeability towards immunoglobulins starts to decrease. 24 hours after birth the permeability fully ceases (Bush & Staley, 1980; Stott et al., 1979). The IgG concentration in the colostrum is significantly reduced when the colostrum gets fed to the calf 6, 10 and 14 hours after calving (Constable et al., 2010; Moore et al., 2005). Already a delay in feeding colostrum to a newborn calf of 6 hours after birth decreased the transfer of IgG compared to calves that received colostrum right after birth (Fischer et al., 2018).

Not only the timeframe in which calves receive the colostrum but also the amount as well as the quality in terms of IgG concentration in the Colostrum are crucial for a calf's development (Godden, 2008). Calves that have a blood serum concentration of less than 10 mg IgG per ml at 24h of age (Lora et al., 2018; Shivley et al., 2018) or 48h of age (Besser et al., 1991) are considered to have a failed passive immunity (FPI). A successful passive immunity (SPI) is achieved when a calf has more than 10 mg IgG per ml blood serum (Quigley, 2004).

The failure of a sufficient immune transfer is a common problem amongst dairy calves (McGuirk & Collins, 2004). Calves with a FPI have a higher risk of getting ill in the first four weeks of life (Lora et al., 2018; Quigley, 2004). A FPI does not only lead to a higher probability of disease but also to a higher mortality rate. Calves with a FPI have a 11 times higher mortality rate than calves with a SPI (Lora et al., 2018). A SPI can lead to a 6-day delay in the age at first disease compared to calves with a FPI. The odds of disease occurrence can be up to 24 times higher when having a FPI compared to having a SPI, with rotavirus and *cryptosporidium spp.* as well as overall diarrhea incidences being among the most present enteric infections.

1.2 Neonatal Calf diseases

1.2.1 Diarrhea pathogens and clinical picture

During different age stages the calves are more vulnerable to different pathogens. Especially neonatal calf diarrhea (NCD) is a major concern being one of the leading causes of calf mortality (Becker et al., 2020), accounting for more than 50 percent of all calf mortality as well as an impaired welfare and economic losses for the farmer (Cho & Yoon, 2014; Goharshahi et al., 2021).

1.2.1.1 Escherichia coli

In the first 4 days of life the main cause of diarrhea is *Escherichia coli (E.coli*) with *Enterotoxigenic Escherichia coli* (ETEC) being the most prominent bacteria of the *E.coli* family (Foster & Smith, 2009). The calves ingest the bacteria orally typically via feces where ETEC colonizes the gut. The main antigen is K99 which bonds to the epithelium in the calf's small intestine. This attachment allows ETEC to colonize the Ileum and from there spread throughout the whole small intestine (Foster & Smith, 2009). After colonizing the Ileum not only K99 but also the antigen STa are expressed. While K99 allows an attachment to the epithelium, STa induces secretion which ultimately leads to diarrhea and dehydration (Constable PD., 2003). The severity of infection with ETEC depends both on the exposure and ingestion of the organism as well as the age of the calf. ETEC rarely leads to diarrhea in older calves or adult cows (Foster & Smith, 2009). K99's ability to attach to the calf's epithelium decreases gradually from 12 hours to two weeks of age (Foster & Smith, 2009). Yet the deciding factor for older calves not showing any symptoms is that the pH inside the abomasum drops from pH 6 – 7 to less than 2 by the age of 5 days which then is enough to kill the bacteria (Constable PD., 2003; Foster & Smith, 2009).

1.2.1.2 Cryptosporidium parvum

Between day 3 and day 5 of their lives, calves often show clinical signs of an infection with the parasite *Cryptosporidium parvum (C.parvum).* Being one of the most common gastrointestinal pathogens in dairy calves with up to 100 % of all dairy calves getting infected (Foster & Smith, 2009). *C.parvum* is a large environmental contamination source. Infection is possible by ingesting Oocysts from the environment, via feces or contaminated food or water. The ingested oocysts typically infect the Ileum but are able to infect the calves whole gastrointestinal tract leading to diarrhea outbreaks (Foster & Smith, 2009). These outbreaks lead to a large contamination of the environment with calves shedding up to 10^7 oocysts per gram feces when they reach two weeks of age (Fayer et al., 1998). Even though the clinical signs reach their peak between day 3 and 5 they can last between 4 up to 17 days after the initial infection. Nonetheless, a diarrhea outbreak based on a *C.parvum* infection rarely occurs after 3 months of age. Once infected, calves appear to be resistant to a second infection (Foster & Smith, 2009).

1.2.1.3 Rotavirus

A third major cause for NCD is an infection with Rotavirus. Antibodies can be found in more than 90 % off all unvaccinated calves as well as in twenty percent of all calf diarrhea samples (Foster & Smith, 2009). Rotavirus is stable to low temperatures and is therefore an infection concern throughout most of the year. Similar to *E.coli* and *C.parvum,* Rotavirus gets ingested via the fecaloral route meaning that calves ingest the virus by ingesting infected feces from the environment. Calves typically get infected with Rotavirus in the first three weeks of life with a peak incidence at 6 days of age (Foster & Smith, 2009). With an incubation period of 24 hours a spread of the virus is fairly easy and isolation of infected individuals becomes difficult. The virus replicates within the calf's cells, often leading to enterocyte death. Due to an malabsorption of carbohydrates like glucose an osmotic pull leads to secretion of fluid into the lumen which ultimately leads to diarrhea (Foster & Smith, 2009).

1.2.1.4 Coronavirus

Another virus which plays a crucial role in NCD occurrence is Coronavirus. Epidemiology as well as physiology have a significant overlap with Rotavirus. Being again ingested from an contaminated environment it typically affects calves in their first three weeks of life peaking between 7 and 10 days of age. Clinical signs lasts usually for 3 to 6 days after showing first symptoms (Foster & Smith, 2009). The infection typically starts in the small intestine and normally spreads throughout the jejunum, ileum and colon. The diarrhea begins by the time the virus enters the cell and is caused by a malabsorption and an increased fluid secretion (Vlasova & Saif, 2021).

1.2.1.5 Salmonella

Within hours after birth, calves can be infected with a variety of *Salmonella* serotypes with *Salmonella enterica* and *Salmonella Dublin (S.dublin)* being the most relevant in dairy cattle (Holschbach & Peek, 2018; Mohler et al., 2009). An infection via the fecal-oral route is the most prevalent way of infection with the gram-negative bacteria (Holschbach & Peek, 2018). Disease outbreaks occur often between 4 and 28 days of age with older calves also being able to get infected. Clinical signs include fever, loss of appetite and diarrhea. The severity and duration of clinical symptoms is related to the virulence of the strain, the amount of bacteria ingested, the calf's age with the efficiency of the passive immune system, dehydration as well as nutrition and the degree of environmental stress. The dehydration follows as a result of diarrhea (Mohler et al., 2009). Pneumonia is seen increasingly more often in calves with a *S.dublin* infection (Holschbach & Peek, 2018). Once *Salmonella* is ingested by the calf it attaches to mucosal cells and is able to destroy enterocytes. The attachment increases significantly when the calves normal gastrointestinal flora has not yet been established fully. A inflammation in the colon can lead to blood in the feces of the calves. The diarrhea is then caused as an inflammatory reaction to the infection (Holschbach & Peek, 2018).

1.2.2 Bovine respiratory disease

With NCD being the leading cause of morbidity in calves Bovine respiratory disease (BRD) comes in at second. In the US, BRD has been found to be the second most common cause of mortality in preweaned dairy calves and the most common cause of mortality in weaned dairy heifers (Maier, Love, et al., 2019; Maier, Rowe, et al., 2019). BRD is a multifactorial disease complex which includes pneumonia, bronchitis, tracheitis, laryngitis, rhinitis and otitis media. It affects the lower and upper respiratory tract (Cummings et al., 2022; Deepak et al., 2021). Clinical symptoms often include fever, coughing, ocular or nasal discharge, abnormal breathing, and auscultation of abnormal lung sounds (Mcguirk & Peek, 2014). The pathogens causing BRD include Bovine respiratory syncytial virus, bovine herpes virus 1, parainfluenza 3, bovine viral diarrhea virus and bovine coronavirus as well as bacterial pathogens such as *Pasteurella multocida* or *mannheimia haemolytica* (Deepak et al., 2021). Costs associated with BRD could be veterinary treatments or an increased labor for diseased calves. It has been shown, that BRD also affects the animal in later stages of life showing poorer performances (Bowen et al., 2021). Calves with a higher stress level as well as group housing, a poor ventilation and air circulation can significantly increase the risk for BRD (Bowen et al., 2021; Cummings et al., 2022). To detect BRD or abnormal lung sounds associated with it, a stethoscope can be used to hear thoracic auscultation. This method comes with two downsides nonetheless. It requires a skilled operator on the one hand and is a very subjective procedure (Deepak et al., 2021).

1.2.3 Umbilical infections

Umbilical infection or omphalitis can occur in up to 30 % of all newborn calves. It is harmful to the calf's general condition and health (Mee, 2008). Besides a local infection and inflammation of the navel, it can spread into the animals joint, lungs, kidneys and other organs where it can cause severe complications, lead to a decreased growth rate and increased mortality (Wieland et al., 2017).

The mentioned diseases often do not appear alone. A study visiting 731 dairy farms in Germany found that almost half of the observed calves were found to have at least one of the mentioned health disorders and 7% of the observed calves were found to have more than one of the mentioned diseases (multimorbidity). Calves in the first two weeks of age were found to primarily have omphalitis, diarrhea and multimorbidity. Respiratory diseases increased gradually with the animals age (Dachrodt et al., 2021). Omphalitis was mostly diagnosed in summer months while respiratory diseases, diarrhea and multimorbidity were predominantly observed in the fall.

The mentioned pathogens are infectious and can be transmitted through contact between calves for example as described via the fecal-oral route. The contact between the calves depends on the calf housing systems as well as the management (Marcé et al., 2010).

1.3 Housing systems

1.3.1 Single housing

Housing systems can vary immensely from farm to farm. The most common housing system for newborn calves is a single housing where the calves get separated from the cows shortly after birth and housed in individual pens (Busch et al., 2017; De Paula Vieira et al., 2010). The Danish legislation states that a calf must stay with the cow for at least 12 hours after calving before separation is allowed (Bekendtgørelse Om Dyrevelfærdsmæssige Mindstekrav Til Hold Af Kvæg §89). This is to ensure that the calves receive the colostrum within this period. Although the legislation also states that calves must receive the colostrum no later than 6 hours after birth (Bekendtgørelse Om Dyrevelfærdsmæssige Mindstekrav Til Hold Af Kvæg §48, paragraph 2). The single boxes have to have openings in the walls for the calves to see and touch other calves (Bekendtgørelse Om Dyrevelfærdsmæssige Mindstekrav Til Hold Af Kvæg, §46 paragraph 3). Typically this separation comes with an artificial feeding with either milk or milk replacer instead of suckling at the cow directly (Kent, 2020). One major reason for early cow-calf separation is a reduced risk of disease transfer to the calf (Marcé et al., 2010) as well as stopping the cow and the calf to form a bond which prevents calf and dam from stress associated with the separation (Busch et al., 2017). Additionally many farmers argue that an early separation allows them to receive the maximum amount of milk from the dam for them to sale (Wagenaar & Langhout, 2007). In recent years, this method has received more criticism declaring that the welfare of both the calf and the dam is getting deprived (von Keyserlingk & Weary, 2007).

1.3.2 Pair housing

Another popular housing method is pair housing where two calves are held together in pairs. It is argued that paired housing throughout the milk-feeding phase reduces the calf's response to weaning as well as improving performance after weaning when calves are held in groups (De Paula Vieira et al., 2010).

Even though this method allows calves to perform more natural behavior compared to single housing many consumers and farmers wish for calf and dam not to be separated (Agenäs, 2017 (Editorial); Busch et al., 2017). Arguments for a later separation contain for example to allow a more natural way of living for dam and calf, emotional benefits for both and biological benefits for the calf including better weight gains as well as fewer diarrhea cases (Kent, 2020). Housing calves individually seems to limit the calves cognitive abilities (Costa et al., 2014). Additionally research shows that individually reared calves show an increased response to stress, a decline in learning and social skills and tend to be dominated by nursed calves when held together after weaning (Kälber et al., 2014). The same study found on the other hand that heifers reared conventionally without dam contact and dam reared heifers showed no behavioral differences during the first 12 hours after integration into a dairy herd antepartum (Kälber et al., 2014). Not only the calf seems to benefit from a dam rearing. The dam seems to have a higher milk production, longevity and overall health as well as a lower age at first calving (Bar-Peled et al., 1997; Johnsen et al., 2016).

1.3.3 Cow-calf-contact systems

A housing form which takes the consumer concerns into account are cow-calf-contact systems (CCC-System). It describes any housing or management in which calves have contact with either their dam or a foster cow (Sirovnik et al., 2020). In many CCC-systems calves are able to choose the frequency and amount of their meals themselves (Grøndahl et al., 2007). When looking at the amount of milk calves tend to drink while suckling their dam, being able to decide the amount themselves, it shows a large discrepancy to the amount calves are typically fed in conventional systems (Khan et al., 2011). Calves which grow up in a CCC-System tend to mirror the behavior of older calves and start to eat roughage at an earlier point (Wagenaar & Langhout, 2007).

1.3.3.1 Mother-bound-rearing

The variety of options on how to execute a CCC-system on a farm is wide. A first version of a CCC-system would be mother-bound rearing in which calf and dam have physical contact and behavioral interactions. This system can be subdivided into multiple variants with free cow-calf contact being the first one. In this system the calf and the dam are kept together mostly for 24h per day for 6 to 12 weeks. They are free to interact and able to nurse at any given point (Johnsen et al., 2016; Sirovnik et al., 2020). Advantages of this system include high weight gains, care taking behavior by the dam, less abnormal behavior and less cross sucking shown by calves (Grøndahl et al., 2007). Disadvantages include lower observed weight gain after weaning, since calves often have a low intake of solid feed before weaning (Roth et al., 2009) and large amounts of vocalization after finally separating calf and dam (Johnsen et al., 2015).

A second variety of the mother-bound rearing would be a restricted suckling contact. In this system the dam suckles the calf at given timepoints typically 1–2 times per day usually before or after milking and are separated for the remaining time (Johnsen et al., 2016; Sirovnik et al., 2020). Dam and calf show behaviors that indicate recognition and bonding between them (Roth et al., 2009). Even though the calves are able to suckle as much as they need throughout the suckling times weight gains both post and pre weaning vary widely (Johnsen et al., 2016). Other disadvantages of this system include a lower intake of concentrate by the calves compared to calves reared without a dam as well as lower growth rates post weaning. Less possibilities for the calf to learn behaviors from the dam or other cows, and increased labor for the farm because they need to lead the cows to the calves after separation or vice versa (Johnsen et al., 2016).

A third possibility for mother-bound rearing is a half day cow-calf contact. In this system dam and calf are kept together daily for around 12 hours. Either during the day or during the night (Johnsen et al., 2016; Sirovnik et al., 2020). Calves in this system showed higher weight gains pre and post weaning (Veissier et al., 2013). Since the calves are used to being separated from the dam for longer periods they seemed to be less dependent on them (Johnsen et al., 2016). Even though being less dependent on them the calves still form a bond with their dam (Føske Johnsen et al., 2015). Again, like in the restricted suckling system the daily separation of dam and calf is a labor-intensive procedure for the farm (Johnsen et al., 2016).

1.3.3.2 Foster cow system

A second version on how to execute a CCC-System is a foster cow system. Here one cow fosters 2–4 calves at the same time. The cow typically is not getting milked throughout this period. The dams own calf can be within the fostered calves, but does not have to be (Johnsen et al., 2016; Sirovnik et al., 2020). This system can follow a dam-rearing period in which the calves are being reared by their dam for the first weeks of their life and later will be transferred to a foster cow (Ellingsen et al., 2015). Calves in this system usually stay in groups in which they have contact to other calves and adult cows and therefore perform natural behaviors (J. Loberg & Lidfors, 2001). One large disadvantage of this system is the possibility of the foster cow not accepting one or multiple calves to rear. It is often observable that foster cows show preferences for specific calves (J. M. Loberg et al., 2007). The weight gains of the calves can vary depending on the amount of milk the foster cow is able to produce. Weaning tends to be easier when done with a foster cow than with a dam (J. M. Loberg et al., 2007; Wagenaar & Langhout, 2007). This can be based on multiple reasons. One being the weaker binding of a calf with a foster cow and another being the natural reduction in amount of milk every calf is able to receive from the foster cow over time (J. M. Loberg et al., 2007; Wagenaar & Langhout, 2007). Like in the mother-bound-rearing, the separation seems to also cause a considerable stress reaction in both calf and dam (J. M. Loberg et al., 2007, 2008).

1.3.3.3 Disadvantages of CCC-systems

One large disadvantage that all CCC-Systems share is a higher risk of infection due to having constant contact with other calves and cows. The risk of getting infected with for example *Cryptosporidium* is significantly higher in shared stables with calves of the same age than in single housing. Another risk factor is the transmission of oocysts from one foster mother to multiple foster calves (Constancis et al., 2021). The transmission of other pathogens like *Pasteurella multocida, Staphylococcus aureus, Streptococcus suis* and *Staphylococcus sciuri* is likely to be considerably high (Köllmann et al., 2021). Although there seems to be a lower intensity and frequency of emitting diarrhea. Wagenaar and Langhout (2007) found on the other hand less diarrhea occurrence in CCCsystems. Another reason for a possibly higher occurrence of diarrhea could be the large amount of milk consumed by the calves (Wagenaar & Langhout, 2007). Additionally, calves in CCC-system are harder to observe compared to single or pair housed calves. In single or pair housed systems the calves get fed with milk or milk replacer one or multiple times per day. During these feeding times an observation of the calf's health status is possible. If held in a CCC-system this observation period vanishes and calf observation becomes more difficult with the calves blending into a larger group. If not found in an early state, these diseases can not only be an animal welfare burden by causing pain and suffering but also affect performance as well as productivity of the diseased animals later in life or lead to death (Mahmoud et al., 2017; Santman-Berends et al., 2019). The common practice currently is that the farmer observes the health status of a calf. This comes with different disadvantages. The calves which will be identified as sick typically already show clinical symptoms and could have possibly been sick for some time. Clinical symptoms of for example NCD are only visible when a lot of the intestinal submucosa is already damaged. Visual observations and clinical examinations of the calves are not reliable in identifying calves, and therefore many sick calves go undetected or require a retreatment because of an delayed intervention (Mcguirk & Peek, 2014; Schroeder et al., 2012). However, individually housed calves are being observed during feeding times, at least once per day. If a calf shows any signs of disease or at least does not react to the milk being brought or does not start drinking it is rather easy for the farmer to detect such calves. Calves in a CCC-System do not receive this kind of observation. Typically they drink milk from their dam or a foster cow and therefore don't get fed additionally. Especially in larger groups, signs of sickness can therefore easily be overseen (*Types of Housing Systems for Nursing Calves – The Dairyland Initiative*).

An early detection of disease, a targeted treatment and tools for an automated monitoring of individual calves and herds would therefore help massively with health management of the animals (Gardaloud et al., 2022).

1.4 Sensors in dairy farming

The use of Sensors in dairy farming has spread widely in the last decade (Borchers et al., 2016). It enables the possibility to monitor cows continuously and find differences in behavior, feed intake, rumination time, activity or heat stress (Hut et al., 2019). By monitoring the cows on an ongoing basis even slight differences in the measured parameters are found and the farmer can be notified in best case even before the occurrence of any clinical signs of disease (Rutten et al., 2013). This lowers the labor for animal observation significantly and reduces subjectivity in observations (Leso et al., 2021). The implementation of Sensors has been a great success in farms all over the world (Shalloo et al., 2018).

1.4.1 Data collection

These sensors collect data for individual animals based on for example accelerometers, cameras or temperature measurements. Once collected a sensor specific algorithm processes the data and typically sends an alert if the measured data exceeds a prior defined threshold (Sharma & Koundal, 2018). Based on this alert the farmer is able to detect sick cows without actively observing them.

1.4.2 Sensors in CCC-system

When looking at CCC-Systems the possibility of sensor usage differs from conventional systems. Automatic milking systems (AMS) for example are getting more and more frequent. One of the main reasons for the implementation of sensors such as an AMS is the reduction of labor (Steeneveld & Hogeveen, 2015). The cow is able to walk into an AMS at any given time. The farmer therefore is able to reduce labor in the form of milking inside a milking parlor. Implementing an AMS into a CCC-System is very difficult. The fact that foster cows do not get milked at all rules out the possibility of an AMS in a foster-cow system. Implementing an AMS in a mother-bound-rearingsystem would be possible. The cow's possibility of being milked at any given point gives uncertainty if the calf receives a sufficient amount of milk.

