THE EFFECTS OF FREESTALL SURFACES AND GEOMETRY ON DAIRY CATTLE BEHAVIOR

by

Cassandra Blaine Tucker

B. Sc., University of California, Davis 1998

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

In

THE FACULTY OF GRADUATE STUDIES

(Faculty of Agricultural Sciences)

(Department of Animal Science)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

September 2003

ABSTRACT

An important aspect of providing appropriate housing systems for dairy cattle (*Bos taurus)* is a suitable space for lying down. This thesis describes a series of eight experiments, and is a systematic attempt to test the effects of commonly used freestall surfaces (sand, sawdust, mattresses) and configurations (width, length, height, etc.) on the behavior of cattle. Two main categories of behavior were measured: preferences for options during choice tests, and the time spent lying and standing in the freestall area when the animals had no choice among treatments. Lying behavior was influenced by components of the freestall that cattle have contact with while lying down: freestall surface and space between partitions. Deep-bedded or heavily-bedded stall surfaces resulted in an increase in the number of lying events and total lying time, and the animals demonstrated clear preferences for these softer surfaces. In contrast, average duration of lying bouts and total lying time were higher in wider stalls, but cattle did not demonstrate clear preferences for stall size. The placement of the neck rail had no consistent effect on stall preference or lying behavior. All aspects of freestall design influenced the time spent standing in the stall. Cattle spent more time standing on mattresses than deep-bedded sand or sawdust and in stalls where the neck rail had been moved farther from the entrance to the stall or raised farther above the stall surface. In addition, cattle spent more time standing with only the front hooves in smaller stalls than larger ones. These experiments provide insight into how dairy cattle perceive the space provided for lying and standing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

There are acknowledgment sections at the end of each experimental chapter in this thesis, and it is in these sections that I've thanked the various people who made contributions to each specific project. I am indebted to these people and it has been a pleasure working with them, but I will not repeat my thanks here.

First and foremost, I want to thank my supervisors, David Fraser and Dan Weary. When they first took me on as a student (and for sometime after that, I imagine) I was a risk- a student with little experience, many pesky questions, and probably too much confidence. I was a far cry from the postdoctoral collogue they had originally envisioned as the ideal building block for their fledgling program. However, they took this risk and after five years I've nearly become the post-doctoral fellow they originally sought. During the course of my degree, Dave has listened to my ideas and questions patiently and provided his ever-thoughtful comments and editorial changes to dozens of drafts. He has a way of making me feel supported- by nodding when I speak and then reflecting my ideas back to me in an infinitely more eloquent manner than I ever could have come up with on my own. Without reservation, Dave welcomed me into his world of monks and Vikings where I found good company, good food, good books, and a good friend in his daughter, Chris. Dan has played an equally important role in the last five years. Dan empowers me. He has listened to my ideas and questions- his door was always open- and on occasion he would agree with what I had to say, but more often than not, he would shake his head and ask a challenging question. Through this questioning process, he has taught me about the joys of critical thought and discussion. Dan has provided me with boundless opportunity- to engage in research projects outside my thesis, to supervise students, to write grants with him- he has held every door I could have imagined open for me. He has also read and re-read drafts of every manuscript. From Dan and Dave I have learned many things, but there are two lessons that stand out to me. From the beginning, they emphasized that high quality research comes from working with others. Secondly, and more recently, I've realized that as much as I love the logic and rigor of research- I don't enjoy it solely for these reasons. I find the process of working with others, in particular Dan and Dave, delightful.

In addition to my supervisors, I have also had the support of other researchers. Jeff Rushen has offered sound advice throughout the course of this thesis. Indeed, he has been an island of decisiveness in what sometimes seemed to be an ocean of doubt. With perfect timing he has said, "Yes, you should do this experiment." or "No, this is not a suitable thesis topic." He has provided candid and insightful comments on each manuscript and has always seen that I should have been able to complete this degree in much less time that I've actually taken. To Anne Marie de Passillé I am grateful for valuable discussion throughout the last five years, about scientific issues, but also for her kind words of encouragement and the occasional hug. I'd also like to thank the late Jim Shelford for his support as a supervisory committee member. Jim was great company during the many trips out to Agassiz and his stoic nature continues to inspire me.

