Environmental Preferences and Behavior of Transition Dairy Cattle Kept on Pasture at the Time of Calving

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DEDICATION

To my Dad

Thank you for being my biggest supporter, spending hours talking with me about cows,

and pushing me to dream my biggest dreams

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ABSTRACT

Around calving, dairy cows must cope with nutritional, physiological, and environmental stressors, which puts them at an increased risk for detrimental outcomes. Understanding dairy cows' maternal behaviors and their preferred calving environment can aid in addressing how to properly manage and house them. The objectives were to determine (1) dairy cattle's preference for calving environment and factors associated with their preference, (2) the herd's location in relation to individual animals that did or did not separate from the group for calving, (3) lying behaviors at calving, (4) individual animal's movement throughout the environment at calving, and (5) if lying behaviors and movement throughout the environment change based on calving location preference when group-housed in a bedded-pack barn with free access to pasture. The barn served as section 1, and the pasture was divided into 8 sections. Sections 2 through 8 were areas of flat, open pasture. Section 9 was surrounded by natural forage cover at the end of the pasture. Cattle most frequently selected the barn and natural forage cover area for calving. Parity and heat stress were associated with selection of calving location. When cattle separated from the herd to calve, the majority of the herd was at least 2 sections away, while cattle that did not separate to calve stayed within the same section as the majority of the herd. On the day of calving, lying time and lying bout duration decreased, and lying bouts, steps, and movement throughout the environment increased. None of these behaviors were affected by preference for calving location. These results suggest dairy cattle have different preferences at calving and will seek out an area where they have cover overhead and surrounding them. When designing calving facilities, various

preferences should be considered. Furthermore, cattle's lying behaviors and movement change leading up to calving when provided with a barn and pasture. Future research should focus on determining how to accommodate these behaviors in indoor calving facilities.

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CHAPTER I

A COMPARISON OF CALVING ENVIRONMENTS' EFFECT ON PREPARTUM MATERNAL BEHAVIOR IN CATTLE

INTRODUCTION

Calving is one of the most stressful events a dairy cow will experience during a production cycle (Mainau and Manteca, 2011). Around this time, the cow must cope with physical and physiological changes associated with the periparturient period (e.g. calcium homeostasis, lactogenesis, tissue damage associated with stage two of labor, etc.), changes in her environment, regrouping with other cattle, and diet changes (Fig. 1). Afterward, the cow must cope with separation from her calf and the onset of lactation. When cattle are unable to cope with these changes, they are at risk for dystocia, common periparturient diseases of dairy cattle, and experiencing poor welfare (Cook and Nordlund, 2004; Proudfoot et al., 2009; Proudfoot et al., 2013). Approximately 30 to 50% of transition dairy cows will contract a metabolic or infectious disease (LeBlanc, 2010). Researchers have focused on understanding nutrition and lactational physiology to reduce the incidence of transition cow disease. The National Animal Health Monitoring System (1996, 2002, and 2007) reports that the prevalence of various transition cow diseases (i.e., retained placenta, metritis, and displaced abomasum) have remained the same or increased until 2007. Since then, the prevalence of most diseases have decreased (NAHMS, 2014). While these areas have reduced the prevalence of disease, there are opportunities for research in other areas like calving environment to improve transition cow health.

The incidence of transition cow disease raises welfare concerns. Welfare is defined using three broad concepts: (1) animals should be able to express natural and

adapted behaviors, (2) animals should be happy and free of pain and suffering, and (3) animals should be healthy and productive. Animal welfare is a key area of concern that must be considered and implemented in order for the dairy industry to remain viable (von Keyserlingk et al., 2013). Housing facilities must be considered as they can negatively impact maternal behavior and parturition (Lawrence et al., 1992; Lawrence et al., 1994; Oliviero et al., 2008). This creates a welfare issue due to the potential for reduced health and inability to express natural behaviors. It has been estimated that 14% of multiparous cows and 23% of nulliparous heifers in the U.S. experience dystocia (Mee, 2008). Dystocia is perceived by veterinarians as one of the most painful events cattle can experience (Huxley and Whay, 2006). Cow and calf morbidity and mortality is increased from dystocia events (Lombard et al., 2007). Cattle that experience one periparturient disease will often experience multiple illnesses due to physiological links between various diseases (Esposito et al., 2014). Whether cattle succumb to a metabolic or infectious disease or both, they are at risk for decreased reproductive efficiency, decreased milk production, and premature culling (LeBlanc, 2010). This further impairs welfare (Fig. 1).

It has been suggested that understanding maternal behaviors of transition dairy cows can aid in addressing how to properly manage and house them (von Keyserlingk and Weary, 2007). Maternal behaviors are any behaviors expressed by the dam in the hours before calving and are directed toward the calf post-calving. Cattle should be able to express these behaviors to remain in good welfare. Currently, transition cows are housed in a multitude of calving facilities (i.e., pasture, bedded pack, free-stall, etc.). We

provide a critical review of an environment's effect on physiology and behavior at parturition, prepartum maternal behaviors expressed within various calving environments, and discuss science-based recommendations for calving facilities.

STAGES OF LABOR

Labor is defined in three stages as one stage progressively transitions into the next (Noakes et al., 2001). During stage one labor, the cervix dilates, myometrial contractions begin, and the calf moves into position for expulsion. This stage is highly variable, and it is thought this stage can last 4 to 24 h (Noakes et al., 2001). These clinical signs associated with stage one labor are not overtly visible; therefore, behavioral observations may be used to predict the onset and completion of this stage of labor in cattle. These behaviors will be discussed in detail below.

Stage two labor in cattle is overtly visible beginning with abdominal contractions and appearance of the amniotic sac protruding from the labia and continues until complete expulsion of the calf (Noakes et al., 2001). This stage lasts approximately 45 minutes for multiparous cow and 90 minutes for nulliparous heifers (Mee, 1991). Throughout this thesis, primiparous and multiparous cattle refers to cattle that have given one or multiple births. Nulliparous heifers refers to cattle that have never given birth. As cattle transition from stages one and two similar behaviors that were observed during stage one will continue to be displayed (Noakes, et al., 2001).

Stage three of labor last approximately 6 h in cattle and begins immediately following expulsion of the calf and ends following expulsion of the placenta (Noakes et

al., 2001). Cattle's latency to stand after giving birth ranges from standing almost immediately to standing after about 30 minutes with multiparous cows standing sooner (George and Barger, 1974; Edwards and Broom, 1982). Cattle spend the majority of the 6 h post-calving standing (Edwards and Broom, 1982; Jensen, 2012). Multiparous cows spend more of the first hour standing post-calving than nulliparous heifers, but nulliparous heifers increase their standing time from the first to second hour (Edwards and Broom, 1982). The first behavior observed after standing is predominantly licking the calf. This behavior is mostly observed during the two hours post-calving (Edwards and Broom, 1982; Jensen, 2012). Overall, cattle decrease their time spent standing and licking their calf during the 6 h post-partum. Cattle also spend time eating the placenta (Edwards and Broom, 1982) and increasing their feeding and drinking (Jensen, 2012).

EFFECTS OF ENVIRONMENT ON PHYSIOLOGY AND BEHAVIOR DURING PARTURITION

Hormonal Changes at Calving

Progesterone is the predominant hormone maintaining pregnancy (Hafez, 1974). Plasma progesterone increases through 250 d until the last 30 d of gestation. At this time, progesterone steadily decreases and then quickly falls to undetectable serum concentrations on the day before calving. Fetal cortisol stimulates the conversion of progesterone into 17α-hydroxyprogesterone, which converts into androstenedione and then to estrogens during the last 3 to 4 weeks before parturition (Noakes et al., 2001). Serum estrogen is maintained at lower concentrations through the early gestation

pregnancy and then increase into mid-gestation (Hafez, 1974). Concentrations remain unchanged until fetal cortisol concentrations increase. Estrogen stimulates the release of prostaglandin $F_{2\alpha}$ from the uterus (Noakes et al, 2001), subsequently decreasing serum concentrations of progesterone and a rapid decline in serum concentrations the day before calving (Stabenfeldt and Edquist, 1984). Prostaglandins also initiate myometrial contractions to aid in progression in stage one of labor by helping move the calf to the cervix and ultimately initiating Ferguson's reflex (Noakes et al., 2001). Ferguson's reflex results in greater release of oxytocin from the posterior pituitary gland in response to greater stretching and dilation of the cervix, ultimately leading to further myometrial contractions (Noakes et al., 2001) and prompting the expression of maternal behaviors (Williams et al., 2001). Maternal serum concentrations of prolactin reach a maximum the day before calving, and maternal cortisol concentrations begin to increase about 3 d before calving and reach a maximum at parturition (Stabenfeldt and Edquist, 1984).

Environmental Effects on Physiology and Behavior

The environment experienced by the dam at parturition can cause hormonal changes and therefore impact maternal behavior in cattle and other species like pigs (Fig. 2). Lawrence et al. (1992) moved sows from a straw-bedded pen to a crate after giving birth to their first pigs. This change in environment resulted in decreased serum oxytocin concentrations and an increase in standing, standing bouts, and oral activity directed at the floor in the sow. In a subsequent study, sows were moved to a straw-bedded pen or a crate without straw five days before expected farrowing (Lawrence et al., 1994). Sows

housed in the crates had higher plasma cortisol concentrations before parturition and had increased standing bouts, while sows housed in the pen spent more time standing. Sows housed in farrowing crates spent time directing oral activities to the floor and bars and were more alert, while sows in the pen directed their behavior towards the straw. Cortisol can inhibit oxytocin release from the posterior pituitary, which negatively impacts the expression of maternal behavior (Lawrence et al., 1992), and prolongs parturition (Oliviero et al., 2008). Since these behaviors continued in the days leading up to farrowing, it is understood that restricted environment rather than the novelty of the environment effects pre-parturient behaviors.

Less research has focused on the effects of environment leading up to and at parturition on hormonal changes in cattle. Nulliparous Herefords housed in a pen at calving experienced an increased incidence in dystocia due to vulvar constriction compared to heifers that remained in a paddock or large yard (Dufty, 1981). It is possible that the stress of being in a pen impaired the release of oxytocin, which interfered with the progression of calving. Dairy cattle housed on pasture at calving spent less time lying and lied down more frequently than animals housed in an individual maternity pen (Black and Krawczel, 2016). Additionally, it has been suggested that cattle group-housed in confinement systems become more restless leading up to calving due to their inability to find an appropriate birthing site (Rørvang et al., 2018b).

Time of movement to the calving environment also plays a significant role in expression of behavior (Proudfoot et al., 2013). When multiparous cows were moved from a group pen to an individual pen during late stage one labor, lying time and lying

bout duration decreased while number of lying bouts increased compared to being moved before labor or during early stage one labor (Proudfoot et al., 2013). The length of stage two labor also prolonged by approximately 30 minutes if parturient behavior was disrupted, and multiparous cows spent more time exploring their new environment. In this case, novelty of environment may cause the disrupted maternal behavior as cattle moved 3 d before calving had lower serum concentrations of cortisol (Heuwieser et al., 1987).

BEHAVIORS EXPRESSED IN VARIOUS CALVING ENVIRONMENTS

Calving Behaviors in Pasture-Based Calving Environments

Pasture is considered the most natural environment because this type of system provides the most space and is more likely to allow for all calving behaviors to be expressed. Depending on the pasture environment, cattle may or may not separate from the herd at calving. When beef and dairy cattle were kept on 20 ha of pasture, 64% of the cattle separated from the herd (more than 30 m from their nearest neighbor and out of sight) on the day of calving (Lidfors et al., 1994). In this study, nulliparous heifers separated further than multiparous cows particularly when disturbed by herd mates. All animals that separated sought out areas of dry, soft ground and tree cover. Red Angus cattle on 320 ha of range land also sought out areas that hid them (hallowed areas of sandy soil and small bushes) for calving (Flörcke and Grandin, 2014). The majority (88%) of the cattle separated more than 100 m from the herd, while 95% separated more than 50 m from the herd during the 12 to 24 h before parturition. Multiparous cows

distanced themselves further from the herd in this study. Edwards (1983) reported that fewer cattle (22%) separated from the herd to calve in the pasture when they were housed in a covered straw yard with free access to a 1 ha pasture. Nearly 81% of the cattle that separated did so during the night. Fewer cattle may have separated from the herd due to the covered yard where cattle were fed daily. The author also stated that the pasture did not have forage cover. Therefore, the cattle may have perceived staying with the herd as more advantageous for survival and protection. It has been suggested that cattle separate themselves to calve as part of their prey-predator instinct and to bond with their calf (Leuthold, 1977). This thought is supported by a study where only two animals separated before calving from a herd of 380 cross-bred dairy and beef cattle housed on 30 ha without trees and access to 3 open air barns (Lidfors and Jensen, 1988). There was no preference for a particular calving site.

Hereford beef cattle housed on 2 ha of pasture expressed increased walking, restlessness, pawing the ground, licking the flank, and a raised tail during the last 12 h of parturition (George and Barger, 1974). When beef and dairy cattle were housed on 4 ha of pasture, cattle became restless 142 min before birth of the calf (Owens et al., 1985). It was also reported that cattle increased walking, tail swishing, and tail raising. Black and Krawczel (2016) measured lying behaviors at calving when primiparous and multiparous cows were housed on 1.7 ha of pasture. Cows had a decreased total lying time and lying bout duration and an increased number of lying bouts and steps. Rice et al. (2017) reported similar results from multiparous dairy cows managed on 3.2 ha of pasture where lying behaviors changed on the day of calving. Cows experience some level of

discomfort during calving no matter the difficulty (Mee, 2008). Therefore, cattle may change their behavior before calving due to the discomfort experienced and to seek out a birthing site.

Calving Behaviors in Individual Maternity Pen Environments

As the number of dairy cattle on farms have increased, the use of pasture has decreased (NAHMS, 2014). Therefore, more farms are managing their cattle in indoor calving facilities. One way periparturient cattle are managed is by moving them to an individual maternity pen in the days or hours before calving (Mee et al., 2013). Wehrend et al. (2006) moved nulliparous and multiparous cattle from tie stalls to an individual maternity pen with straw after they were predicted to be in stage one labor. A cervical palpation was conducted to confirm this prediction. The first behaviors observed from these cattle was exploration and sniffing the ground, which transitioned into nest-building.

Wehrend et al. (2006) reported that 32% of multiparous cows expressed calm behavior at calving, while 100% of nulliparous heifers had frequent changes in standing and lying positions. Cattle had an increased degree of restlessness (bouts of standing, walking, and change in lying postures) during the final 2 h before calving with lying bouts increasing 4 h before calving (Barrier et al., 2012). Similarly, multiparous cows in an individual pen on deep-bedded straw began to increase their number of lying bouts by nearly 2 bouts per h during the final 4 h before parturition (Jensen, 2012). Primiparous and multiparous cows managed on mattresses in individual maternity pens at calving had

a decreased total lying time and lying bout duration and increased number of lying bouts and steps (Black and Krawczel, 2016). Barrier et al. (2012) reported lying time increasing 2 h prior to calving, which is when cattle may have been transitioning into stage two labor and became laterally recumbent to push.

