The Effects of a Gel Mat Stall Surface on the Lying Behavior of Dairy Cattle

by

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ABSTRACT

THE EFFECTS OF A GEL MAT SURFACE ON THE LYING BEHAVIOR OF DAIRY CATTLE

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This thesis is an investigation of the effects of gel mat stall flooring on the activity, lying behavior and stall preferences of dairy cattle. In the first study, lactating cows (n=24) were housed in tie stalls on four flooring surfaces for one week each, in a cross-over design. Observations showed that housing cows on gel mats increased total lying time and decreased the time required to transition between lying and standing. The same cows housed on the foam mats and rubber mattresses spent longer standing. In the second study, non-lactating cows (n=18) in a free stall environment spent more time lying, and had a shorter latency to lie down after entering the gel mat stall. Cows restricted to the foam mat spent the most amount of time standing. Cows did not show a particular preference for either stall flooring surface during the final choice phase of the experiment. Results from both studies indicate that housing cows on gel mats promotes lying behavior.

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INTRODUCTION

Dairy products are very popular all across North America, and consumption of certain dairy products such as cream, yogurt and cheese are increasing (Government of Canada, 2011). To meet this demand, the number of dairy cows in Canada are increasing (StatCan, 2011), but they are being housed more intensively due to environmental constraints, biosecurity, health and welfare, and for ease of management. Understanding normal patterns of behavior is important for managing dairy cows properly; and in turn, the management of the dairy cows will influence their behavior. Assessing cow behavior is a useful tool to indicate their welfare and will be discussed in this literature review.

One of the most important behaviors cows exhibit is lying behavior. In general, cattle housed indoors spend about half of their day lying (Gomez and Cook, 2010; Tucker et al., 2009; Jensen et al., 2005; Drissler et al., 2005). Lying behavior serves many functions to the dairy cow. From a milk production standpoint, blood flow to the mammary region is increased when cattle are lying (Metcalf et al., 1992) and circulating growth hormone is decreased in cattle that are deprived of lying for 14 hours/day (Munksgaard and Løvendahl, 1993). From a welfare standpoint, it has been documented that prevention of lying is aversive, and increases the stress response to novel situations (Fisher et al., 2002; Munksgaard and Simonsen, 1996). In fact, after deprivation of feeding and lying, cows will forgo feeding in favor of lying (Cooper et al., 2007; Metz, 1985), and show increased circulating hormones associated with stress (Ndibualonji et al., 1995). Furthermore, abnormal lying times have been linked to increased hoof problems and lameness (Ceballos et al., 2004; Leonard et al., 1996). In a survey of 28 commercial dairy farms in British Columbia, it was possible to predict very lame (lameness score of 4/5, where 5 indicates severe lameness) cattle housed on deep-bedding simply by the amount of time they spent lying and their lying bout duration (Ito et al., 2010).

There are many factors both internally within the cow and externally in her environment that influence lying behavior. Internal factors discussed in this literature review include stage of lactation, milk yield, age, parity, social rank, and circadian rhythm. External factors to be discussed include: environmental conditions, social conditions and behavioral synchrony, management factors (such as time of feed delivery), and stall design. With regards to stall design, both stall size and stall flooring surfaces greatly affect lying behavior so must be taken into account when designing indoor lying areas for dairy cows. It has been suggested that many issues with poor stall design, such as stalls that are too small, will be tolerated so long as the stall surface is well cushioned (Nordlund and Cook, 2003). Observing cow behavior in the stall, in particular lying behavior will indicate if the stall environment is actually providing a comfortable place to rest

ANIMAL-BASED MEASURES FOR ASSESING DAIRY COW WELFARE

Before delving into the assessment of animal welfare, it is important to know what exactly is being referred to. The World Organization for Animal Health (2008) defines an animal as having good welfare if “it is healthy, comfortable, well nourished, safe, able to express innate behavior, and if it is not suffering from unpleasant states such as pain, fear, and distress”. When considering animal-based measures for assessing welfare, three questions are typically asked. Firstly, is the animal functioning well (i.e. good production, in good health), is the animal feeling well (i.e. not in pain), and is the animal able to perform natural behaviors (von Keyserlingk et al., 2009)? We can use measurements of cattle behavior, physiology and health to aid our understanding of their welfare under various management conditions.

Health

It is widely accepted that health is the foundation to good welfare (Dawkins, 2004). Measures of health typically focus on reproduction, disease, lameness and injury (von Keyserlingk et al., 2009; Hemsworth et al., 1995). Methods of detecting ill-health prior to clinical illness or mortality will improve cattle welfare by reducing suffering. One excellent example where early detection of disease improves welfare is a sensitive method of gait scoring that corresponds to the development of hoof lesions (von Keyserlingk et al., 2009). Monitoring changes in health at an early stage, allows the animal to be treated quickly before they are clinically ill, thus improving their welfare.

Lying behavior as an indicator of health

Changes in lying behavior are associated with various health challenges (e.g. mastitis, lameness). This literature review will focus on lameness, as it is one of the greatest health concerns of the dairy industry, and a large body of literature is available for this condition. Lying behavior is both a risk factor and preventative factor for lameness and claw ulceration. In a study of 103 free stall dairy farms in Germany and Austria, recording data on 3,514 cows, Dippel et al. (2009) found abnormal lying behavior to be a good predictor of lameness risk. They defined abnormal behavior as interrupted lying down and rising movements, lying down or rising lasting longer than 20 s, reversed lying (lying down with hindquarters first), horse-like rising (rising with forequarters first), and dog-like sitting (sitting on hindquarters like a dog). In addition to predicting lameness risk, lying times may be also used as an indicator of lameness. It has been observed on farms that used deep-bedding, that cows that lay for more than 14.5 h/d had significantly higher odds (16.2) of being very lame (Ito et al., 2010).

There is evidence that insufficient lying time acts as an exacerbating factor in the development of lameness (Leonard et al., 1996). Cows housed in free stalls on rubber mats and no bedding with long lying times (10 hours or more) developed lameness less frequently than their short-lying (less than 10 hours) counterparts (Leonard et al., 1996). Longer lying times are particularly beneficial when cows lie in dry, clean and well-cushioned stalls, as they then spend less time standing in moisture and manure in the alleyway (Tucker and Weary, 2001; Cook, 2001). When a cow is suffering from laminitis it has been suggested that increased lying times will decrease the severity of damage caused to the foot (Cook, 2001).

Physiology

Physiological measures such as sampling urine, blood, and milk are most commonly used to monitor the health of an animal (von Keyserlingk et al., 2009), however, in research these measures may also be used as an indicator of welfare. For instance, blood cortisol levels have been used as an indicator of stress (Barnett and Hemsworth, 1990). Respiration and heart rate have also been used to indicate whether an animal is acutely stressed (Barnett and Hemsworth, 1990). Under chronic stress, the animal’s physiological response may divert resources (such as energy) from biological functions deemed less critical to survival (e.g. reproduction and production) (Barnett and Hemsworth, 1990). Thus, some studies have suggested that lower-than-average lifetime milk production levels indicate poor ‘fitness’ and by extension, poor welfare (Barnett and Hemsworth, 1990). The validity of the previous statement has more recently been questioned. For dairy cows in North America milk production is widely recorded on farm. Studies have shown that ill and stressed cows have a reduced milk yield (von Keyserlingk et al., 2009). However, changes in milk yield are also related to nutrition, genetics and environment, some of which may have no effect on the animal's welfare. Additionally, cows that produce very high quantities of milk may be at higher risk for disease development and culling (von Keyserlingk et al., 2009). To provide better evidence of an animal's welfare, physiological measurements can be coupled with behavioral observations (Dawkins, 2004). For instance, measuring cortisol in cows deprived of lying, and then providing them with the option of standing, or lying down may give a clearer indication of the animal's welfare status.

Physiological response to lying behavior

Measures of hormones associated with stress, such as cortisol, are a useful method of measuring the effects associated with lying deprivation. Depriving 32 lactating cows of lying for nearly 16 hours a day for seven days caused a significant increase in plasma cortisol concentrations compared to cows that were able to lie at will (Fisher et al., 2002). As blood samples were collected when cows were free to lie down, the authors assumed that the elevated cortisol was due to the ongoing stress of insufficient lying opportunities, rather than transient stress caused by immediate prevention of lying (Fisher et al., 2002). Similarly, cows that were confined to a concrete yard for four days to preserve pasture quality, lay down for only 7 hours/day, and exhibited significantly higher fecal glucocorticoid metabolites than cows housed in a wood chip pen, that lay down for 11.9 hours/day (Fisher et al., 2003). When deprived of lying for 16 hours a day for 8 weeks, cattle show increased circulating adrenocorticotropic hormone (ACTH) concentrations (Munksgaard and Simonsen, 1996). ACTH is released by the anterior pituitary gland in response to stress.

From a production standpoint, hormones association with milk production and muscle development may be affected by lying behavior. One study found that growing bulls that were experimentally prevented from lying for 14 hours/day for ten weeks tended to have a lower concentration of insulin-like growth factor 1(impacts muscle anabolism) than bulls that were allowed to lie freely (Ingvartsen et al., 1999). Similarly, it has been observed that cows that experienced a lying deprivation of 13 hours for 22 days had significantly reduced concentrations of circulating growth hormone (lying deprived cows: 1.05 ng/ml; control cows: 1.59 ng/ml) (Munksgaard and Løvendahl, 1993) and blood flow to the mammary region was greater when cattle were lying rather than standing (Metcalf et al., 1992). It has been estimated that the blood flow through the mammary glands increases by 2 litres/minute when cows are lying rather than standing (5 vs. 3 litre/min) (Greenough, 2007 in Boone, 2009). In more recent work, a survey of 1,923 free stall dairy farms in Norway found significantly higher milk yield when cows were stalled on mattresses or multilayer mats compared to concrete. The difference in milk yield was 1-5.8% higher than animals housed on concrete (Ruud et al., 2010). The authors attributed this difference in part to improved lying opportunities on the mattress and mat farms. There is very little research able to prove the causal relationship between lying behavior and milk production, if one does indeed exist. There are several reasons for this lack of data. A common problem is related to study length. Studies only a few weeks in duration are likely too short to find any correlation between milk yield and lying behavior. It is probable that changes influencing lying behavior take quite some time to have an impact on the physiological processes related to milk production, and therefore week-long studies will not capture any variations. It is also difficult to control for all farm management variables that may confound the relationship between lying behavior and milk production.

Behavior

Behavior can be used to help us determine if our animals are healthy and if they have what they want (Dawkins, 2004). Behavioral measures have two major advantages over other measures of welfare as they are typically non-invasive and non-intrusive (Dawkins, 2004). In terms of 'having what they want' consumers are most concerned with dairy cows being able to live naturally, and thus express their natural behaviors (von Keyserlingk et al., 2009). Changes due to genetic selection, however make it difficult to discern what behaviors are both natural and important to the modern dairy cow (von Keyserlingk et al., 2009). The preference test is one method researchers use to get a sense of what the animal finds important. This allows animals to 'vote with their feet' and tell us of the options presented to them, which one they judge best (Kirkden and Pajor, 2006). However, preference tests only tell us the relative ranking of the options presented. Both options may be quite good, or quite poor. Additionally, animals may select options that are positive in the short term, but have detrimental effects in the long term (von Keyserlingk et al., 2009). Furthermore, the animals previous experience with the options being presented (including prior to initiation of the study, and experience during the study before observations are collected) may all inadvertently influence the animals' choices (Tucker et al., 2003). Finally, while preference tests are very useful in a research setting, they are impractical in commercial settings, therefore development of methods for assessing what animals want in a commercial setting is required (Dawkins, 2004).

There are many behaviors that may indicate an animal's welfare status. Some of the most commonly utilized behaviors in research include sickness behavior, stereotypies and vocalizations. Changes in behavior due to sickness or pain (such a reduced activity, feeding and grooming) are controlled by the immune system and appear when the immune system is challenged (von Keyserlingk et al., 2009; Dawkins, 2004). For example, monitoring feeding behavior is proving to be a useful tool in the early detection of diseases impacting the transition cow (von Keyserlingk et al., 2009) as reduced feed intake can be a symptom of subclinical illness. Stereotypies are fixed, repeated sequences of behavior with no apparent function (Dawkins, 2004). The use of stereotypies as a behavioral indicator of welfare is controversial since there is disagreement regarding if stereotypies actually indicate poor welfare or not. Some have argued that if stereotypies take up a portion of an animal's time where it could be performing productive behaviors, welfare must be poor. Others have suggested that stereotypies may be used by the animal to enrich its environment or calm itself, possibly indicating neutral or good welfare (Dawkins, 2004). Vocalizations are unique because they are signals that have specifically evolved to change the behavior of a conspecific (for example, a hungry calf bawling) and can therefore be listened to by those concerned with welfare as an indicator of their needs. Not all animals will vocalize when 'in need', which makes it more difficult to understand their state (Dawkins, 2004).

Lying behavior as an indicator of welfare

In a practical setting, producers may find quantifying the amount of time cattle spend lying in a stall a useful measure of how comfortable the cows are in their stalls (Tucker et al., 2003). In un-crowded conditions (at least one resting area/cow) cows will spend approximately 12-13 hours/day lying down (Herlin, 1997). Cows are highly motivated to lie down. Studies have been able to illustrate the averseness and stress associated with forced standing, as well as the precedence lying has over other critical activities such as feeding. One study found that cows deprived of lying by confining them to an area with slatted floors for three hours showed a significant increase in lying for three hours following confinement on the slats (Metz, 1985). This increase in lying allowed cows to compensate for about half of their lost lying time. In another experiment by the same author, when cows were prevented from both lying and eating for 3 hours, lying took priority when the cows were released (Metz, 1985). Cooper et al. (2007) observed cows that were deprived of a suitable lying surface for two or four hours showed a significant increase in weight-shifting, leg stomping and repositioning behaviors, which were thought to alleviate discomfort in the limbs. Head swinging behavior (swinging of the head either vertically or horizontally), thought to be a behavioral expression of discomfort (Sandem et al., 2002), was also observed to significantly increase from a median of 0.25 observations/hour in the control cows to 0.48 observations/hour in the cows that were deprived of lying for four hours. Observing specific factors of lying behavior such as total lying time, the frequency and duration of lying bouts, and behavior prior to lying can provide information regarding the comfort of the resting area, and this will be discussed later in this review.

MEASURING COW COMFORT AND LYING BEHAVIOR

There are numerous methods of measuring cow comfort and lying behavior ranging from simplistic to highly complex. A very basic measurement of cow comfort involves observing cows to see if any are lying in the alley, which indicates the cow finds the available stalls unsuitable for use (Nordlund and Cook, 2003), or the facility is over-stocked. A measure used in on-farm assessments of cow comfort is the cow comfort index (CCI), which is defined as the proportion of cows touching a stall that are lying down (Ito et al., 2009; Cook et al., 2005; Nelson, 1996) . Other measures include: the stall use index (SUI), which is the proportion of cows in the pen that are not feeding or being milked that are lying down (van Gastelen et al., 2011), and the stall standing index (SSI) which is the proportion of cows touching a stall that are standing or perching (Ito et al., 2009; Cook et al. 2005). Stall use is best observed one or two hours before the morning feeding or milking (Cook et al., 2005; Overton et al., 2002) as at this time the majority of cows will be using stalls rather than feeding. The SSI in particular has been useful for illuminating potential herd lameness problems if the SSI is 0.2 (20% of cows touching a stall that are standing or perching) or greater two hours prior to milking (Cook et al., 2005). The measures discussed above assume that cow behavior is linked to their comfort (Cook et al., 2005), and is independent of other factors, such as the presence of farm-workers. Measuring specific features of lying behavior (such as the time required to stand up, or lie down) is labour intensive, but has the potential to provide a more specific indication of cow comfort. To record lying behavior, clear operational definitions are essential (Table 1.2).