Finally, I would like to thank three people who have supported me personally through this process and who I am truly blessed to have in my life: Jennifer Jasper, Cathy Schuppli, and Heiko Wittmer. Jen was one of the first people I met when I came to UBC, and at the time I had no idea what a stroke of luck this was. Among her gifts, Jen provides me with an example of how critical thought can be incorporated into a personal life- to question the basic assumptions about everything from cat food to pregnancy. She is true friend- a bar buddy, like her dog Indus, and whom I know stands behind me in all situations. Cathy has also been a constant in my life in Vancouver. She has always been available with a listening ear and commiserated with me over the struggles I've faced- academic, equestrian, etc. Like Cathy, Heiko's personality helps balance me. He has washed endless loads of laundry, logged kilometers with the vacuum, and listened to hours of end-of-the-day debriefings. He appreciates my cooking, and once I learned to ask for it, provides support whenever I need it. He is always full of surprises and I love him for that.

Finally, I would like to thank my parents for always valuing education and supporting me through many years of school; my grandma Elsie for her fiery spirit; my grandpa Gene for always making me smile; my Aunt Nancy who like my fourth grandparent; Bev for understanding pretty much everything, from gray hair and receding gums to shared values about animal welfare; Amanda for good chats on horseback; Lee and Frances for afternoon coffee; and Ross for listening to endless talk about feces.

DESCRIPTION OF THE AUTHORS' ROLE

Chapter 2:

I was responsible for the experimental design, data collection, all statistical analysis, and writing the manuscript.

David Fraser and Dan Weary contributed to the experimental design, the choice of statistical tests and to the interpretation and presentation of the manuscript.

Chapter 3:

I was responsible for the experimental design, data collection, all statistical analysis, and writing the manuscript.

Dan Weary contributed to the experimental design and to the interpretation and presentation of the manuscript.

Chapter 4:

I was responsible for the experimental design, data collection, all statistical analysis, and writing the manuscript.

David Fraser and Dan Weary contributed to the experimental design, the choice of statistical tests and to the interpretation and presentation of the manuscript.

Chapter 5:

I was responsible for the experimental design, data collection, all statistical analysis, and writing the manuscript.

David Fraser and Dan Weary contributed to the experimental design, the choice of statistical tests and to the interpretation and presentation of the manuscript.

CHAPTER 1: General Introduction

1.1 Concern for animals

There is growing concern about how our society houses and handles animals used for human purposes. In the last 50 years, animal agriculture has undergone immense change, and the intensive practices (e.g. housing laying hens in cages, zero-grazing management of cattle, use of antibiotics in feed) have been fiercely criticized. The different groups involved manifest concern about these issues in different ways. These groups range from those interested in humane education such as the Society for Prevention of Cruelty to Animals, to anti-animal-use activists such as People for the Ethical Treatment for Animals. In addition, the scientific community is addressing the concern about how society treats animals. By using research to identify more humane methods of housing animals, we use science as a tool to address these moral concerns.

There are a variety of concerns raised about the welfare of dairy cattle, particularly those managed and housed intensively. The top three reasons given for culling dairy cattle in the United States are mastitis, lameness, and reproductive failure (United States Department of Agriculture or USDA, 2002). Indeed, the prevalence of hoof diseases among dairy cattle ranges between 25 and 98% (reviewed by Manske et al., 2002). In addition, there are concerns that rough human handling has a negative impact on dairy cattle well-being. Other concerns include short-term procedures such as separation of calves from their dams within 24 h after parturition and longer-term problems like inadequate access to (or poorly designed) resources such as feed-bunk space and freestalls.