Dairy cattle housed in individual pens on mattresses with straw spent 49.4% of the 12 h before calving standing and 40.6% in semi-lateral recumbency (Houwing et al., 1990). Standing increased from -12 to -3 h and then decreased the last 3 h before calving, while the inverse occurred for semi-lateral and lateral recumbency. Cattle housed in individual maternity pens on the day before calving became more restless as indicated by an increased number of standing bouts compared to the pre-calving period (17.3 and 11.7 bouts/d, respectively; Huzzey et al., 2005). Additionally, cattle had an increased total standing time at calving compared to the pre-calving period (14.4 and 12.3 h/d, respectively).

Nulliparous heifers and multiparous cows decreased their feeding and drinking times during the 4 to 6 h before calving (Miedema et al., 2011a; Jensen, 2012). When cattle were housed in an individual maternity pen bedded with sawdust, feeding time decreased during the 24 h before calving compared to a 24 h baseline (138.9 and 205.1 min/d, respectively; Schirmann et al., 2013). Additionally, cattle decreased their rumination time (362.8 and 426.1 min/d, respectively). The greatest decline in rumination occurred during the 4 h before calving.

Other behaviors observed during calving include looking at the abdomen, tail raising, tail swishing, grooming, vocalizing, pawing the ground, urination and defecation (Wehrend et al., 2006). Multiparous cows turned their head more to their abdomen in the final 2 h before parturition from 1.71 to 4.05 turns/h (Jensen, 2012). Cattle spent 14.1% of the time raising their tail 6 h before calving and this increased to 79.2% by 2 h before calving (Barrier et al., 2012). When housed in individual maternity pens on deep-bedded sand, cattle spent 0.86 min/h self-grooming and 0.15 min/h scratching or rubbing themselves (Newby et al., 2013).

Calving Behaviors in Indoor Group-Housed Calving Environments

Farms also use group-housed indoor calving pens to calve their cattle (NAHMS, 2014). Rørvang et al. (2017b) investigated the influence of a multiparous cow's birthing site on subsequent birthing sites in a group-housed setting. In one pen all of the cattle calved within 1 m of the first cow's birthing site when her birthing site was only partially cleaned. In another pen the birthing site was completely cleaned after the first multiparous cow. The second multiparous cow calved in another area of the pen and all subsequent multiparous cows calved within 1 m of this cow's birthing site. This suggests that cattle may select their birthing site based on where previous cattle have calved.

More frequent changes in posture and walking are also observed in indoor group housing. When cattle were housed on a straw deep-bedded pack, their number of lying bouts increased during the 24 h before calving compared to the same 24 h period in the week before calving (24.2 and 16.4 bouts/d, respectively), while total lying time

decreased (12.6 and 13.6 h/d, respectively; Miedema et al., 2011b). Lying bouts began increasing 6 h before parturition, while there was no specific point at which lying time began to change. In another study, cattle in this same environment increased their number of lying bouts beginning 12 h before calving with the greatest change occurring in the 2 h before calving (Miedema et al., 2011a). Cattle increased their walking bouts in the 24 h before calving compared to a 24 h period during the week before calving (529.3 and 388.0 bouts/d, respectively), and walking duration also increased (31.5 and 21.0 min/d, respectively; Miedema et al., 2011b). Nulliparous heifers decreased their walking time during the final 2 h (Miedema et al., 2011a).

Other behaviors observed in group housing are tail raising, ground licking, and decreased feeding time. Cattle increased their number of tail raises during the 24 h before calving compared to another 24 h period during the week before calving (59.3 and 19.1 no./d, respectively; Miedema et al., 2011b). The greatest increase in number of tail raises occurred during the last 6 h before parturition. In another study with the same environment, nulliparous heifers began raising their tails more beginning 4 h before parturition, while multiparous cows began raising their tails more 2 h before calving (Miedema et al., 2011a). Both nulliparous heifers and multiparous cows raised their tails for the longest during the final 2 h before parturition. Duration of ground-licking increased during the 24 h before calving compared to a 24 h period during the week before calving (5.2 and 2.1 min/d, respectively; Miedema et al., 2011b). Ground-licking began increasing 6 h before parturition, while feeding duration decreased.

Calving Behaviors and Use of Hides at Calving

Within the last several years, there has been a growing body of literature investigating cattle's use of a shelter or hide for calving when it is provided in an indoor calving facility (Proudfoot et al., 2014a; Proudfoot et al., 2014b; Rørvang et al., 2017a). As described above in the previous literature, these cattle may be kept in groups or individual maternity pens. These pens are often in high traffic areas of the barn, so farm staff can keep a close watch on calving progress. However, this may result in a disturbance of calving behavior as it has been previously discussed above that cattle will try to separate from their herd mates at calving in a more natural environment. Therefore, more research is needed to better understand calving behaviors associated with cattle in confinement, semi-confinement, pasture-intensive or extensive housing conditions.

Proudfoot et al. (2014a) housed two animals in a maternity pen with an "open" deep sand-bedded area and a "shelter". The "shelter" built with plywood on all four sides and left with an opening on one side for cattle to enter. Single-housed cattle used the shelter for calving more than the pair-housed cattle (62% vs. 34%, respectively). When the single-housed cattle calved during the day, they used the shelter more than the open area (81% vs. 19%, respectively). If they calved during the night cows used the open and shelter area equally. Cattle began to use the shelter approximately 8 h before calving. When cattle were in a pair, the animal calving began to spend more than one cow length away from its partner beginning 8.3 h before calving. Although pair-housed cattle did not use the shelter as much at calving, they still tried to separate from their partner.

Therefore, authors speculated that they may have avoided fighting to use the shelter at a vulnerable time.

Multiparous cows also tried to visually isolate from their herd mates at calving when they were housed in an individual maternity pen that was adjacent to a group pen of 12 to 15 multiparous cows (Proudfoot et al., 2014b). When half of the individual pen was covered with a piece of plywood, 79% of multiparous cows calved on the side of the pen that was covered. Multiparous cows began to use this corner of the pen approximately 1 h before calving. Multiparous cows housed in an individual pen that had no cover calved on both sides of the pen equally.

Rørvang et al. (2017a) observed multiparous cows' preference for degree of isolation in individual maternity pens from herd mates housed in an adjacent group pen by varying the cover of the individual pen. Multiparous cows had 3 options: 1) tall and narrow covering 50% of the individual pen, 2) low and wide covering 50% of the individual pen, and 3) tall and wide covering 75% of the individual pen. Multiparous cows showed no preference for any of the 3 options for isolation at calving. However, multiparous cows that had the longest stage two labor showed a preference for the most isolation (tall and wide covering 75% of the individual pen).

Preference for isolation or use of an individual maternity pen has also investigated within a group-housed setting (Rørvang et al., 2018a). Multiparous cows had the opportunity to go from the group area to individual pens (referred to as motivation-based calving). Individual pens were either permanently open or had to be pushed open and

then would close and lock after an animal entered to prevent other cattle from entering. Thirty-four multiparous cows calved in an individual pen, while the other 32 multiparous cows calved in the group area. Multiparous cows were more likely to use the permanently open individual pens over the individual pens that had to be pushed open. Multiparous cows with a higher social rank were more likely to use the individual pen along with multiparous cows that experienced their first abdominal contractions in the individual pen.

COMPARING MATERNAL BEHAVIOR WITHIN AND ACROSS ENVIRONMENTS

Cattle express isolation seeking behavior or separation behavior in both outdoor and indoor calving environments (Lidfors et al., 1994; Proudfoot et al., 2014a). Based on cattle's motivation to isolate in other pasture environments, it may be best then that pasture environments provide somewhere for cattle to go to for visual seclusion. As research continues investigating isolation indoors, there are many factors that should potentially be considered for accommodating this behavior. It would be beneficial to gain a further understanding of shelter use if multiple shelters were provided for group-housed cattle. It is possible that cattle in a motivational-based calving system did not perceive individual pens as being far enough away from the group to actually provide isolation. Since an individual pen only provided one place to enter and exit, lower ranked cattle may have also perceived the individual pen as disadvantageous. They are trapped if another multiparous cow or a predator tried to enter. Some aspects future research should

focus on to understand calving facility design and accommodate isolation behavior indoors are social dynamics, distance to shelter/individual pen, and design of the shelter/individual pen. The Canadian Code of Practice recommends and the Danish Law requires that cattle calve in an individual calving pen because research has indicated that cattle want to isolate and it prevents mismothering post-calving. However, not all cows prefer to isolate during calving (Rørvang et al., 2018a); therefore, calving facilities should be designed with individual cow preferences in mind to accommodate for some diverse cattle behavior associated with calving.

A change in lying behaviors relative to calving has been observed in both pasture-based and indoor calving facilities. Cattle do not prefer certain lying surfaces (i.e., mattresses) at calving, which may explain some of the differences within and across environments. Furthermore, Rørvang et al. (2018b) suggests cattle in an indoor group-housed environment may change their lying behaviors out of frustration for their inability to separate. Lying behavior may also differ due nulliparous heifers and multiparous heifers expressing behaviors differently at calving (Wehrend et al., 2006). Finally, a change in behavior can indicate pain, and thus suggests that cattle experience pain and discomfort at calving (Mainau and Manteca, 2011).

Technology has become useful in detecting changes in behavior and predicting calving. It can improve the welfare of cattle by allowing us to better manage them around calving (Saint-Dizier and Chastant-Maillard, 2015). For example, it can help determine when cattle should be moved to the calving pen. Various technologies have been

validated to track changes in lying behaviors (Borchers et al., 2016), which is one way to detect calving. These technologies work to sense a change in lying behavior (i.e., lying time, lying bout duration, lying bouts, and steps) and then alert the farm of these changes. Technologies are also being used in research to measure behaviors within different calving environments (Black and Krawczel, 2016) and aiding us in understanding how they should be housed and managed.

CURRENT TRANSITION COW HOUSING RECOMMENDATIONS

Currently, in the United States operations use tie stalls (18%), free stalls (10%), free stalls with access to a dry lot (20%), a barn with access to a dry lot (23%), dry lots (7%), indoor group pens (11%), primarily on pasture (11%) or providing access to pasture (72%) to house their dry cows (NAHMS, 2014). The majority (64%) of calvings occur within a group pen or area, while most of the remainder (31%) occur within an individual pen or area. Recommendations vary for housing dairy cattle at calving. The USDA National Animal Health Monitoring System (2014) recommends designing calving areas that are clean, dry, quiet, and allow cattle to separate from their herd mates. Therefore, it is ideal to make available individual calving pens or a group pens/areas as long as these recommendations are met. However, in some European countries laws require that cattle calve in individual maternity pens (Rørvang et al., 2018b).

Most recommendations for calving facilities and calving management are based on observation and previous experiences. Therefore, many recommendations vary between sources. For example, Cook and Nordlund (2004) recommend providing cattle

with 11 m^2 of resting space at calving, while Pennsylvania State University recommends 13.9 to 18.6 m^2 per animal during calving (Graves et al., 2006). However, it is clear that some dairy cattle are motivated to separate from herd mates to calve in a variety of environments (Lidfors et al., 1994; Flörcke and Grandin, 2014; Proudfoot et al., 2014a), which makes it critical for animal welfare to design calving facilities that accommodate this behavior. Science-based recommendations are needed to determine appropriate stocking densities at calving. Shelters or hides in the calving pen (Proudfoot et al., 2014a) may facilitate calving behaviors and alleviate cattle being in more restricted areas. Yet, cattle may also need more space in the calving area as distance can be perceived as an important part of separating from the herd (Rørvang et al., 2018b). Larger group pens should also be tested to determine if this would better allow for all parities to separate indoors and establishing how this resource is utilized by different ranks in the hierarchy.

Another important management factor to consider is when cows will be moved to their calving area. Cattle should be moved to their calving area approximately 1 to 2 days prior to calving (Mee, 2004). However, it may be difficult to accurately predict when cattle will calve, and cattle are at risk for contracting health disorders when they remain in the maternity pen for longer than 3 days (Cook and Nordlund, 2004). Motivation-based calving systems are promising for addressing this issue. A motivation-based calving system could provide the space needed to accommodate cattle's change in lying behaviors and other behaviors occurring before calving, while allowing them to separate themselves when they want. Future studies measuring lying behaviors and other behaviors in the acute period of calving in this system would be beneficial.

CONCLUSIONS

This review discussed how environment can impact animals' behavior and welfare while giving birth, behaviors observed within different calving environment, and compared the behaviors observed in those environments. Cattle will continue to express some of the same behaviors in an indoor calving environment as they would in an outdoor calving environment (Lidfors et al., 1994; Proudfoot et al., 2014a). However, not all behaviors are expressed to the same degree between and within these environments. Therefore, facilities will need to be designed that accommodate all cattle within the environment. Cattle's behavior can aid us in developing an environment that accommodates their needs and promotes welfare. It can also play a role in telling us how to manage different aspects of calving like when cows need to be moved to their calving environment, how social dynamics will affect calving outcomes, and how much space cattle needs. As a result, a strong knowledge of cattle's behavioral needs and preferences may improve calving outcomes. Currently, calving environment and management recommendations are based upon field observations. Therefore, studies must focus on understanding cattle's environmental preferences at calving in a more natural environment (i.e., pasture) and the behaviors expressed within this environment around the acute calving period. This will help us to begin building science-based recommendations and applying this knowledge to our outdoor and indoor facilities and various calving management practices.

CHAPTER II

CALVING LOCATION PREFERENCE OF DAIRY CATTLE WITH ACCESS TO A BARN AND PASTURE

ABSTRACT

The objectives were to determine (1) dairy cattle's preference for calving environment and factors associated with their preference and (2) the herd's location in relation to cattle that did or did not separate from the group for calving. Seventy-two Holstein dairy heifers and cows (n = 36 nulliparous, n = 19 primiparous, and n = 17 multiparous) were housed in a covered bedded-pack barn (167.4 m^2) with free access to 2.1 ha of pasture. The group was dynamic as cattle were moved into the environment every Tuesday, 23 ± 3 d (mean ± SD) before their expected calving date and were removed after calving. To determine calving location, the pasture was subdivided into 8 sections [sections 2 - 8 (open pasture) were of approximately equal size (2,402 ± 60 m^2), and section 9 (natural forage cover) was 3,593 m^2]. The barn (167.4 m^2) served as section 1. Sections 1 through 9 were condensed into 3 areas (section 1 = barn, sections 2 - 8 = open pasture, and section 9 = natural forage cover) to determine factors that were associated with calving location. To determine where the herd was located when each animal chose her calving location the percentage of cattle (1) within the same section, (2) within an adjacent section, and (3) within all other sections were determined. The bedded-pack barn and natural forage cover were most frequently selected for calving. Parity and heat stress were associated with calving location preference. Cattle remained within the majority of the herd to calve if they did not separate. When cattle separated from the herd to calve, a greater percentage of the herd was at least 2 sections away compared to cattle that did not separate. This suggests cattle have different preferences

for their environment at calving. Preferences should be considered when designing calving facilities to potentially improve the welfare of dairy cattle.