Cows lying on pasture may adopt one of five normal resting positions (Anderson, 2008) (Figure 1.1) (the fifth position is lateral recumbency). Information regarding the type of rest the cow is getting can be gleaned from observing the position she is lying in. During rapid eye movement (REM) sleep, the neck muscles become atonic so the head typically cannot be supported, and must be rested on the body or ground (Ternman et al., 2012; Ruckebusch, 1975). Recent work found that this definition predicted REM sleep when compared to electrode recordings 61% of the time in a study using 6 pairs of dairy calves (Hänninen et al., 2008). Cows exhibit approximately 3 h/24 h of non-rapid eye movement sleep and 45 min/24h of REM sleep. There is an additional sleep state often referred to as drowsing, (Ruckebusch, 1972) however the definition and purpose of drowsing in cattle is not well understood (Ternman et al., 2012).

In addition to measuring lying behavior, observations of abnormal behaviors may indicate compromised cow comfort (Haley et al., 2001). Idle standing refers to standing in the alley or stall with no apparent purpose, or performing stereotypic behaviors such as mouthing the stall dividers (Anderson, 2008). Perching happens when the cow is standing with the front feet in the stall while the back feet are in the alley, and may be in response to insufficient stall size, uncomfortable stall surfaces (Anderson, 2008), or in sand bedded stalls, due to the neck rail location. Diagonal standing and lying involve placing the body at a 45 degree angle within the stall to allow the cow to fit in a stall that is too short, or to increase social space between a cow and her neighbour in the facing stall. Lying backwards occurs when the cow lies with her head facing the alley and may be a learned behavior from early in life, or due to avoidance of uncomfortable stall features (Anderson, 2008), such as insufficient lunge space. Restlessness occurs when the cow constantly changes lying position and is typically due to high brisket locators (Anderson, 2008). Alternate occupancy, or the 'checkerboard effect', in a free stall environment, occurs when there is insufficient forward lunge space or social distance between cows. Dog-sitting behavior, or rising like a horse (with the front end rising first) is due to obstructions within the stall that prevent normal rising or lying behavior (Anderson, 2008).

RISING & LYING BEHAVIORAL PATTERNS

As touched upon above, rising and lying behaviors are dictated largely by the stall environment. When rising, cattle will make approximately 30 different postural changes with 80 percent of the cow's weight put on her knees and one hock (Hughes, 2000). To stand, the hind end is raised by one leg only (as the other leg is effectively trapped until she rises higher) (Hughes, 2000). She then moves her front legs caudally and lifts herself onto her knees. The knees act as a pivot point when the cow lunges forward and lowers her nose towards the ground. This action transfers the weight onto her front limbs where she is then able to fully stand. The rising motion is completed by extending the front legs and stepping back until the forelimbs are properly vertical (Nordlund and Cook, 2003). In a survey of 70 French free stall dairies, it was observed that cattle made on average 1.1 rising intentions (defined as the cow extending her head forwards)/successful rise

(Veissier et al., 2004). There are limited studies investigating the standing up movement, as the majority of the literature focuses on the lying down movement as it is easier to capture.

Several factors may impact the duration of time it takes a cow to lie down. It has been shown that it takes significantly longer to complete the lying-down pattern for cattle housed in tie stalls compared to loose-housed cattle on deep bedding (Krohn and Munksgaard, 1993). When housed in tie stalls, Herlin (1997) found that their 15 cows took significantly longer to lie down (starting with the investigation of the stall surface, which could be up to 300 s before being fully recumbent) on harder surfaces (108 s on concrete, 79 s on hard rubber mats, and 50 s on soft rubber mats). The cows also demonstrated more lying intentions on harder surfaces (73 intentions on concrete, 35 intentions on rubber mats, and 24 intentions on comfort mats /24 h). Krohn and Munksgaard (1993) found that the 'lying down movement' (defined as the initiation of kneeling to when the cow is fully lying) of cows housed in stalls with concrete bedded with 2 kg of straw took significantly longer (14 s) compared to cows housed on rubber mats with the same amount of straw bedding (9 s). Comparing tie stall, loose-housed, and cows on pasture, tie stall cows spent the longest (42 to 51 s) on examining movements, defined as standing still swinging its head from side to side with its muzzle close to the ground, compared to loose-housed (21 s), and pasture-based (8 s) (Krohn and Munksgaard, 1993) animals. Head-swinging behavior prior to lying down may reflect the cows' hesitation to lie, and this behavior decreases when cattle have access to deeply bedded stalls (Tucker and Weary, 2004). Others however, found no difference in head-sweeping movements based on flooring type (Haley et al., 2001).

The longer duration of lying-down movements associated with harder flooring (Wechsler et al., 2000) may be an indicator of the cow's hesitation to lie on such a surface (Tucker and Weary, 2004). As portions of the cow's body can reach an instantaneous velocity of 220 cm/s when lying down (Ceballos et al., 2004) her hesitation to lie on hard surfaces is justifiable! Measurements recorded from cattle lying down showed they used 300 cm of linear space (equivalent to 300% of back length) and 76 cm of forward lunge space (approximately 78% back length), which is typically greater than what is provided for in modern dairies. Cows used 109 cm of lateral space, with the vast majority of movements made in the hips (181% of hip width). Typically stall width is suggested to be twice the cattle's hip width, which appears an appropriate amount of space based on the findings of this experiment (Ceballos et al., 2004). Interestingly, lying down behavior took significantly longer for cattle in their third lactation compared to cattle in their first lactation, which was attributed to their larger body size (Krohn and Munksgaard, 1993). In a free stall environment, cows will make on average 1.4 intentions (defined as the cow sniffs the ground and swings her head) to lie-down/successful lying-down movement (Veissier et al., 2004).

OVERVIEW OF FACTORS IMPACTING LYING BEHAVIOR

As has been touched upon above, both internal and external factors influence cows' lying behavior. In this literature review internal factors to be discussed include stage of lactation and gestation, milk yield, age parity, social rank and circadian rhythm. External factors include environmental conditions, social conditions, management factors, and the impact of stall design, specifically stall size and stall flooring.

Internal Factors

Internal factors that influence lying behavior that will be discussed in this thesis include: stage of lactation and gestation, milk yield, age, parity, social rank, and circadian rhythm. Increased lying times have been recorded later in lactation (Chaplin and Munksgaard, 2001); another way of looking at this is, lying increased as days in milk increased (Bewley et al., 2010; Fregonesi, 2002), likely due to reduced time spent feeding as milk production decreased. For dry cows, stage of gestation plays a role in lying behavior, particularly in the final months before calving when fetal growth is at its fastest rate (Chaplin and Munksgaard, 2001). At approximately 40 days pre-calving, cows showed a decrease in lying bout length (22.5% vs. 33.5% of their mean daily time budget) (Dechamps et al., 1989). Cattle tended to show an increased amount of time standing in stalls with increasing parity, and older cows generally lay for longer bouts than their younger counterparts (Wierenga and Hopster, 1990). Primiparous cows, however, showed reduced time standing within free stalls. Gomez and Cook (2010) suggested this disparity in amount of stall-standing may be related to larger amounts of their time budget spent feeding, severe lameness causing her to lie for longer periods, or competition for resources, such as access to stalls and feed in overcrowded conditions.

Social status plays an important role in the lying behavior of dairy cows, particularly in overstocked conditions. More dominant cows will displace subordinate cows if access to lying resources are limited, resulting in reduced lying times for subordinate animals (Leonard et al., 1996). Friend and Polan (1974) observed that subordinate cows chose to lie further away from more dominate cattle. Cows with high social rank lay more often in the most popular stalls (Jakob et al., 1988 in Wierenga and Hopster, 1990). Low ranking cows tended to spend less time in alleyways (Metz and Mekking, 1984 in Wierenga and Hopster, 1990) and three times longer with their head and front legs in the stall than high ranking cows, which was attributed to using the stalls as a refuge from more dominate animals (Potter and Broom, 1987 in Wierenga and Hopster, 1990).

Perhaps the most obvious, but in fact the least studied (due to difficulties in controlling for the effect of management routines) influence on lying behavior is the cows' circadian rhythm. It has been determined that cattle show a diurnal pattern for lying and eating behavior (DeVries and von Keyserlingk, 2005; Overton et al., 2002). Between morning and afternoon milking (a period of approximately 8.5 hours), cows in a free stall system spent approximately half of their time in stalls, with about half an hour of this time standing either fully or partially in the stalls. In the period between afternoon milking and four hours prior to morning milking about two-thirds of their time was spent in the stalls, with one hour spent standing. In the period between four hours prior to morning milking and milking, the cows spent the majority of their time in stalls, spending approximately half an hour standing (Wierenga and Hopster, 1990). However, it is important to note that this study did not control for lameness, which can impact standing behavior.

External Factors

There are many external factors that may influence lying behavior, including: environmental conditions, social conditions and behavioral synchrony, management factors (such as time of feed delivery), stall design, and stall flooring. Environmental conditions, particularly temperature and precipitation greatly influence lying behavior. It has been repeatedly demonstrated that lying decreases as temperature increases in attempt to aid heat dissipation (Tucker et al., 2008; Overton et al., 2002; Shultz, 1984). When exposed to precipitation and wind, cattle reduced their lying time, and adopted postures that reduced their exposure to the elements, such as standing with their heads lowered or standing with their heads under feeder covers (Tucker et al., 2007).

Although cattle are social animals, there is evidence that they prefer to have some distance between conspecifics (Cook and Nordlund, 2004; Arave and Walters, 1980). Overcrowding (more than 1 cow/stall) strongly influenced lying times, as the frequency of stall evictions increased as available stalls decreased, which decreased lying time, particularly for low ranking cows (Fregonesi et al., 2007a; Leonard et al., 1996; Friend et al., 1977). As overcrowding increased, time spent standing in the stall decreased in favor of lying in the stalls, illustrating the importance cattle place on lying rather than standing (Wierenga and Hopster, 1990). The National Farm Animal Care Council recommends a stocking density of no more than 1.2 cows/stall (National Farm Animal Care Council, 2009). Behavioral synchrony plays an important role in the activities of herd species, including dairy cows (O'Driscoll et al., 2008). While synchrony affected the timing of lying and standing, it does not necessarily affect the total lying time (Wierenga and Hopster, 1990). Lying synchrony is most pronounced several hours prior to the morning milking, when the majority of cows were found lying down (Overton et al., 2002; Wierenga and Hopster, 1990).

It is difficult to isolate the effects of the innate circadian rhythm vs. management routines on lying behavior. While altering management routines to observe how lying behavior is influenced is possible, in many instances this is not practical (i.e. on commercial farms, or segregating certain cows in a research facility). There are several experiments, however, that have determined that the time of milking and feeding influence lying behavior. The majority of cattle lay down one to two hours after returning from morning milking (Cook et al., 2005; Overton et al., 2002). Furthermore, as milking time drew nearer, more cows were observed to rise, possibly in anticipation of milking, or due to increased intramammary pressure (Österman and Redbo, 2001) caused by a full udder. The delivery of fresh feed at return from milking has been demonstrated to decrease lying behavior at this time, as the delivery of fresh feed encourages feeding behavior (DeVries and von Keyserlingk, 2005; Overton et al., 2002).

While the factors discussed above certainly impact lying behavior, they are difficult to address practically (for instance, farmers typically do not have the resources available to group cows based on social status). Arguably the most easily implemented factor affecting lying behavior is stall design, specifically the stall flooring surface. As there is a vast body of research on the effects of stall design and stall flooring surface on lying behavior, they will be discussed in depth below.

IMPACTS OF STALL DESIGN

Design of the stall significantly influences cows' cleanliness, health, behavior, stall usage and lying behavior. There are a variety of features of the stall that impact lying behavior. These include: stall dimensions, placement of the neck rail, brisket locator design, type of stall divider and stall flooring surface.

Stall size

Stall size is determined by a variety of factors. The divider rails determine stall width. The location of the brisket locator and neck rail determines the resting and standing area's length. Vertical space within the stall is constrained by the height of the neck rail. The effects of stall size on cow cleanliness, lameness and injuries, behavior, preference and lying behavior will be discussed.

Cleanliness

Stall size impacts cow cleanliness by positioning the cow a particular way within the stall. Length and width of the stall both impact cow cleanliness. In short stalls cattle will stand diagonally within the stall to better fit all four feet within that space (Anderson, 2003), provided the stall is wide enough to permit them to do so. Diagonal standing increases the likelihood that the cow will defecate in the stall, rather than in the alley. Should the cow lie down before the stall is cleaned her hind limbs and udder will become dirty (Zurbrigg et al., 2005). Additionally, when lying diagonally, the tail is more likely to lie in the alley where it may become dirty, and then may transfer the contaminants onto the hind quarter (Cook and Nordlund, 2004). As mentioned above, stall width influences stall standing behavior, and by extension, stall cleanliness. Tucker et al. (2004) observed a linear, positive relationship between stall width and amount of fecal material in the pen (mean kg feces per pen/24 h: 22.5, 33.3, 53.9, for stall widths 106, 116 and 126 cm) which was attributed to significantly greater time spent standing with all four feet in the stall in the wider stalls (85 min vs. 58 min for 126 cm and 106 cm respectively). If cows are not able to stand diagonally (due to narrow stall widths), shortening the stall by having a more restrictive neck rail or brisket locator increases stall cleanliness (Ruud et al., 2011). This is likely because the cow is prevented from entering the stall past a certain point. Tucker et al. (2005) found that stalls were twice as likely to be defecated in (1.3 vs. 0.5 defecations/24 h) when neck rails were removed. In a study using 30 Holsteins, with five neck rail positions (130, 145, 160, 175, and 190 cm from the rear curb) it was observed that stall cleaning time tended to be greater when the neck rail was placed 190 cm from the curb compared to 130 cm from the curb (0.4±0.16 min/d vs. 1.6±0.35 min/d). Also, higher mean udder cleanliness scores (a higher score indicates dirtier) were found the longest stalls (1.2±0.07 vs. 1.4±0.08) (Fregonesi et al., 2009). Illustrating the confounding effect of stall management on cow cleanliness, in a study of 317 tie stall farms in Ontario, investigating the associations between injury, lameness, cow cleanliness and stall design, stalls with shorter bed lengths were significantly associated with dirtier hind limbs (Zurbrigg et al., 2005). In this study, management factors such as stall cleaning routine were not collected which the authors noted should be included in similar studies in the future. Anecdotally, low neck rails, are associated with cleaner cows. Zurbrigg et al. (2005) observed the opposite result in their tie stall study: with each 2.5 cm increase in the tie-rail height, the prevalence of clean udders increased by 0.2%. Here again, the authors suggested there may have been unmeasured management factors related to this finding as they did not record how often the stalls were cleaned and bedded.

Lameness & Injuries

Injuries and lameness are typically scored on a numeric scale where each number relates to specific criteria that must be met to achieve a particular score. Lower numbers usually indicate less severe injury or lameness while higher numbers indicate a greater extent of injury or lameness. For instance, in Flower and Weary's method for gait scoring, 0 indicates a flat back and steady head carriage, while a score of 5 indicates an extremely arched back and an obvious head bob (2006).