The implementation of health monitoring tools on the other hand is very common. Since these types of sensors do not care about the housing format they can be equally used in an CCC-system as they can be in a conventional system. Especially in foster cow systems health monitoring tools can be of use. Due to the fact that foster cows don't get milked, a possibility for an health check during the milking process gets lost. By sending alarms if something is out of a defined range, a farmer does, once again, not have to use additional labor in cow observation.

Nonetheless, a widespread use of Sensors in calves is lacking. Various sensor data models have been proposed throughout the last years but have failed to gain widespread acceptance (Sun et al., 2021).

1.4.3 Early detection of diseases

Studies found that calves drank milk slower 4 days prior to getting diagnosed by clinical examination and had fewer visits at a milk dispenser 3 days prior. Calves diagnosed with NCD had a lower milk intake and spend less time at a water trough 4 days prior to examination. When diagnosed with BRD calves had a reduced step count, less lying bouts and lower standing time. Lastly calves that were diagnosed with an inflamed navel had a reduced lying time compared to healthy calves (Sun et al., 2021). Based on these findings it appears to be possible to find early signs of disease with sensor based data.

The goal was therefore to investigate, if calves which were clinically observed to be sick can be found by using activity sensor data.

2. Objective and Hypotheses

The objective was to investigate, if calves which were clinically observed to be sick can be found by using activity sensor data.

The calves on the test farm were followed from 0 to 28 days of age and were held in a cowcalf-contact system. Therefore, the following hypothesis was formulated:

H0: Calves in a cow-calf contact system show the same or more activity in the days leading to a disease when compared to healthy calves throughout the first 28 days of life. The alternative hypothesis therefore looks like this:

H1: Calves in a cow-calf-contact system show less activity in the days leading to a disease compared to healthy calves throughout the first 28 days of life.

3. Methods

3.1 Literature research

For the literature research, multiple databases including PubMed, Web of Science and ResearchGate were scanned for literature. Keywords like “calf diseases”, “NCD”, “BRD”,

“Colostrum”, “CCC”, “Cow-Calf-Contact”, “Foster Cow”, “Mother-bound rearing”, “Sensors” were used.

3.2 Study design

The study was designed as an longitudinal observational study. It was declared at the Animal Ethics Institutional Review Board of the Faculty of Health and Medical Sciences in the University of Copenhagen and received approval to conduct the study as described below.

3.3 Animals and Housing

The study population consisted of 52 dairy calves of which 50 were crossbreds and 2 were Red Danish Mælkkvæg. The herd was located on an organic dairy farm in Silkeborg, Denmark, using a cow-calf-contact system to rear the calves. Starting on 18/01/2024 the calves were chosen based on their birth date. From this date on every newborn calf was included into the study until 50 calves were born. Because 2 calves died during the first 10 days of their life, 2 additional calves were included in the study. Shortly after birth, the farmer equipped the calves with an Ear-Tag sensor provided by CowManager (CowManager B.V., Harmelen, the Netherlands). After birth, calf and dam stayed in an approximately 12-13 square meter single calving box (figure 1) for 2-3 days (some calves stayed longer in the calving box, because of twin births, or because the farmer declared them to be not strong enough) until being transferred into a larger enclosure measuring 330 square meters with typically around 20 -25 calves and their dams (figure 2). Once a day the dams were separated from the calves for 4 hours between 10am and 2pm. During this period the dams stayed in a separate enclosure in a different building and were milked in a rotary milking parlour towards the end of the separation period. After three weeks, the calves and dams were separated and 4 calves were assigned to a foster mother until being weaned. Based on the amount of foster groups, the foster mother with her calves stayed in a new enclosure (figure 3) measuring between 40 and 132 square meters with at least two foster groups staying in one enclosure until being transferred to a bigger group. None of the calves in this study moved with the foster group to the bigger group before they were 28 days old.

The calves had *ad libitum* access to water and starter feed. Except for the 4-hour separation period, the calves had access to milk from their dam and later from the foster cow.

Every enclosure consisted of a straw bedding, receiving a new layer once a day and getting changed regularly.

Figure 1. A calving box on the study farm.

Figure 2. The group pen on the study farm.

Figure 3. A group pen with foster cows on the study farm.

3.3 Observations & Sampling

The herd was visited by the same observer, the author of this thesis, twice a week on Tuesdays and Fridays. Observations were taken from every calf from earliest day 0 until day 28 of their life between 18/01/2024 and 20/03/2024. The examinations were conducted between 10am and 2pm while the dams were separated from the calves in the large group to allow easy access to the calves.

3.3.1 Clinical observations

The clinical observation consisted of 5 variables being heart girth, lung auscultation, external navel examination, feces consistency and overall level of sickness. To measure the body weight of the calves, the heart girth in cm was measured using a measuring tape. To calculate the body weight in kg the following formula, which allows to estimate body weight in kg based on circumference measurements in cm was used (Heinrichs et al., 1992):

$$BW\ (kg) = 65.36 - 1.966 * HG + 0.01959 * HG^2 + 0.00001691 * HG^3$$

With BW being the body weight (in kg) and HG being the heart girth measurement (in cm).

The lung auscultation was evaluated using a stethoscope listening to the lungs and scoring the result from 1 to 5 with 1 = no obvious findings, 2 = aggravated breathing, 3 = attenuated breathing, 4 = abnormal sounds and 5 = tubular breathing (Dachrodt et al., 2021).

For examination of the external navel, the outer navel was palpated searching for signs of inflammation. The scoring was from 1 to 2 with 1 = normal and 2 = signs of inflammation (thick, swollen, painful, or hot) (Dachrodt et al., 2021).

The feces consistency was observed while the calf was excreting and scored from 1 to 3 with 1 = normal consistency, 2 = diarrhea and 3 = watery diarrhea.

The level of sickness was evaluated by looking at the calf's general condition. The position of the bulbus of the eye within the orbita was checked, roughness of fur, nasal discharge and the overall impression of the calf was observed. The observations were scored from 1 to 3 with 1 = an apparently clinically healthy calf, 2 = a calf with mild sickness and 3 = a calf showing signs of severe sickness (e.g. not standing up when being approached, showing severe signs of dehydration).

It was discussed with the farmer that when two or more variables were pointing towards a disease occurrence, body temperature was measured and he was being informed. The Animal Ethics Institutional Review Board did not allow us to measure body temperature routinely in all calves at each visit.

3.4 Pathogen testing

Three feces samples were taken from three different calves with diarrhea to test for pathogens causing the diarrhea. The calves were chosen based on two factors. Firstly they needed to have a feces consistency score of 3 and they should be newly sick calves (i.e. they did not have a feces consistency score of 2 or 3 on any prior visit).

To test the diarrhea samples Fassisi BoDia Antigen rapid tests (Fassisi GmbH) were used. The four pathogens the rapid test is testing for are Rotavirus with a sensitivity of 96.15% and a specificity of 98.48%, Coronavirus with a sensitivity of 90.91% and a specificity of 98.77%, *E. coli* K99 (ETEC) with a sensitivity of 90.00% and a specificity of 98.78% and *Cryptosporidium* spp. with a sensitivity of 97.92% and a specificity of 97.73% (Rapid Test for Calf Diarrhoea - BoDia - Fassisi GmbH).

3.5 Sensor Data

The Ear-Tags continuously registers movements of the cows ear. The data are sent via wireless routers and connectors to a computer. The software collects the acceleration measurements and preprocesses it into five different activities given in a hourly amount for each Activity. This preprocessed data was used for further analysis. For each of the 52 calves the data set provided by CowManager contained the calves registration number, a shortened ID number, a timestamp containing date and hour, a behavior measurement count which contained the number of measurements during the specific hour, the ear temperature and five behaviors, being 'Not Active', 'Active', 'High Active', 'Ruminating' and 'Eating'. For later calculations only the behaviors as well as the timestamp and shortened ID number were taken into account.

The number of measured behaviors per hour added up to the behavior measurement count. An average of 62.45 was calculated by adding all behavior measurement counts together and dividing it by the number of behavior measurement counts. To even out the data and to make it more comparable the five behaviors were individually divided by the corresponding behavior measurement count to turn them into percentages (i.e. proportion of each activity type per observed hour).

3.6 Statistics

All analyses were performed using the software package R Studio version 12.1 (R Core Team, 2021). Packages used were ggplot2, readr, tidyverse, zoo, reshape2, lsmeans and lmerTest (Kuznetsova et al., 2017; Lenth, 2016; Wickham, 2007, 2009; Wickham et al., 2019, 2024; Zeileis & Grothendieck, 2005).

3.6.1 Body weight development

To understand the development of each calf, the body weight development and daily weight gain were calculated. Even though the body weight development is not a direct measurement of a calf's health status, it gives an insight into its wellbeing. If a calf does not gain weight, its welfare is impaired.

The body weight development of each calf was calculated by using the body weight in kg that was calculated based on chest circumference as described above.

An upper and lower quantile were calculated by separating the 25% calves with the highest and lowest body weight development respectively. To divide the development into "Age-Steps" meaning to summarize multiple age in days into one value, all observations in the specific age steps were added up and then divided by the total number of observations in the specific age step to receive an average weight for the specific time period.

The body weight development per level of sickness score was calculated by first dividing the calves into level of sickness groups. Calves that have never been assigned a 'level of sickness' score of 2 or 3 were put into the group "Level 1". Calves that have at least once been assigned with a 'level of sickness' score of 2 but never with a 'level of sickness' score of 3 put into the group "Level 2". Calves that at least once been assigned with a 'level of sickness' score of 3 have been put into group "Level 3". The body weight development as well as the age steps have been calculated the in the same way as described earlier.

3.6.2 Average daily weight gain

Starting from the second observation for each calf, The daily average weight gain in kg was calculated by subtracting the body weight in kg of the previous observation from the newly calculated body weight in kg, and afterwards dividing this value with the result of subtracting the age in days from the previous observation with the age in days from the current observation.

$$Average\ daily\ weight\ gain\ (kg) = \frac{Body\ weight\ (kg)_{current} - Body\ weight\ (kg)_{previous}}{Age\ in\ days_{current} - Age\ in\ days_{previous}}$$

Additionally the body weight development and average daily weight gain respectively were calculated for the different levels of level of sickness.

3.6.3 Number of investigated calves per age in days

The number of investigated calves and those that have been marked as sick (calves either scored with a 'level of sickness' score of 2 or 3, a 'feces consistency' score of 2 or 3, a 'lung auscultation' score other than 1, or an 'external navel' score of 2 per age in days was shown to understand when the calves in this herd show the highest occurrence of diarrhea or disease (figures 6, 7, 8, 10).

3.6.4 Average activity data

To understand the general Activity scheme of all calves in the group, the different behaviors 'High Active', 'Active', 'Not Active' and 'Eating' were plotted. To be able to do so, firstly the Average value for 'High Active', 'Active', 'Not Active' and 'Eating' of each hour of the day per 'Age in Days' for all calves was calculated. Secondly, a daily average of the three behaviors for all calves was calculated based on the hourly averages. As a last step, these values were then shown in a graph (figure 13).

3.6.5 Distribution of activity data

The sensor data was analyzed by firstly checking the different behavior data for normal distribution (figure 4 - distributions of all behaviors can be found in the Appendix). As none of the behavior variables was normally distributed, the data were transformed into a new variable. To receive normally distributed data, firstly the group mean for the different behaviors for every hour on every date was calculated. Afterwards, for each behavior each calf´s difference from the group mean (differenceMean) at the given date was calculated (figure 5 – distributions of all behaviors can be found in the Appendix). The differenceMean values were afterwards inverted to ease the interpretation.

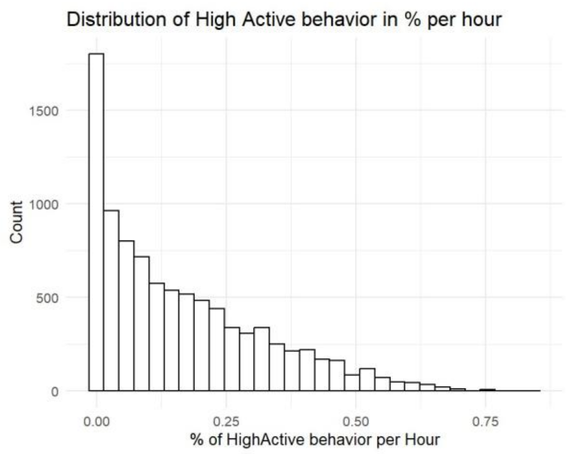

Figure 4. Distribution of 'High Active'

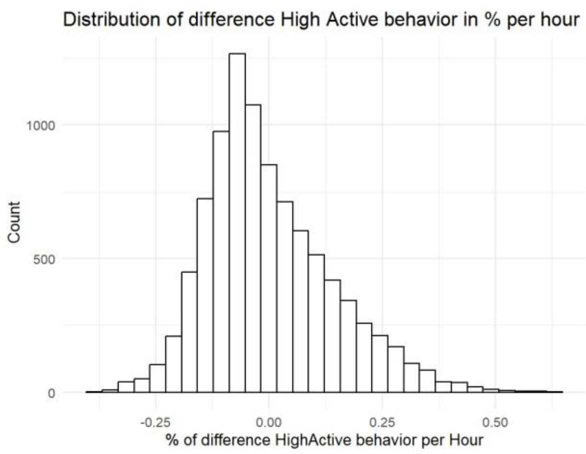

Figure 5. Distribution of the difference for 'High Active'

3.6.6 Univariable Analysis

Further on statistical differences were analyzed by conducting an ANOVA to compare the difference in the chosen behaviors between different levels of the variables 'level of sickness' and 'feces consistency'. Predictors were considered significant at P < 0.05. The behaviors were tested with different calf groups (calves with 'level of sickness' 1, 2 and 3, 'feces consistency' 1, 2 and 3). The analysis was additionally conducted for different age steps (8-11, 14-16 days of age) to include the age spans with the highest occurrence of disease. For calves that appeared twice in each period one of the observations was excluded to include each calf only once in each age step. For those that have been scored as sick during that period once, the non-sick observation was excluded. For those that have not been sick or have been sick in both observations one observation was excluded randomly. Because each calf had 24 measurements, one for each hour of the specific day, a daily average of the 'difference High Active', 'difference Active', 'difference Not Active' and 'difference Eating' behavior for each calf based on their hourly measurements was calculated to exclude repeated measurements.

A linear model was made to calculate the least square means and receive upper and lower control limits.

To visualize the results of the linear model, Boxplots for the 'differenceMean High Active' ('dHA') and 'differenceMean Not Active' ('dNA') were made (figure 14).

3.6.7 Sensitivity and Specificity

To calculate sensitivity and specificity firstly, activity data for the calves in the age group 811 days and 14-16 days was extracted. The 'High Active' data for every hour on that date for every observed calf was extracted. Group mean values for both behaviors and ‘differenceMean’ values were calculated. As thresholds five different values were chosen. The mean threshold being the lsmean of ‘level of sickness’ 3 calves. The other thresholds were chosen by adding and subtracting respectively, the standard deviation from the lsmeans value until changes in sensitivity and specificity were visible.

The sensitivity was calculated by using the Equation: SN = $\frac{TP}{TP+FN}$ (Fenn Buderer, 1996), SN being the Sensitivity, TP being the True Positive and therefore the calves scored with a ‘level of sickness’ of 3 and FN being the false negative and therefore sick calves were below the used threshold, and were hence classified as healthy.

The specificity was calculated by using the Equation: SP = $\frac{TN}{TN+FP}$ (Fenn Buderer, 1996), with SP being the specificity, TN being the true negative calves and therefore calves scored with a ‘level of sickness’ of 1 or 2, and FP being the false positive and therefore healthy calves that were above the threshold, and were hence classified as sick.

As a gold standard to determine the amount of true positive and true negative calves respectively, the results of the clinical observations were used.

3.6.8 Visualize ‘differenceMean’ for ‘"High Active"' behavior for ‘level of sickness’

The calculated ‘differenceMean’ values were then summarized for each group of ‘Age in Days’ stratified by sickness level of the calves and plotted to visually investigate differences between the groups (figure 15). A comparison of the behavior for the whole observation period of sick calves (‘level of sickness’ score of 3) with the mean of all apparently healthy calves (‘level of sickness’ score of 1) was being conducted.

3.6.9 Control Charts

To see actual differences in ‘High Active’ between apparently healthy calves and specific sick calves, control charts were made. The procedure was divided into two steps. Firstly a comparison of the ‘dHA’ values was calculated. This was done by calculating difference from the group mean value for ‘High Active’ behavior of all calves scored with ‘level of sickness’ equal to 1 for every hour on every day. For each calculated mean value the corresponding standard deviation was calculated. This standard deviation was then added and subtracted respectively from the corresponding mean value to mark an upper and lower control limit. The calculated means as well as upper and lower standard deviation were plotted as lines. On top of this, the ‘dHA’ values for each specific calf separately and later an average value of all sick calves were added as dots to see visual differences between them (figures 16).

3.6.9.1 Shewhart Control Charts

Secondly Shewhart Control Charts were created to receive alerts if a calf shows less 'dHA' than the group mean. This was done by defining the needed parameters, being the' dHA' values from the sick calves, a mean value, being the mean value of the 'dHA' for all apparently healthy calves, and a standard deviation, being the standard deviation of the prior 'dHA' value for all apparently healthy calves. A publicly available code that applies the Montgomery Rules (DC Montgomery, 2005) to the data used in this project and creates Shewhart Control Charts was used (Jensen, 2024).

The Montgomery rules define, when a process is out of control. Referring to the activity of the calves, this means that a calf is "out of control" when one of the four rules is applying, meaning that a calf is showing less or more activity than the group mean to an extend where a rule applies. Rule one defines that one observation point is outside a three-sigma limit with sigma being the standard deviation.

Rule two defines that two out of three consecutive points are outside a two-sigma limit. Rule three defines that four out of five consecutive points are outside a one-sigma limit. Rule four defines that eight consecutive points are on the same side of the expected level, meaning the group mean value.

Therefore the group mean value as well as the group mean value plus and minus the standard deviation, the group mean value plus and minus two times the standard deviation and the group mean value plus and minus 3 times the standard deviation were plotted. The rules were then tested for every observation of each sick calf, meaning that it was tested if 'dHA' for a sick calf in every hour on every day throughout the first 28 days of life was being "out of control". If one of the rules was being applied they were marked with a specific color. Rule one being red, rule two being purple, rule three being blue and rule four being green. The charts show either the whole observation period of each calf or if the calf died throughout the observation period the chart shows the observation period up until the death of the specific calf (figures 17-18).

4. Results

52 calves were observed over the first 28 days of their lives over a period of 9 weeks between the 18/01/2024 and the 20/03/2024. Each calf was clinically observed twice a week by the author of this study. 42 calves were observed 8 times, 5 were observed 9 times, 2 were observed 7 times, 1 calf was observed 5 times, 1 calf 4 times and 1 calf 2 times. Differences in number of observations are based on the birth date or death of the calf. 29 calves were female and 23 calves were male. Three calves died before they reached 28 days of life.

4.1 Observations

4.1.1 Respiratory Diseases

Figure 6 shows the number of investigated calves by age in days and those diagnosed with respiratory diseases. It is visible that on almost every age in days, a calf has been diagnosed with a respiratory disease. 11 calves were never diagnosed with a 'lung auscultation' score other than 1. To clinically observe the calves, they needed to be caught from a group of calves. This normally resulted in chasing the calves. This process together with the clinical observation may have caused stress in the calves and therefore increased their heart rate and respiratory rate (Dachrodt et al., 2021). The findings of this study lead to the decision that increased respiratory rates of the calves influenced the results and to hence exclude this observation from further analysis.

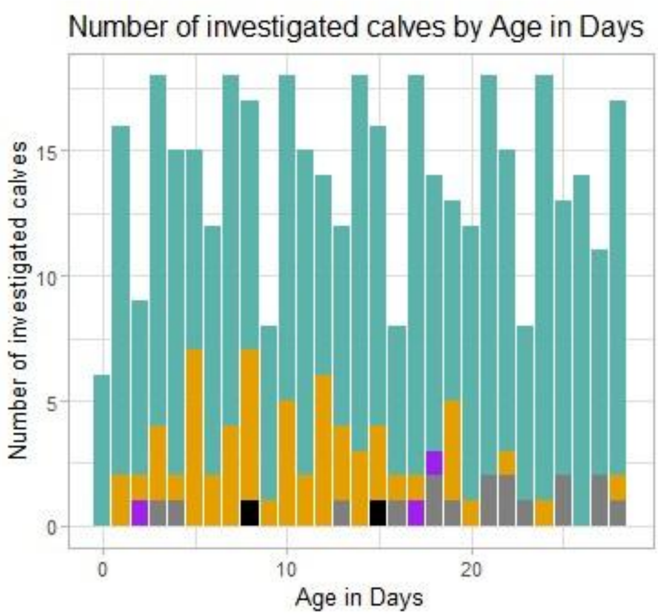

Figure 6. Number of investigated calves per age in days and the number of calves scored with respiratory diseases. The number of calves per age in days varies between 6 and 18.