Key words: dairy cow; calving location preference; pasture

INTRODUCTION

Parturition is a stressful experience for females of all species, including dairy cattle (Mainau and Manteca, 2011). Dairy cattle must be able to cope with labor along with changes in their environment, regrouping with other cattle, separation from their calf, diet changes, and the onset of lactation. During this time, cattle are at high risk for experiencing dystocia and contracting disease (Cook and Nordlund, 2004; Proudfoot et al., 2009; Proudfoot et al., 2013). It has been suggested that understanding maternal behaviors of dairy cattle and what cattle value from their environment can aid in addressing how to properly manage and house them (von Keyserlingk and Weary, 2007). This may reduce the risk of dystocia and disease by reducing environmental stress.

The majority (64.3%) of calvings on U.S. commercial dairy farms occur with cattle group housed/pastured, while 31.1% occur with cattle housed individually (NAHMS, 2014). As the number of cattle on farms have increased, the use of pasture has decreased. Therefore, more farms are managing their cattle in indoor calving facilities by moving them to an individual maternity pen in the days or hours before calving or keeping them within group pens. Rørvang et al. (2018b) suggests that cattle calving indoors can become frustrated due to their inability to seek out a birthing site as they would in a pasture environment.

Separation from the herd and selection of a secluded birthing site are the first behaviors observed at calving in order to find protection from predators and bond with the calf (Leuthold, 1977). When housed on extensive pasture, cattle will distance themselves 25 to 1,250 m on the day of calving and seek out secluded areas of forage cover (i.e., tree and bushes), hallowed ground, and dry, soft ground (Lidfors et al., 1994; Flörcke and Grandin, 2014). Cattle will also express this behavior while calving in an indoor pen. When housed in a maternity pen with an "open" deep sand-bedded area and a "shelter", single-housed cattle will seclude themselves in the shelter, especially when calving during the day (Proudfoot et al., 2014a). Although pair-housed cattle used the shelter less for calving compared to the single-housed cattle, they still separated from their partner beginning 8.3 h prior to calving. However, group housing may also alter this dynamic and influence calving location preferences.

No research to date has determined cattle's preference for calving environment when group-housed in a commercial pasture setting, where there are fewer opportunities to separate from the herd compared to an extensive, pasture-based system. The objectives of our study were to determine (1) dairy cattle's preference for calving environment and factors associated with their preference and (2) the herd's location in relation to cattle that did or did not separate from the group for calving when housed in a bedded-pack barn with free access to pasture.

MATERIALS AND METHODS

All animal procedures were approved by the University of Tennessee IACUC committee (IACUC Protocol #2399-1115). This study was conducted at the University of

Tennessee's Little River Animal and Environmental Unit (Walland, TN; 35° 46' 5.8116" N, 83° 50' 55.446" W) from July to December 2016.

Animals, Housing, and Management

Seventy-two Holstein dairy heifers and cows (n = 36 nulliparous, n = 19 primiparous, and n = 17 multiparous) were used in this experiment. Throughout this paper, primiparous and multiparous cows are referred to and analyzed as a group. Cattle were housed in a covered bedded-pack barn (167.4 m^2) with free access to 2.1 ha of pasture for calving (Fig. 3). The group was dynamic as cattle were moved into the environment every Tuesday, which was approximately 23 ± 3 d (mean ± SD) prior to their expected calving date and were removed after calving. Cattle's locomotion was scored using a 3-point scoring system (1: sound; 2: moderately lame; 3: severely lame) when entering the study and at calving. The mean; range of animals entering the study each week was 3; 0 to 16 animals. Group size was 11; 1 to 18 animals (mean; range). There were 2 incidences where 1 animal was in the pasture. A new group of cattle was moved into the environment within 24 h to prevent cattle from calving alone. Cattle spent 21; 11 to 34 d (mean; range) in the environment. The barn was deep bedded with straw and cleaned as determined by the farm. The barn was equipped with 23 headlocks, and cattle were fed a TMR once daily at 1600 h and had ad libitum hay in the barn. Two automatic waterers (Thrifty-King CT4-2000, Ritchie Industries, Inc., Conrad, IA, USA) were provided (one in the barn and the other at the far end of the pasture). While most of the pasture (82.4%) was flat and open with no forage cover, there was an area at the far end of the pasture (17.6%) surrounded by natural forage cover (i.e., trees, tall grasses, and

bushes). Man-made, v-shaped hides (n = 6) were built by bolting corrugated metal sheets to one side of a metal gate (3.7 x 1.8 m) and connecting two metal gates (Fig. 4). Hides were placed in sets of two throughout the pasture to serve as alternative areas for calving. A pair of hides were placed 5 m apart opened away from each other with the opening also measuring 5 m (Fig. 4).

Calving Environment Preferences

Behaviors were continuously recorded using 11 1.0-Megapixel Outdoor IP67 Bullet Cameras (Amcrest, Houston, Texas) mounted on wooden poles 4 m above the ground. Cameras had IR-LED lights to facilitate night viewing. One camera was placed in the barn and the other ten cameras were placed along the fence line of the pasture (Fig. 3). The digital video data was continuously saved to two 8-channel 720p HDCVI DVRs (Amcrest, Houston, Texas) and transferred to a Seagate 6TB External Hard Drive (Seagate, Cupertino, California) daily.

Calving Location. Video data were used to determine the time and location of calving, defined as the time the animal stood up after calving or if the animal was already standing when the calf's hips were expelled. Due to camera placement, the exact calving time for some cattle (n = 31) could not be determined. The farm's estimated time of calving was used for these cattle. Calving location was still determined using video data as cattle were observed entering a section before calving and leaving that section when the farm staff was collecting their calf. To determine calving location, the pasture was divided with Quik Shot Spray Paint (LA-CO Industries Inc., Elk Grove Village, Illinois) into 8 sections (Fig. 3). Sections 2 through 8 (i.e., open pasture) were of approximately

equal size (2,402 ± 60 m^2; mean; SD). Section 9 (i.e., natural forage covered area) was 3,593 m^2. The covered barn (167.4 m^2) served as section 1 (Fig. 3). Man-made hides were placed in pairs and rotated weekly between sections. During one week hides would be in sections 3, 6, and 7 and the next week in sections 4, 5, and 8. Hides were rotated to determine whether there was a preference for the hide or the section the hide was located. Cattle were considered to be using the hide if they calved within one cow length of the hide (Proudfoot et al., 2014a).

Data were collected for how soon cattle selected their calving location before calving. This was calculated by subtracting the time at which cattle entered their calving section for the last time before calving from their calving time. To determine how much time cattle spent in their calving location on the day of calving and how it compared to a baseline prior to calving, cattle's location was collected using 10-min scan samples for the 24 h prior to calving (referred to as the calving day) and the same 24-h period 4 to 11 d (median = 7) prior to calving. This served as a baseline comparison (referred to as the pre-calving day). Cattle were assigned different pre-calving days to compare calving and pre-calving days with similar weather conditions (n = 11) or due to camera malfunction (n = 8). Previous research has used a pre-calving comparison period 1 to 10 d before calving (Miedema et al., 2011b).

Factors Affecting Calving Location. Sections 1 through 9 were condensed into 3 areas (section 1 = barn, sections 2 through 8 = open pasture, and section 9 = natural forage cover) to determine factors that were associated with calving location. A weather station at University of Tennessee's Little River Animal and Environmental Unit

collected hourly temperature and humidity data. These data were used to calculate the mean temperature humidity index (THI) for the 8 h prior to calving (NOAA, 1976). This method was selected due to cattle selecting their calving site approximately 8 h prior to calving in an indoor pen (Proudfoot et al., 2014a). Cattle were then assigned to a heat stress category based on environmental conditions (THI ≤ 68 = no heat stress and THI > 68 and ≤ 79 = mild to moderate heat stress; Cook et al., 2007). Time of day was separated into A.M. (0400 to 1559 h) and P.M. (1600 to 0359 h) with P.M. beginning when cattle were fed their daily TMR. Cow to heifer ratio was determined by calculating the number of primiparous and multiparous cows and nulliparous heifers in the environment at each animal's calving time.

Use of Man-Made Hides. To determine use of the man-made hides, 10-min scan samples from video data were collected for calving and pre-calving days. Cattle were considered to be using the hide if they were within one cow length of the hide (Proudfoot et al., 2014a).

Separation at Calving. Cattle were considered to be separated from the herd to calve when they entered their calving location for the last time before calving and remained alone for at least 10 min. To determine where the herd was located when each animal chose her calving location the percentage of cattle (1) within the same section, (2) percentage of cattle within an adjacent section, and (3) percentage of cattle within all other sections were determined.

Statistical Analysis

Inclusion Criteria. If an animal calved within 7 d of entering the study, it was assumed she did not have adequate time to become familiar with all areas of the barn and pasture and therefore was excluded. Grant and Albright (2001) reported that after regrouping it takes approximately 3 d and no more than 7 d for the social hierarchy to establish. Cattle (n = 1) were excluded if their locomotion was scored a 3 on the 3-point scale as these animals may not have been able to fully explore the environment or calve where they preferred. Cattle (n = 5) that experienced severe dystocia and required the assistance of farm staff or a veterinarian were excluded due to being moved into the barn for assistance. Therefore, their preferred calving location could not be determined. If cattle aborted their calf or calved twins, they were removed from the study. One animal was also excluded because she got out of the pasture and was not moved back into the study pasture until she was already in stage two labor. This left 65 animals (n = 32 nulliparous heifers and n = 33 primiparous and multiparous cows) for analysis.

This experiment was an observational study, and the experimental unit was the cow. All statistical analyses were performed with SAS software v9.4 (SAS Institute Inc., Cary, NC). Significance was declared at $P \leq 0.05$. A chi-square was performed using the PROC FREQ procedure to compare the frequency of calvings that occurred within each section and the frequency of calvings that would occur if there was no preference for any particular section. A multinomial logistic regression was preformed using the PROC GLIMMIX procedure to test the factors of interest (parity, THI, time of day, and cow to heifer ratio) association with calving location preference for area. A multinomial

distribution was specified and a GLOGIT link. Backwards manual elimination was used to remove any non-significant factors. The barn served as the reference because this is considered the standard for housing. For all remaining analyses, one animal was removed due to camera malfunction leaving 64 animals (n = 32 nulliparous heifers and n = 32 primiparous and multiparous cows) for analysis. A mixed model analysis of variance was performed using the PROC GLIMMIX procedure to test the fixed effects of calving location section and parity on the time cows entered their calving section. To determine time spent within the calving location section, mixed model analyses of variance were performed using the PROC GLIMMIX procedure to test the fixed effects of parity, day, and calving location section. Cow nested within parity was included as a random effect. A logistic regression model was performed using the PROC GLIMMIX procedure to test the probability for an animal to utilize a hide with the fixed effects of parity, day, and a parity by day interaction. Cow nested within parity was included as a random effect. To determine factors of interest (parity, calving location area, and time of day) association with the probability for cattle to separate at calving, a logistic regression model was performed using the PROC GLIMMIX procedure. A logistic regression model was performed using the PROC GLIMMIX procedure to separately test if the percentage of the herd in the same section as the focal animal, percentage of the herd in an adjacent section from the focal animal, and percentage of the herd in all other sections from the focal animal was associated with the probability for an animal to separate to calve.

RESULTS

When comparing the farm's estimated time of calving with other calving times confirmed by video (n = 34), the time difference was 49.7 ± 8.6 min (mean ± SE). Throughout the study, temperature ranged from -9.2 to 34.5 °C, and THI ranged from 18.1 to 81.8.

Calving Location Preference

The bedded-pack barn ($P = 0.002$) and natural forage cover ($P = 0.004$) were more frequently selected for calving compared to equal selection of each sections (Fig. 5). When the environment was condensed into 3 areas, 25 (39%) of the calvings occurred within the barn, while 17 (26%) calvings occurred in the open pasture and 23 (35%) calvings occurred in the natural forage cover.

Section of calving (i.e., 1 through 9) did not affect when cattle selected their section for calving (3.5 ± 1.4 h; $P = 0.25$). There was no effect of parity (nulliparous heifers vs. primiparous and multiparous cows) on when calving location was selected prior to calving (4.1 vs. 2.9 ± 0.8 h, respectively; $P = 0.20$). Cattle spent a greater percentage of the day in their calving section on the day of calving compared to the pre-calving day (17.8 vs. 9.0 ± 1.7%; $P < 0.001$). Cattle that calved in the barn spent a greater percentage of the calving and pre-calving days in their calving section compared to cattle calving in the other sections (Fig. 6; $P < 0.001$). Parity (nulliparous heifers vs. primiparous and multiparous cows) did not affect the percentage of the calving day cattle spent in their calving section (12.6 vs. 13.0 ± 1.9%, respectively; $P = 0.85$).

Factors Affecting Calving Location

Parity was associated with selection of calving location ($P = 0.02$). Primiparous and multiparous cows selected the bedded-pack barn more frequently for calving, while nulliparous heifers selected the natural forage cover more frequently. When comparing the natural forage cover to the bedded-pack barn, nulliparous heifers were more likely to calve in the natural forage cover (OR = 6.9; 95% CI [1.8, 26.4]). Nulliparous heifers were equally as likely to calve in the open pasture or the barn (OR = 2.7; 95% CI [0.7, 10.2]). Heat stress was also associated with selection of calving location ($P = 0.02$). When comparing the natural forage cover to the barn, cattle were more likely to calve in the natural forage cover if they were not experiencing heat stress conditions (OR = 7.4; 95% CI [1.2, 45.1]). Cattle were equally as likely to calve in the open pasture or barn regardless of heat stress conditions (OR = 0.6; 95% CI [0.2, 2.1]). Time of day ($P = 0.25$) and cow to heifer ratio ($P = 0.62$) did not affect selection of calving location.

Man-made Hide Use

Cattle (n = 2 of 65) used the hides for calving, and both animals were multiparous. When comparing the percentage of time cattle spent utilizing a hide on the calving and pre-calving days, there was a day by parity effect (Fig. 7; $P = 0.02$).

Separation at Calving

Cattle (n = 16 of 64) separated from the herd to calve. Of the 16 that separated, 10 were nulliparous heifers, and 6 were primiparous and multiparous cows. Cattle separated to sections 4 (n = 1), 6 (n = 2), 7 (n = 3), 8 (n = 2), and 9 (n = 8). Parity ($P = 0.87$), calving location area (i.e., barn, open pasture, and natural forage cover; $P = 0.73$), and

time of day ($P = 0.19$) did not affect the probability for cattle to separate from the herd to calve. When cattle did not separate to calve, they remained with the majority of the herd (66 ± 5%). A greater percentage of the herd was within the same section for cattle that did not separate to calve compared to cattle that did (66 vs. 0 ± 2%; $P < 0.001$). The percentage of the herd within adjacent sections to the focal animal did not differ whether cattle separated to calve or not (6 vs. 11 ± 4%; $P = 0.41$). When cattle separated from the herd to calve, a greater percentage of the herd was at least 2 sections away (i.e., other sections) compared to cattle that did not separate (90 vs. 28 ± 7%; $P < 0.001$).

DISCUSSION

Cattle express similar behaviors within indoor maternity pens and extensive pasture-based systems. The present study aimed to determine dairy cattle's calving behavior associated with calving environment and factors associated with these behaviors while group-housed in a pasture setting. We observed that cattle most frequently selected the bedded-pack barn and natural forage cover for calving. Parity and heat stress were associated with selection of calving location. Furthermore, cattle that separate from the herd to calve separated a greater distance from the herd, while cattle that did not separate stayed with the majority of the herd to calve. This suggests that individual animals have different preferences for their calving environment.