The most studied aspect of stall size related to injuries is neck rail height. This is because of the strong association with injuries due to repeated daily contact between the top of the neck and the underside of the neck rail. Zurbrigg et al. (2005) categorized neck rail height into low (71 to 96 cm) midrange (99 to 114 cm) and high (116 to 132 cm) categories for 317 tie stall dairies in Ontario. Midrange neck rails had 70% more neck lesions than the low and high rails. They hypothesized that very low neck rails allowed cows to put their necks over top of the rail, preventing chaffing, while the high neck rails did not come into contact with the top of the neck at all. Veissier et al. (2004) visited 70 free stall farms in France, and using body size for each cow calculated their ideal neck rail height. From this they discovered significantly more neck injuries when the neck rail was higher than ideal.

Stall size influences lameness by affecting the amount of time cows will spend in the stalls. Stalls that allow cows to stand fully in the stall are beneficial for reducing lameness as they provide a ‘refuge’ from the wet, hard alley surface (Bernardi et al., 2009). Bernardi et al. (2009) studied 32 free stall cows in a cross-over design, where pens of cows were exposed to a neck rail allowing full standing in the stall for five-weeks, and then switched to a neck rail position that did not allow full standing in the stall for another five-weeks. Increased time standing in the stall with all four feet was related to a decreased number of new cases of lameness and sole lesions. After switching to the more restrictive neck rail, they found the median gait score worsened from 2.5 to 3.5. Similarly in a large-scale tie stall survey, Zurbrigg et al. (2005) found a significant positive association between cows with no hind claw rotation and greater stall length. Dippel et al. (2009) similarly found an increased risk of lameness with shorter curb to neck rail lengths from a survey of 103 free stall farms in Europe.

Behavior & Preference

The expected results of providing larger stalls are higher lying times and increased stall usage. When eight lactating cattle were exposed to tie stalls with concrete flooring and pens with mattress flooring in a cross-over design, when in the pens, cows spent more time lying (4.2 h/d more), and also showed higher lying bout frequencies (5.4 more bouts) of shorter duration (18.7 min shorter) than their tie stall counterparts (Haley et al., 2000). Frequent short bouts of lying may be attributed to increased comfort when rising and lying. However, stall surface and size of the resting area were confounded in this experiment. Tucker et al. (2004) found that cattle preferred stalls that were either wide, or long, but showed no preference for a wide-long stall when all stalls were provided with the same flooring surface. Tucker et al. (2004) used a 2x2 factorial design (stall length: 229 and 274 cm; stall width: 112 and 132 cm) to determine how altering stall length and width influenced lying times. It was observed that the median lying time was longest in wide stalls (wide: 10.8 vs. narrow: 9.6 h/24 h).

Studies recorded increased perching behavior with more restrictive neck rails (i.e. shorter stalls) (Bernardi et al., 2009; Fregonesi et al., 2009; Tucker et al., 2005). One explanation for this, is the neck rail may force a cow to lie uncomfortably far back in the stall, or make it difficult to rise swiftly (Zurbrigg et al., 2005). As mentioned previously, the brisket locator plays a similar role in restricting stall length. Tucker et al. (2006) found that cattle had reduced lying times in stalls with 8 in. high brisket locators (1.2 h/d less) compared to cows in stalls without. In the same study, when cows were given the choice between stalls with and without brisket locators, they chose to spend 68% of their time lying in the stalls without the locators, indicating a preference for stalls without brisket locators. If brisket locators are used, they should be a maximum of four inches above the bedded surface (Nordlund and Cook, 2003) to allow the cow to extend her forelegs when lying and also to thrust her front legs forward when rising (Cook and Nordlund, 2004). Abnormal behaviors such as diagonal lying can be caused by too-high brisket locators (Cook and Nordlund, 2004).

Stall Flooring

The quality of the stall floor is determined by the base (such as concrete, mats and mattresses) and the bedding used on top of the base. The quantity and quality (such as wet vs. dry), and type of bedding (such as sand, straw or shavings) impacts cow cleanliness, injuries, behavior and preference.

Cleanliness

It is well documented that stalls that are used more are dirtier (Fregonesi et al., 2007b; Tucker et al., 2004). Chaplin et al. (2000) believed that cows on softer stall bases are likely more comfortable, and thus do not stand as much as cows housed on harder stall bases. Increased lying increases the exposure to soiled stall surfaces. Work by Chaplin et al. (2000) observed 58 lactating cows, and found a tendency for cows to have a higher total dirtiness score (indicating more dirty) when housed on rubber-filled mattresses rather than solid rubber mats (7.06 vs. 6.95) and significantly dirtier udders (7.5 vs. 6.52). Deep-bedded sand stalls are a unique flooring surface because the sand acts both as the stall base and bedding. There is conflicting evidence regarding the effects of sand bedding on cow cleanliness. A producer survey of free stall barns in Wisconsin by Bewley et al. (2001) found that producers were significantly more satisfied with cow cleanliness and udder health when sand bedding was used compared to mattresses. However, after surveying 100 free stall dairies in the United States, Fulwider et al. (2007) found cows on waterbeds or rubber crumb filled mattresses to be cleaner than cows housed on sand. The authors hypothesized this could be due in part to sand’s tendency to cling to the cows body, carrying excrement with it. Their study took into account the frequency of bedding, and found sand-bedded stalls to be bedded significantly less often (1.9 vs. 3.6 times /wk). It is critical to include management factors such as frequency of bedding, amount of bedding used, and frequency of stall cleaning into studies regarding cow cleanliness.

Beddings vary in their ability to support bacterial life, which is of interest to many producers as a method of controlling mastitis. Studies have shown bacteria from bedding may be transferred onto the teat ends (Hogan and Smith, 1997). Traditionally, inorganic bedding material is preferred for improved sanitation, since it does not support bacterial growth as organic bedding does (Nordlund and Cook, 2003). Interestingly, one study found no significant difference in Gram-negative bacteria between organic (box compost from human waste) and inorganic bedding (sand), both when cultured from the bedding and from bulk tank samples (van Gastelen et al., 2011). Another study actually found a 10-fold increase in *streptococcus* bacteria on teat ends from cows housed on sand vs. sawdust (Zdanowicz et al., 2004). There is likely a confounding effect of stall maintenance on bedding sanitation, so if feasible this should be included in future studies regarding stall hygiene.

Lameness & Injuries

Stall floors have several attributes that can impact lameness and injuries. It is important that stalls provide good traction (or friction) for rising, lying, and changing resting positions, but are not abrasive. Very abrasive floors can cause lesions on the limbs or claw damage. Concrete flooring is generally considered undesirable as it may predispose cattle to claw horn lesions and increase hoof trauma (Cook et al., 2004b), and may cause pain when rising and lying (Herlin, 1997).

Lameness is a major concern for the dairy industry as it is linked to decreased milk production, longevity in the herd and fertility (Cook, 2003). Cook and Nordlund (2004) observed that cows housed on mattresses with scant bedding were more likely to be clinically lame (and spend more time standing) than cows housed on deep sand. Another study compared two free-stall herds, one with a history of lameness problems and one without, which were similar in all aspects except the quantity of straw bedding used. The herd with lameness problems used 75% less straw/day than the herd without lameness problems (Colam-Ainsworth et al., 1989). Other surveys observed the prevalence of very lame cows (lameness score of 4/5) to be significantly higher in free-stall farms that used mattresses compared to farms that used deep bedding (Ito et al., 2010; Dippel et al., 2009).

For lame cows, the stall floor she is provided with can influence her behavior. Softer flooring can help to alleviate the pain of lameness. Telezhenko and Bergsten (2005) found slightly lame cattle appeared sound (stride length and speed increased) when they walked across soft rubber flooring compared to concrete, likely due to increased traction when the foot pressed into the cushioned surface (Rushen and de Passillé, 2006). Similarly, Platz et al. (2008) found stride length, number of steps, mounting and caudal grooming to be significantly increased after transitioning from a concrete to a rubber coated floor. Additionally, when cows were offered the choice between walking on concrete or rubber mats on the way to the milking parlour, 2/3 of the animals chose to walk on the rubber mats (Platz et al., 2008).

Regarding lying behavior, lame cows from multiple farms housed on sand showed similar lying behavior to their non-lame counterparts, while lame cows on mattresses spent much more time standing, possibly due to pain caused by the harder surfacing when rising and lying (Cook and Nordlund, 2004). Ito et al. (2010) found lame cows on farms that used deep-bedding lay down longer (12.8 h/d), and had longer lying bout durations than their none-lame counterparts who lay for 11.2 h/d. As will be discussed further on, cows stand more on less comfortable flooring surfaces. Stall standing time is a concern for lameness. Cook (2002) found that cows standing fully or partially in stalls one hour prior to milking was positively correlated to lameness prevalence. Indeed, Rushen et al. (2009) found that standing fully, or partially in the alley predisposes cows to lameness (particularly if concrete flooring is utilized). Regardless of the quality of stall flooring, it is important that there is one stall available/cow in a free stall system, as it has been repeatedly shown that overstocking is linked to an increase in foot lesions (Leonard et al., 1996; Singh et al., 1993; Wierenga and Hopster, 1990).

Leg injuries are more frequent on mattresses with scant bedding compared to cows housed on deep-bedded stalls (Mowbray et al., 2003; Wechsler et al., 2000; Weary and Taszkun, 2000). Furthermore, as bedding was scored increasingly dry and soft, the severity of hock injuries declined (van Gastelen et al., 2011). It is critical that the quantity of bedding be included into studies of injury and hair loss. Mowbray et al. (2003) found cattle on deep-bedded sand stalls had more hair loss on their hocks than cows on mattresses, which they attributed to insufficient bedding allowing contact with the cement curb and point of hock. When comparing only the effect of stall base on injuries, mattress-housed cows had fewer swollen knees than cows housed in concrete stalls (Rushen et al., 2007; Haley et al., 1999) indicating mattresses better absorbed the force of impact when lying, assuming the primary cause of swollen knees was due to physical impact.

Behavior & Preference

As previously mentioned, cattle show a strong preference for soft stall surfaces (e.g. Herlin, 1997) and in particular, lie for longer in deep bedded stalls compared to soft mattresses with minimal bedding (Jensen et al., 1988). It has been argued that surface cushion is the most critical determinant of stall use, to the extent that many other stall flaws will be tolerated so long as the stall has a comfortable surface (Nordlund and Cook, 2003).

The most widely studied behavior in regards to stall surface is lying behavior. The most frequent measures used in studies regarding flooring surface are total lying time, and frequency and duration of lying bouts. Multiple studies have shown that total lying decreased as bedding quantity decreased (Drissler et al., 2005; Tucker et al., 2003). Tucker et al. (2009) observed that cows lay down a 9 longer minutes for every 1 cm increase in shaving compressibility, and 6 minutes longer for every 1 cm increase in straw compressibility. Cows exhibited fewer lying bouts on harder surfaces (Tucker and Weary, 2004; Haley et al., 2001). Regarding lying bout duration, results ranging from longer duration of lying bouts (Haley et al., 2001), no difference (e.g. Tucker and Weary, 2004), to shorter duration bouts (e.g. Drissler et al., 2005) have all been recorded in response to decreased surface softness. When the duration of lying bouts were longer with softer flooring, it was attributed to enhanced comfort for the cow (van Gastelen et al., 2011; Chaplin et al., 2000). Conversely, when short lying bouts occurred with greater frequency on softer flooring, this was attributed to the ability to rise and lie down comfortably (Haley et al., 2001). For a summary of findings please refer to Table 1.2.

While quantity of bedding is certainly of importance to the cow, quality is also important. When forced to lie in wet stalls lying time significantly decreased (8.8 h/24 h vs. 13.8 h/24 h) compared to the same stalls filled with dry bedding (Fregonesi et al., 2007b). When housed outdoors in wet conditions, cows show decreased lying times compared to cows that are kept dry indoors (mean lying time across all BCS: 718 min vs. 240 min /24 h) (Tucker et al., 2007). In general, cattle will spend more time standing on surfaces they are hesitant to lie on (Tucker and Weary, 2004; Haley et al., 2001).

While cattle certainly lie down longer on deep-bedded stalls compared to mattresses with scant bedding, management considerations (such as variable cost and manure storage) tend to make the latter more common (Cook and Nordlund, 2004). Most studies only compare depth or weight of bedding rather than compressibility, or softness of the stall base. Nilsson (1988) illustrated how firm rubber mats can be, when he applied a standardized steel ball with a force of 500-2000 N (representing the force of a kneeling cow) to a range of mats and found that the rubber mats compressed only to a maximum of 2-10 mm. When bedding is sparse, cows appear to prefer to lie on foam-filled mattresses and rubber crumb-filled mattresses, followed by rubber mats, water beds, and lastly, concrete (Cook and Nordlund, 2004; Chaplin et al., 2000; Herlin, 1997).

Dairy Code of Practice & stall design

In Canada, the National Farm Animal Care Committee produces a dairy code of practice which is a guide of requirements and recommendations based on scientific knowledge encompassing many aspects of dairy cow management. Within the code there is a section dedicated to stall design and stall flooring. In particular, the code states “a growing body of research has now demonstrated that the surface we provide for cows is one of the most important factors in designing a suitable lying area”. In the code it is recommended (but not required) that stalls provide sufficient room for cows to lie on a comfortable surface for at least 12 hours, and stalls should be designed to minimize injuries and allow cattle to easily rise and lie down (National Farm Animal Care Council, 2009). In addition, the code recommends that stalls be routinely bedded and cleaned. Producers are also encouraged to ensure cows are actually lying in the stalls and not in the alley (National Farm Animal Care Council, 2009). The NFACC also produces a review of scientific research on priority welfare issues for the dairy industry. In their most recent review, the quantity and quality of bedding as well as the physical structures of the stall (such as the neck rail and brisket locator) were cited as being the most critical factors in ensuring a comfortable resting place (Rushen et al., 2009). While providing an excellent basic guide, the dairy code of practice certainly requires more concrete definitions of what constitutes a suitable resting place for the dairy cow as many of its recommendations are ambiguous (for instance, the code states that bedding is required on mattresses but does not stipulate what quantity and quality provides satisfactory cow comfort.)

Measuring stall flooring softness

Measures of stall flooring softness have only really occurred within the past decade, as the majority of studies previously focused on bedding depth or weight. It is important to have an objective measure of softness or compressibility to determine if this is truly a factor important to cows (Tucker et al., 2009). Producers may choose to use subjective tests, such as kneeling in the stall to check that the surface moulds around the knee, or dropping to the knees from a short distance to assess the depth of cushion (Nordlund and Cook, 2003), however these tests would require validation prior to use in research. A more objective tool is the Clegg Impact Soil Tester (model 95051, Lafayette Instruments, Lafayette, IN), which is conventionally used to measure soil compaction by measuring peak deceleration (Boone, 2009) when dropping a 20 kg hammer from a height of 30 cm. In cow research it has been used to measure flooring softness, with results correlating to stall preference (Cook and Nordlund, 2004; Nordlund and Cook, 2003). Fulwider and Palmer (2004) found that the lowest Clegg impact value (40) corresponded to cow preference for the softest flooring material (a rubber-filled mattress), and the highest value (146) corresponded to the hardest, a rubber mat. While authors found Clegg impact value results correlated to flooring softness and cow preference, it is more appropriate to use a 2.25 or 4.5 kg hammer for stall flooring, as a the 25 kg hammer is actually intended for use on concrete (Boone, 2009). Tucker et al. (2009) utilized a 100 kg weight to assess bedding compressibility by measuring reduction in bedding depth after the weight was applied for one minute; results from this method also correlated to expected lying time. In the future, particularly as new products continue to be developed, introduction of a ‘gold-standard’ compressibility tester will be critical to ensure that objective, consistent measurements of flooring softness occur across research trials.