Green = 'lung auscultation' 1, brown = 'lung auscultation' 2, purple = 'lung auscultation' 3, black = 'lung auscultation' 2 and 4, and grey = No data available

4.1.2 Umbilical infections

Figure 7 shows the number of investigated calves by age in days and those diagnosed with umbilical infections. The amount calves with umbilical infections stays relatively consistent throughout the age in days. 23 calves were never diagnosed with an 'external navel' score of 2. Umbilical infections has also been excluded from further analysis since no differences in behavior could be found for this factor.

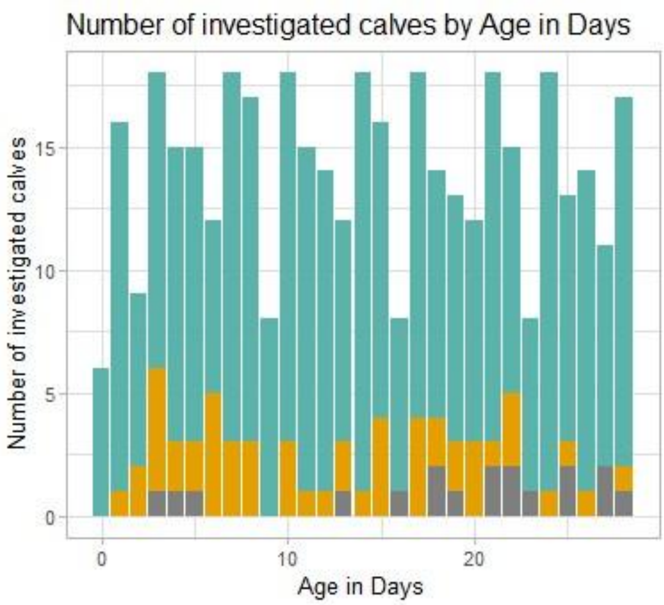

Figure 7. Number of investigated calves per age in days and the number of calves scored with Umbilical infections 1 and 2. The number of calves per age in days varies between 6 and 18. Green = 'external navel' 1, brown = 'external navel' 2 and grey = No data available

4.1.3 Factor 'feces consistency'

The number of investigated calves by age in days and those diagnosed with diarrhea is displayed in figure 8. It is visible, that the number of calves diagnosed with diarrhea has a peak time between days 7 and 12. After day 12 the number of calves with diarrhea falls again. From day 25 on no calf had been diagnosed with diarrhea.

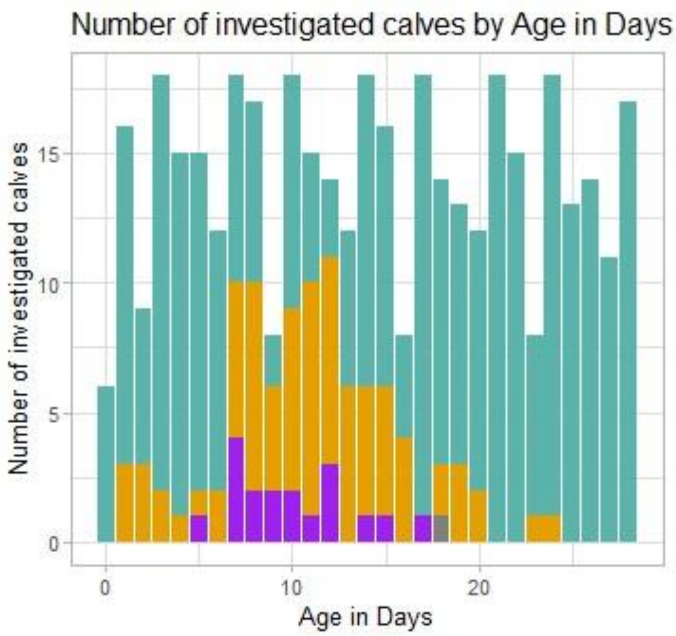

Figure 8. Number of investigated calves per age in days and the number of calves scored with feces consistency 1,2 and 3.. The number of calves per age in days varies between 6 and 18. Green = 'feces consistency' 1, brown = 'feces consistency' 2 and purple = 'feces consistency' 3.

Additionally, three calves with a 'feces consistency' score of 3 were tested for pathogens in their feces (figure 9). A pathogen quick test was used to determine if a calf had been infected. The test for calf 7624 turned out positive for *C.parvum*, the test for calf 7528 turned out positive for *C.parvum*, Rotavirus and Coronavirus, the test for calf 7631 turned out positive for Rotavirus and *C.parvum*.

Figure 9. Fassisi pathogen rapid test. Tested for calves 7624, 7628, 7631. ROTA = Rotavirus, CORO = Coronavirus, ECOL = e. coli, CRYP = C.parvum. Line only at "C" = negative, additional line at "T" = positive.

4.1.4 Factor 'level of sickness'

Figure 10 shows the number of investigated calves and those that have been scored with a 'level of sickness' 2 or 3 per age in days The number of sick calves fluctuates throughout the observation period. The most calves with a 'level of sickness' 3 occur between days

7 to 12 and 14 to 16. From day 12 on the number of calves with a ‘level of sickness’ 2 tends so decrease again with the exception of day 16. After day 19 no calf has been scored as sick with the exception of day 20 and day 24.

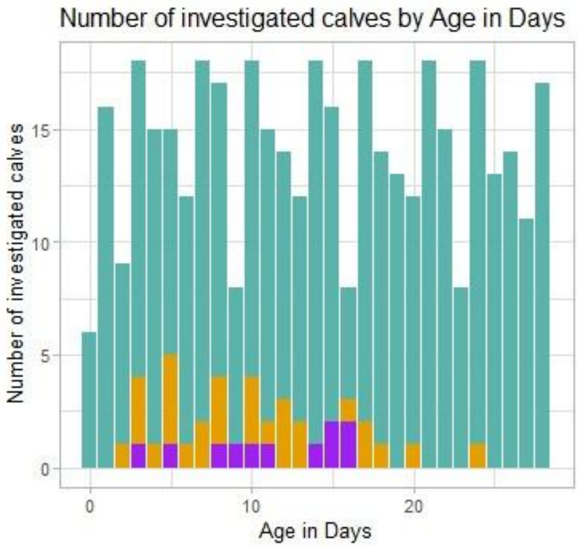

Figure 10. Number of investigated calves per age in days and the number of calves scored with ‘level of sickness’ 1,2 and 3.. The number of calves per age in days varies between 6 and 18. Green = ‘level of sickness’ 1, brown = ‘level of sickness’ 2 and purple = ‘level of sickness’ 3.

4.1.5 Body weight development and average daily weight gain

4.1.5.1 Average body weight development

Figure 11 shows the average body weight development of all 52 calves. The mean value (red line) shows that the calves gain weight until days 4-8. Here the body weight stays more or less constant until days 12-15, from which it constantly rises again.

4.1.5.2 Average daily weight gain

Figure 11 shows the average daily weight gain of all 52 calves. The red line describes the mean value. A drop in daily weight gain to zero from days 4-7 to days 8-11 is visible. From days 8-11 to 12-15 the average daily weight gain stays at 0 grams per day. After this period it rises again to approximately one kilogram per day at days 16-19 and fluctuates around this value until the end of the observation period.

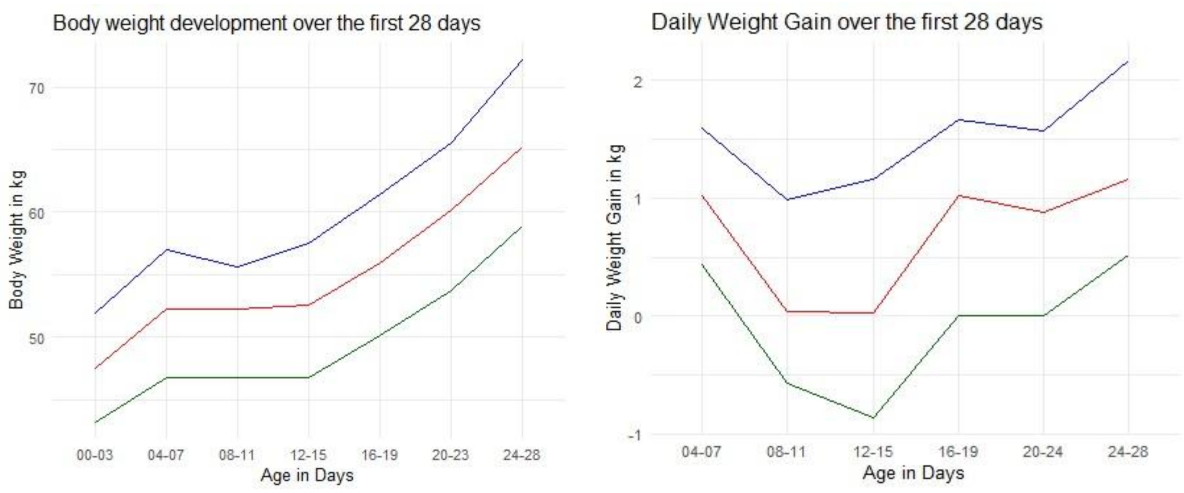

Figure 11. Average body weight development (left) and average daily weight gain of all calves (right). n = 52. Red line = mean value, blue line = upper quantile, green line = lower quantile.

4.1.5.3 Factor 'Level of Sickness'

Body weight development

Calves that were never classified with a 'level of sickness' score of 2 or 3 had a lower birthweight than calves that throughout the first 28 days of life have been classified with a 'level of sickness' score of 2 or 3 at least once (figure 12). It is visible that calves with a 'level of sickness' of 1 on average consistently gained weight except for the period from 4-7 to 8-11 days (red line). Calves that at least once have been classified with a 'level of sickness' score of 2 but never with a score of 3

(blue line) show a drop to almost no weight gain from 4-7 to 8-11 days. Until days 12-15 those calves lost weight. From then on the body weight rises again. The line of calves that have at least once been classified with a 'level of sickness' score of 3 differs from the first two. It starts at a higher body weight and first rises until days 8-11. From 8-11 to 12-15 days the body weight decreases to 50kg. From 12-15 to 16-19 it rises again but decreases again from 16-19 to 20-23 days. After this the body weight rapidly rises again to the same 'level of level of sickness' group 2.

Average daily weight gain

The daily weight gain between calves with different 'level of sickness' scores differs The calves that have only been scored with 'level of sickness' 1 (red line) show a drop in daily weight gain from days 4-7 to 8-11 of more than 1 kilogram to slightly below zero (figure 12) . Between days 8-11 to 12-15 the average daily weight gain starts to rise again until it reaches its peak with 1 kilogram per day from days 16-19 to 20-23.

It stays around this value until the end of the observation period. Calves that have at least once been scored with ‘level of sickness’ 2 but never with ‘level of sickness’ 3 (blue line) show a similar weight gain until days 8-11. From days 8-11 to 12-15 instead of rising like level 1 they drop further to almost -0.5 kilograms per day. From 12-15 to 16-19 days they have a rise in daily weight gain to around 1 kg again. Until the end of the observation period the average daily weight gain stays constant. Calves that have at least once been scored with ‘level of sickness’ 3 (green line) show a different pattern. The average daily weight gain decreases constantly until days 12-15. From days 12-15 to 16-19 it rises to more than one kilo, just to fall below zero again from days 16-19 to 20-23. It rises again from 20-23 to 24-28 days to almost 1.5kg.

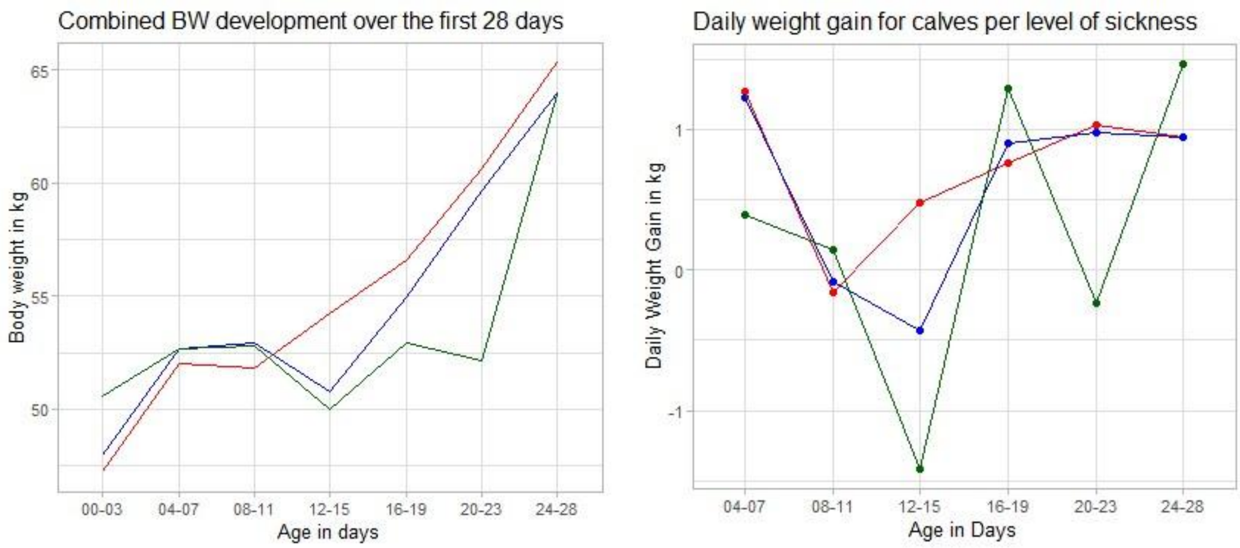

Figure 12. Average body weight development(left) and average daily weight gain of all calves(right). n = 52. Red line = level of sickness 1, blue line = level of sickness 2, green line = level of sickness 3.

4.2 Activity Measurements

Since the rumen development of the calves is still in progress during the observation period (Diao et al., 2019) the behavior ‘Ruminating’ has been excluded. Figure 13 shows the average Activity pattern of all calves throughout the first 28 days of life. ‘Not Active’ behavior decreases until day 4. After this day it rises again and reaches its peak at day 8 and stays comparably high until day 12. From there on it constantly decreases. The ‘High Active’ behavior contrary to ‘Not Active’ behavior increases until day 4. Then decreases again with a low around day 7-8 and from there on consistently increases again. ‘Active’ and ‘Eating’ follow a similar pattern as ‘High Active’. The behavior pattern for each hour of the day can be seen in figure 13. ‘High Active’ peaks can be seen at 5 o’clock, 9 o’clock and 14 o'clock. 'Eating' follows the same pattern. 'Not Active' behavior shows the same pattern as well just mirrored, With negative peaks at the same hours of the day.

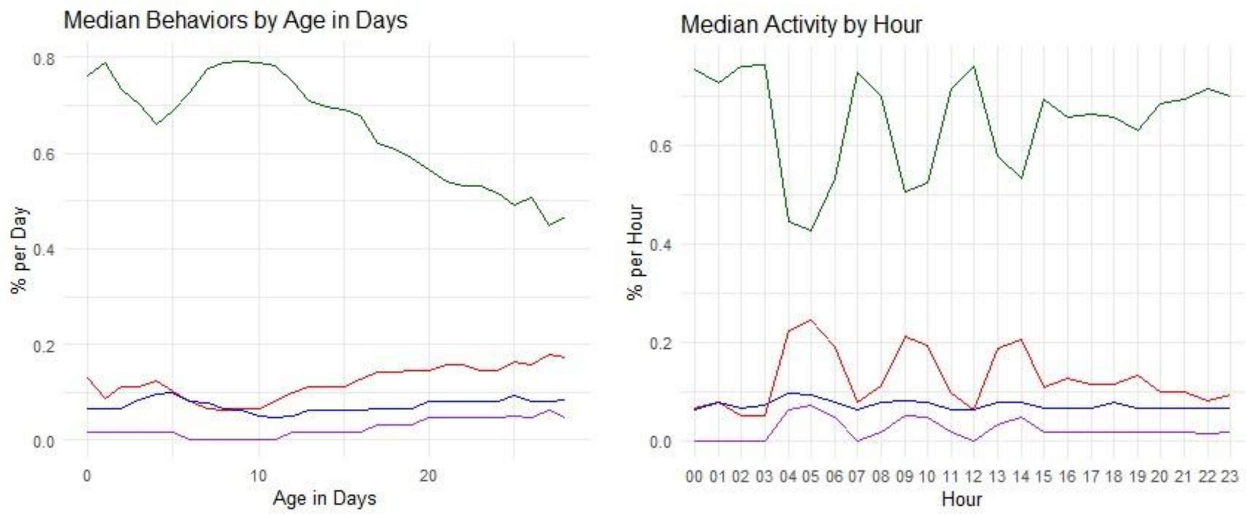

Figure 13. Average Activity of all calves (n = 52) for Age in Days (0-28) (left) and Average Activity of all calves (n = 52) per Hour (right). Green line = 'Not Active' behavior. Red line = 'High Active' behavior. Blue line = 'Active' behavior. Purple line = 'Eating' behavior.

4.3 Statistical Analysis

To conduct an ANOVA for the different behaviors normally distributed data is of need. Additionally, later conducted calculations (i.e. control charts) assume normally distributed data. After checking the activity data for normal distribution it was clearly visible that they are not (Figure 4). 'High Active', 'Active' and 'Eating' behavior showed a high frequency at 0% . With rising percentage of those behaviors per hour, the frequency reduces. The 'Not Active' behavior shows a contrary pattern. A large frequency of 'Not Active' behavior is visible at 100 percent per hour. With decreasing percentage, a decrease in frequency is visible. At 0%, a peak in frequency is visible (figures in the appendix).

A data transformation lead to 'High Active', 'Active', 'Not Active' and 'Eating' being accepted as normally distributed (figure 5 – distributions for the other activities can be found in the appendix).

After seeing the highest number of calves with 'level of sickness' 2 and 3 in the timespan of 8-11 days as well as 14-16 days, these two were used to compare different 'level of sickness' groups to the activity measurements 'High Active', 'Not Active', 'Active' and 'Eating'. The 'feces consistency' had the highest prevalence between days 7-12, the age span of 8-11 days was therefore used for comparisons.

Based on this decision the relationship between the different behaviors 'High Active', 'Active', 'Not Active' and 'Eating', with the 'factors level of sickness' and 'feces consistency' were tested by conducting an ANOVA. The visual differences in 'dHA' and 'dNA' between the 'level of sickness' groups are visible in figure 15. 'dHA' shows a significant difference ($p < 0.05$) between 'level of sickness' 1 and 'level of sickness' 3, while 'dNA' shows differences between 'level of sickness' 1 and 'level of sickness' 3, but no significant ones. In the age span of days 14-16 'level of sickness' 1 showed a significant relationship with 'level of sickness' 2 and 3 respectively for 'dHA' and a significant relationship of 'level of sickness' 1 with 'level of sickness' 3 for 'dNA'. The only behavior showing a significant relationship in both age groups was 'dHA' for 'level of sickness' 1 with 'level of sickness' 3. These findings led to the decision to continue only with 'dHA' for 'level of sickness' 1 and 'level of sickness' 3.

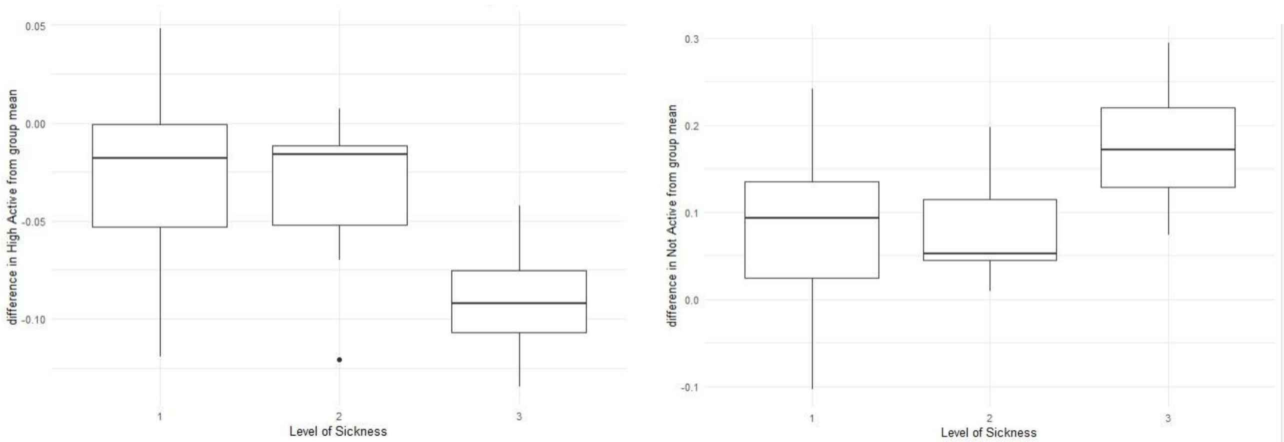

Figure 14. Boxplots of 'dHA' Behavior (left) and 'dNA' behavior (right) based on the 'level of sickness'.