Dairy cattle utilized the bedded pack barn (38%) and the natural forage covered area (35%) for calving, which is in agreement with other studies on pasture where similar areas were provided (Edwards, 1983; Lidfors et al., 1994; Flörcke and Grandin, 2014). Lidfors et al. (1994) observed 9 of 14 beef and dairy cattle seeking out areas of natural

forage cover (i.e., trees and small bushes) and dry, soft ground, while the other 5 animals calved in or near the shelter. In another study, fewer dairy cattle (22%) selected the pasture for calving when a straw covered yard was also provided (Edwards, 1983). There was no forage cover in the pasture, so cattle may have perceived the straw covered yard as better protection from predators (Leuthold, 1977). Cattle in the present study may have chosen the barn and natural forage cover to calve because they are the best areas for hiding and protection.

Providing cattle with choices can be beneficial for establishing calving environment preferences (Nicol et al., 2009). However, preferences must be interpreted carefully because cattle are making choices based on what we provide them, yet their true preference may be for an environment that was not provided. Our results suggest that not all cattle have the same environmental calving preferences, and this should be taken into consideration when designing calving facilities.

Calving location was affected by parity. Primiparous and multiparous cows were more likely to calve in the bedded pack barn, while nulliparous heifers were more likely to calve in the natural forage cover. Lidfors et al. (1994) reported similar results, where the majority of nulliparous heifers calved in natural forage cover, and multiparous cows calved in the natural forage cover and barn. In a motivational-based calving facility where cattle can separate from a group calving pen into an individual pen, older cows were more likely to calve in the individual pen whereas younger cows were more likely to stay in the group area (Rørvang et al., 2018a). Older cows may have used the individual pens more because they had established dominance over this resource. Neave

et al. (2017) reported nulliparous heifers being replaced at the feedbunk more than multiparous cows during the weeks before calving (26.3 vs. 25.5 ± 1.4 n/d, respectively). Therefore, we speculate nulliparous heifers may have been the receiver of agonistic behaviors while in the barn, particularly at the feed bunk, which made the natural forage cover more preferable for calving. Future studies should focus on understanding what role social hierarchy has on calving location preferences.

Calving location was also affected by environmental heat stress conditions. Cattle were more likely to calve in the natural forage cover when they were not experiencing heat stressed conditions. Legrand et al. (2009) reported that primiparous and multiparous cows spent less time on pasture and more time in the freestall barn as THI increased between 0800 and 2200 h. In the present study, cattle calved in the barn during heat stress conditions, where there was the most protection from solar radiation. This suggests that cooling strategies like providing shade or fans should be used to prevent cattle from experiencing heat stress at calving. Furthermore, it would be beneficial to investigate the dynamic of multiple factor's influence on calving location and what factors are the greatest motivators.

Calving location was not affected by time of day. Most cattle calved during daytime, and. this may have been because cattle were fed each day at 1600 h. When dairy cattle were fed between 2000 and 0800 h, 68% of the cattle calved between 0600 and 1800 h (Pennington and Albright, 1985). Therefore, areas utilized by dairy cattle for calving are likely influenced by multiple variables including but not limited to management decisions related to when cattle are fed.

Calving location was also not affected by cow to heifer ratio. The majority of calvings occurred when the cow to heifer ratio was ≤ 2:1. The ratio of primiparous and multiparous cows to nulliparous heifers was not controlled but random. Cattle were enrolled into the study according to their anticipated calving date. Therefore, subsequent studies are needed to effectively determine the roles of parity and social hierarchy and their interaction on utilization and preference of calving environment. There were typically more primiparous and multiparous cows than nulliparous heifers. This may have created more incidences where primiparous and multiparous cows socially censored nulliparous heifers leading to parity being associated with calving location.

There was no effect of calving location and parity on when cattle selected their calving location. Cattle selected their calving location 2.2 to 5.8 h prior to calving. Nulliparous heifers selected their calving location 4.1 h before calving, while primiparous and multiparous cows selected their calving location 2.9 h before calving. In previous studies, cattle calving on pasture selected their calving location on the day of calving (Lidfors et al., 1994) and 12 to 24 h prior to calving (Flörcke and Grandin, 2014). Time of calving location selection was generally reported for these studies. Cattle in an indoor calving pen selected their calving location 8 h prior to calving (Proudfoot et al., 2014a). When lactating cows were provided with a larger freestall, they moved 60 m more per d (Telezhenko et al., 2012). Cattle on pasture have more space, which suggests they will spend more time moving throughout their environment before selecting their calving location.

We hypothesized that cattle would calve in the section where they spent most of their time because this would be an area they were familiar with and perceived as safe. Cattle that calved in the barn spent the greatest percentage of their day (46.0%) in the barn compared to cattle that calved in other sections (3.3 - 16.3%). Edwards (1983) discussed cattle calving in the shelter because it was where feeding occurred. This idea agrees with our study, where cattle were also fed within the barn. Cattle may want to calve where they spend most of their time, but factors like social hierarchy influence their choice.

In the present study, 2 of the 65 animals used the hides for calving. Cattle may not have perceived the hide as sufficient for hiding, which made the barn and natural forage cover more preferable. Lidfors et al. (1994) reported cattle preferred areas of natural forage cover (i.e., trees and small bushes), which visually secluded them from herd mates. In future studies, hides should be designed differently, perhaps with cover over head, to make them more suitable for calving. Although cattle did not calve near the hides, cattle still spent time near the hides before calving. It is possible that cows were investigating the hides for potential use at calving, but ultimately selected a different calving location.

Twenty-five percent of cattle separated from the herd to calve. Cattle that did not separate to calve remained within the same section as the majority of the herd (66%), while cattle that did separate calved at least 2 sections away from the majority of the herd (90%). Separation from the herd at calving on pasture has varied. Lidfors et al. (1994) reported 64% of cattle housed on 20 ha separated to calve, especially nulliparous heifers

that were disturbed during labor. When cattle were housed on 1 ha of pasture, 22% of cattle separated to calve with 81% of these animals separating at night (Edwards, 1983). Rørvang et al. (2018b) reviews the idea that distance is an important aspect of separation. This suggests that cattle are more likely to separate when housed on larger areas of pasture. However, results reporting separation may also vary based on definition. Lidfors et al. (1994) defined separation as cows that were more than 30 m from their herd mates and were visually isolated. In the present study, it was difficult if not impossible for cattle to isolate themselves visually from the herd. Consequently, calving facilities should be designed for cattle that do and do not want to separate.

CONCLUSIONS

Our results provide evidence that the bedded-pack barn and natural forage cover were most frequently utilized for calving. Parity and heat stress were associated with selection of calving location. Nulliparous heifers were more likely to calve in the natural forage cover compared to the barn. Cattle in non-heat stressed conditions were also more likely to calve in the natural forage cover compared to the barn. Furthermore, cattle that did not separate remained within the majority of the herd to calve, while cattle that did separate calved at least 2 sections away from the majority of the herd. This suggests individual animals have different preferences for their environment at calving. Therefore, multiple preferences should be considered when modifying and designing calving facilities.

CHAPTER III

THE EFFECT OF CALVING LOCATION ON LYING BEHAVIORS AND MOVEMENT THROUGHOUT PASTURE OF PERIPARTURIENT HOLSTEIN DAIRY CATTLE

ABSTRACT

The objectives were to determine (1) dairy cattle's lying behaviors at calving, (2) their movement throughout the environment at calving, and (3) if these behaviors change based on selection of calving environment when housed in a bedded-pack barn with free access to pasture. Seventy-two Holstein dairy heifers and cows (n = 36 nulliparous, n = 19 primiparous, and n = 17 multiparous) were housed in a covered bedded-pack barn (167.4 m^2) with free access to 2.1 ha of pasture. The group was dynamic as cattle were moved into the environment every Tuesday, 23 ± 3 d (mean ± SD) before their expected calving date and were removed after calving. To determine calving location, the pasture was subdivided into 8 sections [sections 2 - 8 (open pasture) were of approximately equal size (2,402 ± 60 m^2), and section 9 (natural forage cover) was 3,593 m^2]. The barn (167.4 m^2) served as section 1. Cattle were fitted with an accelerometer on their hind leg to measure lying time (h/d), lying bout duration (min/bout), lying bouts (n/d), and steps (n/d) for the 24 h prior to calving (calving day) and the same 24-h period 4 to 11 d (median = 7) prior to calving, which served as a baseline comparison (pre-calving day). Video data, reviewed with 10-min scan samples, were used to record the section the animal was located in. The minimum number of sections required to cross between successive observations was then determined for the calving and pre-calving days to determine movement across sections. To determine if calving location affected lying behaviors and the number of sections crossed, the environment was condensed from 9 sections into 3 areas (section 1 = barn, sections 2 - 8 = open pasture, and section 9 = natural forage cover). Lying time and lying bout duration decreased, while lying bouts

and number of sections crossed increased on the day of calving compared to the pre-calving day. Steps were affected by a day by parity by heat stress interaction. Calving location did not affect any of these behaviors on the day of calving. This suggests that cattle change their lying behaviors and move throughout their environment more on the day of calving. Allowing changes in behavior is important in the calving area to promote good welfare. Key words: dairy cow; calving location; lying behavior

INTRODUCTION

Around the time of calving, dairy cows must cope with a number of nutritional, physiological, and environmental stressors, which puts them at an increased risk for dystocia and disease. Challenges at this time have continued to be addressed by understanding nutritional demands and changes in lactational physiology and then modifying management practices in these areas to reduce these risks (Overton and Waldron, 2004; Ingvartsen, 2006). However, there is potential to further improve calving outcomes by evaluating environmental stressors. Recent research has determined that cattle will continue to express some of the same behaviors across calving environments (Lidfors et al., 1994; Proudfoot et al., 2014a; Black and Krawczel, 2016). Calving facility design and management can be improved by understanding how to accommodate cattle's maternal behaviors (von Keyserlingk and Weary, 2007).

The environment at parturition can impact maternal behavior. When comparing individual maternity pens and pasture environments, cattle on pasture transitioned between lying and standing more at calving suggesting pasture is more comfortable (Black and Krawczel, 2016). Cattle moved to an individual maternity pen during late

stage one labor decreased their lying time due to increased exploration of the new environment (Proudfoot et al., 2013). Environment also has the potential to influence the degree of calving difficulty (Mainau and Manteca, 2011). Nulliparous heifers housed in a pen at calving experienced an increased incidence in dystocia due to vulvar constriction compared to heifers that remained in a paddock or large yard (Dufty, 1981). This evidence further supports that calving environments must be designed with maternal behaviors in mind as they can negatively affect calving outcomes.

Changes in lying behaviors are frequently observed as calving approaches (Jensen, 2012; Black and Krawczel, 2016; Rice et al., 2017) potentially due to the discomfort experienced from myometrial and abdominal contractions (Mainau and Manteca, 2011). When cattle were housed on pasture at calving, lying time and lying bout duration decreased, while number of lying bouts and steps increased (Black and Krawczel, 2016; Rice et al., 2017). Cattle in an individual maternity pen decreased their lying time on the day of calving and increased their lying bouts 4 h prior to calving as they transitioned into stage two labor (Jensen, 2012). In an indoor group-housed setting, cattle changed their behaviors similarly to being in an individual pen at calving (Miedema et al., 2011b). Altered lying behaviors have been observed in all calving environments, which indicates they are key behaviors to accommodate for in the calving environment.

Although lying behavior changes have been documented, little is known about how cattle will utilize and move throughout their environment at calving. Lactating cattle housed in a large freestall pen utilized the extra space provided and moved greater

distances compared to cattle in a small freestall pen (Telezhenko et al., 2012). As cattle become restless, it may be important to them to explore various areas of the environment to seek out the ideal birthing site.

Little research has been done to determine behavioral changes during the hours around calving and how cattle use their environment at calving when primiparous and multiparous cows and nulliparous heifers are group-housed on pasture. The objectives of our study were to determine (1) dairy cattle's lying behaviors at calving, (2) their movement throughout the environment at calving, and (3) if these behaviors change based on preference for calving environment when housed in a bedded-pack barn with free access to pasture.

MATERIALS AND METHODS

All animal procedures were approved by the University of Tennessee IACUC committee (IACUC Protocol #2399-1115). This study was conducted at the University of Tennessee's Little River Animal and Environmental Unit (Walland, TN; 35° 46' 5.8116" N, 83° 50' 55.446" W) from July to December 2016.

Animals, Housing, and Management

Seventy-two Holstein dairy heifers and cows (n = 36 nulliparous, n = 19 primiparous, and n = 17 multiparous) were used in this experiment. Throughout this paper, primiparous and multiparous cows are referred to and analyzed as a group. Cattle were housed in a covered bedded-pack barn (167.4 m^2) with free access to 2.1 ha of pasture for calving (Fig. 3). The group was dynamic as cattle were moved into the environment every Tuesday, which was approximately 23 ± 3 d (mean ± SD) prior to

their expected calving date and were removed after calving. Cattle's locomotion was scored using a 3-point scoring system (1: sound; 2: moderately lame; 3: severely lame) when entering the study and at calving. The mean; range of animals entering the study each week was 3; 0 to 16 animals. Group size was 11; 1 to 18 animals (mean; range). There were 2 incidences where 1 animal was in the pasture. A new group of cattle was moved into the environment within 24 h to prevent cattle from calving alone. Cattle spent 21; 11 to 34 d (mean; range) in the environment. The barn was deep bedded with straw and cleaned as determined by the farm. The barn was equipped with 23 headlocks, and cattle were fed a TMR once daily at 1600 h and had ad libitum hay in the barn. Two automatic waterers (Thrifty-King CT4-2000, Ritchie Industries, Inc., Conrad, IA, USA) were provided (one in the barn and the other at the far end of the pasture). While most of the pasture (82.4%) was flat and open with no forage cover, there was an area at the far end of the pasture (17.6%) surrounded by natural forage cover (i.e., trees, tall grasses, and bushes). Man-made, v-shaped hides (n = 6) were built by bolting corrugated metal sheets to one side of a metal gate (3.7 x 1.8 m) and connecting two metal gates (Fig. 4). Hides were placed in sets of 2 throughout the pasture to serve as alternative areas for calving. A pair of hides were placed 5 m apart opened away from each other with the opening also measuring 5 m (Fig. 4).

Environmental Measurements

A weather station at University of Tennessee's Little River Animal and Environmental Unit collected hourly temperature and humidity data. These data were used to calculate the hourly and mean daily temperature humidity index (THI; NOAA,

1976) for the 24 h prior to calving (referred to as the calving day) and the same 24-h period 4 to 11 d (median = 7) prior to calving. This served as a baseline comparison (referred to as the pre-calving day). Cattle were assigned different pre-calving days to compare calving and pre-calving days with similar weather conditions (n = 11) or due to camera malfunction (n = 8). Previous research has used a pre-calving comparison period 1 to 10 d before calving (Miedema et al., 2011b). Cattle were then assigned to a heat stress category (THI ≤ 68 = no heat stress and THI > 68 and ≤ 79 = mild to moderate heat stress (Cook et al., 2007) for the calving and pre-calving days, and each hour on the calving day.