AVENUES FOR FUTURE RESEARCH

There is limited research that specifically isolates the effects of stall base on the activity and lying behavior of dairy cows. Many studies have confounded differences in stall base with other factors that may influence lying behavior. These include: amount of bedding, stall design, or cow-specific factors, such as lameness or level of production. Work that investigates varying stall bases while controlling for these other factors is critical to determine if the comfort of the stall base is something that the cow finds important. Future research should investigate what specific features of the stall flooring surface (such as cushion or traction) are important to the cows, this will allow for the development of products that better meet the cows' needs. This is especially important as there is a trend for producers to provide softer stall bases with scant bedding. According to the research available now, the development of a stall surface that provides excellent traction, for even lame and large animals to rise and lie easily, that is not abrasive and is exceptionally comfortable would be prudent.

Lying time, and lying bout frequency and duration are often studied to gain a sense of the comfort of the lying surface, but there are other behavioral measures that are not commonly studied which may also provide insight. In a free stall system, the latency to lie down after entering a stall is one measure that requires further research. The time required to complete the lying down and standing up movement may indicate how stall bases differ in the traction and comfort they supply. Finally, head swinging behavior prior to lying is attributed to a hesitancy to lie down, but studies including this behavior on different stall bases, with all other housing factors kept constant, are lacking.

CONCLUSIONS AND THESIS OBJECTIVES

Lying behavior is important to cows for a wide variety of reasons. Cattle that are deprived of lying have demonstrated higher cortisol levels (Fisher et al., 2002) and behaviors indicating discomfort (Cooper et al., 2007). This suggests that the prevention of lying is stressful and uncomfortable to cattle. Cows are highly motivated to lie down, as they will forgo eating in favor of lying after several hours of feed and rest deprivation (Metz, 1985), and will perform an operant task to maintain 12-13 hours of daily lying time (Jensen et al., 2005). There is an association between circulating growth hormone and blood flow to the mammary region: both aspects important to milk production (Munksgaard and Løvendahl, 1993; Metcalf et al., 1992). Lying for extreme amounts of time (very low or very high lying times) may be a risk factor or symptom of lameness. A wide body of evidence demonstrates that lying comfortably for approximately 12 h/d is an important aspect of dairy cow welfare. Many factors influence lying behavior in an intensive environment, particularly stall design and the stall flooring surface. It is widely agreed upon that stalls that are too small, or contain design features that make it difficult or uncomfortable to rise and lie down will result in decreased lying times. Additionally, cows have a strong preference for softer lying surfaces which is reflected in the amount of time they choose to spend lying. More research is required on the effects of varying the stall base, while holding all other stall factors constant on the activity and lying behavior of dairy cows.

The objective of this thesis is to determine the effects of gel mat stall surfaces on the activity and lying behavior of dairy cows. In the second chapter, the objective was to determine the effects of gel mat stall surfaces on the activity and lying behavior of lactating dairy cows in a tie stall system. The objective of the third chapter was to determine the effects of gel mat surfaces on the activity, stall preference of non-lactating dairy cows in a free stall system.

Table 1.1. Sample behavioral definitions for describing lying behavior (with modification from Krohn and Munksgaard, 1993)

Behavioral Category	**Description**
Lying (Lying Behavior)	The body is supported by the ground
Flat on Side (Lying position)	The cow is lying flat on one side, the neck is stretched and the head rests on the ground
Head Back (Lying position)	The cow is lying on the sternum, the head is turned backwards and rests on the body
Head on Ground (Lying position)	The cow is lying on the sternum, the neck is stretched and the head rests on the ground
Head Up (Lying position)	The cow is lying on the sternum and the head is raised (normal position for rumination)
Search (Lying down behavior)	The cow walks slowly with its muzzle close to the ground (occurs only in the pasture and deep-bedding area)
Examine (Lying down behavior)	The cow stands still, swinging its head from side to side with its muzzle close to the ground. If the cow stops this behavior and raises its head the movement is said to be interrupted
Kneel (Lying down behavior)	The cow bends one foreleg and falls down on one or both knees. If the cow stops this behavior and goes back to standing on both forelegs, the movement is said to be interrupted
Total lying down time	From the initiation of searching (or examining in the tie stalls) until the cow is lying, including all interruptions and intervals with other behavior
Lying down movement	From the initiation of the final kneel until the cow is lying

Figure 1.1. Normal resting positions for the dairy cow (Anderson, 2008).

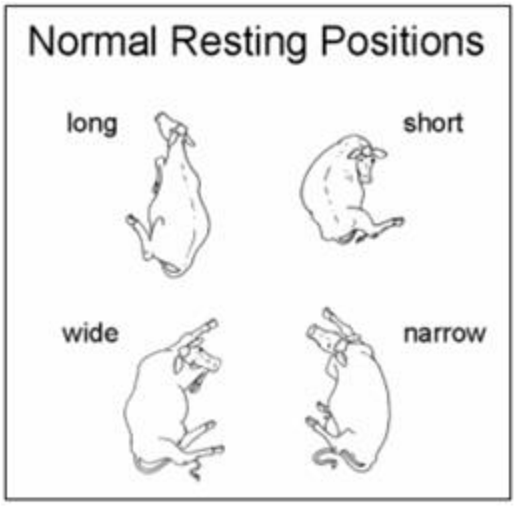

Table 1.2. Summary of findings regarding lying behaviors and flooring (including stall base and bedding) softness.

Behavior	↑ *with* ↑ *flooring softness*	↑ *with* ↓ *flooring softness*	*No difference*
Total lying time	(Tucker and Weary, 2004; Tucker et al., 2009; Karakok et al., 2009; Drissler et al., 2005; Haley et al., 2001)		(Wechsler et al., 2000; Krohn and Munksgaard, 1993; Absmanner et al., 2012)
Number of lying bouts	(Tucker and Weary, 2004; Tucker et al., 2009; Haley et al., 2001; Absmanner et al., 2012; Calamari et al., 2009)	(Lidfors, 1989)	(Tucker et al., 2009; Krohn and Munksgaard, 1993)
Average duration of lying bout	(van Gastelen et al., 2011; Drissler et al., 2005)	(Lidfors, 1989; Haley et al., 2001; Calamari et al., 2009)	(Tucker and Weary, 2004; Tucker et al., 2009; Wechsler et al., 2000)
Standing		(Calamari et al., 2009; Haley et al., 2001, 2000; Tucker et al., 2003; Gomez and Cook, 2010)	(Tucker and Weary, 2004; van Gastelen et al., 2011)
Perching		(Tucker and Weary, 2004)	(van Gastelen et al., 2011)
Head-swinging behavior		(Tucker and Weary, 2004; Krohn and Munksgaard, 1993)	(Haley et al., 2001)

Chapter 2: The effects of gel mat stall flooring surface on the behavior of lactating dairy cattle in tie stall housing

ABSTRACT

The objective of this study was to determine the effects of gel stall surfaces on the activity and lying behavior of dairy cattle housed in tie stalls. Twenty four lactating Holstein dairy cows were housed in tie stalls on four stall surfaces: a gel mat filled to 10 pounds per square inch (psi) (GEL10), a gel mat filled to 5 psi (GEL5), a foam mat (FOAM), and a rubber crumb filled mattress (CRUMB). Cows were housed on each flooring surface for 1 week in a cross-over design. Total lying time and the number of lying bouts were recorded with accelerometers. The final day on each surface was video recorded to observe general activity and specifics of lying behavior. When cows were housed on the gel mats, they spent the greatest proportion of time lying (mean proportion±SE: GEL5: 0.57±0.061; GEL10: 0.57±0.062; FOAM: 0.53±0.061; CRUMB: 0.54±0.062). Cows required less time to transition between lying and standing when housed on GEL5 (mean time: GEL5: 6.7±0.57 s; GEL10: 7.3±0.55 s; FOAM: 7.6±0.53 s; CRUMB: 7.9±0.54 s). When housed on the GEL10, cows spent a greater proportion of time standing than when housed on the GEL5, and when housed on the FOAM and CRUMB, cows spent a greater proportion of time standing than on either gel mat (GEL5: 0.13±0.092; GEL10: 0.16±0.092; FOAM: 0.19±0.097; CRUMB: 0.18±0.090). This study was the first to investigate the effects of gel mats at two levels of compressibility on general activity and lying behavior. Results from this study indicate that the gel mats provide a surface that is more conducive for lying, as measured by time spent lying and the time required to transition between lying and standing postures. Additionally, in some instances, the cows' behavior differed between GEL5 and GEL 10, indicating cows are sensitive to subtle changes in stall compressibility.

Keywords: cow comfort, tie stall, stall base, lying behavior

INTRODUCTION

Dairy cows housed indoors spend approximately half their day lying (Gomez and Cook, 2010; Tucker et al., 2009; Drissler et al., 2005), making the comfort of the stall surface a critical feature of stall design. While stall flooring can be made softer by adding more bedding, due to various farm management issues (e.g. manure handling and variable cost), soft stall bases such as mattresses that are thought to provide cushion with less bedding have become increasingly popular. One problem many producers face is that after several years of use, soft mattresses filled with material such as rubber or foam, compress and harden. Recently, a novel stall base has been developed that anecdotally retains its softness over time. This product has a similar design to a rubber crumb filled mattresses, but is filled with a gel substance rather than a solid material. Another unique feature of the gel mat is that it is filled with water on farm, allowing for customization of the mats' internal pressure. The internal pressure dictates how hard or soft the mat is. As the gel mattress is a new product, there is a lack of published research regarding its effects on lying behavior compared to other stall bases.

Lying behavior is of interest to producers and dairy scientists for several reasons. Cows are highly motivated to lie down. Indeed, cows will forgo eating in order to lie after deprivation for 3 h (Metz, 1985), and will learn an operant task, such as pushing a lever repeatedly to gain additional hours of rest above their 9 h/d baseline, to maintain lying times of 12-13 h/d (Jensen et al., 2005). Lying provides several important physiological functions to the dairy cow. Blood circulation to the mammary region is increased in cows that are lying (Metcalf et al., 1992) and circulating growth hormone is decreased in cattle that are deprived of lying for 14 h/d (Munksgaard and Løvendahl, 1993). Additionally, depriving cows of lying opportunities increases corticosteroid levels. Fisher et al. (2002) found depriving cows of lying opportunities for 13 h/d increased plasma cortisol concentrations from a baseline of 14.9 nmol/ l to 19.3 nmol/l. Another study by Fisher et al. (2003) found that housing cattle in a wet concrete yard decreased lying time by 5 h/d and significantly increased fecal glucocorticoid metabolites by 1.4 ng/g compared to cows that were housed in a dry pen bedded with wood chips.

Studies have shown that the environment the cow is in influences her lying behavior. Environmental factors include temperature (Tucker et al., 2008), feed delivery (DeVries and von Keyserlingk, 2005), stall size (Tucker et al., 2004), location of the neck-rail (Fregonesi et al., 2009) and presence of the brisket locator (Tucker et al., 2006). Particular emphasis has been placed on the softness of the resting surface as an important environmental determinant of lying behavior (e.g. Tucker and Weary, 2004). This is likely because producers can practically address stall surface softness, whereas other factors (such as stall size) may be more difficult to modify. Softer stall floors are associated with longer lying times (e.g. Drissler et al., 2005; Tucker and Weary, 2004) and greater lying bout frequency (e.g. Tucker et al., 2009). Stall standing time (e.g. Haley et al., 2001), perching (Tucker and Weary, 2004), head swinging (Tucker and Weary, 2004), and the time required to transition from standing to lying (e.g. Krohn and Munksgaard, 1993; Herlin, 1997) decreases with increasing stall flooring softness. Additionally, researchers have suggested that internal factors such as weight, and body size may impact lying behavior, as heavy or large cows may be more reluctant to lie down due to the increased pressures exerted on their body (such as their knees) as they do so (Tucker et al., 2009).

The objective of this study was to test gel mats, comparing the impact of two different psi ratings on general activity and specifics of lying behavior (including the time required to transition from standing to lying and vice versa) for lactating dairy cows housed in a tie stall system.

MATERIALS AND METHODS

Animals and cow selection

Twenty-four lactating Holstein cows were used as subjects averaging (± SD) 108±50 DIM at enrollment, and in their 2nd (± 1.3) lactation. Cows were on average 3.6 (± 1.3) years old, weighed 660 (± 62) kg, and had an average BCS of 2.7 (± 0.3). Average daily milk production during the experiment was 17.9 (± 4.9) kg. To reduce sample variability, we enrolled a uniform group of cows that were more than 60 DIM, not lame, injured or of an extreme body condition.

Cows were gait scored using a 5-point scale to assess lameness, as outlined by Flower and Weary (2006). Cows scoring a 3 or higher were not included in our study. Cows were also evaluated for the presence of injuries on the front of knees with a 4-point scale (Capdeville and Veissier, 2001) and lateral side of both hocks with a 4-point scale (Cornell Cooperative Extension). Cows that scored a 3 on either body part were not included in the study. Cows were also body condition scored using a traditional 5 point scale (Elanco, 1997). We avoided using animals with extreme BCS (< 2.5 or > 3.5). Cows that met the above inclusion criteria were then weighed and body dimensions were recorded. Animals were measured to determine their height (measured from the floor to the top of the hook bones) and width (defined as the span across the hook bones). Length was also measured from the furthest caudal protrusion of the pin bones to the withers. These dimensions were included in the subsequent models to determine if dimensions of the body affect lying behavior.

Housing and management

Cows were housed in tie stalls within one barn (length: 193 cm, width: 132 cm, tie chain length: 70 cm, neck rail height: 114 cm). Prior to the experiment, cows were housed on 8 year old rubber-crumb filled mattress (Pasture Mat®, Promat, Ltd., Seaforth, ON) and bedded with chopped straw in tie stalls of the same size within the barn. Cows had *ad libitum* access to fresh water from shared water bowls and were provided approximately 55 kg of total mixed ration as fed distributed over 3 feedings /24 h, with feed pushed up 3 × /24 h. Cows were milked twice daily (0430 and 1430 h) in a parlour. Milk yield was recorded at milking for each cow.

Experimental methods

All experimental methods used in this study were approved by Animal Care Services (University of Guelph). Animals were housed at the Elora Dairy Research Centre (University of Guelph, ON, Canada) and were cared for in accordance with the Recommended Code of Practice for the Care and Handling of Dairy Cattle (National Farm Animal Care Council, 2009). The experiment was carried out between mid-August and mid-November, 2012.

Four different flooring surfaces laid over a concrete bed were utilized. Treatments were: 1) softer gel mat filled to a 5 psi rating (Pasture Gel Mat® Promat, Ltd., Seaforth, ON) 2) harder gel mat filled to a 10 psi rating (Pasture Gel Mat® Promat, Ltd., Seaforth, ON), 3) two layers of ¾" (1.9cm) polyurethane foam (PremiumPad®, Promat, Ltd., Seaforth, ON), and 4) a rubber crumb-filled mattress with a foam top layer (Pasture Mat® and PremiumPad®, Promat, Ltd., Seaforth, ON). All stalls were covered with the same solid rubber top cover (TC505-SRP, Promat, Ltd., Seaforth, ON). Every stall received 3 kg of chopped straw bedding daily. Stalls were cleaned 4-5 × daily.