4.4 Sensitivity and Specificity

After the ANOVA, the least square means (lsmeans) for dHA were calculated. Table 1 displays the result of this. When looking at the control limits, it shows that 'level of sickness' 1 is completely contained withing the range on 'level of sickness' 2. The control limits of 'level of sickness' 3 on the other hand do not overlap with the control limits of 'level of sickness' 1, but overlap with those of the 'level of sickness' 2.

It needs to be noted that the 'level of sickness' 1 also differs from the group mean. In figure 13 the average behavior of all calves for each age in days can be seen. It is noticeable that between days 8-11 the 'High Active' behavior decreases slightly. What needs to be considered is that the mean of the difference for 'High Active' is a constant value (0) at each individual date and hour. The ANOVA was conducted for calves in the period of 8-11 days. Since the ‘High Active’ behavior in this period is lower than usually, the intercept for ‘High Active’ behavior is negative. For the age group of 14 to 16 days, ‘level of sickness’ 1 also differs from the group mean for the same reason.

Table 1. results of a lsmeans analysis for ‘dHA’ and the ‘level of sickness’ between days 8-11. lsmeans = least square means, Std. Error = Standard Error, lower cl = lower control limit and upper cl = upper control limit.

difference ‘High Active’ Behavior days 8-11

Level of sickness	lsmean	Std. Error	Lower cl	Upper cl
1	- 0.0267	0.00691	-0.0406	-0.0128
2	-0.0360	0.01673	-0.0696	-0.0234
3	-0.0892	0.02213	-0.1337	-0.0447

Table 2. results of a lsmeans analysis for ‘dHA’ and the ‘level of sickness’ between days 14-16. lsmeans = least square means, Std. Error = Standard Error, lower cl = lower control limit and upper cl = upper control limit.

difference ‘High Active’ Behavior days 14-16

Level of sickness	lsmean	Std. Error	Lower cl	Upper cl
1	0.00828	0.00476	-0.00106	0.0176
2	-0.10734	0.02858	-0.16341	-0.0513
3	-0.08476	0.01278	-0.10984	-0.0597

Not Active, Active and Eating as well as the factor feces consistency showed no significant p-values and were therefore excluded.

Table 3 and Table 4 show the results of Sensitivity and Specificity calculations for the ‘dHA’ behavior for different thresholds in the age group 8-11 and 14-16 respectively. In table 3 and 4 it is visible that the sensitivity decreases and the specificity increases the further the threshold moves from zero.

Hogeveen et al. (2010) declared that a sensor system, in their case for mastitis detection, should at least have a sensitivity of 80% and a specificity of 99%. Because of this, it was continued to find a better solution to detect sick calves.

Table 3. Sensitivity and Specificity ‘dHA’ behavior for different thresholds. Days 8-11.

Threshold	Sensitivity	Specificity
0.03386	1	0.417
0.06707	0.75	0.791
0.0892	0.5	0.916
0.10027	0.25	0.916
0.12241	0.25	1

Table 4. Sensitivity and Specificity for ‘dHA’ behavior for different thresholds. Days 14-16.

Threshold	*Sensitivity*	*Specificity*
0.03336	1	0.892
0.05049	0.8	0.892
0.08476	0.4	0.946
0.10761	0.4	0.973
0.11903	0.4	1

4.5 Comparison of ‘dHA’

Afterwards, the ‘dHA’ of sick calves (‘level of sickness’ = 3) compared the ones of apparently healthy calves (‘level of sickness’ = 1) were compared. Figure 15 shows the ‘dHA’ throughout the first 28 days of life for the two mentioned ‘level of sickness’ groups. There are no strong differences between the groups until day four. From day 4 on, level 1 (red line) first decreases below the group mean value. After day seven it starts to rise again, reaching the mean value at day 11. From day 11 on it consistently stays above the group mean. Level 3 (blue line) on the other hand follows an almost similar pattern just on a lower level with the largest visual differences between them occurring between days eight to 23.

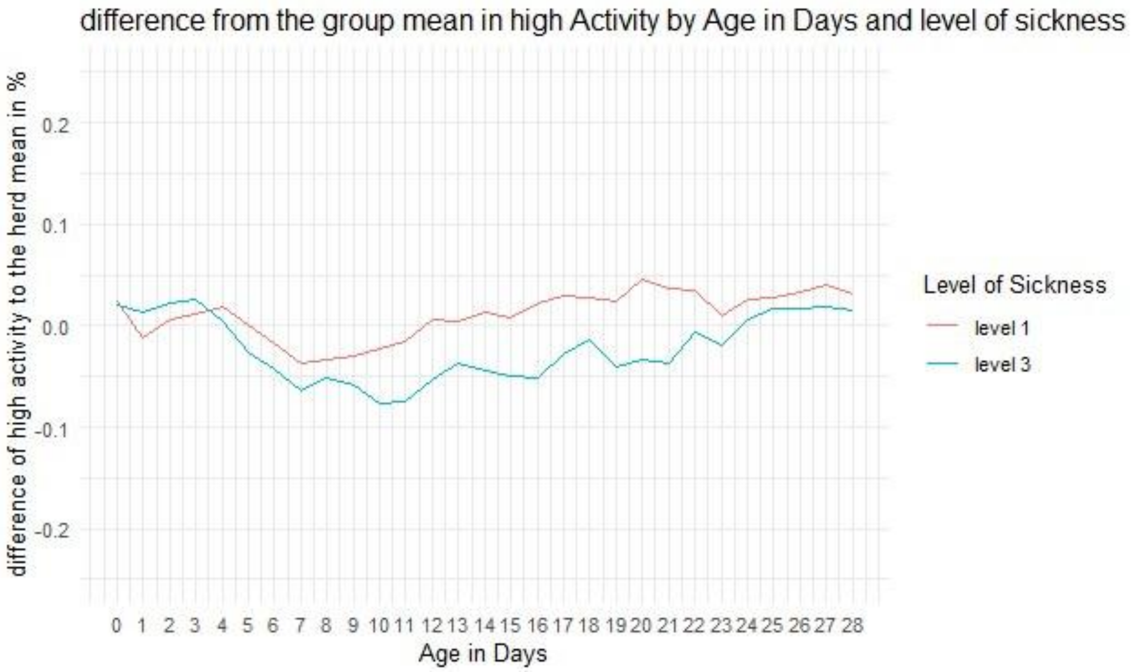

Figure 15. ‘dHA’ by Age in Days and ‘level of sickness’. Red line = ‘level of sickness’ 1 and blue line = ‘level of sickness’ 3.

4.6 Control Charts

Figure 16 shows the ‘dHA’ for calf 7635 when compared to a healthy group mean. Until around day 5 the sick calves fluctuate around the mean value (all control charts of sick calves can be found in the Appendix). After day 5 most of the values stay below the mean value. They therefore show less ‘High Activity’ compared to the mean difference value of the healthy calves. Calf 7635 shows a negative difference in ‘High Activity’ throughout the whole observation period compared to the healthy group mean.

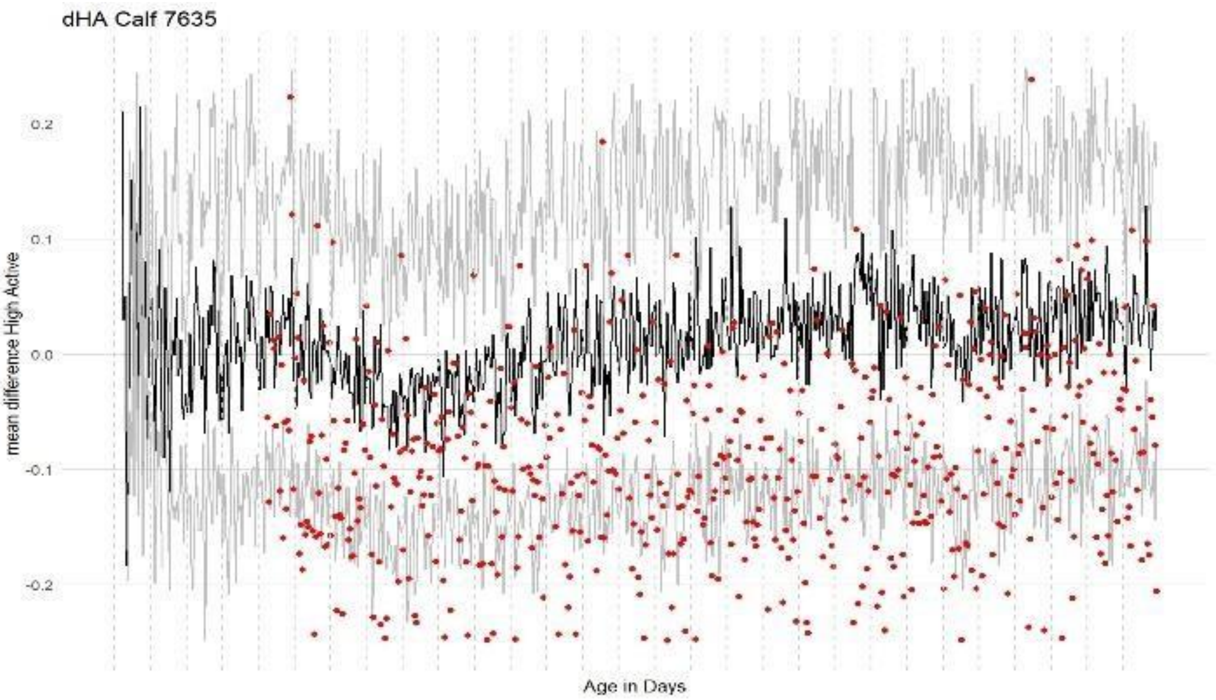

Figure 16. 'dHA' of calf 7635. black line = 'dHA' for all calves with 'level of sickness' 1 for each timepoint in observation period; grey line = 'dHA' plus and 'dHA' minus standard deviation; red dots = specific 'dHA' values for each calf with 'level of sickness' 3 for each timepoint in the observation period. The grey dashed lines in the background mark the days.

Figure 17 show the Shewhart Control Charts for sick calves 7635 and 7611 (all Shewhart Control Charts of sick calves can be found in the Appendix). For calf 7635 the first alerts occur already around 20 hours after the sensor started to collect data. Until hour 450, so around day 19 calf 7635 gets alerts almost constantly. After that point the alerts occur less frequently. The dominant rule being applied in this example is rule four. During the observations the calf has been marked with a 'level of sickness' 3 twice, around hour 120 and hour 350. At both timepoints alerts occur.

The Shewhart Control Chart for calf number 7611 applies almost no rules despite the calf be observed as sick around hour 120. No alert occurs during that time.

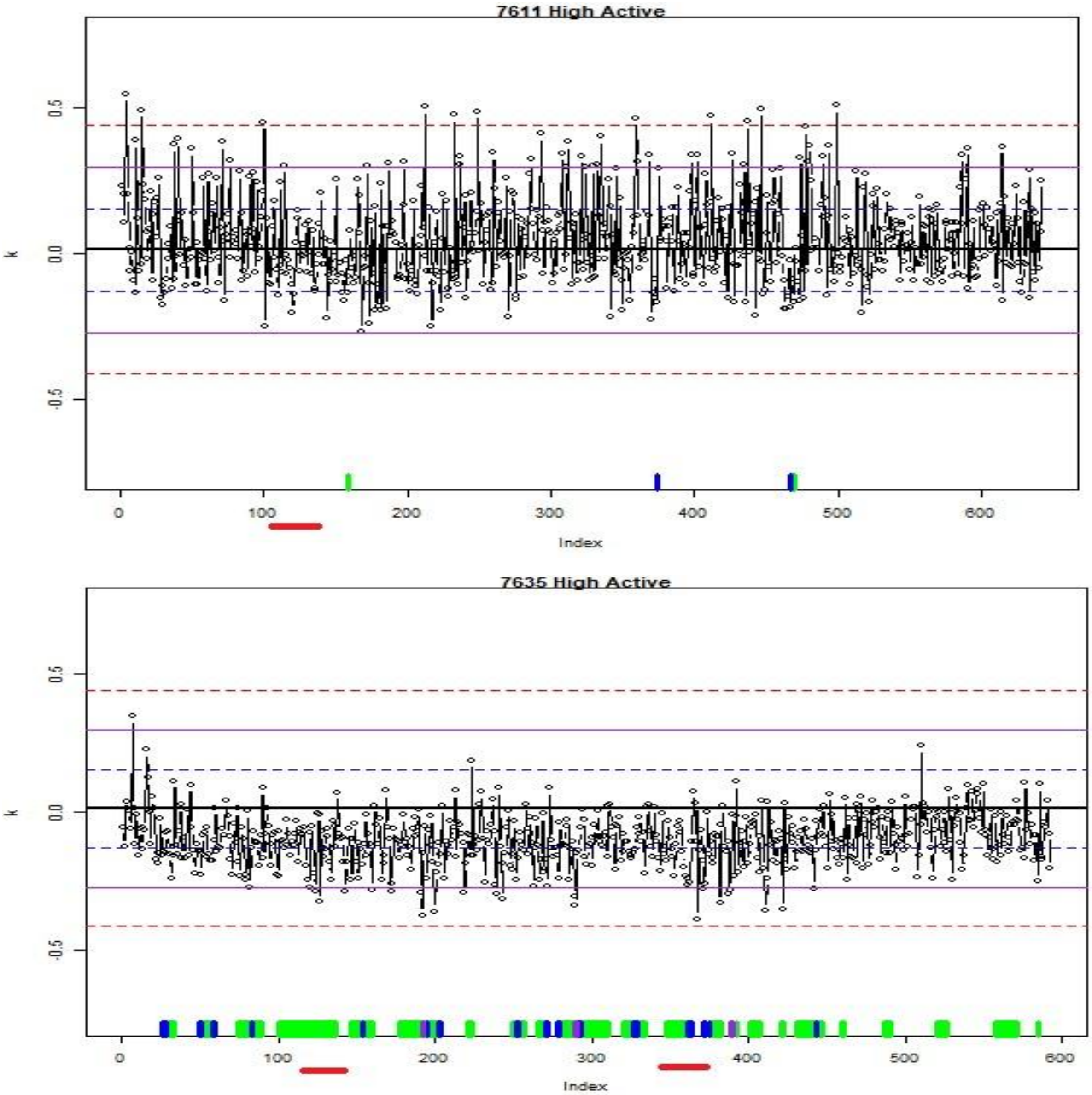

Figure 17. Shewhart Control Charts for the sick calves 7611 and 7635. Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as 'level of sickness' 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart either stops at the end of the observation period, or when a calf died.

Calves 7610 and 7623 are apparently healthy calves (Figure 18). The 'differenceMean' values of both calves lays above or on the healthy group mean value most of the times. Calf 7623 shows one drop below the mean value with several alarms (The Shewhart Control Chart of a third apparently healthy calf can be found in the Appendix).

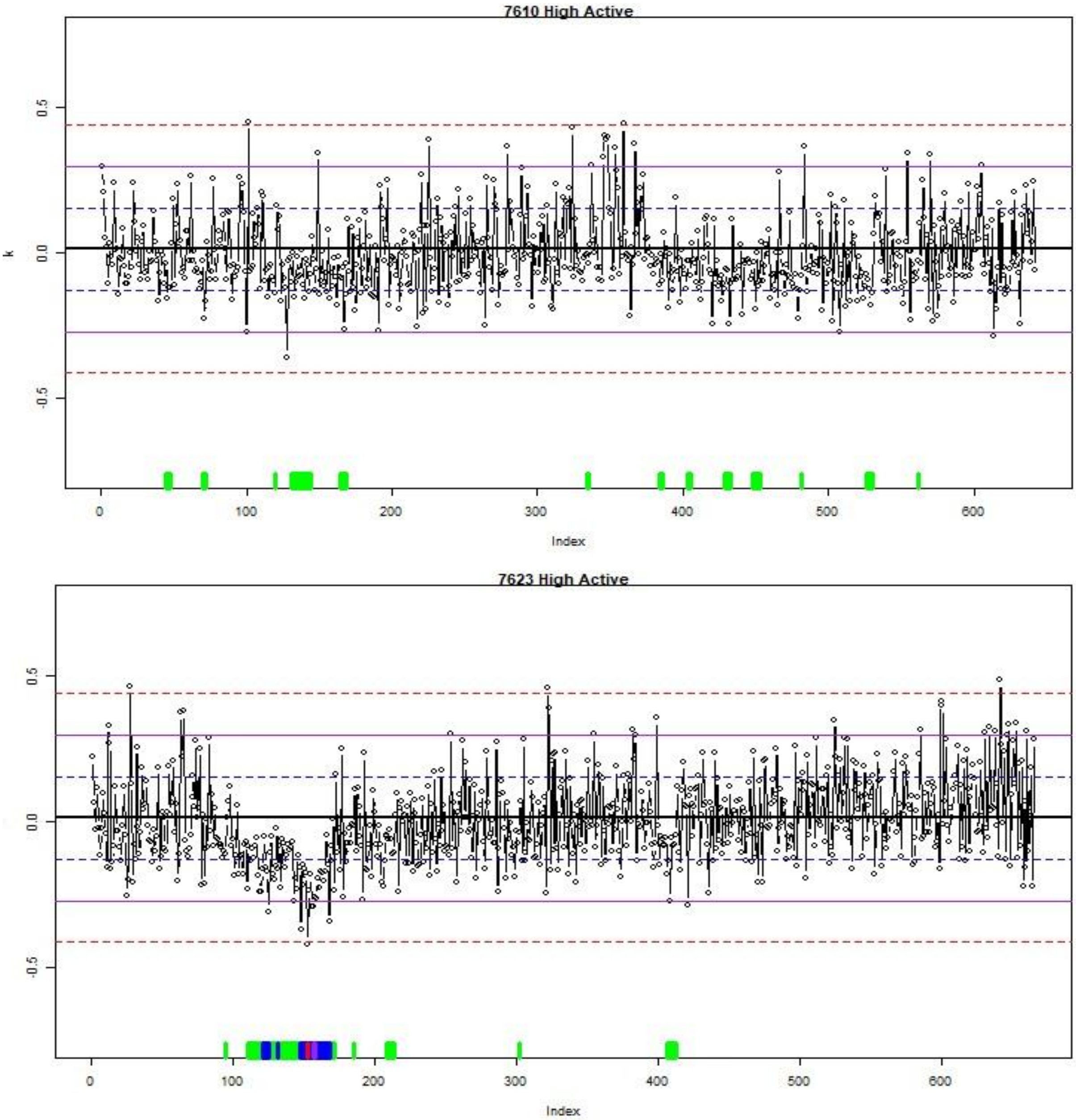

Figure 18. Shewhart Control Charts for two healthy calves (7610 and 7623). Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as 'level of sickness' 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two.

5. Discussion

The objective of this study was to investigate if it is possible to identify sick calves in a herd using activity data from Ear-Tag sensors. For this, multiple factors were investigated during observational examinations. Next to other factors also the calf's 'feces consistency' as well as their 'level of sickness' were scored to help identify sick calves.

Different behaviors were analyzed and afterwards compared for the different health indicators. ‘High Active’ behavior data was further analyzed for apparently healthy and sick calves and compared by using Shewhart Control Charts.

The ‘High Active’, ‘Active’, ‘Not Active’ and ‘Eating’ behavior were plotted to understand an overall tendency in activity. Between approximately day 7 and day 12 a rise in ‘Not Active’ behavior and therefore also a decline in ‘High Active’ behavior was visible (figure 13). This goes hand in hand with the observations in body weight development and the occurrence of disease and diarrhea. The rise in ‘Not Active’ behavior was then followed by a consistent decline in ‘Not Active’ behavior towards day 28. However, a drop in this behavior and a rise in ‘High Active’ behavior can be seen around day 4. The reason for this drop could likely be the relocation of calves and dams from the calving pen into the group pen and therefore a larger space to explore. The results also indicate that calves show less ‘Not Active’ behavior and more ‘High Active’ behavior the older they get. Santo et al. (2020) found, that calves in a cow calf contact system showed lying behavior for up to 20 hours per day. These 20 hours translate to around 80% per day. The results of this study show that ‘Not Active’ behavior which partly consists of lying behavior reaches 80% only in the period between days 8-11 where the calves show the highest sickness prevalence. Especially in the second half of the observation period the ‘Not Active’ behavior decreases down to almost 40%. The ‘High Active’ behavior on the other hand increases by only around five percent, while ‘Active’ behavior and ‘Eating’ stay at the same value. One of the reasons for the decrease in ‘Not Active’ behavior without an equal increase in the other three behaviors could be a possible increase in rumination. The Ear-Tags used in this study measure rumination as an own behavior even if the calf is lying throughout the process. Santo et al. (2020) do not analyze this.