Behavioral Measurements

Behaviors were continuously recorded using 11 1.0-Megapixel Outdoor IP67 Bullet Cameras (Amcrest, Houston, Texas) mounted on wooden poles 4 m above the ground. Cameras had IR-LED lights to facilitate night viewing. One camera was placed in the barn and the other ten cameras were placed along the fence line of the pasture (Fig. 3). The video was continuously backed up onto two 8-channel 720p HDCVI DVRs (Amcrest, Houston, Texas) and transferred to a Seagate 6TB External Hard Drive (Seagate, Cupertino, California) daily.

Calving Location. Video data were used to determine the time and location of calving, defined as the time the animal stood up after calving or if she was already standing when the calf's hips were expelled. Due to camera placement, exact calving time for some cattle (n = 31) could not be determined. The farm's estimated time of calving was used for these cattle. To determine calving location, the pasture was divided

with Quik Shot Spray Paint (LA-CO Industries Inc., Elk Grove Village, Illinois) into 8 sections (Fig. 3). Sections 2 through 8 (i.e., open pasture) were of approximately equal size (2,402 ± 60 m^2; mean ± SD). Section 9 (i.e., natural forage covered area) was 3,593 m^2. The covered barn (167.4 m^2) served as section 1 (Fig. 3). Man-made hides were placed in pairs and rotated weekly between sections. During one week hides would be in sections 3, 6, and 7 and the next week in sections 4, 5, and 8. Hides were rotated to determine whether there was a preference for the hide or the section the hide was located. Cattle were considered to be using the hide if they calved within one cow length of the hide.

Lying Behaviors. Cattle were fitted with an accelerometer (IceTag, IceRobotics, Edinburgh, UK) on their hind leg upon entering the study, and accelerometers were removed 14 d after calving. Accelerometers measured lying time (h/d), lying bout duration (min/bout), lying bouts (n/d), and steps (n/d). All lying bouts ≤ 2 min were removed (Endres and Barberg, 2007). To determine changes in lying behaviors at calving, all behaviors were collected for the calving and pre-calving days. Lying time (min/h) and steps (n/h) were calculated by hour during the calving day and compared to the respective hour during the pre-calving day to determine when these behaviors began to change at calving.

Movement across Sections. To understand how cattle moved throughout their environment, ten-min scan sampling of video data were used to record the section the animal was located in. To determine the number of sections crossed, the minimum

number of sections required to cross between successive ten-min observations was then calculated for the calving and pre-calving days (n/d; Telezhenko et al., 2012).

Statistical Analysis

Inclusion Criteria. If an animal calved within 7 d of entering the study, it was assumed she did not have adequate time to become familiar with all areas of the barn and pasture and therefore was excluded. Grant and Albright (2001) reported that after regrouping it takes approximately 3 d and no more than 7 d for the social hierarchy to be established. Cattle (n = 1) were excluded if their locomotion was scored a 3 on the 3-point scale at either time point as these cattle may not have been able to fully explore the environment or calve where they preferred. Cattle (n = 5) that experienced severe dystocia and required the assistance of farm staff or a veterinarian were excluded due to being moved into the barn for assistance. Therefore, their preferred calving location could not be determined. If cattle aborted their calf or calved twins, they were removed from the study. One animal was excluded from the data due to accelerometer malfunctioning; only the first four days of data were recorded. Another animal was also excluded because she got out of the pasture and was not moved back into the study pasture until she was already in stage two labor. This left 64 animals (n = 31 nulliparous heifers and n = 33 primiparous and multiparous cow) for analysis.

This experiment was implemented using an observational study design, and the experimental unit was the cow. All statistical analyses were performed with SAS software v9.4 (SAS Institute Inc., Cary, NC). Significance was declared at $P \leq 0.05$. A chi-square was performed using the PROC FREQ procedure to compare the frequency of

calvings that occurred within each section and the frequency of calvings that would occur if there was no preference for any particular section. The frequency of calvings for no preference was calculated by dividing the number of total calvings by the 9 sections.

Mixed model analyses of variance were performed using PROC GLIMMIX procedures to test the fixed effects of day, parity, heat stress, and all interactions on lying behaviors. The response variables of interest were lying time, lying bout duration, lying bouts, and steps. Backward manual elimination was used to remove all non-significant interactions. In all four models, cow nested within parity was included as a random effect.

To determine if lying time and steps began to change at a certain hour on the day of calving, the fixed effects of parity, hourly heat stress, day, hour, and day by hour were tested using the PROC GLIMMIX procedure. To determine if calving location affected lying behaviors, sections 1 through 9 were condensed into 3 areas (section 1 = barn, sections 2 through 8 = open pasture, and section 9 = natural forage cover). Mixed model analyses of variance were performed using PROC GLIMMIX procedures to test the fixed effects of area, parity, and area by parity on lying behaviors during the calving day. Backward manual elimination was used to remove all non-significant interactions.

To validate the use of 10-min scan sampling, 5-min scan sampling was used for a subset of cattle (n = 20) during the calving and pre-calving days. Both scans were highly correlated (r = 0.90). Mixed model analyses of variance were performed using PROC GLIMMIX procedures to test the fixed effects of day, parity, heat stress, and all

interactions on the number of sections crossed with a random effect of cow nested within parity. Backward manual elimination was used to remove all non-significant interactions.

RESULTS

When comparing the farm's estimated time of calving with other calving times confirmed by video (n = 34), the time difference was 49.7 ± 8.6 min (mean ± SE). Throughout the study, temperature ranged from -9.2 to 34.5 °C, and THI ranged from 18.1 to 81.8.

Calving Location Preference

When comparing the frequency of calvings in each section to the frequency of calvings if there was no preference, the bedded-pack barn ($P = 0.002$) and natural forage covered section ($P = 0.004$) were more frequently selected for calving (Fig. 5).

Lying Behaviors

Cattle spent less time lying on the day of calving compared to the pre-calving day (7.4 vs. 9.9 ± 0.2 h/d; $P < 0.001$). Lying time for nulliparous heifers was lower than for primiparous and multiparous cows (7.6 vs. 9.7 ± 0.3 h/d; $P < 0.001$). Cattle that were experiencing mild to moderately heat stress conditions spent less time lying than cattle that were not experiencing heat stressed conditions (7.7 vs. 9.6 ± 0.3 h/d; $P < 0.001$).

Cattle had shorter lying bout durations on their calving day compared to their pre-calving day (34.0 vs. 65.4 ± 2.5 min/bout; $P < 0.001$). There was no effect of parity (nulliparous heifers vs. primiparous and multiparous cows) on lying bout duration (47.5 vs. 51.9 ± 2.8 min/bout, respectively; $P = 0.27$). There was also no effect of

environmental conditions (no heat stress vs. mild to moderate heat stress) on lying bout duration (51.7 vs. 47.7 ± 2.8 min/bout, respectively; $P = 0.32$).

Lying bouts increased on the day of calving compared to the pre-calving day (14.9 vs. 9.8 ± 0.6 n/d; $P < 0.001$). There was no effect of parity (nulliparous heifers vs. primiparous and multiparous cows) on lying bouts (11.6 vs. 13.1 ± 0.7 n/d, respectively; $P = 0.14$) along with cattle experiencing non-heat stressed and mild to moderately heat stressed conditions (13.0 vs. 11.7 ± 0.7 n/d; $P = 0.27$). Figure 8 depicts the day by parity by heat stress interaction for steps (n/d; $P = 0.008$).

There was a day by hour effect for lying time (Fig. 9A; $P = 0.001$) and steps (Fig. 9B; $P = 0.007$). Cattle spent more time lying during the -17 to -5 h prior to calving and laid for similar amounts of time from -4 h up until calving. Cattle began taking more steps beginning -22 h before calving and consistently took more steps until -10 h before calving.

On the day of calving, nulliparous heifers spent less time lying than primiparous and multiparous cows (6.6 vs. 8.5 ± 0.4 h/d; $P = 0.001$). There was no effect of parity (nulliparous heifers vs. primiparous and multiparous cows) on lying bout durations at calving (32.4 vs. 35.8 ± 3.0 min/bout, respectively; $P = 0.44$). At calving, there was no effect of parity (nulliparous heifers vs. primiparous and multiparous cows) on lying bouts (14.5 vs. 15.7 ± 1.0 n/d, respectively; $P = 0.44$). Nulliparous heifers took more steps than primiparous and multiparous cows on the day of calving (5,730 vs. 4,669 ± 291 n/d; $P = 0.02$).

Calving location area (i.e., barn, open pasture, and natural forage cover) did not affect lying time on the day of calving (7.9 vs. 6.7 vs. 7.9 ± 0.5 h/d, respectively; P = 0.11). It also did not affect lying bout duration (41.0 vs. 32.0 vs. 29.4 ± 3.6 min/bout; P = 0.07). There was no effect of calving location area on lying bouts (16.2 vs. 15.7 vs. 13.3 ± 1.3 n/d; P = 0.23). Calving location area did not affect steps during the day of calving (5,195 vs. 5,370 vs. 5,033 ± 352 n/d; P = 0.80).

Movement across Sections

There was a day by parity effect for the number of sections that were crossed (Fig. 10; P = 0.05). Heat stress conditions did not affect the number of sections crossed (P = 0.71). Parity (P = 0.39) and calving location area (i.e., barn, open pasture, and natural forage cover; P = 0.92) did not affect the number of sections crossed on the day of calving.

DISCUSSION

While previous studies have observed lying behaviors at calving on pasture and in indoor maternity pens, the present study aimed to measure lying behaviors and movement throughout the environment at calving and if these behaviors differed based on calving location preference. Our results provide evidence that lying time and lying bout duration decrease, while lying bouts, steps, and the number of sections crossed increase at calving when cattle are housed in a bedded-pack barn with free access to pasture. Yet, none of these behaviors differed based on calving location preference. These results confirm that cattle become more active on the day of calving.

Our finding that lying time and lying bout duration decreased on the day of calving agrees with other studies on pasture (Black and Krawczel, 2016; Borchers et al., 2017; Rice et al., 2017) and indoor maternity pen housing (Huzzey et al., 2005; Miedema et al., 2011b; Jensen, 2012). Cattle in the present study decreased their lying time from 9.9 h during the pre-calving day to 7.4 h on the day of calving. Bout duration decreased by 31.4 min/bout. Rice et al. (2017) reported similar results, where cattle housed on pasture decreased their lying time from 10.3 to 8.0 h/d, and bout duration decreased by approximately 40 min/bout at calving. However, Black and Krawczel (2016) observed similar lying bout durations during the weeks leading up to calving. Although, numerically lying bout duration did decrease by approximately 35 minutes. Cattle in indoor group and individual maternity pens laid for longer at calving (12.6 to 14.9 h/d) and decreased lying time by less (1 – 1.3 h; Miedema et al., 2011b; Jensen, 2012). Overall, the decrease in lying time and bout duration suggests cattle experience pain while calving from uterine pressure and cervical dilation (Mainau and Manteca, 2011). When comparing indoor and pasture environments, lactating cattle have different time budgets (Krohn et al., 1992; Legrand et al., 2009). It would be beneficial to determine if time budgets across environments are also different at calving to further understand how lying behaviors need to be accommodated for whether cattle are on pasture or in an indoor calving pen.

While lying time and lying bout duration decreased, lying bouts increased at calving. On the day of calving, cattle transitioned from lying to standing 14.9 times compared to 9.8 times on the pre-calving day. This is in agreement with previous studies

housing cattle on pasture (Black and Krawczel, 2016; Borchers et al., 2017; Rice et al., 2017) and in indoor maternity pens (Miedema et al., 2011b; Jensen, 2012). Black and Krawczel (2016) reported cattle increasing their bouts on pasture from approximately 8 bouts/d during the close-up period to approximately 14 bouts on the day of calving. In another study on pasture, cattle also increased their lying bouts from approximately 9 bouts/d to 14 bouts/d (Rice et al., 2017). Cattle in indoor maternity housing had a greater number of lying bouts. In an individual maternity pen, cattle had 17 bouts/d during the 3 d before calving, and transitioned from lying to standing 24 times on the day of calving (Jensen, 2012). Cattle in an indoor group pen express lying bouts similarly, where bouts increase from 16.4 to 24.2 on the day of calving. As previously discussed, time budgets vary between environments (Krohn et al., 1992; Legrand et al., 2009). However, Rørvang et al. (2018a) suggest periparturient cattle in indoor group housing become frustrated as indicated by increased activity, which may be why they have an even greater increase in lying bouts compared to pastured cattle. Future studies should focus on building recommendations for space needed at calving to allow cattle to express behaviors similarly as they would on pasture at calving.

An interaction of day, parity, and heat stress affected steps. All groups took significantly more steps on the day of calving compared to the pre-calving day, except mild to moderately heat stressed cattle. Heat stress affected nulliparous heifers on the day of calving, but not primiparous and multiparous cows. Previous studies measuring steps of cattle on pasture at calving disagree with the present study (Black and Krawczel, 2016; Rice et al., 2017). Cattle took approximately 3,600 steps on the day of calving, which was

similar to the days before calving (Rice et al., 2017). Multiparous cows were used in their study, while in the present study primiparous and multiparous cows and nulliparous heifers were used. Multiparous cows remain more calm at calving than nulliparous heifers (Wehrend et al., 2006), which may be why there is a difference in results. Black and Krawczel (2016) reported that steps were similar from the close-up period to calving. Although, there was a numerical difference, where cattle increased their steps by approximately 1,100 on the day of calving. This study was also conducted from August to January, so cattle may have experienced some heat stress. As heat load increases, cattle will spend more time in shaded areas (Schütz et al., 2010). Black and Krawczel (2016) housed cattle in pastures, where only natural forage cover was provided. Therefore, cattle may have remained in this area rather than moving throughout their environment. In the present study, cattle had shaded areas (barn and natural forage cover) at opposite ends of the pasture. Cattle had to travel up and down the pasture for shade and may have resulted in more steps taken.

Lying time began decreasing 21 h prior to calving, while steps began increasing 22 h prior to calving. Rice et al. (2017) observed cattle on pasture changing their lying time only during the hour before calving, when comparing the proportion of lying time for the 6 h before calving to its respective hour in a baseline period. Steps were also observed, and the authors reported that steps during the 6 h before calving were similar to their respective hour during the baseline period. Results may have been more similar with the present study if 24-h periods were being compared. In the present study, lying time was only different at h -5, and steps were different at h -2 and -6 for the 6 h before

calving. Environment at calving can also influence behavior at parturition (Black and Krawczel, 2016). Although cattle in both studies are on pasture, the environment may still be different (i.e., pasture size and location of natural forage cover). Barrier et al. (2012) reported cattle increased their lying time by 15.9 min/h during the 2 h before calving. This may be because as they enter stage two labor cattle will become recumbent to expel their calf.

In the present study, parity affected cattle's lying time. On average, nulliparous heifers laid for 7.6 h/d, while primiparous and multiparous cows laid for 9.7 h/d. Sepúlveda-Varas et al. (2014) reported similar results, where nulliparous heifers laid 7.5 h/d, and multiparous cows laid 8.5 h/d on pasture during the 3 wk after calving. However, lying time was not affected by parity during the transition period in freestall housing. During the 2 wk before calving nulliparous heifers spent more time feeding compared to multiparous cows (Neave et al., 2017). Nulliparous heifers may spend a lesser portion of the day lying due to allocating that time toward other behaviors, like feeding or grazing.