To control for possible effects of location within the barn, the cows in this experiment were randomly allotted to one of two locations. Four animals/location were then randomly assigned stalls. So that each cow acted as her own control, the study was run in a cross-over design. At the end of every 7-d period each cow was randomly assigned in a balanced fashion, to one of the three remaining stalls in her assigned location within the barn. Four repetitions occurred until each cow had cycled through the four stalls. After the final repetition for each set of cows, the flooring surfaces were removed, and new flooring surfaces were installed, so that each set of cows were housed on surfaces of a similar age.

Automated activity recording

To see if there were any treatment differences in lying time and frequency of lying bouts during each 7-d period, every cow was fitted with an accelerometer (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA). On d 1, each cow had the accelerometer attached to the hind leg with Vet Wrap (Co-Flex, Andover Coated Products Inc., Salisbury, MA), in accordance with the methods outlined by Ledgerwood et al. (2010). HOBOs were pre-programmed to record at 1-min intervals for 7 d, starting at 1200 h on day 1. The data loggers were removed from the cows on d 7 and the data were downloaded using Onset HOBOware Software (Onset Computer Corporation, Pocasset, MA). These data were exported to Microsoft Excel and then imported into SAS (SAS 9.3 Software, SAS Institute, Inc., Cary, NC, US). Daily lying times and lying bouts for each cow were calculated in SAS according to the methods outlined by Ledgerwood et al. (2010).

Video recording of behavior

Four digital cameras (Panasonic Color CCTV Camera Model No. WV-CP484) were mounted (3.25 m horizontally and 2.2 m vertically away from the manger) so that each camera recorded two adjacent stalls. Lights were kept on along the feed alley at night to facilitate recording. Cameras were linked to a central monitor and digital video recorder (UVS 1240E2, GeoVision Inc., USAVisionSys, Irvine, CA).

Behavior observations

Behavior was coded by one observer from video recordings of the final 24-h period (d 7) that cows spent on each stall surface. The videos were played back in continuous mode at 8 or 16 × speed until a behavior change occurred. Behaviors recorded were: 1) lying (with lying with the head up and lying with the head supported on the ground or body), 2) standing in the stall, and 3) feeding and drinking combined (Table 2.1). To gain insight on how different flooring surfaces affect head swinging prior to lying, in the 1-min period before each lying bout, the number of times the cow swung her head from one side of the body to the other (crossing the center line) in a continuous motion with the nose oriented toward the stall surface was recorded. Similarly, the duration of the lying down and standing up movements, were recorded (Table 2.1).

Stall surface testing

On the first and final day of each 4 wk period the compressibility of each stall surface was assessed with a stall surface tester. The stall surface tester (Figure 2.1) was utilized to measure the relative compressibility (by giving an equivalent psi rating) for the stall surfaces in this study.

The device was based on Hooke's Law which states that the magnitude of an applied force required to compress a spring is proportional to the deflection of the material. The pressure contained within the flooring surface directly relates to its compressibility. Initially to calibrate the stall surface tester, the study's engineer used the tester to measure the deflection that occurred with gel mats of known compressibilities so that a chart that extrapolated to a wide range of compressibility values could be created. When the various stall surfaces in the trial were tested with a measured weight there was a corresponding measurable deflection in the surface, allowing for the determination of the relative compressibility with use of the above-mentioned charts.

The stall tester was firmly attached to the stanchions in each stall, which provided a solid reference independent of the stall surface itself. Appendix 1 displays the configuration in which the device was utilized. Once mounted an initial compressibility measurement was taken. This accounts for the self-weight of the device. Subsequently, depending on the average compressibility of the stall surface a weight of either 20.5 or 35 kg was added to the device and the compressibility measurement was taken.

Statistical analysis

All data were analysed using SAS (version 9.3, SAS Institute Inc., Cary, NC). Normally distributed data were analyzed using general linear mixed models (PROC MIXED), with the exception of head swinging behavior which was analyzed with a generalized linear mixed model (GLIMMIX) because of its Poisson distribution. All models included both random effects and repeated measures. Fixed effects tested in the multivariable models were: flooring treatment, stall, set, location, week, parity, age, weight, height, width, length and DIM. For all models, the covariance error structure yielding the lowest Akaike's Information Criterion value was utilized.

To see if there was an effect of flooring surface on the total daily lying time and daily number of lying bouts, two general linear mixed models were run (one for each of the above-mentioned outcomes). General linear mixed models were fit to test for any associations between stall flooring and specifics of lying behavior (latency from lying down to lying with the head supported by the body or ground, time required to transition between lying and standing and vice versa, and head swinging prior to lying) and milk production.

Five models were created for each behavior: total lying time, lying with the head supported by the body or floor, standing in the stall, eating and drinking, and time milking, or otherwise out of the stall. Cow was the repeated measure, nested by repetition and location within the barn. The outcome variable in the models was the proportion of time spent performing each behavior, using the total time observed/24 h for each cow as the denominator. The proportion of time spent performing each behavior was summarized by flooring treatment for each cow. Continuous variables were tested for collinearity (PROC CORR) prior to model building. For collinear variables, i.e. those with Pearson Correlation Coefficient greater than 0.6, the biologically more relevant variable was retained for subsequent model building. Parity was categorized into 1, 2, and 3+. Weight variables were divided by 100 so that any significant associations between weight and behavioral outcomes would be/100 kg weight basis.

Independent variables were tested on their own against the outcome, with quadratic terms tested for continuous variables. Independent variables where $P<0.2$ were tested in the multivariable model. All independent variables selected from the univariable testing were put into the model, and variables with the greatest p-values were removed in a backward step-wise fashion until only variables with $P < 0.1$ remained. Independent variables were considered to be confounders if their removal altered the coefficient of treatment variable by more than 30%, and if this was observed they were retained in the model. Two-way interactions between the independent variables retained in the model were tested univariably, and then were tested in the multivariable model if they had an association with the outcome ($P < 0.2$). As above, interaction terms were removed in a backwards step-wise fashion based on least significance ($P < 0.1$) preserving hierarchy. For the final model, $P < 0.1$ was considered a statistical tendency, while $P < 0.05$ was considered statistically significant.

For behavioral outcomes that were distributed normally, to assess the ANOVA assumptions, residual analyses were conducted. This included testing the residuals for normality using the four tests offered by SAS (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling). In addition, the residuals were plotted against the predicted values and explanatory variables used in each model. These analyses were conducted to reveal outliers, unequal variances, or data requiring transformation.

RESULTS

Over the entire 7 d period, when cows were on the GEL5, they spent more time lying down than when housed on CRUMB (51 min more) or GEL10 (45 min more) (Table 2.2) as recorded by the accelerometers. The accelerometers indicated that when housed on GEL5 or GEL10, cows exhibited fewer lying bouts than when they were housed on FOAM or CRUMB (Table 2.2). From the continuous video data on the last day cows were housed on each flooring surface, floor type was the only variable to significantly ($P < 0.01$) impact the proportion of time spent lying. When housed on GEL5 or GEL10, cows spent more time lying (51 min more) than when housed on FOAM or the CRUMB (Table 2.3).

There was a tendency for floor to impact the proportion of time spent lying with the head supported by the floor or body. When housed on the GEL10 stalls, there was a tendency that cows spent a greater proportion (14 min more) of time lying with their head supported than when the cows were housed on FOAM and CRUMB (mean proportion±SE: GEL5: 0.041±0.011 GEL10: 0.048±0.012; foam: 0.039± 0.013; CRUMB: 0.037±0.012; $P < 0.10$). There was an effect of floor surface on the latency to assume a head supported position after lying down. When housed on the softest surface (GEL5), cows had the longest latency (approximately 7.5

min longer) to lie with the head supported, compared to all other flooring treatments (Table 2.5; $P < 0.10$). Flooring surface did not affect the frequency of head swinging prior to lying down (mean head swing count±SE; GEL5: 2.2±0.23; GEL10: 2.1±0.22; CRUMB: 2.2±0.25; FOAM: 2.3±0.23; $P = 0.532$).

There was a tendency for the flooring surface to influence the time required to transition from lying to standing. When housed on GEL5, there was a tendency that cows took approximately 1 second less to stand up than when they were housed on FOAM and CRUMB (Table 2.4; $P < 0.10$). Stall surface did not affect the amount of time required to transition from standing to lying ($P = 0.116$). When housed on GEL5 and GEL10, cows spent significantly less time standing than when housed on CRUMB and FOAM. Additionally, when housed on the harder gel mat (GEL10) cows spent longer standing then when they were housed on the softer gel mat (GEL5) (Table 2.3; $P = <0.0001$). There was a tendency for the odds of standing in the stall to increase with every 5 cm increase in body width (OR: 1.17; $P < 0.10$).

There was no significant difference in the amount of time spent feeding and drinking, or out of the stall by flooring treatment ($P \geq 0.9618$). For every 5 cm increase in cow width, there was a decrease in the odds of the cow feeding or drinking (OR= 0.91; $P < 0.01$). Flooring surface had no effect on milk production ($P = 0.721$). However, milk production was 5 kg greater in the morning milking compared to the afternoon milking (mean milk production±SE; morning: 20.6±0.80 kg, afternoon: 15.6±0.80 kg; $P < 0.0001$).

Measures from our stall surface tester indicated that the mean compressibility of the gel mats increased (i.e. they became softer), the mean compressibility of the rubber crumb filled mattress decreased (i.e. it became harder), and the foam mat showed no change in compressibility between wk 1 and wk 4 (Figure 2.2).

DISCUSSION

This study is the first to investigate the behavior of lactating dairy cows on gel mats. The proportion of time spent performing each behavior recorded in this experiment were similar to other studies with cows housed in tie stalls (e.g. Norring, 2011; Krohn and Munksgaard, 1993). Data from the video recordings indicated that when cows were housed on both GEL5 and GEL10 they spent a greater proportion of time lying than when housed on the FOAM or CRUMB (0.57 vs. 0.53). These results were consistent with other studies, such as work by Chaplin et al. (2000) who found the proportion of time spent lying was greater (0.5 vs.0.44) for cows on mattresses compared to cows on solid rubber mats (mattresses were considered to provide more cushion). When recording behavior over the entire 7 day period, the HOBO data loggers only captured significant differences between the GEL10 and GEL5, and the GEL5 and the FOAM surfaces. It is likely that since the HOBOs were recording lying time over the entire week, and the HOBOs did not record the initial 1 d of acclimatization, the effect of adaptation to the unique flooring surfaces was only partially captured by the loggers. Since cows had not been previously exposed to any of these surfaces, they likely required several days to adjust to the flooring surfaces, and hence their behavior took several days to adapt.

When cows were housed on the FOAM and CRUMB, there was approximately 1 lying bout more/day compared to the gel mats. Other studies that have compared the number of lying bouts on different floor surfaces have typically observed more frequent lying bouts on softer surfaces. For instance, Haley et al. (2001) observed approximately 13 lying bouts with mattress flooring and 9 bouts with concrete flooring. While Tucker and Weary (2004) found 10 bouts with 7.5 kg of sawdust bedding, and 8.5 bouts with 0 kg of bedding. It has been suggested that softer floors provide more cushion for the changes between standing and lying, and vice versa, so cows are more likely to change position on these surfaces (Tucker and Weary, 2004). However, in this study, the flooring surfaces may not have differed as drastically in softness as other studies. It is possible that all the surfaces provided sufficient traction for rising and lying easily, however FOAM and CRUMB, were less comfortable for lying, hence cows stood up from the lying position more frequently.

In this study, there was no significant difference in the frequency of head swinging prior to lying down on the different flooring surfaces. Previous work found less head swinging behavior when cows were housed on softer surfaces. For instance, Tucker and Weary (2004) found cows housed in a freestall system exhibited fewer head swings/lying bout when housed on 7.5 kg of sawdust (0.63) compared to 0 or 1 kg of sawdust (0.99 and 1.0). Krohn and Munksgaard (1993) found that cows housed in tie stalls either on rubber mats or concrete with the same amount of bedding spent similar amounts of time examining the lying area, but this was significantly longer compared to cows in a deep bedded pen. In this study it is possible that the flooring surfaces did not differ sufficiently to cause a variance in head swinging. Our definition of counting head swinging frequency 1 min prior to lying was selected so that our results could be compared to other work (e.g. Tucker and Weary, 2004), however this time frame may not have been sufficient to capture head swinging that may have occurred prior to this time cut point.

Flooring tended to have an effect on the amount of time required to transition between lying and standing. When housed on FOAM or CRUMB, cows took approximately 1 second longer (13% more time) to stand up, compared to when they were housed on the GEL5. Work by Absmanner et al. (2012) found that the mean duration of standing up was significantly shorter (approximately 3 s faster) for bull calves housed in a straw pen, than calves housed on bare concrete slats or a straw covered concrete slats. Since the GEL5 surface was the softest, it is possible that the additional traction it provided facilitated the getting up movement. The time required to lie down was of interest due to its use in welfare assessment schemes (e.g. Welfare Quality®, 2009). No difference in this measure was observed in the present study. Krohn and Munksgaard (1993) found cows lay down 5 s faster when housed on a rubber mat, and 6 s faster when housed in deep bedded pens compared to concrete tie stalls. The authors, however, did not find a difference in the lying down movement between deep bedded pens or rubber mats with bedding in tie stalls. It is possible that although our treatments had numerically different psi ratings, they did not differ dramatically enough to cause fluctuations in the lying down movement.

More time spent standing is often recorded when cows are housed on harder stall surfaces, which may be attributed to discomfort when transitioning between lying and standing, and vice versa. In this study, cows on the harder surfaces spent more time standing. When housed on the less compressible gel mat (GEL10) cows stood approximately 35 min longer than when housed on GEL5. When housed on FOAM or CRUMB, cows stood for approximately 37 min longer (2.6% more) than when housed on GEL10. The magnitude of this difference is consistent with work by Haley et al. (2001). They compared 16 cows in a tie stall with a cross-over design that were housed on more variable flooring than used in the current study. Cows were first housed on concrete for 3 weeks, followed by mattresses for 3 weeks, both covered with 2 cm of chopped straw. They found that cows spent 7.1% more time standing when housed on the concrete flooring. When comparing the effect of varying both flooring and housing system on standing behavior, the authors found that the time spent standing in pens with mattresses to tie stalls with concrete flooring, was 4.3 h less (a 33% difference). Again, most studies have focused on differences in bedding type (e.g. Tucker et al., 2003), or amount (e.g. Drissler et al., 2005), rather than comparing stall base while controlling for bedding, so this is an area requiring further research.

CONCLUSIONS

The results indicate that housing cows on surfaces of differing compressibilities does impact their behavior. When cows were housed on the softest surfaces (the gel mats), they spent a greater proportion of time lying. They also took less time to stand from the lying position, and spent less time standing in the stall than when they were housed on the harder surfaces (the foam mat and rubber mattress). When housed on the gel mats, cows had a longer latency to assume the head resting position than when housed on FOAM or CRUMB. Finally, this study was the first to investigate the effect of gel mats at two levels of compressibility on general activity and lying behavior, using a novel method of measuring stall surface compressibility. This is one of the first studies on the effects of stall surface where both the top cover, and variety and quantity of bedding were the same across all treatments. Results from this study provide valuable information for researchers and product developers to expand upon in future work, and for producers to use in their decision making when the time comes to replace the stall bases in their farm.

Table 2.1. Operational definitions utilised in this study.