As described above, between days 7-12, a drop in ‘High Active’ and a rise in ‘Not Active’ behavior is visible. Throughout this time period, the average daily weight gain shows an atypical drop (*Average Daily Gain in Preweaned Holstein Heifer Calves NAHMS 2014*, 2021; Martinussen & Mogens Vestergaard) (figure 11). Calves should have a constant rise in weight gain of 800-1000g per day (Martinussen & Mogens Vestergaard). After around three to four days on average the calves and their dams were moved into the large group pen. Here the dams were separated for four hours daily to get milked. The milking of the dams could lead to an insufficient amount of milk the calves receive. This theory could be supported by the fact that the calves on average have a substantial rise in daily weight gain after day 20 (figure 11). During this period, they are being moved once again to a new pen with foster mothers which are not separated.

The occurrence of diarrhea (figure 8), and the amount of sick calves (figure 10) have a noticeable rise during the same time period. Dachrodt et al. (2021) found the prevalence of calves with diarrhea to be slightly below 30 % between days 10-15 of their life. In the current study the peak prevalence is found at day 12 with almost 80% of the observed calves having diarrhea. Between days 10-15 the prevalence in the current study fluctuates daily between 40 to almost 80%. With a peak prevalence of almost 80%, the number of calves having diarrhea in this study is remarkably higher when compared to the literature. The pattern of diarrhea occurrence looks rather similar with a rise in occurrence until day 12 and then a decrease afterwards.

A limited general condition often leads to a limited weight gain. When analyzing calves with a 'feces consistency' of 3 (watery diarrhea) for pathogens, it was visible that all three tested calves were tested positive for *C.parvum*, two were tested positive for Rotavirus and one was tested positive for Coronavirus. All three diseases can lead to diarrhea and symptoms can last multiple days, which could influence weight gain (Foster & Smith, 2009). None of the tested calves had been scored with a 'level of sickness' equal to 3, meaning no calf was scored as severely sick. This indicates that all calves in the herd are infected either clinically or sub clinically with the *C.parvum* and that most of the calves are infected with Rotavirus and Coronavirus, which could also influence the weight development (Foster & Smith, 2009).

It is visible, that calves who are scored with a 'level of sickness' score of 3 were born the heaviest (figure 12). An explanation for the heavy calves getting sick more severely could be that they either experience a more difficult birth compared to lighter calves which could influence the colostrum intake and therefore lead to a weaker immune system. Another influencing factor could be that heavier born calves might receive an insufficient amount of colostrum after birth. Turini et al.
(2020) found that a calf's colostrum intake should be proportional to the birth weight. Heavy calves therefore need to drink more colostrum right after birth.

The 'level of sickness' is a rather subjective factor. It has been chosen because a farmer in the end subjectively looks at the calves and decides based on a calf's appearance, if to him the calf is sick and needs attention. When a farmer would look at specific calves, a calf with ‘level of sickness’ 2 would appear to him as a calf that likely is sick and perhaps needs to be taken care of. A ‘level of sickness’ 3 calf on the other hand would need immediate help.

To investigate how the occurrence of disease and certain behavior relate, ANOVA was used. To be able to do so, the activity data was tested for normal distribution. With all four included behaviors not being normally distributed, the data was transformed to be normally distributed. After transforming the data for all four behaviors into the ‘differenceMean’ values, the received data was found to be normally distributed enough for further analysis (figure 5).

The ANOVAS were conducted for the ‘differenceMean High Active’, ‘differenceMean Not Active’, ‘differenceMean Active’ and ‘differenceMean Eating’ behavior. All four outcomes were tested for a significant relationship with the ‘level of sickness’ as well as the ‘feces consistency’. Since the period between day 8 and day 11 showed the highest occurrence of diarrhea and the same period as well as days 14-16 for the ‘level of sickness’, it was chosen to be used in the analyses.

The analysis showed significant difference between different ‘level of sickness’ groups for both time periods and a significant difference between ‘level of sickness’ groups for days 14-16 for ‘dNA’. ‘Level of sickness’ 3 and ‘Level of sickness’ 1 showed significant differences in ‘dHA’ for both time periods. ‘Level of sickness’ 2 and ‘Level of sickness’ 1 however showed significant differences only in the second time period (14-16 days). Lastly, ‘level of sickness’ 3 and ‘level of sickness’ 1 showed significant differences for ‘dNA’ in the second time period. Because the differences between ‘level of sickness’ 3 and ‘level of sickness’ 1 were the only differences that were consistently significant throughout both periods, it was decided to continue with only this relationship.

The calculated lsmeans showed that calves with a ‘level of sickness’ score of 3 showed a significant decrease in the ‘dHA’ compared to calves with a ‘level of sickness’ score of 1 (Table 1 and 2). To get a first glimpse into the visual differences between the different ‘levels of sickness’, boxplots were made showing the difference in ‘High Active’ and ‘Not Active’ behavior respectively from the group mean value (figure 14). These results indicate that when using this method, calves with a ‘level of sickness’ 2 were not different enough from ‘level of sickness’ 1 calves to be detected with activity data.

As explained in the results, the lsmean of ‘level of sickness’ 1 is not zero. It is good to see, that the lsmean of ‘level of sickness’ 1 is further away from zero in the age span 8-

11 when compared to the age span 14-16. This can be explained by the drop in 'High Active' behavior during this period in all calves that was discussed above.

The lsmeans as well as the standard error were additionally used as thresholds to calculate sensitivity and specificity (table 3 and 4). To find out, how accurate the detection of sick calves is, the lsmean of 'level of sickness' 3 was used as the mean threshold to calculate a sensitivity and specificity. Additionally the mean of 'level of sickness' 3 calves plus and minus multiple times the standard deviation was used as thresholds. For age group 8-11 days the best result with the used thresholds was a sensitivity of 75% and a specificity of 79.1% (table 3). For the age group 14-16 days the best possible result with the used thresholds was a sensitivity of 100% and a specificity of 89.2% (table 4). These results of the calculations were not satisfactory. Hogeveen et al. (2010) mentioned that a sensor system for mastitis detection should at least have a sensitivity of 80% and a specificity of 99%. The results of the calculations in this study do not offer this. Even though mastitis detection systems and the sensor system used in this study differ quite a lot, it was still used as reference values. Therefore different tools were explored to receive a higher accuracy in detecting sick calves.

What needs to be mentioned is, that the number of animals that were found to be sick is four and five respectively in the 8-11 and 14-16 days period. Especially the sensitivity can therefore change a lot even if the threshold is only changed minimally. If instead of three only two of the sick animals are found, the sensitivity drops 25 and 20 percent respectively. The low number of animals tested in general makes these results rather difficult to interpret, since the sensitivity and specificity could look very different with a larger number of animals observed.

To be able to see the extent of differences that sick calves show in 'High Active' behavior compared to apparently healthy calves at times when they were marked with a 'level of sickness' 3 an alert system was found to be a fitting tool.

To achieve these, firstly the differences in 'dHA' between 'level of sickness' 3 and 'level of sickness' 1 calves needed to be investigated further. An average value for each Age in Days from 0 to 28 based on the 'level of sickness' group was calculated as described earlier and plotted to directly compare the two groups.

When looking at the 'dHA' throughout the whole observation period it is noticeable that during the first four days the three groups seem to move rather random and show no particular pattern. After day four a trend becomes visible, in which level 3 calves consistently show a lower amount of 'High Active' behavior than the group mean of level 1 calves (figure 15). First, level 1 follows the same trend to show a negative difference from the mean. This negative difference from the mean simply means that the calves in this group show less 'High Active' behavior than the group mean. However the 'dHA' for level 1 moves closer to zero again after day nine and reaches zero at day twelve, meaning that the calves in this group show the same amount of 'High Active' behavior again as the group mean. From day twelve on they do not fall below zero again. The drop in 'High Active' behavior after day four once again follows the same pattern as the earlier described results, where calves showed less 'High Active' behavior as well as a higher percentage of sickness and diarrhea and a lower daily weight gain respectively. Level 3 on the other hand continuously stays below the zero value and therefore continuously shows less 'High Active' behavior than the group mean. Level 3 continuously stays below level 1 until the end of the observation period but reaches zero around day 23 meaning that they show on average equally as much 'High Active' behavior as the group mean. These results underline again that sick calves on average show less 'High Active' behavior than healthy calves.

The compared 'dHA' showed a clear difference between the groups. They seem to always follow the same pattern with a drop in 'High Active' behavior respectively between day 8 and 12. Although they followed the same pattern, the different levels of sickness showed clear differences in 'High Active' behavior.

To be able to see actual differences in 'High Active' behavior, between healthy calves and specific sick calves, the differences between them had to be shown more clearly by comparing the different groups in control charts.

The first step towards a control chart was to compare the 'dHA' values of all apparently healthy calves with the 'dHA' of every sick calf separately. What needs to be mentioned here is that not every calf has observations for all 28 days of the observation period. The sensors were typically not installed until day 2-4. Therefore data for the first days is often missing. The 'dHA' value of the healthy calves was chosen to compare the sick calves not only to a whole herd mean, but to a mean of healthy calves and therefore exclude all calves scored with a 'level of sickness' of 2. This leads to larger differences between the sick calves and the herd mean value they are being compared to.

The healthy herd mean value together with the standard deviation were put in a graph and the 'dHA' values of each single calf were laid on top separately (figure 16). It was visible that most sick calves showed a negative ‘dHA’ value for a lot of the observations compared to the healthy mean value. This means, that sick calves show less ‘High Active’ behavior than the average healthy calf, which follows the above mentioned results.

Noticeable is, that sick calves show a lower average ‘High Active’ behavior than healthy calves for a longer period than just the period in which they have been classified with a ‘level of sickness’ score of 3. This indicates that a disease in the neonatal period can have an influence on the calves activity for longer than the initial sickness period. Another indication for this is the earlier mentioned result, that calves scored with a ‘level of sickness’ score of 3 show a reduced average daily weight gain for a longer period when compared to healthy calves.

Also visible in each of the graphs is that sick calves do not have a negative ‘dHA’ for every observation but fluctuate in their behavior. A single observation above and below the ‘differenceMean’ value respectively would therefore not be enough to consider a calf as sick. To reduce these false alerts, rules were implemented to predict when a calf can be considered sick.

To do this Shewhart Control Charts we made, which include the four Montgomery rules and make it possible to find sick calves based on these rules.

For the Shewhart Control Charts a stable ‘dHA’ value for the apparently healthy calves was calculated. Shewhart Control Charts assume the data to have a stable mean value. Because the ‘High

Active’ behavior doesn’t change a lot throughout the observation period, a stable mean value was found to be acceptable. The Shewhart Control Charts show the alerts for each sick calf based on the four rules on the negative side of the graph (i.e. deviations towards higher activity were not considered). The red lines below the x-axis represent the dates, in which the calves have been diagnosed as sick during the clinical observations. In 7 out of 9 control charts, the observations and the alerts the charts give occur at the same time point. Only the control chart for calf 7589 and 7611 doesn’t show an alert when it has been observed as sick (figure 17 – calf 7611). Calf 7589 was clinically observed right before it died. A possible alert could have occurred if more observations would have followed (Shewhart Control Chart can be found in the Appendix). ‘High Active’ control charts in majority show alerts based on rule four. This means that the calves are below the mean value for eight consecutive hours.

What is also clearly visible is that these alarms are not the only alarms shown in the charts. This could be based on multiple factors. The first factor being, that the calves have not been visited every day. Because of this, certainty on their health status can only be given on the specific days, the calf has been observed. The alerts could therefore show actual timepoints in which the calves can be considered sick, but had not been visited.

A second factor could be daily and hourly fluctuations in Activity. The stable mean that has been used indicates as described a consistent behavior throughout the whole observation period. As can be seen in figure 13 this is not the case. Especially throughout the day, the amount of 'High Active' behavior changes.

Additionally in the current study an early detection of sick calves is not possible. The calves have only been visited twice a week. The health status of the calves in the remaining 5 days of a week can only be speculated. Even though a calf might show less 'High Active' behavior than the group mean a diagnosis of the calf's health status cannot be given with full certainty. Other environmental factors for example could lead to differences in behavior of the calves compared to the observation day.

Lastly, this method is only able to detect clinically sick calves. Sub clinically infected calves which show no signs of sickness will in this method be ignored. One example for this are the pathogen test results of the three tested calves. All three were diagnosed with one or multiple pathogens and had watery diarrhea but were not classified as sick in the 'level of sickness' score (i.e. they made, apart from the diarrhea, not the impression of a generally impacted sick calf).

Nonetheless, the Shewhart Control Charts give an alert in the majority of cases, in which a calf has been diagnosed as being sick. This method is able to detect clinically sick calves by comparing their 'dHA' data to that of apparently healthy calves.

The identification of clinically sick calves using activity sensor data was found to be possible. Alerts at the times, when calves were observed as sick were received in the majority of cases.

A higher accuracy in finding sick calves could be achieved by increasing the frequency of clinical observations and observing a larger number of calves. Implementing a moving 'differenceMean' value for the healthy calves could help reduce false alerts. Another possibility of identifying sick calves could be to look at the cumulated activity. By including all activities and comparing these with each other a higher difference between the groups could be achieved. These improvements could help detecting sub clinically infected calves. Testing this method in different herds with a variety of rearing methods would be of need.

6. Conclusion

The study aimed to investigate if sick calves in a herd can be found by using activity sensor data.

During clinical observations, multiple factors like body weight, 'feces consistency', respiratory diseases, umbilical infections and the 'level of sickness' were investigated.

Activity data was analyzed. 'Not Active' behavior showed a notable rise between days 7-12. This corresponded with increased disease and diarrhea occurrence as well as a decreased weight gain and 'High Active' behavior during this period. ANOVA showed significant differences in 'dHA' for the 'levels of sickness' 1 and 3. Calves with a 'level of sickness' 3 showed consistently less 'dHA' than calves with a 'level of sickness' 1. This means that sick calves in this study showed less 'High Active' behavior than apparently healthy calves.

Shewhart Control Charts were made to compare the 'dHA' of sick calves with the average 'dHA' of healthy calves. An alert was given if the 'dHA' of sick calves differs too much from the 'dHA' of apparently healthy calves.

With this method the majority of clinically sick calves could be identified by receiving an alert when they were observed as sick. However, due to a limited frequency of clinical observations, alerts outside of the observed periods could neither be verified nor falsified. The method is also not able to detect sub-clinically infected calves.

7. Future Perspectives

By comparing the 'dHA' values of clinically sick calves with those of apparently healthy calves, in the majority of cases alerts at times when a calf was observed as sick were received.

To succeed in detecting sick calves by using sensor data further research is needed.

Longitudinal observational studies with a larger number of calves and daily observations as well as conducting the studies in all four seasons are needed to increase the accuracy of identifying sick calves in a herd. Observing the cumulated activity instead of only the

‘High Active’ behavior would likely lead to larger differences between the groups. Additionally, observing multiple herds with different rearing methods can increase the accuracy and therefore reduce false alarms in monitoring systems and improve sensitivity and specificity. Using different health indicators like the calf’s temperature would broaden the knowledge about the calves health and therefore in combination with the other factors help identifying sick calves earlier and more accurately. The implementation of machine learning into these systems would enable the possibility of finding so far undetected patterns and therefore help in detecting sub clinically diseased calves and additionally help in improving early sickness detection.

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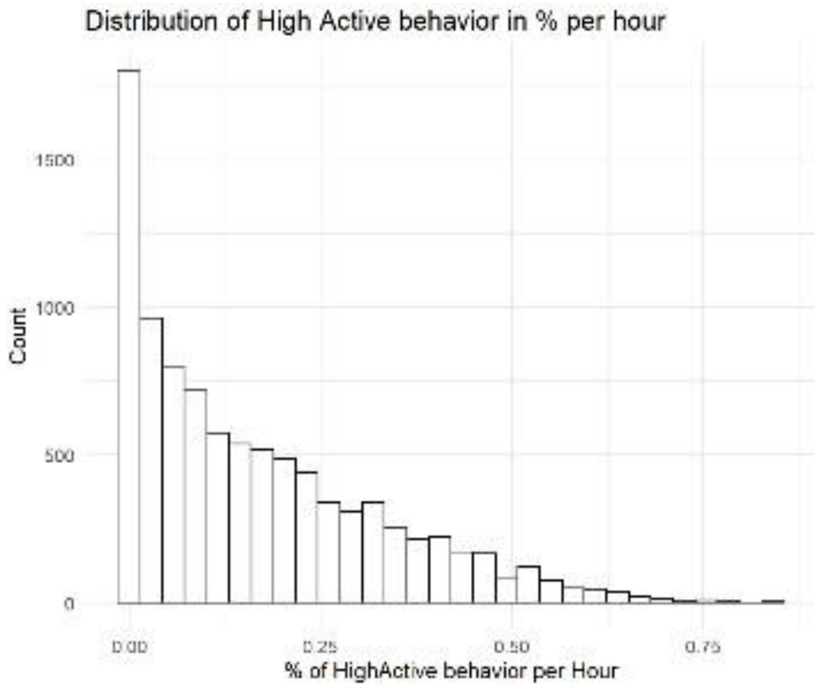
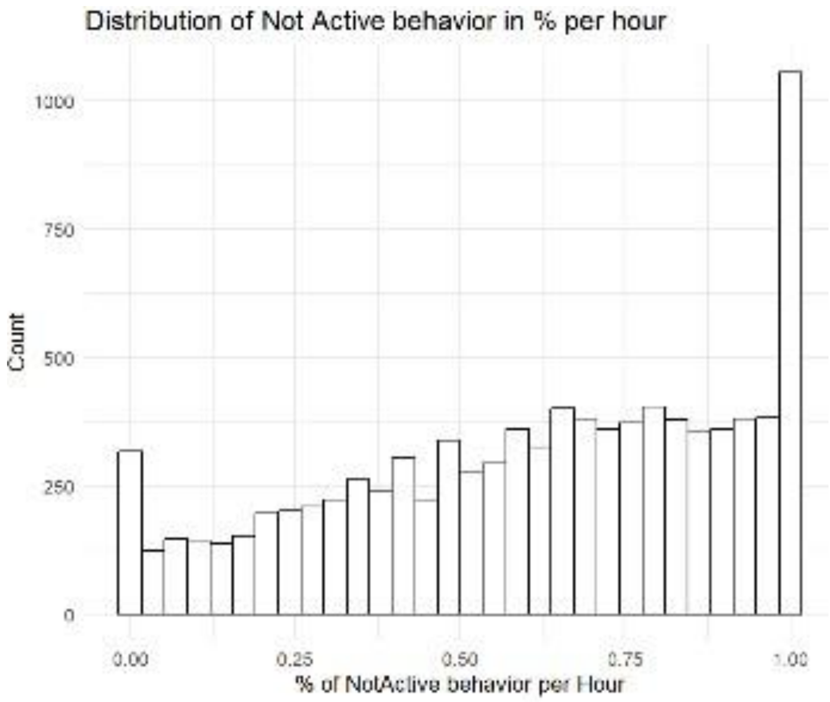
Appendix

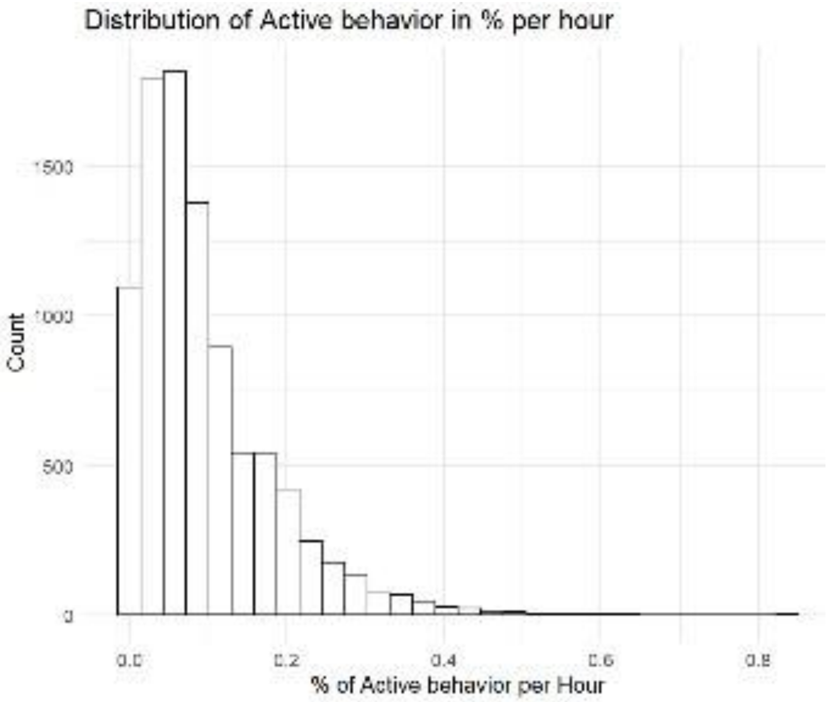
Distribution of ‘High Active’, ‘Active’, ‘Not Active’ and ‘Eating’:



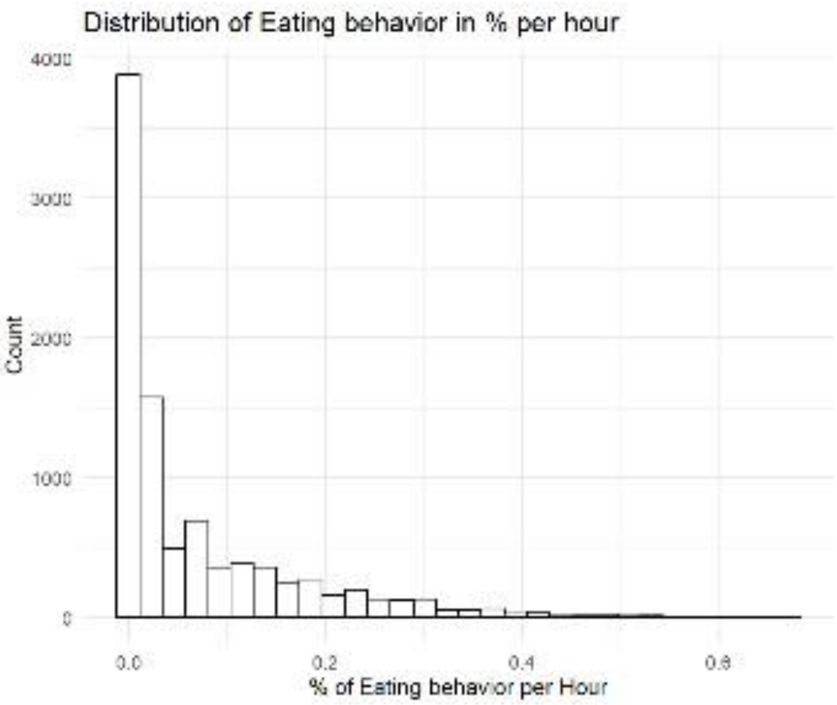
Distribution of ‘High Active’ behavior.