Like parity, heat stress has been reported to affect cattle's behaviors. Cattle that experienced mild to moderately heat stressed conditions laid less than non-heat stressed cattle (7.7 vs. 9.6 h/d, respectively). This is in agreement with other studies of cattle housed indoors and on pasture (Zähner et al., 2004; Cook et al., 2007; Schütz et al., 2010). Cattle decreased their lying time by 3 h/d as they became mild to moderately heat stressed (Cook et al., 2007). Cattle will decrease their lying time as heat stress increases to allow for airflow and greater evaporation of heat (Igono et al., 1987). This supports that cooling strategies are important, otherwise behavior is negatively impacted. In the

present study, cattle were provided with the barn and the natural forage cover for shade. No other cooling strategies were used.

We observed a day by parity effect for the number of times cattle crossed sections. Nulliparous heifers crossed 28 more sections on the day of calving compared to the pre-calving period, while primiparous and multiparous cows crossed 15 more sections on the day of calving. Primiparous and multiparous cows and nulliparous heifers crossed a similar number of sections at calving. Telezhenko et al. (2012) reported that lactating cattle managed in a large freestall pen changed grids 21% of the time, and cattle in a small freestall pen changed grids 19% of the time. This suggests when cattle are provided with more space they will utilize it, especially at calving based on our findings. This further supports that space is again an important design aspect to consider for calving. Rørvang et al. (2018b) reviews the idea that cattle in indoor group calving pens become frustrated due to inability to distance themselves from herd mates for calving, which may indicate cattle need more space. Future studies should focus on determining how much space cattle need at calving to express all behaviors.

We expected all lying behaviors and movement across sections to be affected by calving location area (i.e., barn, open pasture, or natural forage covered area) on the day of calving due to the majority of calvings occurring at opposite ends of the pasture. Therefore, we hypothesized that cattle calving in the natural forage cover would have to increase their steps and movement across sections, while decreasing their other lying behaviors to travel to that area. Anecdotally, these cows would pace up and down the pasture before selecting the natural forage cover to calve, which would support our

hypothesis. However, calving location area did not affect any of these behaviors. This suggests our cows used their environment to move greater distances and decrease lying time no matter what area they chose for calving.

CONCLUSIONS

Our results provide evidence that lying time and lying bout duration decreased, while lying bouts, steps, and number of sections crossed increased at calving. However, none of these behaviors were affected by cattle's calving location. Additionally, lying time began to decrease 21 h before calving, while steps began to increase 22 h before calving. To gain a deeper understanding of how calving facilities should be designed based on accommodating calving behaviors, research is needed to determine why time budgets are different across environments. Furthermore, cattle may need to be provided more space at calving to allow behaviors to be expressed as they would on pasture.

CHAPTER IV

CONCLUSIONS

The transition period is a stressful time for dairy cattle. They must be able to cope with labor along with changes in their environment, regrouping with other cattle, separation from their calf, diet changes, and the onset of lactation. Understanding maternal behaviors of dairy cattle and what cattle value from their environment can aid in addressing how to properly manage and house them. The objectives were to determine (1) dairy cattle's preference for calving environment and factors associated with their preference, (2) the herd's location in relation to cattle that did or did not separate from the group for calving, (3) lying behaviors at calving, (4) cattle's movement throughout the environment at calving, and (5) if lying behaviors and movement throughout the environment change based on calving location preference when group-housed in a bedded-pack barn with free access to pasture.

For the first objective, it was hypothesized that cattle would prefer the barn, natural forage cover, or man-made hides for calving compared to pasture. Additionally, parity, heat stress, time of day, and cow to heifer ratio would be associated with calving location preference. The bedded-pack barn and natural forage cover were most frequently selected for calving. Only 2 of the 65 animals utilized the man-made hides for calving. Parity and heat stress were associated with selection of calving location. Nulliparous heifers and non-heat stressed cattle were more likely to calve in the natural forage cover compared to the barn. The open pasture and barn were used equally for calving regardless of parity or heat stress. This suggests primiparous and multiparous cows and nulliparous heifers have different preferences for calving environment. Furthermore, heat stress plays a role in determining where cattle chose to calve. Multiple preferences should be

considered when designing calving facilities to accommodate all cattle within the calving area. Calving facilities should likely also provide areas of cover overhead and places for cattle to hide for protection and bonding with their calf. Additionally, cooling strategies (i.e., shade or fans) should be used in calving areas to accommodate heat-stressed cattle.

For the second objective, it was hypothesized that cattle would separate from the herd to calve, where the majority of the herd was at least 2 sections from the focal animal. Only 25% of the cattle separated from the herd to calve. When cattle separated to calve, they chose a calving location at least 2 sections away from the majority of the herd. When cattle did not separate to calve, they chose to calve in the same section as the majority of the herd. These results further support that multiple preferences need to be accommodated in the calving area, so cattle can separate from the herd if they desire. Future research should focus on determining how much space cattle need in order to perceive that they have separated far enough from the herd.

For the third objective, it was hypothesized that lying time and lying bout duration would decrease, while lying bouts and steps increased at calving. This is what we observed when comparing the calving day to the pre-calving day. Cattle spent more time lying during the -17 to -5 h prior to calving and laid for similar amounts of time from -4 h up until calving. Cattle began taking more steps beginning -22 h before calving and consistently took more steps until -10 h before calving. The change in lying behaviors suggests cattle may experience some pain and discomfort at calving. However, cattle may be more comfortable on pasture, which is why in the last hours before calving cattle's behavior is similar to its respective h on the pre-calving day.

For the fourth objective, it was hypothesized that movement throughout the environment would increase on the day of calving. Cattle increased the number of sections they crossed during the 24 h before calving. This suggests when cattle are provided with more space they will utilize it, especially at calving based on our findings, and further supports that space is again an important design aspect to consider for calving.

For the fifth objective, it was hypothesized that cattle calving in the natural forage cover would have to increase their activity and decrease lying behaviors as they would have to travel to the back of the pasture to calve there. However, preference for calving location did not affect any lying behaviors or the number of sections crossed. This suggests our cattle used their environment to move greater distances and decrease lying time no matter what area they chose for calving.

The main take-away from this research is that not all cattle have the same preference for their calving environment. Therefore, calving environments should provide diversity in choices. Future research should focus on understanding how social hierarchy and space play a role in calving location preference. Furthermore, research should investigate differences in lying behaviors across outdoor and indoor environments at calving. As we begin to understand cattle's preferences in a more natural environment like on pasture, we should investigate these findings in an indoor calving pen.

REFERENCES

Barrier, A. C., M. J. Haskell, A. I. Macrae, and C. M. Dwyer. 2012. Parturition progress and behaviours in dairy cows with calving difficulty. Appl. Anim. Behav. Sci. 139(3):209-217.

Black, R. A. and P. D. Krawczel. 2016. A case study of behaviour and performance of confined or pastured cows during the dry period. Animals 6(7):41.

Borchers, M., Y. Chang, K. Proudfoot, B. Wadsworth, A. Stone, and J. Bewley. 2017. Machine-learning-based calving prediction from activity, lying, and ruminating behaviors in dairy cattle. J. Dairy Sci. 100(7):5664-5674.

Borchers, M., Y. Chang, I. Tsai, B. Wadsworth, and J. Bewley. 2016. A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors. J. Dairy Sci. 99(9):7458-7466.

Cook, N., R. Mentink, T. Bennett, and K. Burgi. 2007. The effect of heat stress and lameness on time budgets of lactating dairy cows. J. Dairy Sci. 90(4):1674-1682.

Cook, N. B. and K. V. Nordlund. 2004. Behavioral needs of the transition cow and considerations for special needs facility design. Vet. Clin. Food Anim. 20(3):495-520.

Dufty, J. 1981. The influence of various degrees of confinement and supervision on the incidence of dystocia and stillbirths in Hereford heifers. N. Z. Vet. J. 29(4):44-48.

Edwards, S. 1983. The behaviour of dairy cows and their newborn calves in individual or group housing. Appl. Anim. Ethol. 10(3):191-198.

Edwards, S. and D. Broom. 1982. Behavioural interactions of dairy cows with their newborn calves and the effects of parity. Anim. Behav. 30(2):525-535.

Endres, M. I. and A. E. Barberg. 2007. Behavior of dairy cows in an alternative bedded-pack housing system. J. Dairy Sci. 90(9):4192-4200.

Esposito, G., P. C. Irons, E. C. Webb, and A. Chapwanya. 2014. Interactions between negative energy balance, metabolic diseases, uterine health and immune response in transition dairy cows. Anim. Reprod. Sci. 144(3-4):60-71.

Flörcke, C. and T. Grandin. 2014. Separation behavior for parturition of Red Angus beef cows. Open J. Anim. Sci. 4(02):43.

George, J. and I. Barger. 1974. Observations of bovine parturition. Pages 314-317 in Proc. Proc. Aust. Soc. Anim. Prod.

Grant, R. and J. Albright. 2001. Effect of animal grouping on feeding behavior and intake of dairy cattle. J. Dairy Sci. 84:E156-E163.

Graves, R. E., R. Engle, and J. T. Tyson. 2006. Design information for housing special dairy cows. Page 1 in Proc. 2006 ASAE Annual Meeting. ASABE.

Hafez, E.S.E. 1974. Page 196 in Reproduction in Farm Animals. 3rd ed. Lea & Febiger, Philadelphia, PA.

Heuwieser, W., U. Hartig, F. Offeney, and E. Grunert. 1987. Significance of glucocorticoids as a parameter of stress in cattle in the periparturient period. J. Vet. Med., Series A (Germany, FR).

Houwing, H., J. Hurnik, and N. Lewis. 1990. Behavior of periparturient dairy cows and their calves. Can. J. Anim. Sci. 70(2):355-362.

Huxley, J. and H. Whay. 2006. Papers & Articles. Vet. Rec. 159:662-668.

Huzzey, J., M. Von Keyserlingk, and D. Weary. 2005. Changes in feeding, drinking, and standing behavior of dairy cows during the transition period. J. Dairy Sci. 88(7):2454-2461.

Igono, M., H. Johnson, B. Steevens, G. Krause, and M. Shanklin. 1987. Physiological, productive, and economic benefits of shade, spray, and fan system versus shade for Holstein cows during summer heat. J. Dairy Sci. 70(5):1069-1079.

Ingvartsen, K. L. 2006. Feeding-and management-related diseases in the transition cow: Physiological adaptations around calving and strategies to reduce feeding-related diseases. Anim. Feed Sci. Technol. 126(3-4):175-213.

Jensen, M. B. 2012. Behaviour around the time of calving in dairy cows. Appl. Anim. Behav. Sci. 139(3):195-202.

Krohn, C. C., L. Munksgaard, and B. Jonasen. 1992. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments I. Experimental procedure, facilities, time budgets—diurnal and seasonal conditions. Appl. Anim. Behav. Sci. 34(1):37-47.

Lawrence, A. B., J. Petherick, K. McLean, L. Deans, J. Chirnside, A. Gaughan, E. Clutton, and E. Terlouw. 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. Appl. Anim. Behav. Sci. 39(3):313-330.

Lawrence, A. B., J. C. Petherick, K. McLean, C. L. Gilbert, C. Chapman, and J. A. Russell. 1992. Naloxone prevents interruption of parturition and increases plasma oxytocin following environmental disturbance in parturient sows. Physiol. Behav. 52(5):917-923.

LeBlanc, S. 2010. Monitoring metabolic health of dairy cattle in the transition period. J. Reprod. Dev. 56(S):S29-S35.

Legrand, A., M. Von Keyserlingk, and D. Weary. 2009. Preference and usage of pasture versus free-stall housing by lactating dairy cattle. J. Dairy Sci. 92(8):3651-3658.

Leuthold, W. 1977. African Ungulates : A Comparative Review of Their Ethology and Behavioral Ecology. Berlin, Heidelberg : Springer Berlin Heidelberg.

Lidfors, L. and P. Jensen. 1988. Behaviour of free-ranging beef cows and calves. Appl. Anim. Behav. Sci. 20(3):237-247.

Lidfors, L. M., D. Moran, J. Jung, P. Jensen, and H. Castren. 1994. Behaviour at calving and choice of calving place in cattle kept in different environments. Appl. Anim. Behav. Sci. 42(1):11-28.

Lombard, J., F. Garry, S. Tomlinson, and L. Garber. 2007. Impacts of dystocia on health and survival of dairy calves. J. Dairy Sci. 90(4):1751-1760.

Mainau, E. and X. Manteca. 2011. Pain and discomfort caused by parturition in cows and sows. Appl. Anim. Behav. Sci. 135(3):241-251.

Mee, J. 2008. Prevalence and risk factors for dystocia in dairy cattle: A review. Vet. J. 176(1):93-101.

Mee, J. F. 1991. Bovine perinatal mortality and parturient problems in Irish dairy herds. National University of Ireland.

Mee, J. F. 2004. Managing the dairy cow at calving time. Vet. Clin. Food Anim. 20(3):521-546.

Mee, J. F., J. Grant, C. Sánchez-Miguel, and M. Doherty. 2013. Pre-calving and calving management practices in dairy herds with a history of high or low bovine perinatal mortality. Animals 3(3):866-881.

Miedema, H. M., M. S. Cockram, C. M. Dwyer, and A. I. Macrae. 2011a. Behavioural predictors of the start of normal and dystocic calving in dairy cows and heifers. Appl. Anim. Behav. Sci. 132(1):14-19.

Miedema, H. M., M. S. Cockram, C. M. Dwyer, and A. I. Macrae. 2011b. Changes in the behaviour of dairy cows during the 24 h before normal calving compared with behaviour during late pregnancy. Appl. Anim. Behav. Sci. 131(1):8-14.

National Oceanic Atmospheric Administration (NOAA). Livestock hot weather stress. US Dept. Commerce. (C31-76)Natl. Weather Serv. Central Reg. Operations Manual Lett. NOAA, Kansas City, MO; 1976.

Neave, H., J. Lomb, M. von Keyserlingk, A. Behnam-Shabahang, and D. Weary. 2017. Parity differences in the behavior of transition dairy cows. J. Dairy Sci. 100(1):548-561.

Newby, N. C., T. F. Duffield, D. L. Pearl, K. E. Leslie, S. J. LeBlanc, and M. A. von Keyserlingk. 2013. Use of a mechanical brush by Holstein dairy cattle around parturition. J. Dairy Sci. 96(4):2339-2344.

Nicol, C. J., G. Caplen, J. Edgar, and W. J. Browne. 2009. Associations between welfare indicators and environmental choice in laying hens. Anim. Behav. 78(2):413-424.

Noakes, D.E., T.J. Parkinson, G.C.W. England, and G.H. Arthur. 2001. Parturition and the care of parturient animals. Pages 155-187 in Arthur's Veterinary Reproduction

and Obstetrics. 8th ed. D.E. Noakes, T.J. Parkinson and G.C.W. England eds. Saunders, Philedelphia, PA.

Oliviero, C., M. Heinonen, A. Valros, O. Hälli, and O. Peltoniemi. 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Anim. Reprod. Sci. 105(3-4):365-377.

Overton, T. and M. Waldron. 2004. Nutritional management of transition dairy cows: strategies to optimize metabolic health. J. Dairy Sci. 87:E105-E119.