Standing	Upright position with all four hooves on stall surface.
Lying- head up	Body supported by the ground.
Lying- head supported	Lying with head back against flank or supported by the ground.
At feed	Food or water in the mouth, chewing, swallowing, muzzle touching the feed or water.
Standing up movement	Started when cow started lifting the hind quarter from the ground. The rising sequence ended when both front legs touched the ground and the cow stood with her body weight on all four legs. Measured in s.
Head swinging	The number of times when head swung from one side of body to another (crossing center line), in a continuous motion with nose oriented towards stall surface and below shoulder height. Measured as frequency.
Lying down movement	Begins when one carpal joint of the animal is bent (before touching the ground). The lying down sequence ends when the hind quarter of the animal is supported on the ground and the cow has pulled the front legs out from underneath the body. Measured in s.

Table 2.2. Results from Least Squares Means on the mean (h/24 h) time spent lying, and mean daily lying bouts as recorded from HOBO data loggers over entire 7 days housed on each floor surface.[1] Columns with different letters (a, b, c) indicate a significant (*P* < 0.05) difference.

Flooring surface	Mean proportion of daily time±SE (h/24 h)	Mean number of lying bouts/24 h±SE
GEL5	13.9±1.90 a	13.0±0.053 ac
GEL10	13.2±1.61 b	12.5±0.057 a
CRUMB	13.4±1.85 b	13.8±0.057 bc
FOAM	13.0±1.87 ab	14.9±0.055 b

[1]The ar(1) covariance structure was utilized for both models.

Table 2.3. Results from Least Squares Means on the effect of floor on the mean proportion of time spent lying and standing as recorded from the video data, on the final day cows were housed on each surface.[3]Columns with different letters (a, b, c) indicate a significant difference ($P < 0.05$).

Flooring surface	Mean proportion of time lying [1] ± SE	Mean proportion of time standing [2] ± SE
GEL5	0.57±0.061 a	0.13±0.092 a
GEL10	0.57±0.062 a	0.16±0.092 b
CRUMB	0.53±0.062 b	0.18±0.090 c
FOAM	0.54±0.061 b	0.19±0.097 c

[1] Flooring treatment was the only variable to be retained in this model.
[2] Cow width was retained in the model (P = 0.0941), see text.
[3] The ar(1) covariance structure was utilized for both models.

Table 2.4. Results from Least Squares Means on the mean amount of time (s) required to transition from lying to standing.[1] Columns with different letters (a, b, c) indicate a significant difference ($P < 0.05$).

Flooring surface	Mean amount of time to transition from lying to standing±SE (sec)	95% Confidence Interval
GEL5	6.7±0.57 a	6.7 – 8.3
GEL10	7.3±0.55 ab	6.2 – 8.4
CRUMB	7.9±0.54 b	6.8 – 8.9
FOAM	7.6±0.53 b	6.6 – 8.7

[1] The arh(1) covariance structure was utilized for the above model.

Table 2.5. Results from Least Squares Means on the mean latency (min) to rest the head on the floor or against the body after lying down. [1] Columns with different letters (a, b, c) indicate a significant difference ($P < 0.05$).

Flooring surface	Mean latency to lie with head supported±SE (min)	95% Confidence Interval
GEL5	41.2±2.5 a	36.2 – 46.0
GEL10	36.2±2.3 bc	31.6 – 40.7
CRUMB	32.9±2.5 c	28.0 – 37.7
FOAM	31.8±2.4 c	31.7 – 36.4

1 The ar(1) covariance structure was utilized for the above model.

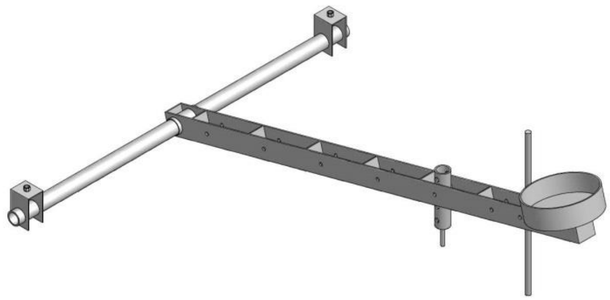

Figure 2.1. Schematic of the stall surface tester.

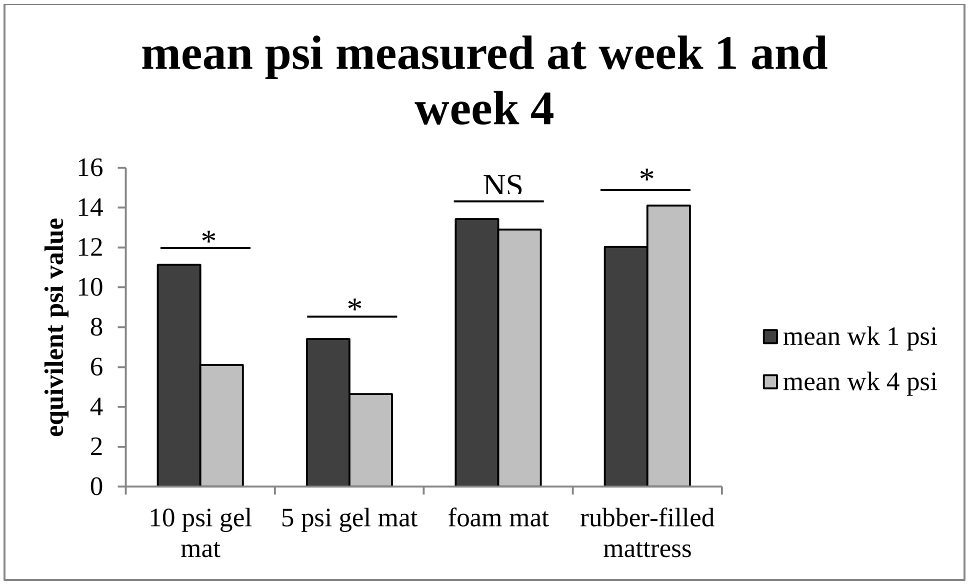

Figure 2.2. Mean stall compressibility (as indicated by psi equivalent rating from stall surface tester) between wks 1 and 4. An asterisk indicates the compressibility values are significantly ($P \leq 0.0106$) different between wks 1 and 4 as determined by paired t-tests.

Chapter 3: The effects of a gel mat flooring surface on the activity and stall choice preferences of loose-housed dairy cattle

ABSTRACT

The objective of our study was to determine the effects of gel mat stall flooring on the activity and preferences of dairy cattle kept in a free stall environment. Eighteen non-lactating Holstein dairy cows were housed individually in sections of a free stall pen, each with access to two stalls. One stall was fitted with a foam mat, and the other with a gel mat. The experiment began with 1 day acclimatization to the housing conditions with access to both stalls. Cows were then restricted to one stall at a time for 3 consecutive days (restriction phase). Cows were then allowed access to both stalls for 3 days (choice phase). Behavior was video recorded during the final 24-hour period of each phase (days 3, 6, and 9) to record general activity and stall preference. During the restriction phase cows spent a greater proportion of their time lying on the gel mats compared to the foam mats (mean proportion±SE; gel: 0.63±0.025; foam: 0.60±0.028). Time spent standing and perching in the stall, were both lower on the gel compared to the foam mats (mean proportion±SE; standing gel: 0.038±0.015; standing foam: 0.061±0.092; perching gel: 0.018±0.012; perching foam: 0.032±0.012). The latency to lie down was greater after entering the foam stalls (mean time±SE; foam: 289±51.3 s vs. gel: 175±34.4 s). Cows did not show any preference for using either stall flooring surface for lying, standing, or perching during the choice phase. This study was the first to investigate the effects of a gel mat stall surface on activity and preference of dairy cows in a free stall system. Results during the restriction phase indicated that the gel mat promotes lying behavior, as measured by the proportion of time spent lying, standing, perching, and the latency to lie down after entering the stall, likely due to its softness compared to the foam mat.

INTRODUCTION

Dairy cows housed indoors spend around half of their daily time budget lying (Jensen et al., 2005; Drissler et al., 2005), making the comfort of the resting surface an important feature of stall design. While stall flooring can be made softer by adding more bedding, due to various farm management issues (e.g. manure handling and variable cost), soft stall bases such as mattresses that are thought to provide cushion with less bedding have become increasingly popular. One problem many producers face is that after several years of use, soft mattresses filled with material such as rubber or foam, compress and harden. Recently, a new stall base has emerged on the market that may have the potential to retain its softness over time. This product has a similar design to a rubber crumb filled mattress, but is filled with a gel substance rather than a solid material. As the gel mattress is a new product, there is a lack of published research regarding its effect compared to other stall bases.

In a free stall system, assuming cows have access to multiple stalls, stall use can be an indicator of stall preference (Herlin, 1997). Preference tests allow animals to choose between different options and therefore allows us to assess which option they prefer (Kirkden and Pajor, 2006). Preference is typically calculated in animal welfare research as the duration of time they spend on, or the frequency with which they select each option. This can provide an indication of the importance they place on one option over another. Presenting multiple stalls that vary by stall surface can give us an indication of what aspects of stall flooring are important to the cows, based on which stalls they choose (Tucker et al., 2003). In addition, the specific behavior observed in the stall may provide further insight into the relative comfort of the surface. For instance, lying times have been observed to be greater on softer stall surfaces (e.g. Haley et al., 2001; Herlin, 1997; Jensen et al., 1988), while greater time standing in the stall has been observed on harder stall surfaces (e.g. Calamari et al., 2009; Haley et al., 2001). Typically, perching behavior (standing with the front two feet in the stall, and rear feet in the alley) is combined with standing behavior (standing with all four feed in the stall). Tucker et al. (2003) found cows stood (including perching) an additional 35 minutes on mattress compared to sawdust or sand bedded stalls. Studies that did differentiate standing and perching behavior have observed an increase in perching in smaller stalls (Tucker et al., 2005, 2004), stalls with wet bedding (Fregonesi et al., 2007b), and stalls with little bedding (Tucker and Weary, 2004).

Preference studies have demonstrated that cows prefer to lie on softer surfaces. For instance, cows preferred solid rubber mats over concrete (Herlin, 1997), and rubber crumb filled mattresses over solid rubber mats (Chaplin et al., 2000). Preferences can also be influenced by the provision of varying amounts of bedding regardless of stall base. Jensen et al. (1988) found that cows preferred concrete stalls when covered with deep bedding to mattresses, but preferred mattresses to concrete if only scant bedding was available. Additionally, studies have shown that cows lie down for less time when the amount of bedding decreases. For instance, in sawdust and straw-bedded stalls, lying times decreased by 3-12 min/d with every 1 kg reduction in bedding (Tucker and Weary, 2004; Tucker et al., 2009). In sand-bedded stalls, lying times decreased by 10 min/d for every 1 cm decrease in bedding depth(Drissler et al., 2005).

The objectives of this study were to determine whether the general activity and lying behavior of cows differed when housed on stalls with a gel mat, compared to stalls with a foam mat. When cows had access to both stall surfaces, we assessed their preference for one flooring surface over another. We hypothesized that cows would spend a greater proportion of time lying when restricted to the gel mats, whereas standing and perching would be greater when restricted to the foam mats. Additionally we hypothesized that the latency to lie down on the gel mats would be shorter than on the foam mats. We expected that cows would show a preference for the gel mats by spending a greater proportion of time lying in those stalls.

MATERIALS AND METHODS

Animals and cow selection

We used 18 non-lactating Holstein cows as subjects that were on average (± SD) 4.7 years old (±1.8), in their 2.5 parity (±1.6), and 203 d in gestation (±51). Mean body weight was 824.3±98.3 kg. To reduce sample variability, we enrolled a uniform group of cows that were not lame, injured or of an extreme body condition. One cow was removed from the study due to health concerns.

Cows were gait scored on a 5-point scale to assess lameness using the methods outlined by Flower and Weary (2006). Cows scoring a 3 or higher were not included in our study. Cows were also evaluated for the presence of carpal injuries with a 4-point scale (Capdeville and Veissier, 2001) and the lateral side of both hocks was scored with a 4-point scale (Cornell Cooperative Extension). Cows that scored a 3 or higher on any scored body part were not included in the study. Cows were also body condition scored using a traditional 5 point scale (Elanco, 1997). We avoided using animals with extreme BCS (< 2.5 or > 3.5). Cows that met the above inclusion criteria had their weight recorded.

Housing and management

Animals were housed at the Elora Dairy Research Centre (University of Guelph, ON, Canada) and were cared for in accordance with the recommended Code of Practice for the Care and Handling of Dairy Cattle (National Farm Animal Care Council, 2009). Animal use was approved by Animal Care Services (University of Guelph). The experiment occurred between June 1st and August 31st, 2012.

Cows were housed in adjacent free stalls (132 × 188 cm) in one section of a free stall barn for the purpose of this experiment. Gates were used to section off the stalls, creating individual pens, each containing two stalls. Alleys were made of rubberized concrete (239 × 343 cm). All cows used in the study had prior experience being housed in the free stall system. Prior to the study, cows were housed on rubber crumb filled mattresses installed 8 years previously (Pasture Mat®, Promat, Ltd., Seaforth, ON) with chopped straw bedding. During the experiment, every stall was covered with 1 kg of chopped straw, with bedding changed daily. Stalls were cleaned 3× /d and the alley scraper ran 14× /d.

Cows had *ad libitum* access to fresh water from individual water bowls and were provided 35 kg of total mixed ration as fed once daily. Feed was pushed up 3 to 4 ×/d. The barn had both natural and forced ventilation, with artificial lighting, which the cows were accustomed to, on between the hours of 0430h and 1800h.

Experimental methods

The stall bases used in the study were a gel mat (Pasture GEL Mat™, Promat, Ltd., Seaforth, ON) filled to a 10 pounds per square inch (psi) rating, and two layers of ¾" (1.9 cm) polyurethane foam (Premium Pad™, Promat, Ltd., Seaforth, ON). The same solid rubber top cover was used in all stalls (TC505-SRP, Promat, Ltd., Seaforth, ON). The position of the two stall bases within each pen was randomly determined, and switched part way through the study period.

Cows in this experiment were randomly allotted to one of the two experimental pens, and then randomly assigned stall order for the restriction phase in a balanced fashion. Two animals were tested simultaneously, with one cow/pen. Cows were allowed a period of acclimatization for approximately 1 d prior to the start of the study, where they had access to both stalls. Cows were then restricted to a single stall by hanging a gate across the rear of the stall not in use. The restriction phase lasted 6 d. Cows had access to one stall in their assigned pen for a period of 3 d (d 1 to 3), and then switched to the other stall in their pen for 3 d (d 4 to 6). During the remaining 3 d (d 7 to 9) each cow had free access to the two stalls in her pen.

Automated activity recording

To investigate treatment differences in total lying time and frequency of lying bouts during the 6-d restriction period based on stall surface, each cow was fitted with an accelerometer (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA). On d 1, each cow had the accelerometer attached to the hind leg with Vet Wrap (Co-Flex, Andover Coated Products Inc., Salisbury, MA), in accordance with the methods outlined by Ledgerwood et al. (2010). HOBOs were pre-programmed to record at 1-min intervals for 6 d, starting at 1200 h on d 1. The data loggers were removed from the cows on d 6 and the data were downloaded using Onset HOBOware Software (Onset Computer Corporation). These data were exported to Microsoft Excel and then imported into SAS (SAS 9.3 Software, SAS Institute, Inc., Cary, NC, US). We then calculated and summarized daily lying time and lying bouts/cow according to the methods outlined by Ledgerwood et al. (2010).