1.2 Approaches for assessing animal welfare

Duncan and Fraser (1997) have outlined three broad types of social concern that arise over the welfare of animals. Each category has given rise to scientific approaches to assess and improve animal well being. However, there is much overlap between the areas of social concern and the research techniques associated with them.

Firstly, concerns are expressed over the subjective experiences of animals, with special emphasis on reducing negative emotional states (e.g. pain), and to a lesser extent, increasing positive states (e.g. comfort). Although there is agreement that such subjective experiences of animals are an extremely important component of their welfare, it can be difficult to assess or quantify subjective experiences directly. Perhaps the most promising models for assessing subjective experiences center around the argument by analogy or that we can infer something about animals because of their similarity to humans. For example, Dawkins (2000) suggests that because humans may scream and struggle when experiencing pain, when humans observe animals squealing and struggling under conditions we would find painful, some individuals would infer the animals are also feeling pain, unless there is evidence to the contrary.

Discussion in this thesis will center around one research technique often thought to reflect the subjective experiences of animals: preference testing. Preference testing involves allowing animals to choose between several options or environments. Animals "vote with their feet" for the most appealing options, relative to the choices presented (Dawkins, 1980). For example, Pajor et al. (2003) asked cattle to choose between different types of handling by stockpersons. One treatment involved a handler speaking to the animal in a quiet voice, the second treatment involved speaking to the animal in a loud voice, and the final treatment was a control where the handler was standing nearby but did not interact with the animal. Pairs of handling treatments (e.g. spoken to in a gentle voice vs. shouting, gentle voice vs. control) were then compared in a y-maze. These authors found that cattle did not show preferences for being spoken to in a gentle tone compared to the control, but did prefer the gentle speaking voice to shouting. These results indicate that the cows found the shouting aversive, and thus avoid this handling treatment. However, the relationship between subjective experiences and preferences is not straightforward and will be discussed further in this chapter.

In addition to preference testing, other techniques are used to understand the subjective experiences of animals. These include using pharmaceutical agents to understand the underlying subjective experience in a given behavioral response. For example, Faulker and Weary (2000) administered a non-steroidal anti-inflammatory drug (ketoprofen) to half of their subjects before hot-iron dehorning. Ketoprofen was given before dehorning as well as 2 and 7 h after the procedure to ten of the twenty dairy calves tested. These authors found that the calves given ketoprofen performed less head shaking and ear flicking in the hours after the procedure than their untreated counterparts. If we assume that ketoprofen mitigates pain, then we can conclude that differences between the two treatment groups indicate that the untreated calves were experiencing more pain (a subjective experience) post-operatively than the treated calves.

The second category of social concern is that animals should "function" well in the sense of freedom from disease and injury, normal growth, reproduction, development and behavior. Hence, many scientists include measures of biological function in their attempts to assess animal welfare. Many measures have been used, including health, longevity, measures of reproductive success, growth rates, and disturbances in physiology and behavior. For example, Müller et al. (1989) found that the heart rate of dairy cattle prior to lying down was higher when housed in a tie stall compared to an open pen bedded with straw. In this example, the authors use heart rate to compare two housing systems, and conclude that the tie stall situation disrupts heart rate (or the mechanisms controlling heart rate such as the hypothalamus-pituitary-adrenal (HPA) axis or sympathetic/parasympathetic nervous system) more than the open pen with straw bedding. This example highlights the potential for overlap between the different conceptions of animal welfare, as heart rate has also been used an indication of an emotional state. For example, Duncan et al. (1986), in trying to compare the level of fear in broiler chickens, collected for slaughter by machine or manual catching, used heart rate as one of the measures. Finding that heart rate returns to baseline levels more quickly when animals were collected by machine, and when these results were interpreted along with other measures, the authors concluded that birds were less frightened after being harvested in this way.