Distribution of ‘Not Active’ behavior.

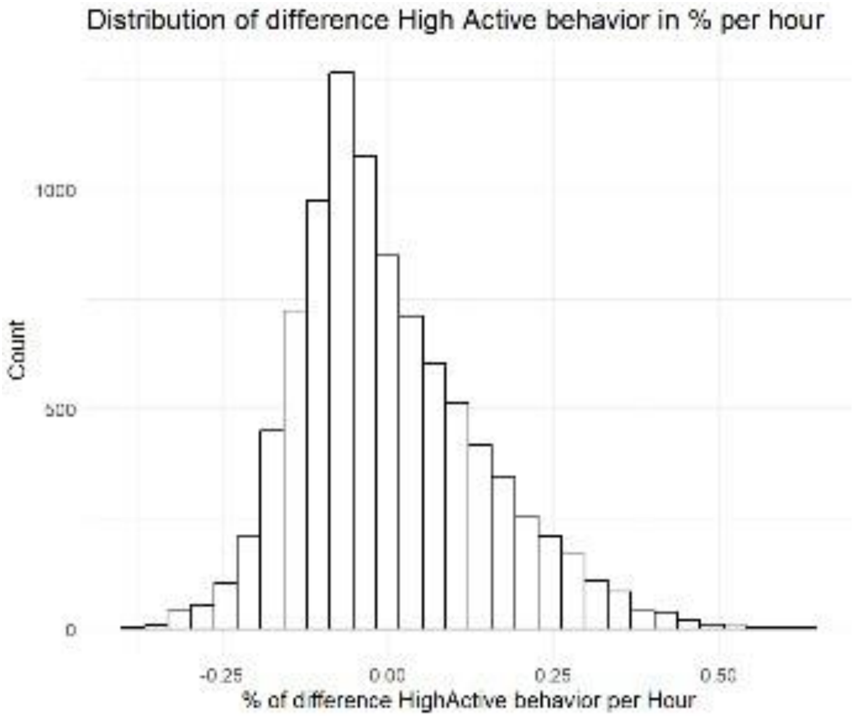


Distribution of ‘Active’ behavior.

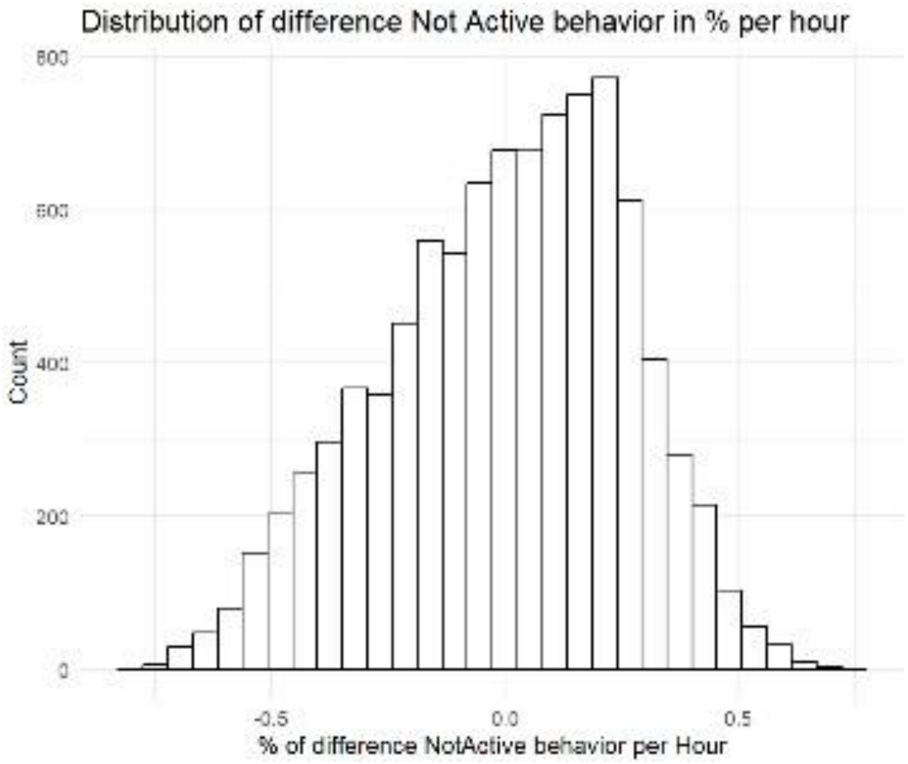


Distribution of ‘Eating’ behavior.

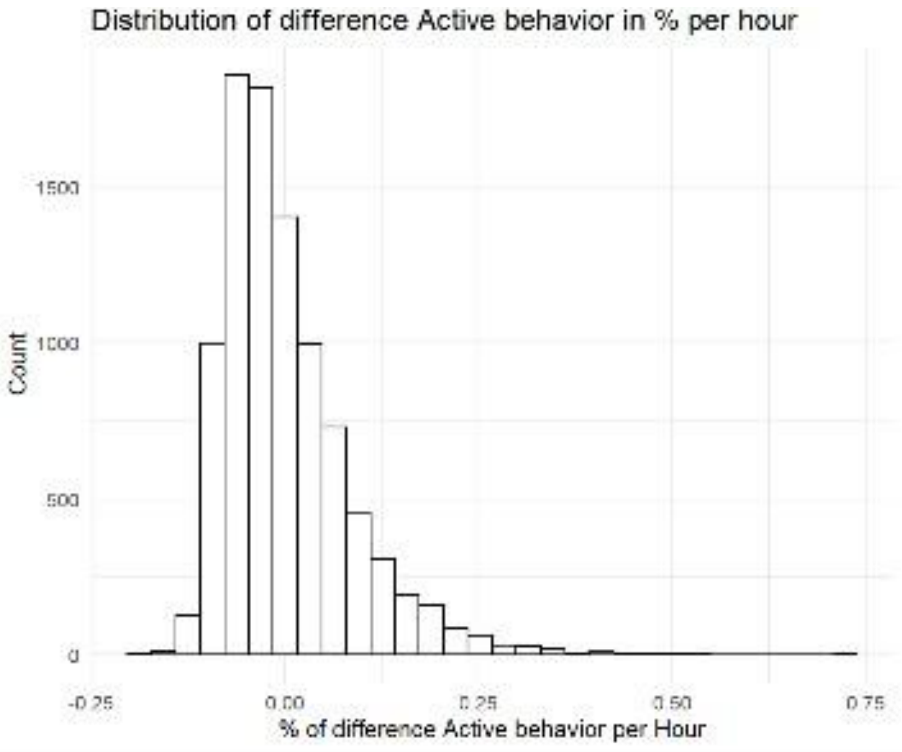
Distribution of ‘difference High Active’, ‘difference Active’, ‘difference Not Active’ and ‘difference Eating’:



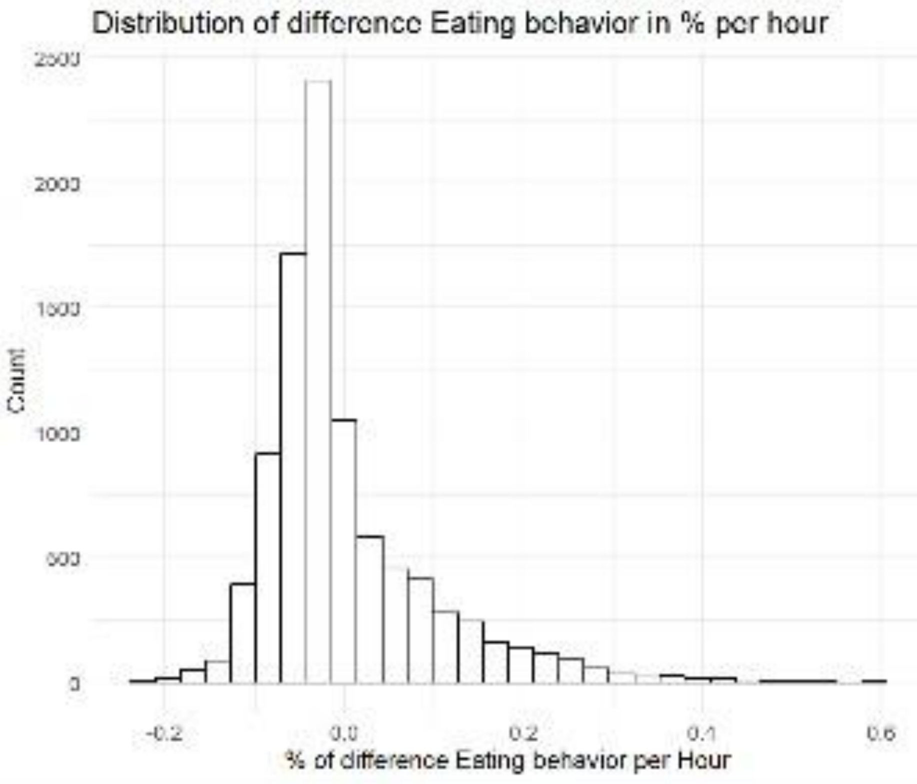
Distribution of ‘difference High Active’ behavior.



Distribution of ‘difference Not Active’ behavior.

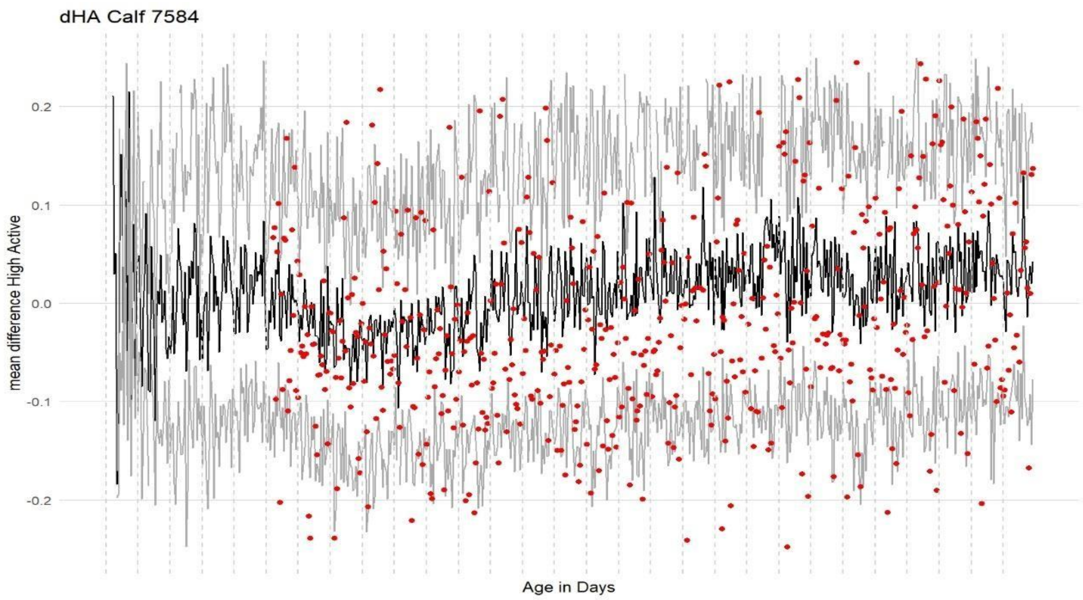


Distribution of ‘difference Active’ behavior.

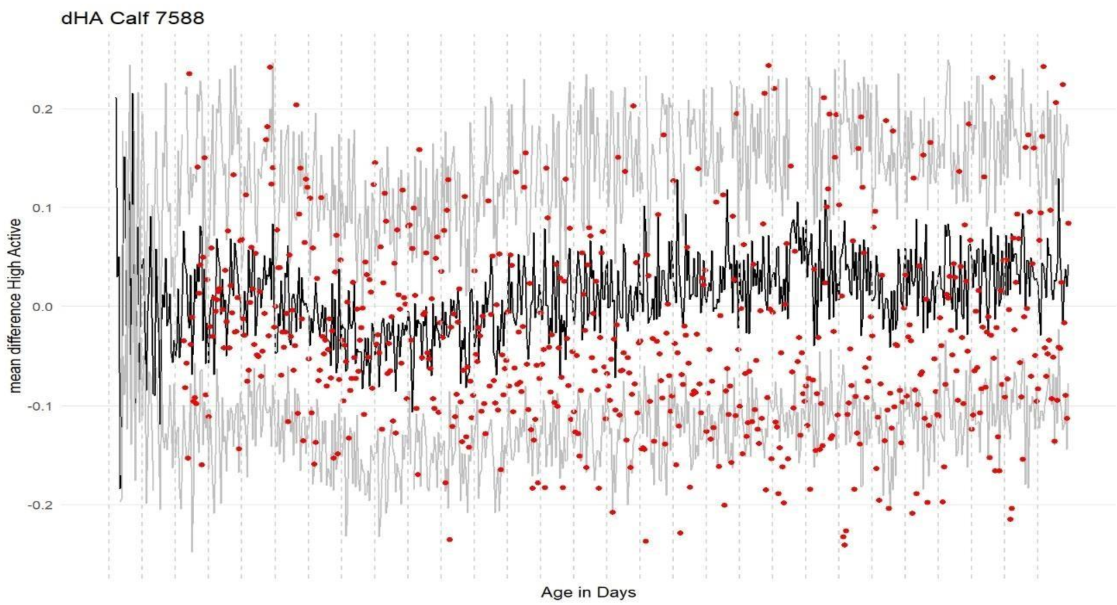


Distribution of ‘difference Eating’ behavior.

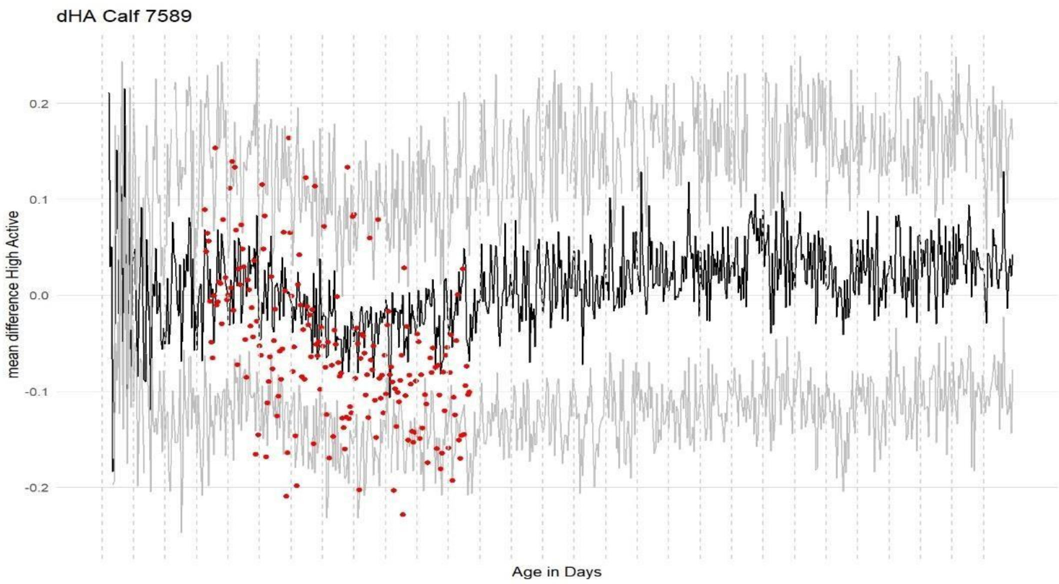
‘dHA’ of sick calves when compared to a healthy group mean:



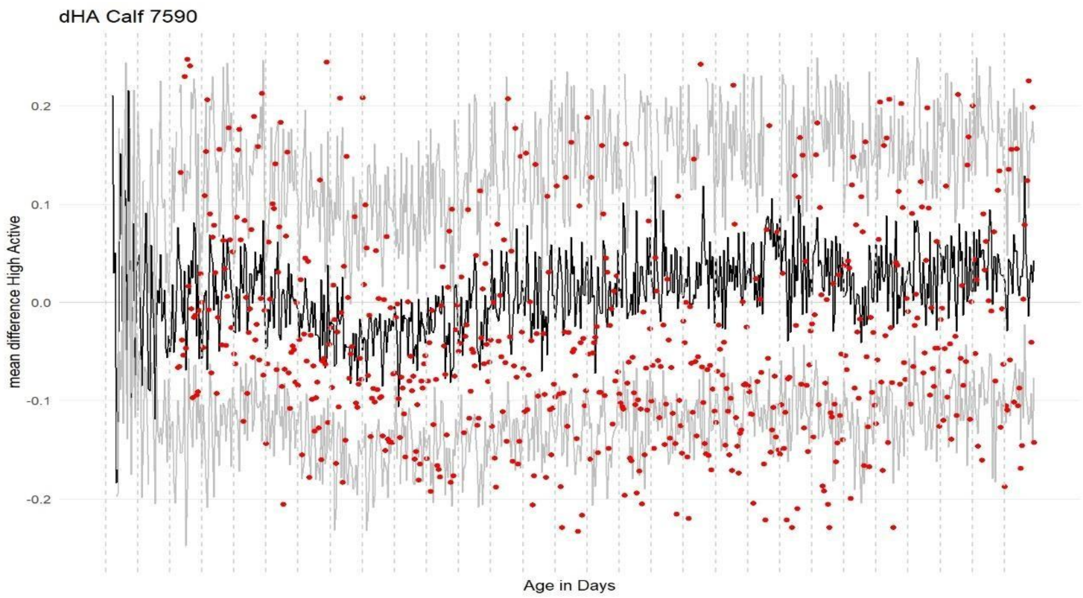
black line = ‘dHA’ for all calves with ‘level of sickness’ 1 for each timepoint in observation period; grey line = ‘dHA’ plus and ‘dHA’ minus standard deviation; red dots = specific ‘dHA’ values for calf 7584 for each timepoint in the observation period. The grey dashed lines in the background mark the days.