Video recording of behavior

Two digital cameras (NDC Digital D & Night Color CCD Camera Model PC-3756) were mounted (260 cm above the ground and 180 cm away from the feed rail) so that each camera covered both stalls in one pen. To allow video recording at night, a red LED floodlight was mounted underneath each camera and set to turn on at dusk and off at dawn. Cameras were linked to a central monitor and digital video recorder (UVS 1240E2, GeoVision Inc., USAVisionSys, Irvine, CA).

Behavior observations

Behavior of the cows was video recorded during the last 24 h of each restriction phase (d 3 & 6) and the last 24 h of the choice phase (d 9) for a total of 3 d of recording. Behavioral observations were coded by one observer. Video recordings were replayed in continuous mode at 8 or 16× speed until a behavior of interest occurred to measure the time spent 1) lying (with lying with the head supported on the body or floor differentiated), 2) standing, 3) perching, 4) out (in the alley), and 5) at the feed bunk, for each stall surface. Additionally, during the restriction phase, latency to lie down once the cow was standing in the stall was calculated based on the behavioral definitions provided (Table 3.1).

Statistical Analysis

All data were analysed using SAS (version 9.3, SAS Institute Inc., Cary, NC). Within the restriction phase, the proportion of time spent performing each behavior was summarized by treatment for each cow. In the choice phase, time spent performing each behavior was summarized by cow and stall choice. Outcomes were calculated as the proportion of time spent performing each behavior, using the total time observed/ 24 h for each cow as the denominator.

Data were analyzed using general linear mixed models (PROC MIXED). Continuous variables were tested for collinearity (PROC CORR) prior to model building. For collinear variables, i.e. those with Pearson Correlation Coefficient greater than 0.6, the biologically more relevant variable was retained for subsequent model building. Parity was categorized into 1, 2, and 3+. Weight variables were divided by 100 so that any significant associations between weight and behavioral outcomes would be/100 kg weight basis. Fixed effects tested during model building were: floor, order of exposure, month, stall, pen side, parity, age and weight.

For the restriction phase six models were created for each behavior of interest: all lying, lying with the head supported by the body or floor, standing in stall, perching in stall, standing in the alleyway, and standing at the feed bunk. Four models were run for the choice phase: all lying, lying with the head resting on the body or floor, standing in the stall and perching in the stall, using linear regression. A random effect of cow nested by treatment side was included within the models (i.e. which stall contained the gel mat). Independent variables were tested univariably against the outcome, with quadratic terms tested for continuous variables. Independent variables with an association of $P < 0.2$ were retained for further testing in the multivariable model. All independent variables selected from the univariable testing were put into the model, and variables with the greatest p-values were removed in a step-wise fashion. Independent variables were considered to be confounders if their removal altered the treatment variable by more than 30%, and if this was observed they were retained in the model. Two-way interactions between the treatment variable and the independent variables retained in the model were tested, and were kept for further testing in the multivariable model if they had an association with the outcome ($P < 0.2$). As above, interaction terms were removed in a backwards step-wise fashion based on least significance ($P < 0.1$) preserving hierarchy. Overall, $P < 0.05$ was considered statistically significant, and $P < 0.1$ was considered a statistical tendency. We did experience some technical difficulty during the experiment that resulted in some lost video data for certain cows, however video loss was equal across both treatments and by time of d.

To assess the ANOVA assumptions, residual analyses were conducted. This included testing the residuals for normality using the four tests offered by SAS (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling). In addition, the residuals were plotted against the predicted values and explanatory variables used in each model. These analyses were conducted to reveal outliers, unequal variances, or data requiring transformation.

RESULTS

Restriction phase

Mean daily lying time, as recorded by the HOBO data loggers, over the 6 d period of restriction was 35 minutes longer on the gel mats than the foam mats (mean h/24 h±SE; gel: 15.4±0.35; foam: 14.8±0.42; $P < 0.05$). The mean number of lying bouts was similar between floor treatments (mean±SE; gel: 9.2±0.51, foam: 9.0±0.43; $P = 0.65$). There was a wide range in daily lying (gel: 9.4 to 19.7 h/24 h; foam: 9.5 to 18.8 h/24 h), and number of lying bouts (gel: 4 to17 bouts/24 h; foam: 4 to 15 bouts/ 24 h) for both floor treatments.

The above results were consistent with the video data. During the last d of the restriction phase (d 3 and 6), the total proportion of time spent lying was greater on the gel mat stalls than the foam mat stalls (gel: 0.63 vs. foam: 0.60; P = 0.044; Table 3.2). Regardless of flooring, cows in their first parity spent a lower proportion of time lying than cows in their 2nd and 3rd parity (mean proportion±SE; 1st parity: 0.5±0.18; 2nd parity: 0.7±0.11; 3rd parity: 0.6±0.19; $P < 0.05$). Cows spent a greater proportion of time lying if they were in the trial during June or July rather than

August (mean proportion±SE; June: 0.7±0.15; July: 0.7±0.15; August: 0.5±0.15; $P < 0.05$). Stall floor had no effect on the proportion of time spent lying with the head supported by the ground or body (mean proportion±SE; gel: 0.04±0.010; foam: 0.04±0.010; $P = 0.317$). Pen side impacted lying with the head supported, where cows in the pen towards the south east end of the facility spent a greater proportion of time lying in this posture (mean proportion±SE; southern pen: 0.05±0.011; northern pen: 0.03±0.010; $P < 0.01$) regardless of flooring surface. Latency to lie down was shorter when cows were restricted to the gel mat compared to the foam mat stalls (mean±SE; gel: 174.8±34.43 s; foam: 288.9±51.29 s; $P < 0.01$; Figure 3.1).

The proportion of time spent standing in the stall was greater on the foam mats (mean proportion±SE; gel: 0.04±0.010; foam: 0.06±0.015; $P < 0.001$; Table 3.2). Regardless of stall floor, cows in their 3rd parity spent a greater proportion of time standing than cows in their 1st or 2nd parity (mean proportion±SE; 1st parity: 0.04±0.034; 2nd parity: 0.03±0.023; 3rd parity: 0.10±0.034; $P < 0.01$). Stall surface tended to have a similar effect on proportion of time spent perching, where cows tended to spend more time perching when restricted to the foam mat stalls (mean proportion±SE; gel: 0.04±0.012; foam: 0.05±0.012; $P < 0.10$). There was no effect of stall flooring on the proportion of time spent standing in the alleyway or at the feed bunk ($P \geq$ 0.6425).

Choice phase

Cows showed no preference ($P \geq 0.301$) for either the gel or foam flooring for lying, standing or perching (Table 3.3). The overall mean proportions of time spent lying, standing, and perching during the choice phase were numerically similar to the proportion of time performing these behaviors during the restriction phase (mean restriction lying: 0.6, preference lying: 0.6; restriction standing: 0.06, preference standing: 0.06; restriction perching: 0.07, preference perching: 0.05). Cows showed a strong preference for stall location regardless of stall flooring. When lying and standing, cows preferred the stalls closest to the southeast corner of the barn (mean proportion±SE; southern lying: 0.5±0.063; northern lying: 0.03±0.063; $P < 0.01$; southern standing: 0.02±0.048; northern standing: 0.01±0.048; $P < 0.05$). There was a wide range in the percentage of lying time spent on the gel mat, but only two cows did not spend the majority of their lying time in the southern stall (range 0 – 100%; Figure 3.2).

DISCUSSION

This trial was the first to study the effect of gel mats on the general activity and stall choice preferences of cows housed in a free stall system.

In the restriction phase, cows spent a significantly greater proportion of time lying when restricted to the gel mat stall (0.032 more). This increased lying on the gel mat is consistent with other research that found higher total lying times on softer stall flooring surfaces. Chaplin et al. (2000) found the proportion of time spent lying was greater (0.50 vs. 0.44) for cows on mattresses compared to cows housed on solid mats (mattresses were considered to provide more cushion). Haley et al. (2001) observed that cows lay down for 1.7 hours longer when housed on a mattresses compared to concrete flooring in tie stall housing. Most studies have focused on the effect of bedding quantity on lying behavior; finding that as the weight or depth of bedding increased so did total lying time. For instance, Tucker et al. (2004) found lying times increased from 12.3 h/d to 13.3 h/d as the bedding amount increased from bare mattresses to 7.5 kg of sawdust covering the mattress. Another study by Tucker et al. (2009) found that for every 1 cm increase in shavings and straw compressibility, lying times increased accordingly by 6 to 9 min.

We found no significant difference in the proportion of time cows spent lying with the head supported on the two stall flooring surfaces. Lying with the head supported on the ground or against the body was recorded due to its association with REM sleep. Hänninen et al. (2008) found that lying with the head supported by the ground or body predicted REM sleep when compared to electrode recordings 61% of the time using 6 pairs of dairy calves. During the REM sleep state, the neck muscles become atonic so the head is typically rested on the ground or body (Ternman et al., 2012; Ruckebusch, 1975). It has been shown that cows in muddy conditions outdoors reduced the amount of time lying with the head resting on the flank or ground, compared to cattle housed in dry conditions indoors (Tucker et al., 2007). This suggests housing conditions can influence the quality of sleep and therefore, we were interested in finding out whether flooring surface would produce a similar effect in resting posture. In this study, it is possible that both surfaces were adequate for a similar quality of sleep. Also, it is possible that differences may have been observed had we used lactating cows due to the increased physiological demands they face during lactation. Alternatively, lying with the head supported on the ground or body may not provide a good indication of REM sleep in adult dairy cows. We did find that pen location had an effect on lying with the head supported by the body or ground. Cows in the southern pen spent a greater percentage of time lying with the head supported by the ground or body. Cattle are a prey species and it has been shown that these species will shift to lighter sleep states in response to perceived threats, including environmental disturbances (Lima et al., 2005). Therefore this result may be due to a quieter environment in the southern pen, which was further from the milking parlour, with potentially less human and animal disturbances.

Cows spent a greater proportion of time standing in the stall (0.022 more) when restricted to the foam mat stalls. Similarly, the proportion of time spent perching tended to be greater on the foam mat stalls (0.014 more). Greater amounts of time spent standing in the stall are often recorded when cows are housed on harder stall surfaces, which is attributed to possible discomfort when transitioning between lying and standing, and vice versa. Haley et al. (2001) compared 16 tie stall cows in a cross-over design that were housed on concrete and mattresses for 3 wks each, both covered with 2 cm of chopped straw, and found cows spent 7.1% more time standing when housed on the concrete flooring. Again, most studies have focused on differences in bedding type (e.g. Tucker et al., 2003), or amount (e.g. Drissler et al., 2005), rather than comparing stall base and controlling for bedding as we have done in our experiment.

In both phases of the experiment, the proportions of time we reported spent standing, lying, and perching in the stall, standing in the alley, and standing at the feed bunk are comparable to other literature regarding the time budgets of free stall-housed dairy cows (Gomez and Cook, 2010; Fregonesi et al., 2004).

This is the first research project to our knowledge that has compared the latency to lie after entering a stall between different stall bases. Researchers have observed that cows housed in tie stalls spent more time 'investigating' the flooring surface (including swinging the head side to side with the muzzle near the ground) prior to lying down, when housed on harder surfaces. It has been proposed that head swinging behavior may reflect the cows' hesitation to lie down (Tucker and Weary, 2004; Krohn and Munksgaard, 1993). Krohn and Munksgaard (1993) observed more time spent on investigation movements when cows were housed on either concrete and 1 kg of straw bedding (51 s), or rubber mats and 2 kg of straw bedding (49 s), compared to cows that were loose-housed with deep bedding (21 s), and cows on pasture (8 s).

While Tucker and Weary (2004) found this behavior decreased when cattle had access to stalls bedded with 7.5 kg of sawdust, compared to stalls with 0 or 1 kg of bedding. It has also been shown that cattle exhibit longer standing bouts prior to lying on harder surfaces (e.g. Calamari et al., 2009; Haley et al., 2000). In our study we observed a shorter latency to lie on the gel mats compared to the foam mats. Latency to lie is a measure that may be useful to include in future studies, particularly in situations where detailed observation of head swinging behavior is not feasible.

Contrary to our hypothesis, we found no significant effect of flooring surface on which stall was preferred for lying or standing. Others have found an effect of flooring surface on preference. Calamari et al. (2009) offered free stall cows the choice between a straw bedded pack (mixture of straw and dry animal waste), rubber mat, mattress, and 20 cm deep sand floors, and found the rubber mat and mattress stalls were preferred for standing (48% and 46% of the total time spent in these stalls was standing) while the bedded pack and sand stalls were utilized mainly for lying (80% and 85% of time spent in these stalls was lying). Herlin (1997) offered cows the choice between concrete, hard rubber mat, and soft rubber mat stalls in a free stall pen and found that there was a significant difference in the observed time spent lying across the flooring surfaces (18%, 55% and 71% of the observed time, respectively).

While our study found no preference for the stall flooring surfaces tested, there are several possible explanations for this result. Cows may have selected the foam because they had more experience with firmer surfaces (Tucker et al., 2003), as they were previously housed on 8-year-old rubber crumb filled mattresses. In addition, it is possible that the two surfaces were not sufficiently different that the cows could distinguish between them. Many preference studies that have observed cows showing a clear stall flooring preference have examined flooring surfaces that were dramatically different from one another. For instance, comparing no bedding to deep bedding, or soft rubber mats to concrete (e.g. Tucker and Weary; 2004; Herlin, 1997). Additionally, to reduce sample variability we selected cows that were non-lame and non-injured. Other work has demonstrated that the amount of time spent standing in a stall was associated both to lameness score and type of stall flooring (Cook et al., 2004a), so stall flooring surface preference differences may well exist between specific groups of animals (e.g. lame vs. non-lame). We recommend further research be conducted on the effects of such animal-based factors on stall base preference. Alternatively, as our preference test occurred when the stall surfaces were new and only captured 1 d of behavior, it is possible that cows may show a preference for the gel mat under conditions where the stall surface options are well-worn. Due to the unique properties of the gel mat, the manufacturer claims this surface maintains (or even increases) softness with use, while other products composed of a solid material (such as foam or rubber) have the potential to compact and harden over time. Therefore, further research regarding the long-term effects of gel mat flooring on behavior and preference are warranted.

During the choice phase cows did show a consistent preference for stall location. This may be due to the fact that the southern stalls were further from the milking parlour, thus potentially had fewer disturbances. Secondly, cows do prefer to have social distance between conspecifics (Cook and Nordlund, 2004), and the preferred stall locations ensured there would be no cow in the stall adjacent to her on the right. We encourage further research to be conducted on the effect of stall and conspecific location on stall preference, and stress the importance of balancing treatments by stall location to reduce the confounding effects of location on stall preference.

CONCLUSIONS

Our results indicate that housing cows on gel mats compared to foam mats, using the same top cover and bedding across treatments, does impact their behavior. The proportion of time spent lying was greater when restricted to the gel mats, while time spent standing and perching in the stall were greater when restricted to the foam mats. The latency to lie down was shorter when restricted to the gel mats compared to the foam mats. These results indicate that the gel mats provide a surface more conducive to lying compared to foam mats and that cows may make the transition from standing to lying more easily. We did not observe any preference for one floor surface over another for lying, standing or perching behavior, possibly indicating both surfaces provided an acceptable level of comfort, or that cows were not able to make a distinction between surfaces that were not dramatically different from one another (such as would be observed between concrete and mattresses). Finally, this study was the first to investigate the effect of gel mats on general activity and preference in a free stall setting. Results from our work provides valuable information for researchers and product developers to expand upon in future work, and producers to use in their decision making when the time comes to replace the stall bases in their farm.