Owens, J., T. Edey, B. Bindon, and L. Piper. 1985. Parturient behaviour and calf survival in a herd selected for twinning. Appl. Anim. Behav. Sci. 13(4):321-333.

Pennington, J. and J. Albright. 1985. Effect of Feeding Time, Behavior, and Environmental Factors on the Time of Calving in Dairy Cattle1, 2. J. Dairy Sci. 68(10):2746-2750.

Proudfoot, K., M. B. Jensen, P. M. Heegaard, and M. von Keyserlingk. 2013. Effect of moving dairy cows at different stages of labor on behavior during parturition. J. Dairy Sci. 96(3):1638-1646.

Proudfoot, K., D. Weary, and M. von Keyserlingk. 2014a. Maternal isolation behavior of Holstein dairy cows kept indoors. J. Anim. Sci. 92(1):277-281.

Proudfoot, K. L., M. Jensen, D. Weary, and M. von Keyserlingk. 2014b. Dairy cows seek isolation at calving and when ill. J. Dairy Sci. 97(5):2731-2739.

Proudfoot, K. L., D. Veira, D. Weary, and M. Von Keyserlingk. 2009. Competition at the feed bunk changes the feeding, standing, and social behavior of transition dairy cows. J. Dairy Sci. 92(7):3116-3123.

Rice, C. A., N. L. Eberhart, and P. D. Krawczel. 2017. Prepartum lying behavior of Holstein dairy cows housed on pasture through parturition. Animals 7(4):32.

Rørvang, M. V., M. S. Herskin, and M. B. Jensen. 2017a. Dairy cows with prolonged calving seek additional isolation. J. Dairy Sci. 100(4):2967-2975.

Rørvang, M. V., M. S. Herskin, and M. B. Jensen. 2018a. The motivation-based calving facility: Social and cognitive factors influence isolation seeking behaviour of Holstein dairy cows at calving. PloS one 13(1):e0191128.

Rørvang, M. V., B. Nielsen, M. S. Herskin, and M. B. Jensen. 2017b. Calving site selection of multiparous, group-housed dairy cows is influenced by site of a previous calving. J. Dairy Sci. 100(2):1467-1471.

Rørvang, M. V., B. L. Nielsen, M. S. Herskin, and M. B. Jensen. 2018b. Prepartum maternal behavior of domesticated cattle: A comparison with managed, feral, and wild ungulates. Front. Vet. Sci. 5:45.

Saint-Dizier, M. and S. Chastant-Maillard. 2015. Methods and on-farm devices to predict calving time in cattle. Vet. J. 205(3):349-356.

Schirmann, K., N. Chapinal, D. Weary, L. Vickers, and M. Von Keyserlingk. 2013. Rumination and feeding behavior before and after calving in dairy cows. J. Dairy Sci. 96(11):7088-7092.

Schütz, K., A. Rogers, Y. Poulouin, N. Cox, and C. Tucker. 2010. The amount of shade influences the behavior and physiology of dairy cattle. J. Dairy Sci. 93(1):125-133.

Sepúlveda-Varas, P., D. Weary, and M. Von Keyserlingk. 2014. Lying behavior and postpartum health status in grazing dairy cows. J. Dairy Sci. 97(10):6334-6343.

Stabenfeldt, G. H., and L. E. Edquist. 1984. Female reproductive processes. Page 798 in Duke's Physiology of Domestic Animals. 10th ed. M. J. Swenson, ed. Cornell Univ. Press, Ithaca, NY.

Telezhenko, E., M. Von Keyserlingk, A. Talebi, and D. Weary. 2012. Effect of pen size, group size, and stocking density on activity in freestall-housed dairy cows. J. Dairy Sci. 95(6):3064-3069.

USDA. 1996. Dairy 1996, Part I: Reference of 1996 Dairy Management Practices, 1996. USDA, ed. USDA-APHIS-VS C, Fort Collins, Co.

USDA. 2002. Dairy 2002, Part I: Reference of Dairy Health and Management in the United States, 2002. USDA, ed. USDA-APHIS-VS C, Fort Collins, Co.

USDA. 2007. Dairy 2007, Part I: Reference of Dairy Cattle Health and Management Practices in the United States, 2007. USDA, ed. USDA-APHIS-VS C, Fort Collins, Co.

USDA. 2014. Dairy 2014, Dairy Cattle Management Practices in the United States, 2014. USDA, ed. USDA-APHIS-VS C, Fort Collins, Co.

von Keyserlingk, M., N. Martin, E. Kebreab, K. Knowlton, R. Grant, M. Stephenson, C. Sniffen, J. Harner, A. Wright, and S. Smith. 2013. Invited review: Sustainability of the US dairy industry. J. Dairy Sci. 96(9):5405-5425.

von Keyserlingk, M. A. and D. M. Weary. 2007. Maternal behavior in cattle. Horm. Behav. 52(1):106-113.

Wehrend, A., E. Hofmann, K. Failing, and H. Bostedt. 2006. Behaviour during the first stage of labour in cattle: Influence of parity and dystocia. Appl. Anim. Behav. Sci. 100(3):164-170.

Williams, G., O. Gazal, L. Leshin, R. Stanko, and L. Anderson. 2001. Physiological regulation of maternal behavior in heifers: roles of genital stimulation, intracerebral oxytocin release, and ovarian steroids. Biol. Reprod. 65(1):295-300.

Zähner, M., L. Schrader, R. Hauser, M. Keck, W. Langhans, and B. Wechsler. 2004. The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables. Anim. Sci. 78(1):139-147.

APPENDIX

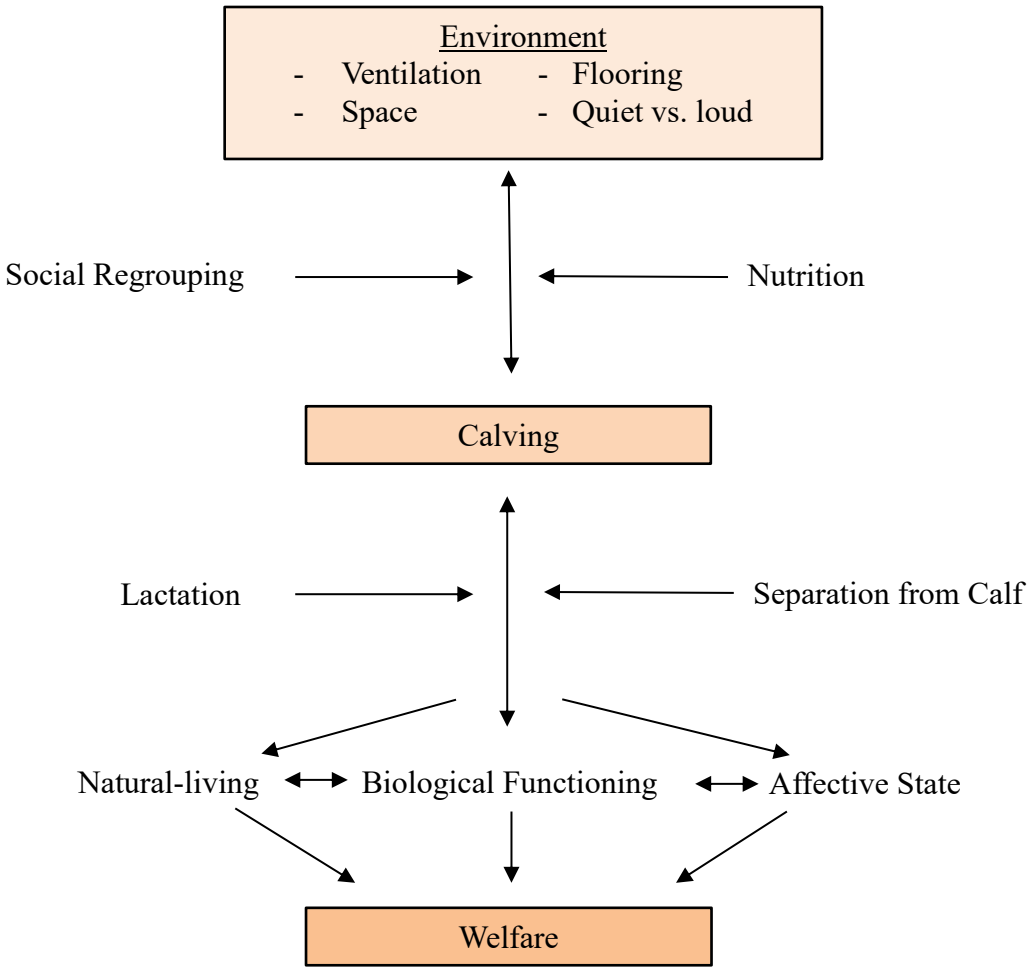


Figure 1. Dairy cattle face a number of stressors around the time of calving. When cattle are unable to cope, they are at high risk for decreased welfare. This can be due to inability to express natural behaviors, disease, or experiencing pain and suffering. Previous research has focused on understanding the role these stressors play in welfare. However, less research has determined the environment's role and how facility design accommodating periparturient cattle's behaviors may improve calving outcomes and therefore improve welfare.

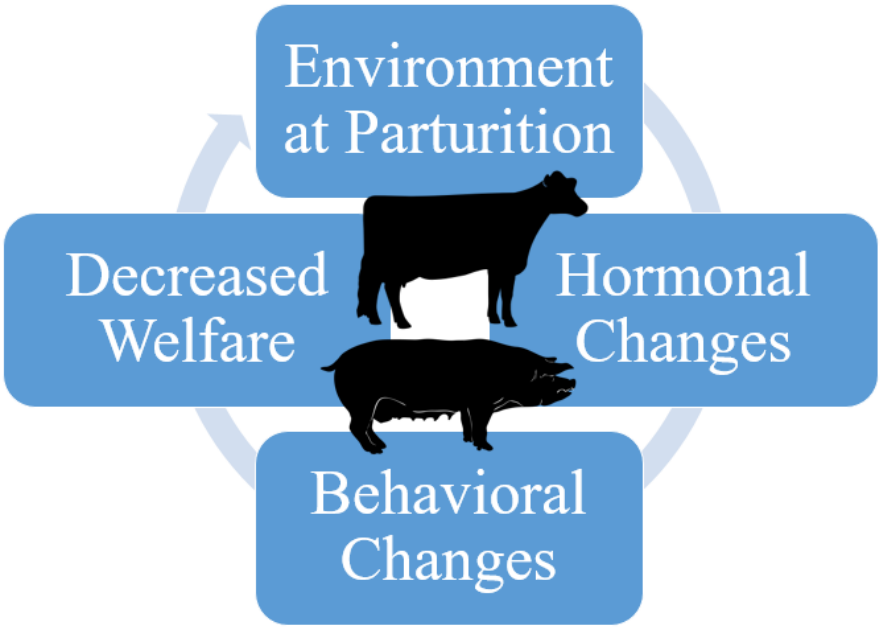


Figure 2. Environment at parturition can cause hormonal changes and therefore impact maternal behavior in pigs and cattle. Cortisol is released when pigs are housed in restricted crate environments for farrowing, which inhibits oxytocin release and leads to a disrupt in maternal behavior. Welfare of the sow and her pigs is then impaired. Less research has investigated hormonal change in different environments for dairy cattle. However, behavioral changes have been observed between calving environments and it is likely the same hormonal changes are occurring due to stress from the environment.

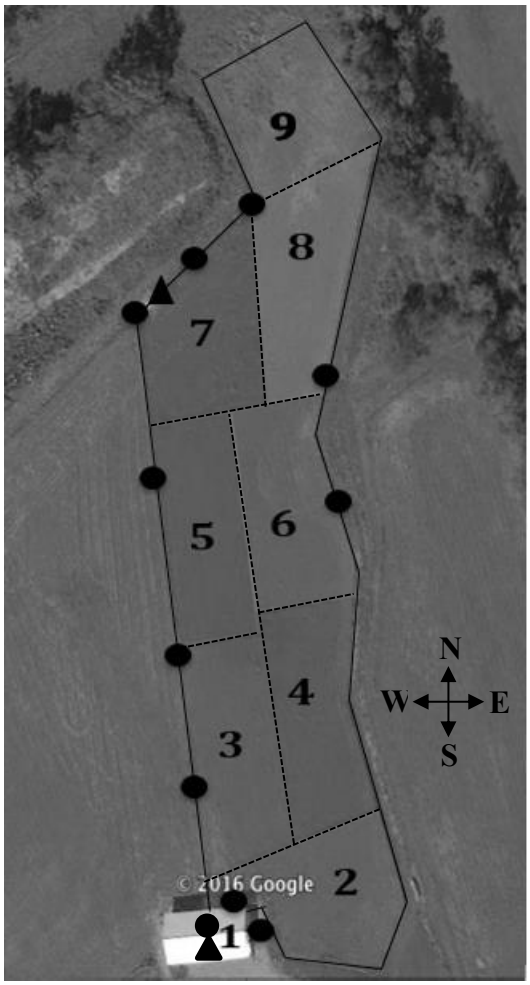


Figure 3. Aerial view of the study environment at the University of Tennessee's Little River Research and Environmental Unit. Cattle were housed in the covered bedded-pack barn with free access to pasture. The barn (167.4 m^2) served as section 1. The pasture was subdivided into 8 sections [sections 2 - 8 (open pasture) were of approximately equal size (mean ± SD; 2,402 ± 60 m^2), and section 9 (natural forage cover) was 3,593 m^2]. Solid lines denote fencing, while dashed lines denote division of the sections. Dots indicate cameras. Triangles indicate automatic waterers. Image obtained from Google Earth (Google, Mountain View, CA, USA).



Figure 4. Photograph of the man-made, v-shaped hides placed in the pasture as potential calving locations. A pair of hides were placed 5 m apart opened away from each other with the opening also measuring 5 m. Hides were rotated on a weekly basis. During one week a set of hides were placed in sections 3, 6, and 7, and the next week they were rotated to sections 4, 5, and 8.

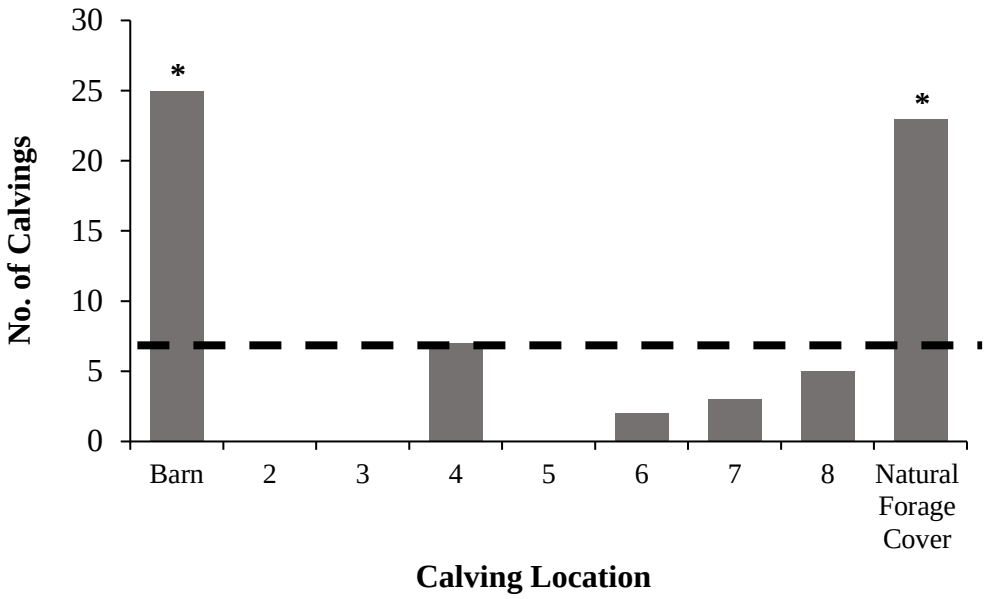


Figure 5. The number of calvings that occurred within each section of the study environment. The black dashed line indicates the number of calvings (n = 7) that would occur if there was no preference for any particular section. A chi-square test was performed using the PROC FREQ procedure of SAS 9.4 (Cary, NC) to compare the frequency of calvings that actually occurred within each section to the frequency of calvings that would occur if there was no preference for any particular section. Asterisks (*) indicate $P \leq 0.05$, where more calvings occurred compared to no preference.