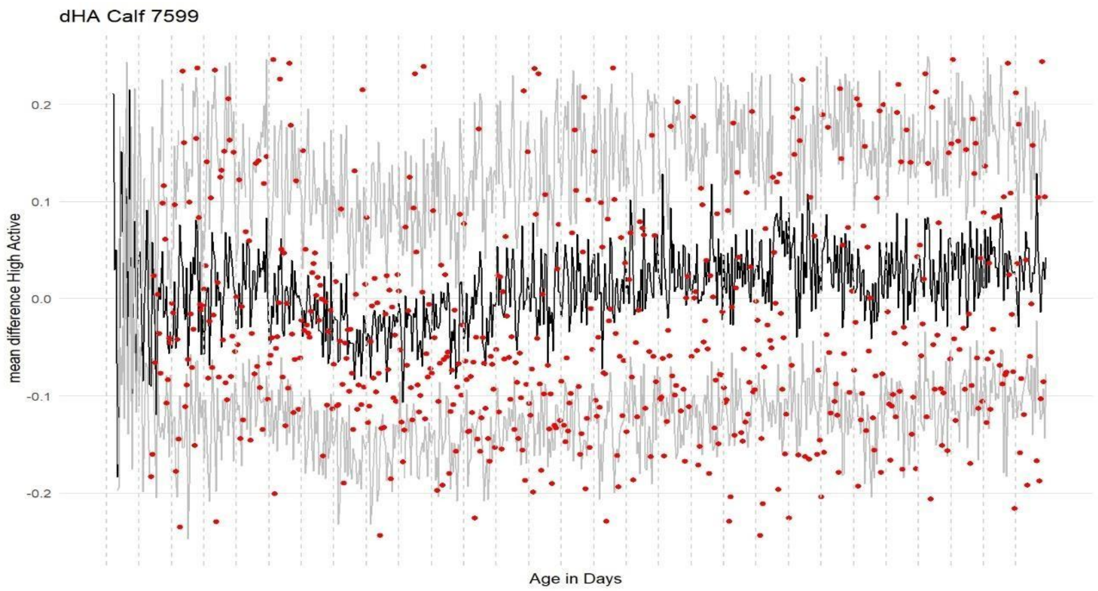
black line = ‘dHA’ for all calves with ‘level of sickness’ 1 for each timepoint in observation period; grey line = ‘dHA’ plus and ‘dHA’ minus standard deviation; red dots = specific ‘dHA’ values for calf 7588 for each timepoint in the observation period. The grey dashed lines in the background mark the days.



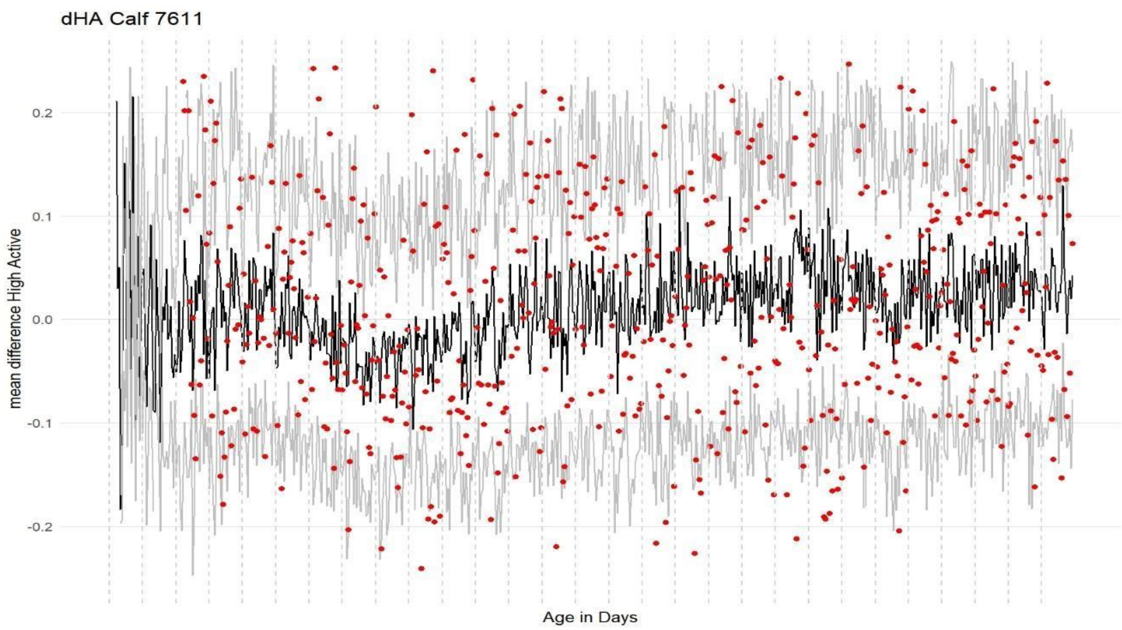
black line = ‘dHA’ for all calves with ‘level of sickness’ 1 for each timepoint in observation period; grey line = ‘dHA’ plus and ‘dHA’ minus standard deviation; red dots = specific ‘dHA’ values for calf 7589 for each timepoint in the observation period. Observation stops when the calf died. The grey dashed lines in the background mark the days.



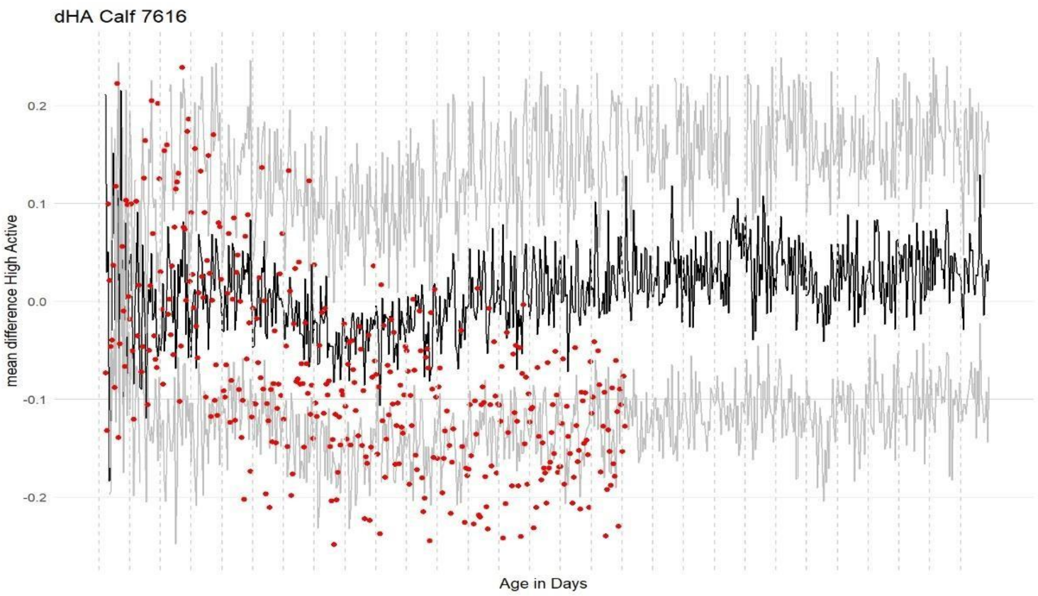
black line = ’dHA’ for all calves with ‘level of sickness’ 1 for each timepoint in observation period; grey line = ‘dHA’ plus and ‘dHA’ minus standard deviation; red dots = specific ‘dHA’ values for calf 7590 for each timepoint in the observation period. The grey dashed lines in the background mark the days.



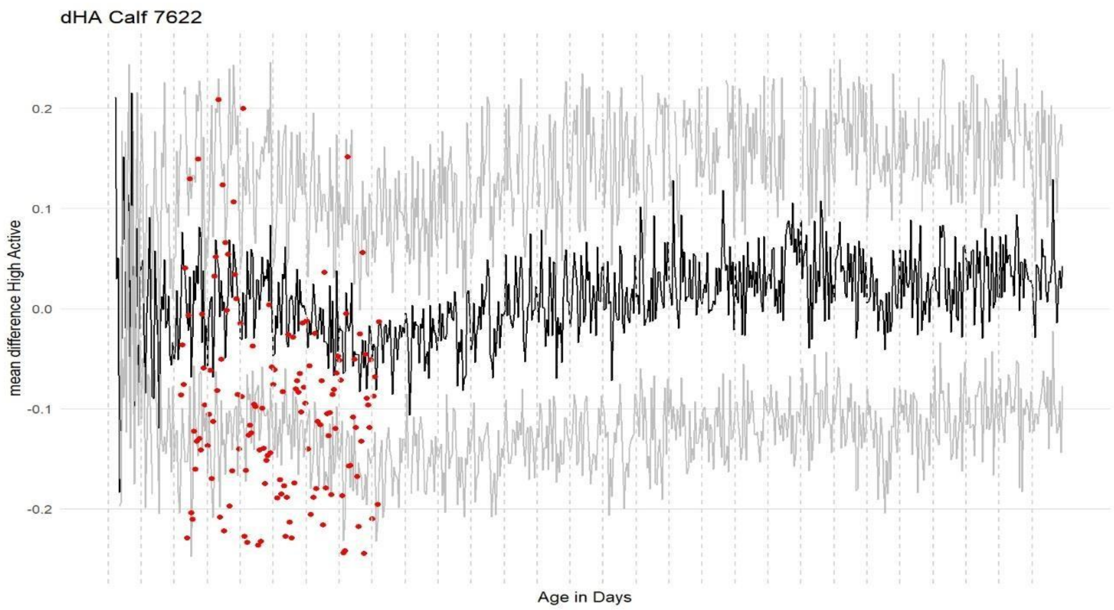
black line = 'dHA' for all calves with 'level of sickness' 1 for each timepoint in observation period; grey line = 'dHA' plus and 'dHA' minus standard deviation; red dots = specific 'dHA' values for calf 7599 for each timepoint in the observation period. The grey dashed lines in the background mark the days.



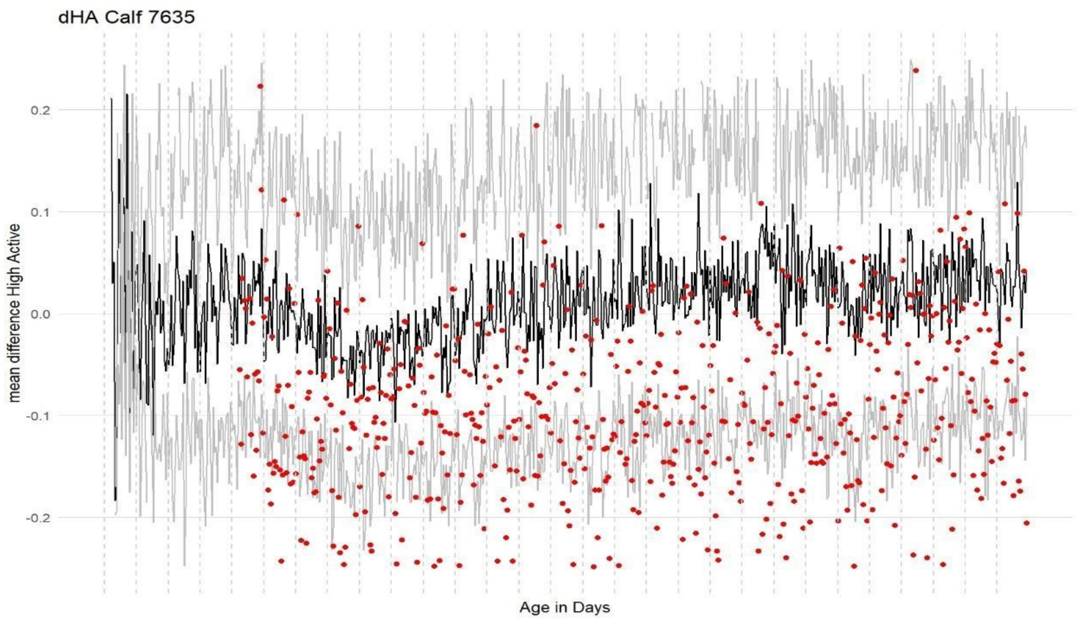
black line = 'dHA' for all calves with 'level of sickness' 1 for each timepoint in observation period; grey line = 'dHA' plus and 'dHA' minus standard deviation; red dots = specific 'dHA' values for calf 7611 for each timepoint in the observation period. The grey dashed lines in the background mark the days.



black line = 'dHA' for all calves with 'level of sickness' 1 for each timepoint in observation period; grey line = 'dHA' plus and 'dHA' minus standard deviation; red dots = specific 'dHA' values for calf 7616 for each timepoint in the observation period. Observation stops when the calf died. The grey dashed lines in the background mark the days.

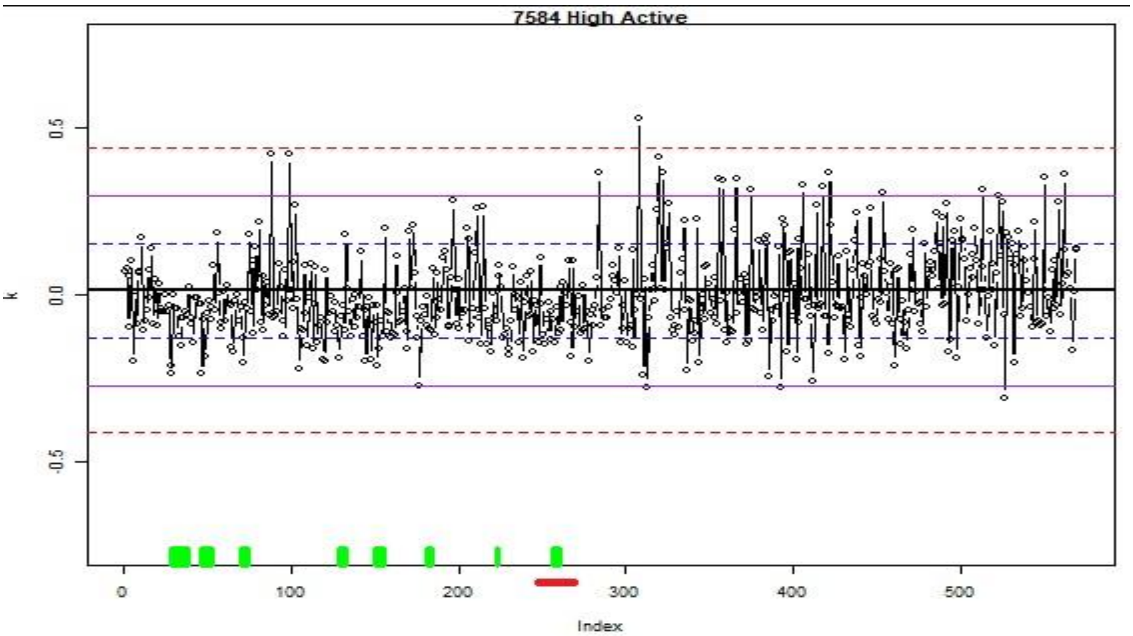


black line = 'dHA' for all calves with 'level of sickness' 1 for each timepoint in observation period; grey line = 'dHA' plus and 'dHA' minus standard deviation; red dots = specific 'dHA' values for calf 7622 for each timepoint in the observation period. Observation stops when the calf died. The grey dashed lines in the background mark the days.

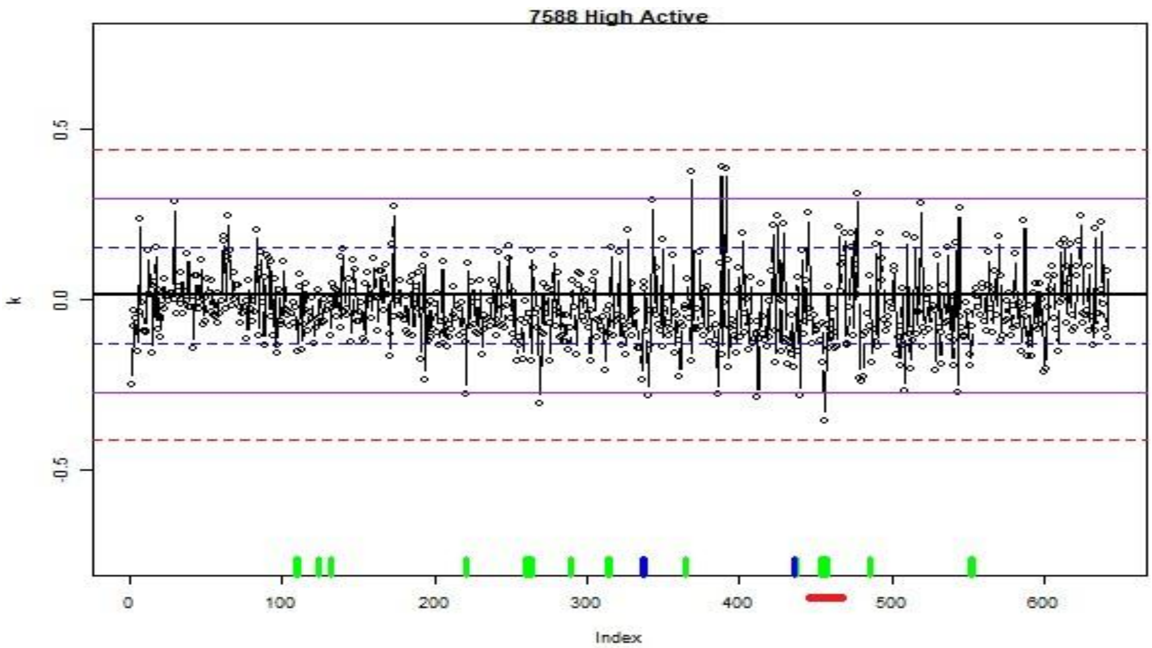


black line = ‘dHA’ for all calves with ‘level of sickness’ 1 for each timepoint in observation period; grey line = ‘dHA’ plus and ‘dHA’ minus standard deviation; red dots = specific ‘dHA’ values for calf 7635 for each timepoint in the observation period. The grey dashed lines in the background mark the days.

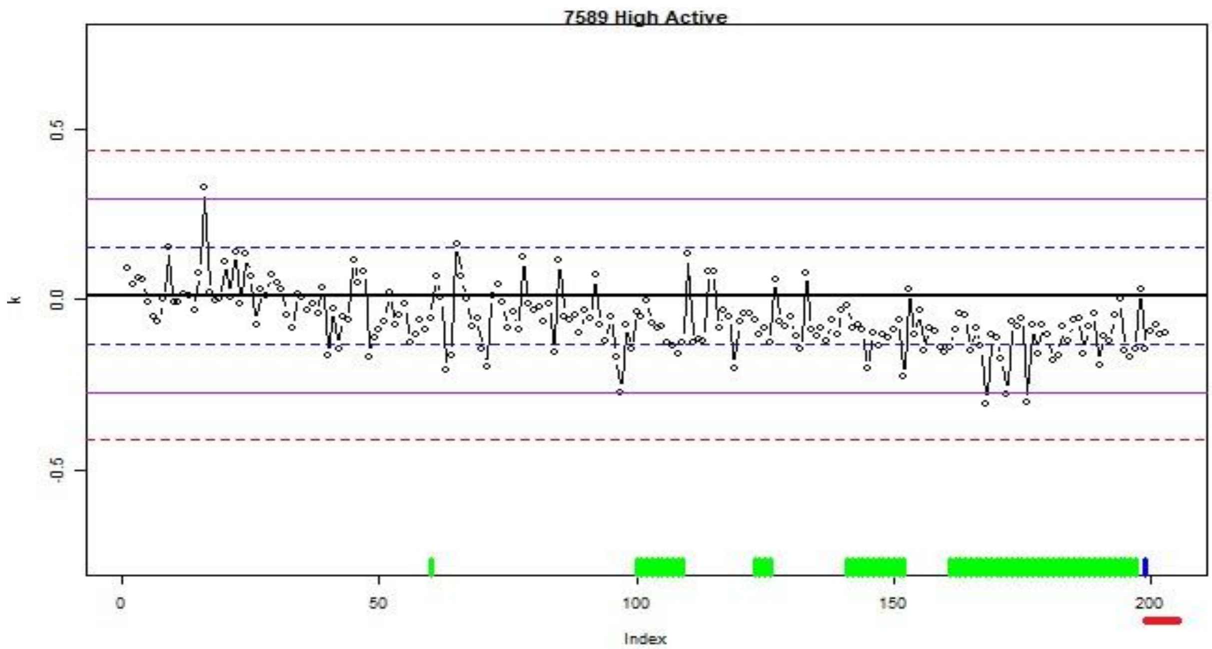
Shewhart Control Charts for the sick calves:



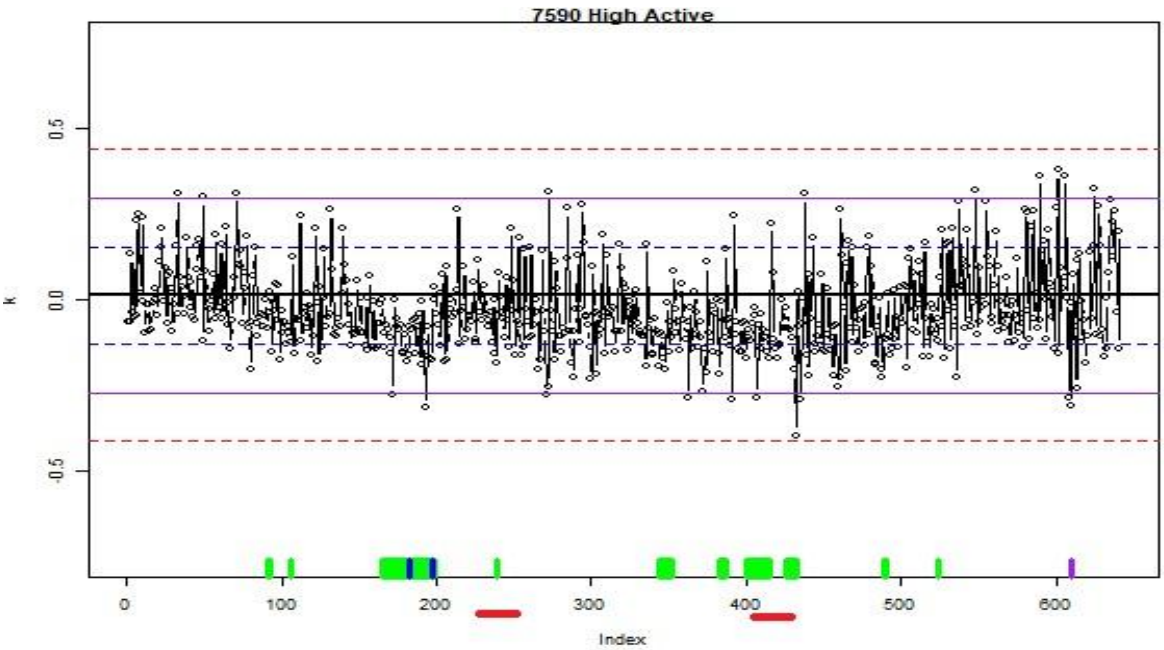
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



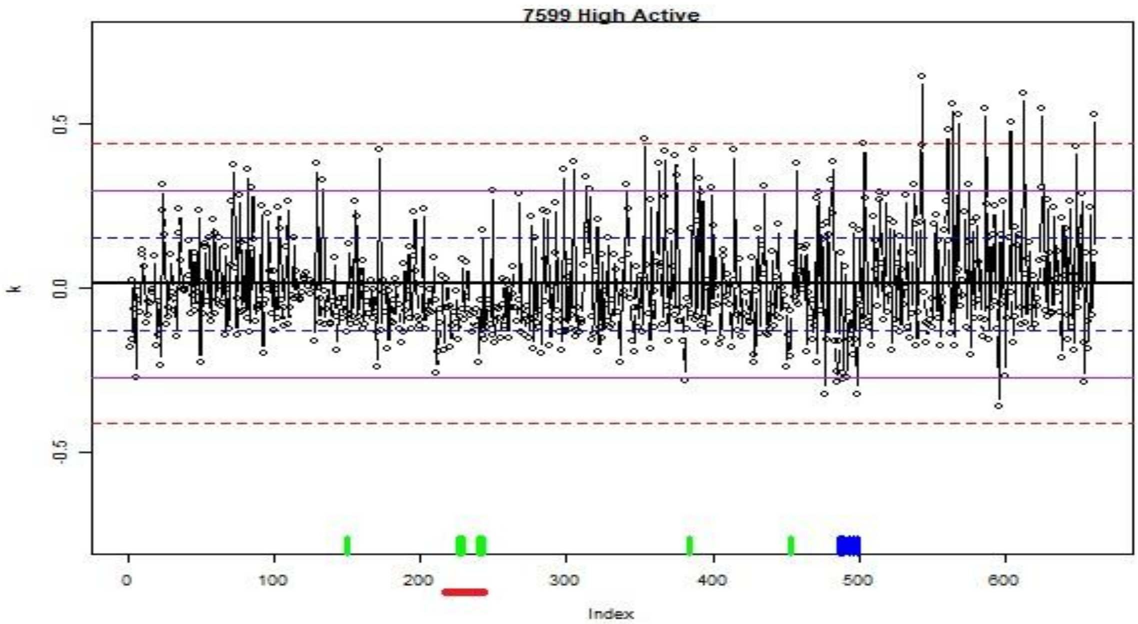
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



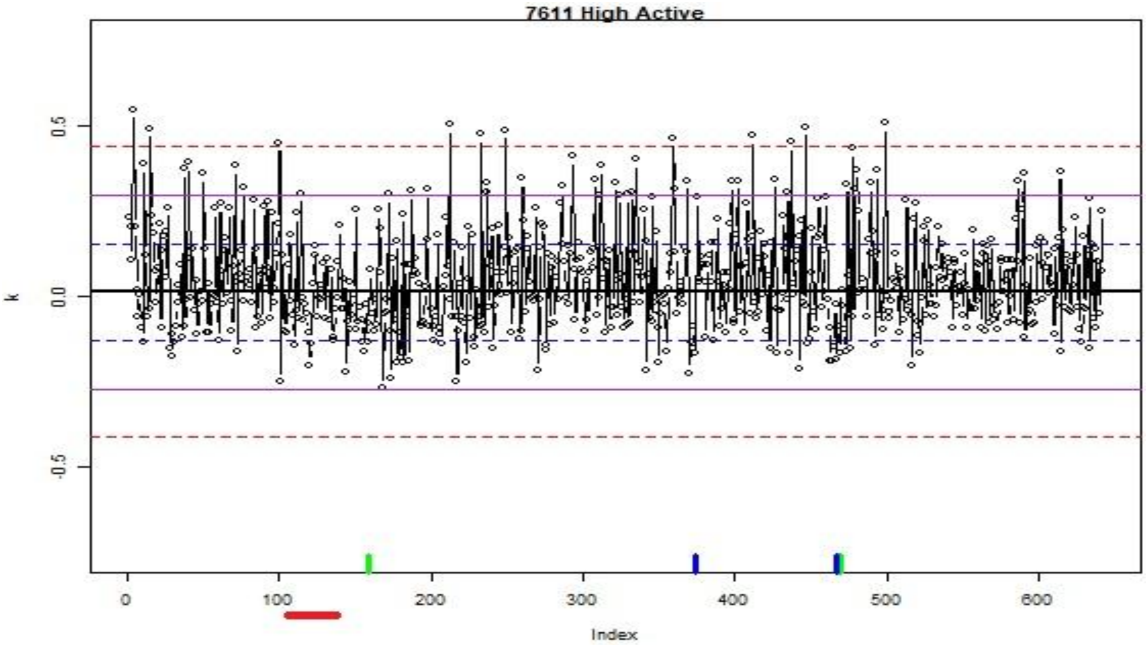
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart when the calf died.



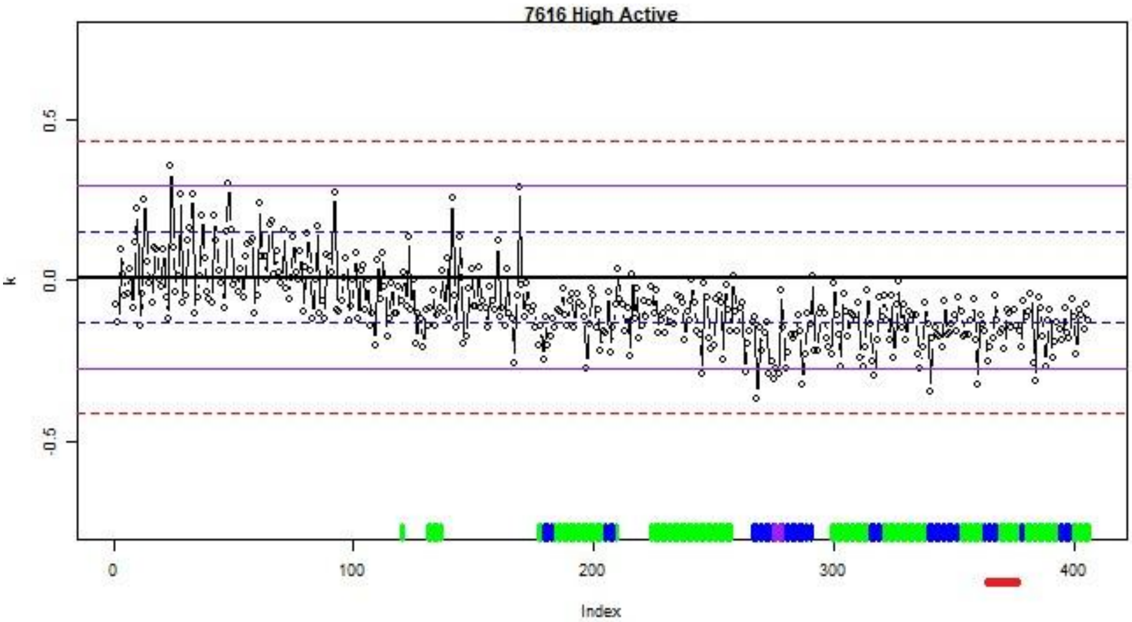
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



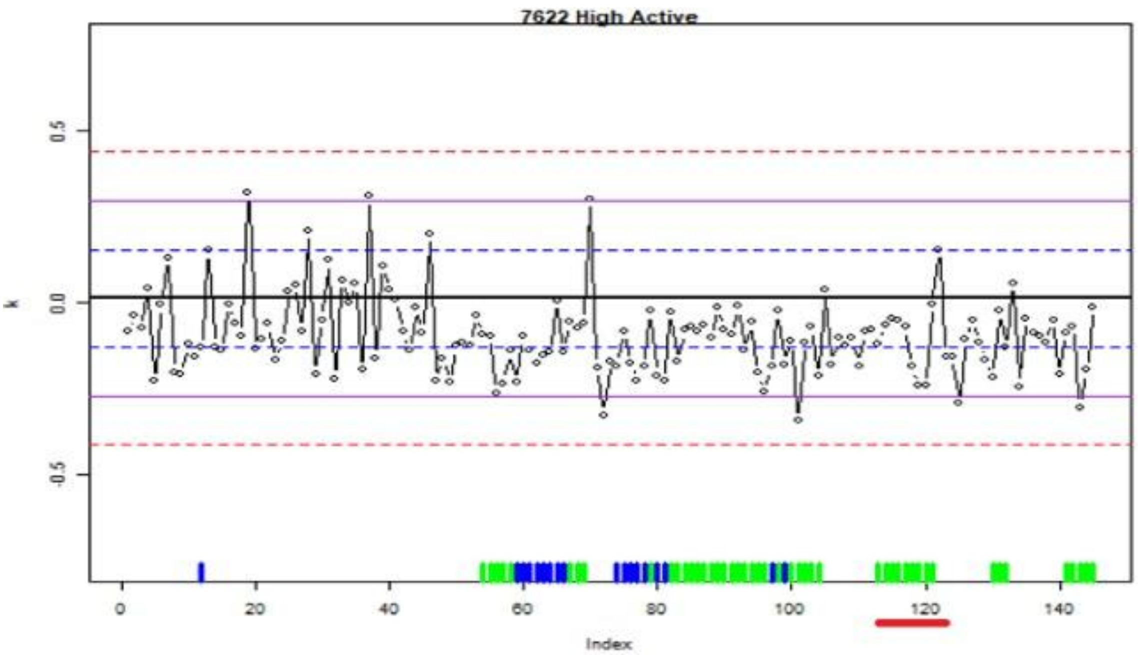
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period



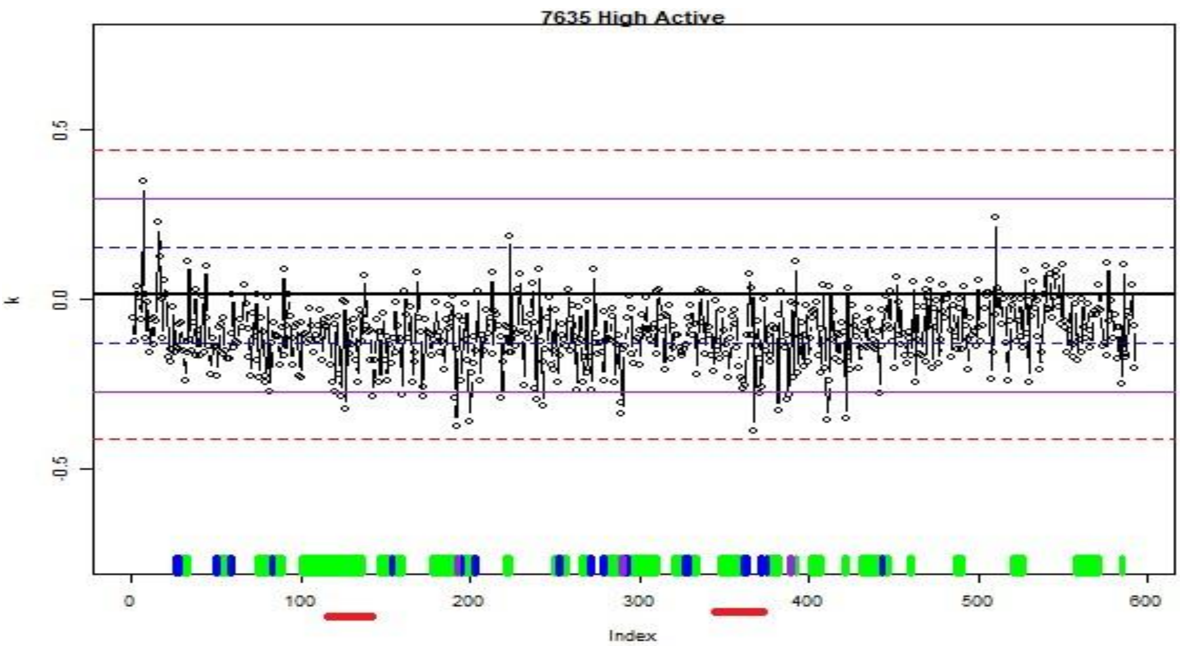
Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



Black line = ‘dHA’ healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops when the calf died.

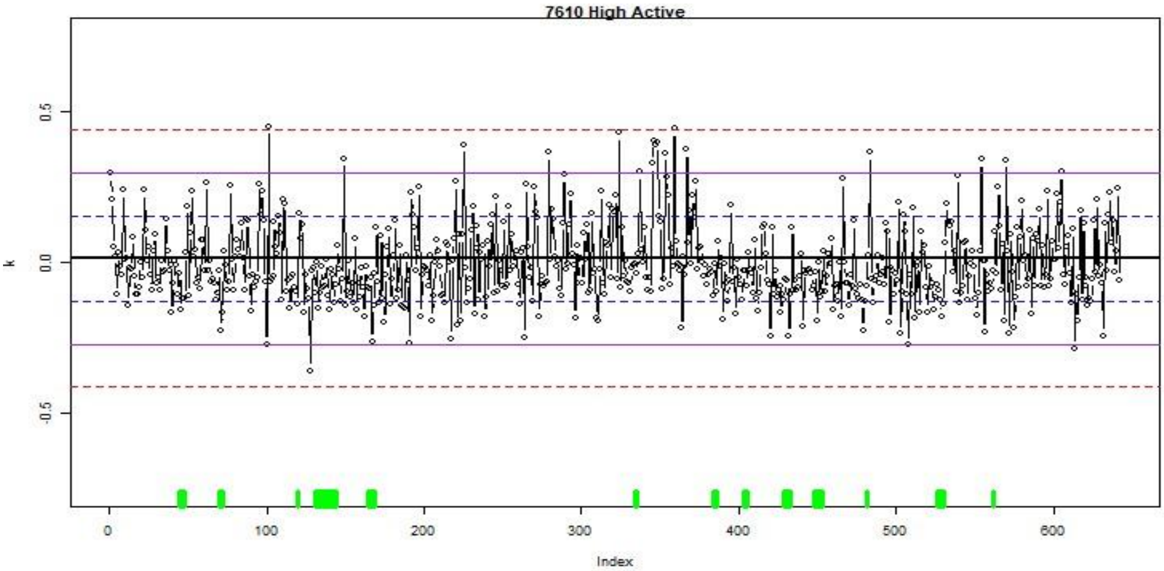


Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops when the calf died.

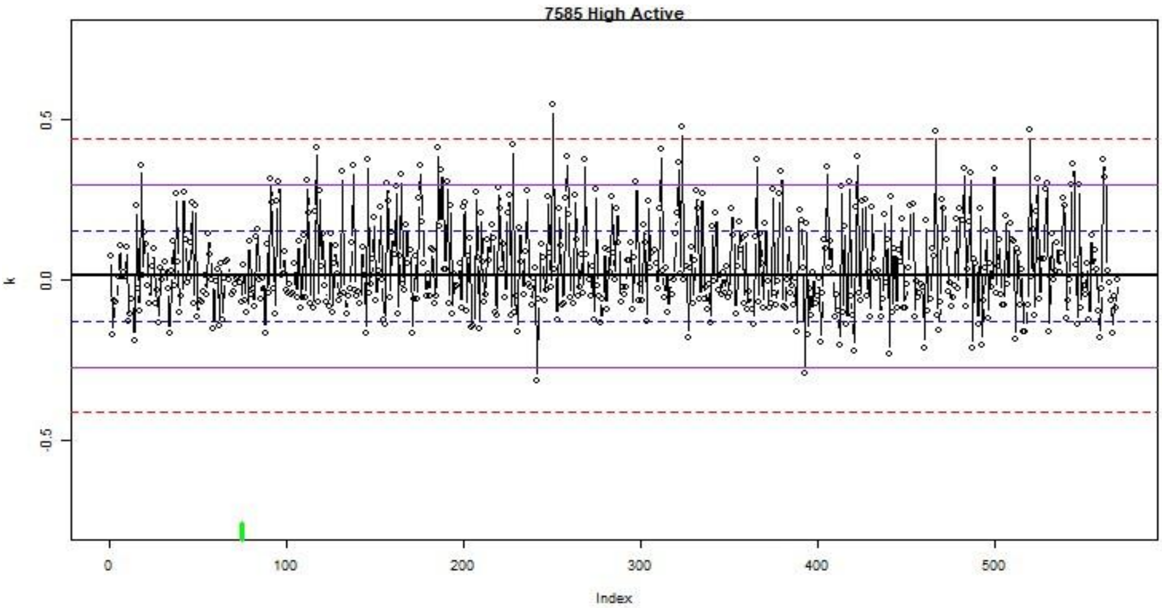


Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.

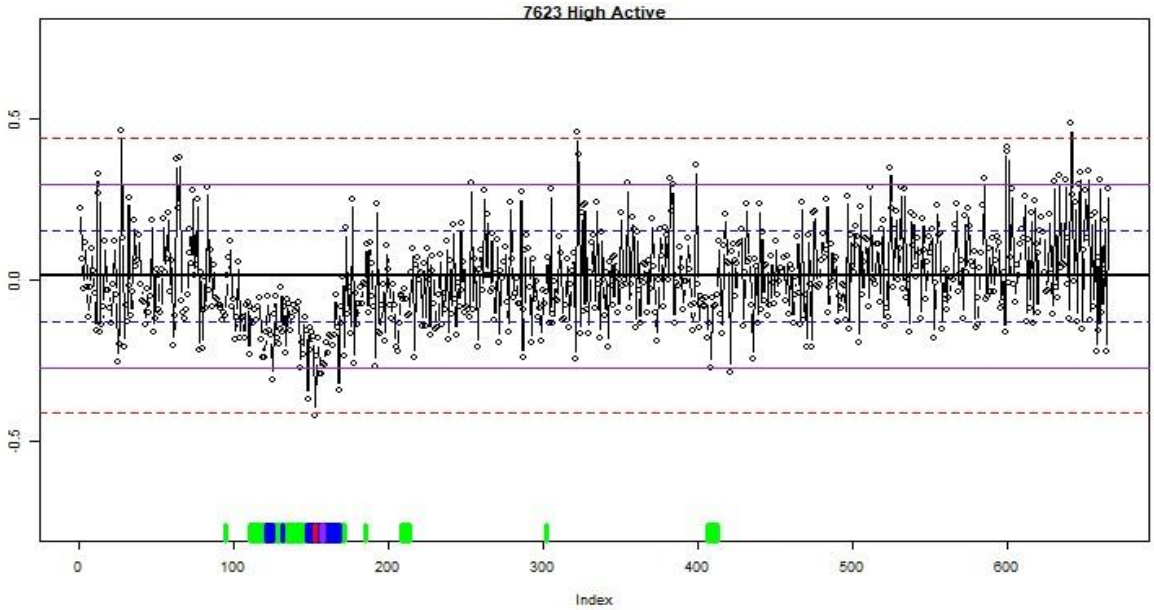
Shewhart Control Charts for three healthy calves:



Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.



Black line = 'dHA' healthy calves, blue line = one standard deviation, purple line = two standard deviations, red line = three standard deviations. The y axis shows the difference from the mean values, the x-axis shows the hours a calf is alive, with 100 being 4.166 days, 200 being 8.33 days, 300 being 12.5 days, 400 being 16.66 days, 500 being 20.833 days, and 600 being 25 days. The red line below the x-axis marks when the calves have been marked as level of sickness 3 during the observation. The marks on the x-axis mark alerts (green = rule four, red = rule one, blue = rule three, purple = rule two. The control chart stops at the end of the observation period.