Table 3.1. Behavior definitions utilised in this study.

Standing	Upright position with weight supported on all four legs.
Perching	Standing in a stall with the rear 2 feet in the alley for at least 10 s.
Latency to lie after entering stall	Time elapsed from standing completely in the stall with all four feet to lying with the head up (see below).
Lying- head up	Body supported by the ground, weight not supported by legs
Lying- head supported	Lying with the side of head supported by the floor or against the flank.
Out	All four feet in alley, not at the feed bunk.
At feed	Standing in the alley, with the body oriented towards the feed bunk, head to withers not visible.

Table 3.2. Results from the linear mixed models (Least Squares Means) on the effects of stall floor during the restriction phase on the mean proportion of time observed for lying, standing, perching, in the alley and at the feed bunk (n=17). [5]

Behavior	mean proportion of time±SE		P-value
	gel	foam	
Lying in stall[1]	0.63±0.092	0.60±0.092	0.0443
Standing in stall[2]	0.038±0.010	0.060±0.015	0.0004
Perching in stall[3]	0.038±0.012	0.047±0.012	0.0864
Standing in alley[4]	0.035±0.009	0.030±0.006	0.8558
Standing at feed bunk[5]	0.22±0.009	0.22±0.012	0.8994

[1] Parity (P = 0.0172) and month (P = 0.0212) were retained in the final model, see text.
[2] Parity (*P* = 0.0059) was retained in the final model, see text.
[3, 4, 5] Flooring treatment was the only variable retained in the final model.

Table 3.3. Results from the linear mixed models (Least Squares Means) on the effects of stall floor during the preference phase on the mean proportion of time observed lying, standing, and perching (n=17).

Behavior	Mean proportion of time ± SE		P-value
	gel	foam	
Lying in stall[1]	0.31±0.051	0.30±0.047	0.30
Standing in stall[2]	0.026±0.006	0.031±0.020	0.57
Perching in stall[3]	0.037±0.022	0.015±0.003	0.53

[1, 2] Stall ($P \leq 0.0178$) was retained in the final model, see text.
[3] Flooring treatment was the only variable retained in the final model.

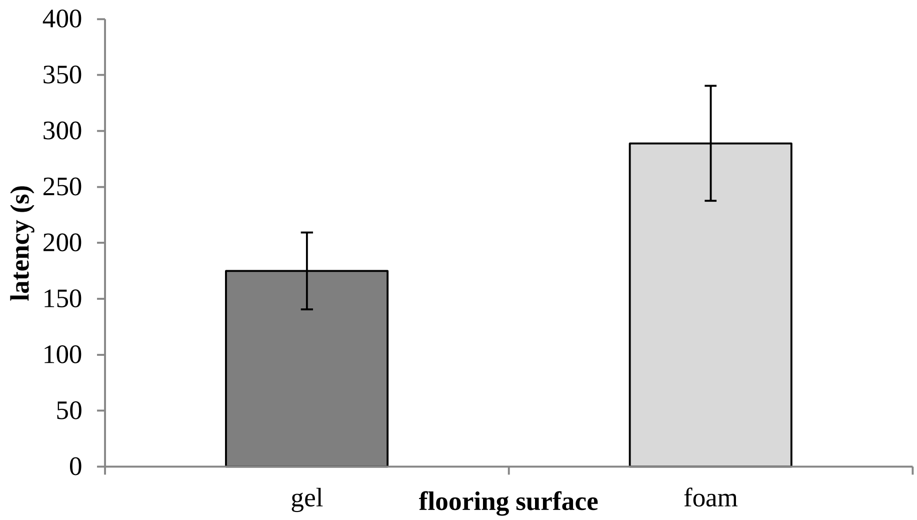

Figure 3.1. Mean±SE latency in s to lie down after fully entering (standing) in stall (gel: 175±34.4; foam: 289± 51.3 s; $P = 0.0014$).

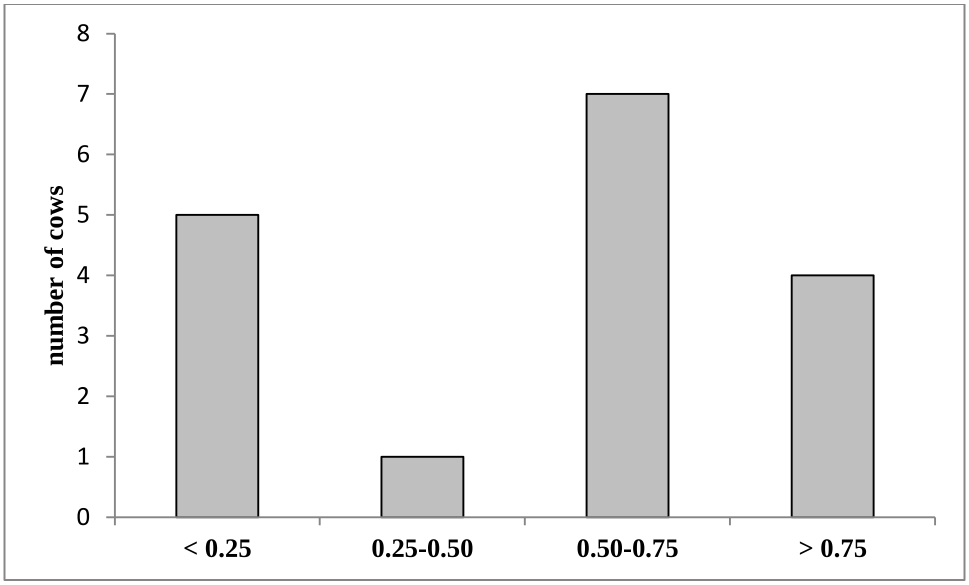

Figure 3.2. Distribution of the number of cows (n = 17) that spent < 0.25, 0.25 to 0.50, 0.51 to 0.75 and > 0.75 of their lying time on the gel mats.

Chapter 4: General summary and conclusions

The objective of this thesis was to determine the effects of stall surface on the general activity and lying behavior of dairy cows. Dairy cows spend around 12 h/d lying (Jensen et al., 2005; Drissler et al., 2005), making the comfort of the resting surface an important feature of stall design. The softness of the stall surface is determined by two factors, stall base and bedding. Providing deep bedding is not always feasible (e.g. due to variable cost and manure handling) so many producers use soft stall bases with little bedding. However, these stall bases can compact and harden over time. Recently, a stall mat filled with a gel substance has emerged on the market that anecdotally retains its softness over time. This study is the first to conduct research regarding the effects of gel mats on cow activity and lying behavior.

Overview of results

The first objective of this thesis was to determine how housing cows in tie stalls on gel mats affected their general activity, compared to housing them on foam mats or rubber-filled mattresses. Two levels of compressibility were studied for the gel mats, to gain insight into how this factor specifically may affect behavior. Cows were housed on each surface for 1 wk in a cross-over design. When housed on the gel mats cows spent approximately 3.6% more time lying than when housed on the foam mats and rubber mattresses. When cows were housed on the foam mats or rubber-filled mattresses they spent the greatest amount of time standing (3.8% more than either gel mat). When housed on the harder gel mat (10 psi) cows spent 2.4% more time standing than when housed on the softer gel mat (5 psi).

The second objective of this thesis was to determine how the above stall bases affected specific aspects of lying behavior. We recorded the time required to transition between lying and standing (and vice versa), the latency to assume the head supported position after lying down, and head swinging prior to lying down. When cows were housed on the softest (5 psi) gel mat, they transitioned from lying to standing 13% faster, compared to when they were housed on the foam mats and rubber mattresses. There was no difference in the amount of time required to transition from standing to lying. When housed on the 5 psi gel mats, cows had the longest latency to assume lying with the head resting, followed by the 10 psi gel mats. The foam mats and rubber mattresses had the shortest latency, and were not significantly different from one another. Head swinging frequency 1 minute prior to lying did not differ between any of the flooring treatments.

The third objective of this thesis was to determine how housing cows on gel mats and foam mats in a free stall environment affected general activity and stall preference. When restricted to using the gel mat, cows spent 3.2% more time lying than when restricted to the foam mat. When restricted to the foam mat stalls, cows spent 3.1% more time standing, and there was a tendency towards more perching (1.4% more). During the choice phase of the experiment, when cows had access to both stalls, they showed no preference for stall based on stall flooring. Interestingly, cows showed a preference for the southern stalls in both pens, regardless of flooring surface.

Implications of this work

These are the first studies to investigate the effects of a novel gel mat on cow activity, lying behavior and preference. Results from this work provides valuable information for researchers and product developers to expand upon, and producers to use in their decision making when the time comes to replace the stall bases on their farm. Consumers are becoming increasingly concerned with farm animal welfare, and dairy producers are becoming similarly interested in improving cow comfort on farm. Providing a comfortable place to rest is important for dairy cow welfare, and is required in the Canadian Dairy Code of Practice (National Farm Animal Care Council, 2009), as well as certain dairy welfare assessment schemes (e.g. RSPCA, 2011; National Milk Producers Federation, 2010; Food Aliance, 2003). Due to the variable cost and management considerations of providing deep bedding in stalls, producers may elect to provide soft stall bases that are thought to require less bedding while maintaining a comfortable resting environment. The problem with many soft stall bases is they compact and harden over time, leading to a reduction in cow comfort. The gel mat may provide a viable solution to this issue. Due to its unique gel filling, the manufacturer states it has the potential to maintain its softness over time. However, prior to these studies there were no data validating this claim, or any work investigating the effects of gel mats on general activity and lying behavior of dairy cows.

Results from both the tie stall and free stall studies indicated that providing gel mats in stalls promotes lying behavior. More importantly, housing cows on gel mats was not associated with an increase in undesirable behaviors, such as perching, or behaviors indicative of discomfort, such as head swinging or a prolonged time required to transition between lying and standing. The tie stall study utilized a novel method of objectively measuring stall base compressibility. Results from this study did validate claims that the gel mats maintain their softness over time, indeed over the four week period the gel mats became more compressible. The method utilized to assess stall surface compressibility in this study may be of use to other researchers interested in studying various stall bases.

There has been a great deal of research regarding stall surface that found that cows spend more time lying down on softer surfaces (e.g. Tucker et al., 2009; Nordlund and Cook, 2003; Haley et al., 2000). Our studies recorded similar results, where cows spent the greatest proportion of time lying on the surfaces with the lowest psi rating (the softest). This is generally accepted to be positive. However, we believe in many cases, there has been too much focus on the benefit of maximising lying time, rather than optimizing it. Studies have shown that cows that lie for extreme amounts of time (high or low) are more likely to be lame (Ito et al., 2010; Leonard et al., 1996). It has also been suggested that cows may actually prefer particular stall surfaces for standing on (Tucker et al., 2003; Galindo et al., 2000), and there may a be benefit to providing standing surfaces outside of the alley-way in reducing lameness (Tucker and Weary, 2001; Cook, 2001). The questions this raises then are, 1) how do we know how much lying and standing is appropriate, 2) how do we know that cows are not simply lying down more on surfaces they find less acceptable for standing on (perhaps it is more fatiguing to balance their weight on a very compressible surface), 3) how do we provide a stall surface that promotes a healthy mix between these two behaviors? We believe these are crucial questions to be answered before the industry delves further into the development and marketing of extremely soft stall bases.

Limitations and future work

For both the tie stall and free stall studies, data were collected over a brief time frame. As one of the most pertinent factors of the gel mat is its ability to maintain softness over time, future work looking at cow behavior over a longer time frame (i.e. several months) is suggested. Regarding the tie stall study in particular, a future study that runs over a longer time frame may be able to yield results above and beyond what was captured within 1 wk Producers are very interested in the associations between stall flooring, lying behavior and milk production. This study was likely too short to capture a causal relationship between milk yield and lying behavior, if one does indeed exist. A study by Karakok et al. (2009) recorded a 4.7 kg increase in milk production after 7 wks of loose-housing cows on deep bedding, compared to no bedding. It is probable that changes influencing lying behavior take quite some time to have an impact on the physiological processes related to milk production, and therefore wk-long studies may not capture any variations caused by stall surfaces. Additionally, longer studies may shed light onto the effects of gel mats on injuries and lameness. It has been shown that cows housed exclusively on deep bedding have a lower prevalence of lameness (e.g. Cook et al., 2004) and injuries (e.g.Wechsler et al., 2000), than cows housed on mattresses. While the injury prevalence for cows housed on waterbeds was found to be similar to cows housed on deep bedding (Fulwider et al., 2007). Studies that benchmark injuries and lameness, and then compares how the injury and lameness status of the cows change when cows are housed on various surfaces (including gel mats) for an extended period of time would provide useful information for the dairy industry.

In both studies, cows were only enrolled if they were non-injured, non-lame, and of an average body condition score. In the tie stall study, cows were also only enrolled if they were at least 60 DIM. This was necessary to ensure we were not confounding the behavioral outcomes by any of the above factors. Previous work has shown that lying behavior is influenced by lameness status (Ito et al., 2010), and also DIM (Chaplin and Munksgaard, 2001), and we suspected that injured animals, or cattle with extreme body condition scores may also show abnormal lying behavior. Future work using a larger sample population should balance subjects by the above-mentioned factors to determine how behavior differs across flooring treatment, and also by lameness, injury, body condition, and production level. It has been shown that stall flooring surface affects the lying behavior of lame cows differently than sound cows (Ito et al., 2010; Gomez and Cook, 2010), which has been attributed to the softness and traction provided by certain stall surfaces. From our findings that gel mats promote lying behavior, and housing cows on gel mats reduces the amount of time required to transition between lying and standing, we suspect that injured, lame, or otherwise abnormal cows would behave similarly to their ‘normal’ counterparts, while housing these same cows on harder surfaces (such as foam) would cause them to exhibit behaviors typically associated with malaise. For instance, it has been observed that lame cows spent more time standing in the stall when housed on mattresses compared to deep sand (Gomez and Cook, 2010). Results from this work may provide producers with the knowledge to improve the environment of cows that fall outside the herd 'norm'.

In the free stall study, we experienced technological failure of the recording system resulting in some lost video data for certain cows. Video loss ranged from 0 to 11 hours, with a mean of 2.5 hours. We were confident in including all cow-days in the models after ensuring that video loss was not significantly different between flooring surface or by time of day (morning: 0600h to 1800h vs. night: 1800h to 0600 h). Additionally, we tested for a floor by time of day interaction for each behavior, and found no significant effect. Finally, results from the accelerometers did validate our video outcomes, and behavioral findings were similar to the tie stall study (which did not experience video loss). It is important, to keep in mind that behavioral results from this study were expressed as a proportion of time, with the amount of time observed as the denominator (which was not in all cases 24 h).

In the free stall study, it was discovered that cows showed a preference for stall location regardless of flooring surface. Cows selected the stalls closest to the southeast side of the barn for all behaviors regardless of flooring. Due to time constraints, location of the gel and foam mats were not balanced evenly across the trial period. We did account for location of the treatment surfaces by including cow nested by treatment location as a random effect for the behavioral models. We also tested for interactions between treatment and stall, and found this interaction to be non-significant. However, ideally the flooring treatment should have been evenly balanced by location to guarantee that the results were not confounded. Our findings indicate that cows can show a preference for stall location regardless of other factors, including treatment. We therefore stress the importance of balancing treatment by location, while controlling for other possible confounders, such as the location of conspecifics in future behavioral research.

Chapter 5: References

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Appendices

Appendix 1. Schematic of stall surface tester indicating how it is set up in the stall.