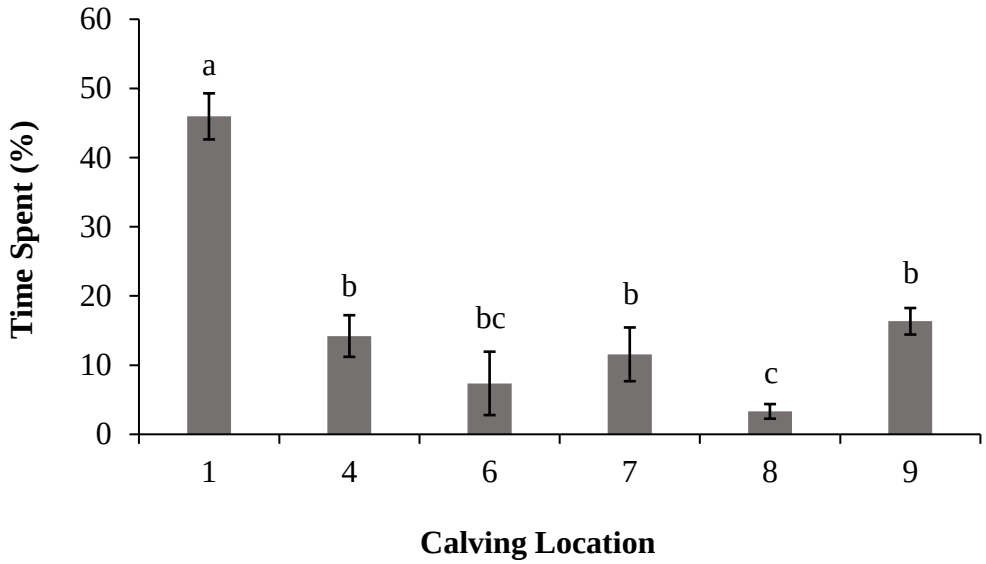


Figure 6. The mean (± SE) percentage of the day that cattle spent in their calving location calculated with the PROC GLIMMIX procedure of SAS 9.4 (Cary, NC) and testing the fixed effects of day, parity, and calving location. Bars without a common letter differ ($P \leq 0.05$).

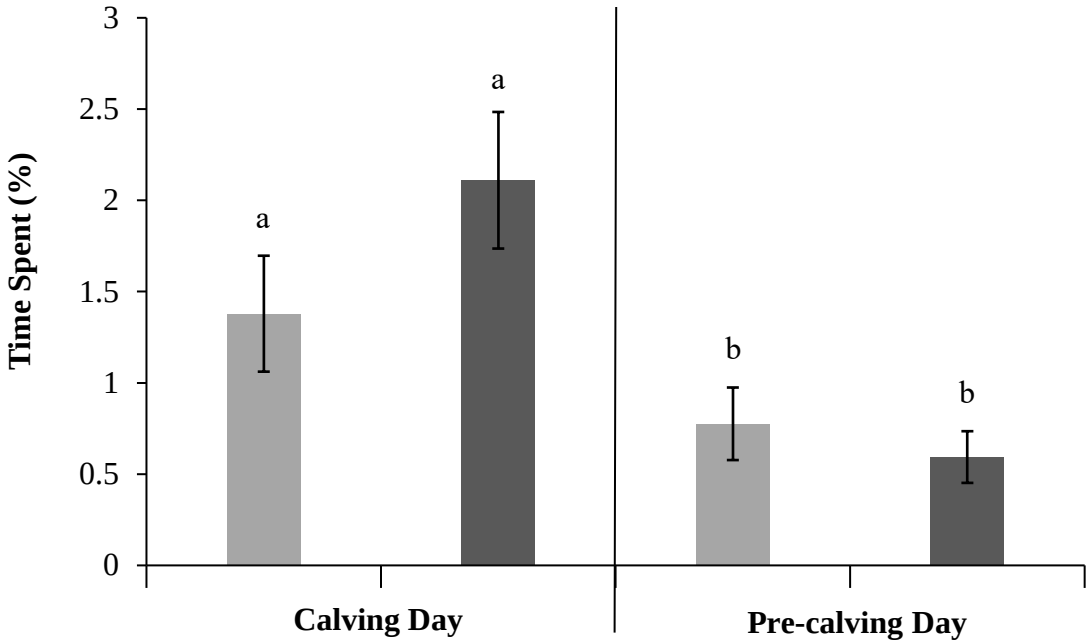


Figure 7. The mean (± SE) percentage of the day that nulliparous heifers (light grey bars) and primiparous and multiparous cows (dark grey bars) spent near (i.e., within one cow length) a hide was calculated for the calving and pre-calving days. Bars without a common letter differ ($P \leq 0.05$).

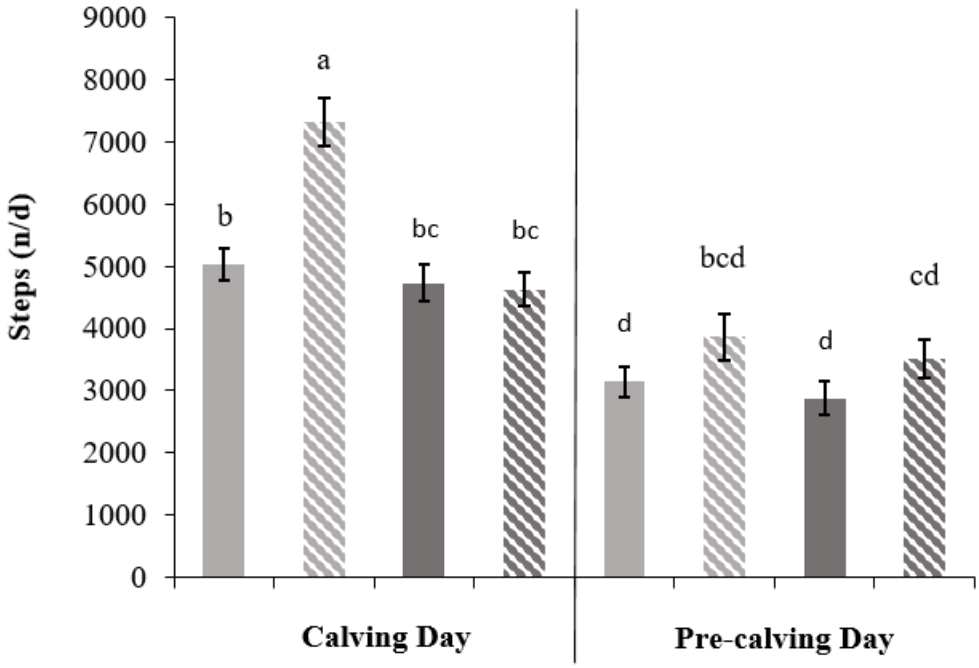


Figure 8. Steps (mean ± SE) was affected by a day by parity by heat stress interaction ($P = 0.008$). Nulliparous heifers are indicated by the light grey bars, while primiparous and multiparous cows are indicated by the dark grey bars. Solid bars denote no heat stress, and dashed bars denote mild to moderate heat stress. Bars without a common letter differ ($P \leq 0.05$).

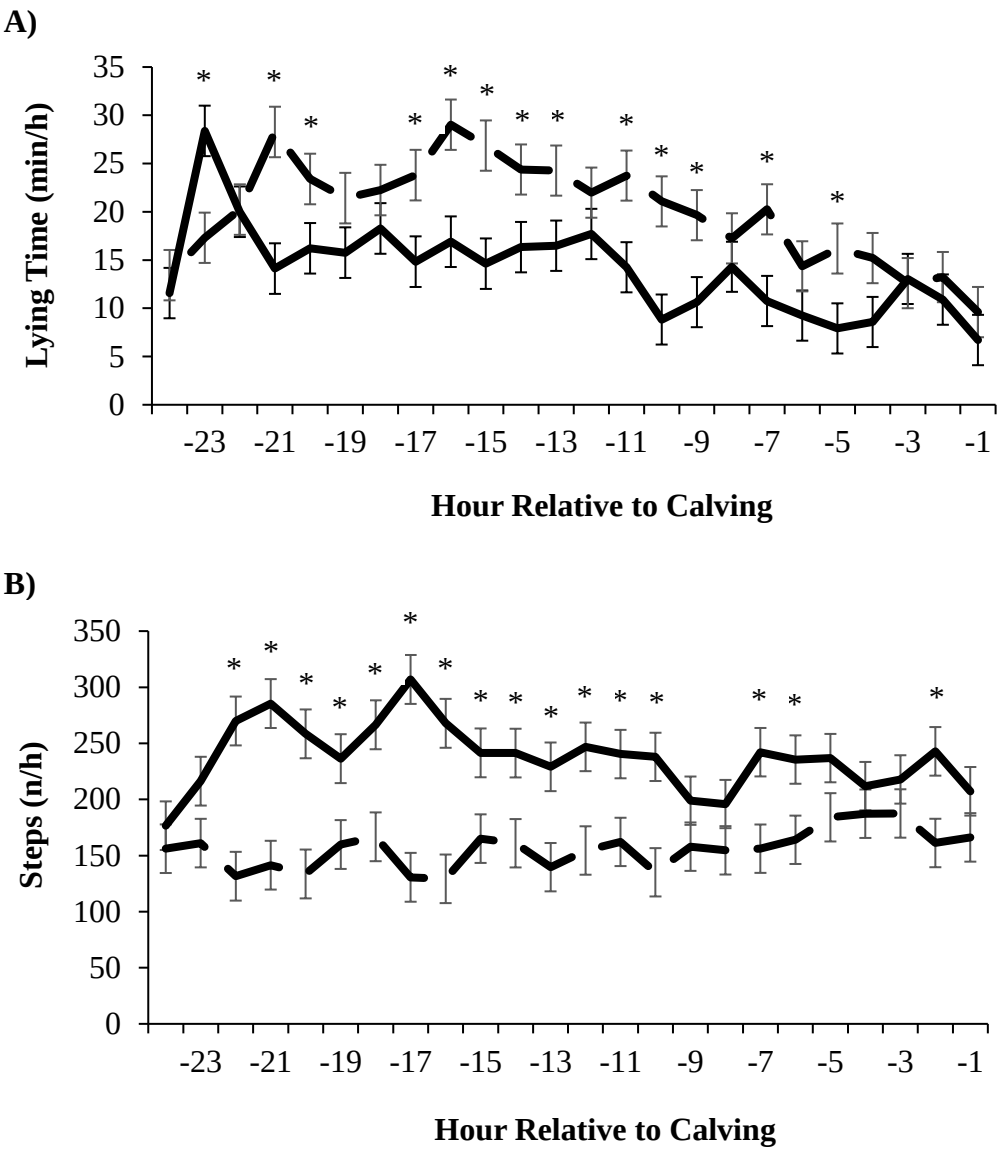


Figure 9. Changes in mean (± SE) hourly lying time (A) and steps (B) for the calving day (solid line) and pre-calving day (dashed line), To determine when these behaviors began to change for calving, each h on the calving day was compared to its respective h on the pre-calving day. H 0 is defined as the time when cattle stood after calving or if they were already standing when the calf's hips were expelled. Asterisks (*) denote significance between an h on the calving day and its respective h on the pre-calving day ($P \leq 0.05$).

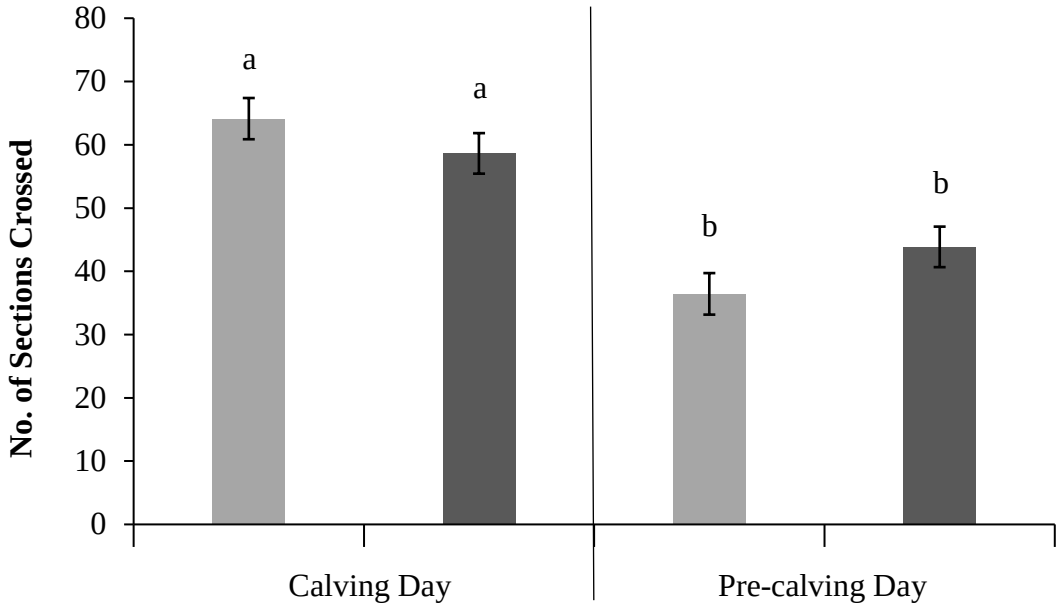


Figure 10. To determine cattle's movement throughout the environment, number of sections crossed (mean ± SE) between successive 10-min scan samples were calculated for nulliparous heifers (light grey bars) and primiparous and multiparous cows (dark grey bars) on the day of calving and the pre-calving day. Bars without a common letter differ ($P \leq 0.05$).

VITA

Erika Mae Edwards was born on July 22, 1994 in Cedar Rapids, IA. Erika graduated from Ballard High School in 2012 and continued her education at Iowa State University. There, she pursued a Bachelor's of Science degree in Animal Science and graduated in 2016. In Fall 2016, Erika began studying for her Master of Science under the direction of Dr. Peter Krawczel and focusing her research on transition dairy cow behavior. Erika has presented her research at one regional, one national, and two international meetings. Erika also participated in the University of Tennessee's Extension Program by presenting at multiple Tennessee Dairy Producer Modules and producing two extension publications.