Finally, Duncan and Fraser (1997) describe a third concern: that animals should be able to lead reasonably natural lives or to perform key elements of their natural behavior. Scientists following this conception of animal welfare have used a number of approaches. In the most radical cases they have observed animals in a reasonably natural environment and then attempted to design commercially workable environments that incorporate most of the animals' natural behaviors. For example, Stolba and Wood-Gush (1984) monitored sows in a semi-natural environment. They recorded specific attributes of the nesting sites (e.g. on a ridge, near cover etc.) and then tested a subset of these features in smaller enclosures. They concluded that nest sites should have an open view, be sheltered against wind, and separated from other activities in the pen (such as feeding). In less radical cases, scientists have tried to incorporate specific elements of natural behavior. However, there are some problems with this approach. Namely, not all natural behaviors are desirable in captive environments. For example, animals in the wild perform some types of predator avoidance (e.g. hiding), but environments which housed predator and prey together would hardly be considered acceptable for the prey species. The importance of the 'naturalness' of life can provide insights into important factors when designing environments for cattle, but because both preference testing and the biological-functioning approach have been used much more extensively in the animal science literature and throughout this thesis, and I provide an outline of the criticisms of these techniques below.

1.2.1 Criticisms of preference testing

Criticisms of preference testing have been the subject of several reviews (Dawkins, 1983; Duncan, 1992; Fraser et al., 1993; Fraser and Matthews, 1997). Below I have summarized key conclusions from these reviews:

1. Environmental preference testing is most useful in studies of animal welfare when specific environmental features are tested, rather than comparing entire housing or handling systems. For example, in this thesis I will compare the preferences of dairy cattle for freestall surfaces. The comparison of specific surfaces is more useful than two housing systems (e.g. pasture and freestalls), because it would be difficult to assess which feature influenced the choice between the two systems (sunshine, space, grass etc.).
2. The motivational state of the animals must be taken into consideration when testing preference, and this state may vary with age, time of day and physiological factors. For example, Phillips et al. (2000) demonstrated that sows preferred farrowing crates with floors heated to 35° C compared to 22°C and 29°C at the time of farrowing and in the 3 days after, but showed no preference for floor temperature in the 7 days before farrowing.
3. The animal must have the sensory capacity to distinguish between the options presented. Fraser and Matthews (1997) present an example to illustrate this point. Many fish species

swim away to avoid specific aquatic pollutants, such as copper. However, fish may fail to avoid other pollutants such as phenol, simply because they lack the sensory capacity to detect these contaminants.

4. Results from a given preference test are relative to choices presented. Hence, a "preferred" option may still not be a good option for the animal, or an "unpreferred" option may still be perfectly acceptable. Duncan (1992) suggests two solutions to this problem: 1) to provide a wide range of choices, so that animals are less likely to choose "a more preferred luxury or the lesser of two evils," and 2) to assess the strength of the preference using motivational testing. Motivational testing assesses what the animal is willing to pay (e.g. time expenditures, work performed, lost foraging opportunities, etc.) to gain access to a specific resource. The price the animal is willing to pay is not necessarily dependent on the other options presented. In addition to Duncan's first solution of offering a range of choices, the acceptability of a resource can also be addressed by forcing the animal to use each choice and monitor its response. Indeed, this is one approach that is used in this thesis.
5. Previous experience by the subjects can affect the results. Both long-term (rearing) experience and short-term experience (some exposure to options presented) can affect preference results. Dawkins (1983) points out that this can be addressed by controlling early experience and amount of exposure to each option. Moreover, the amount of previous experience may simply limit the generalization of the results to other animals with similar previous experience. For example, cows that were raised on straw may continue to show a

preference for straw. This does not mean that the preference is not valid or that the reader would be misled by the preference test. However, it would mean that the results could not be generalized to other cattle without the same experience.

6. Preference does not always predict long-term welfare. An example that is often cited for this criticism is that many animals prefer a level of food intake that leads to obesity. Dawkins (1983) clarifies that the uncoupling of preferences and long-term measures of welfare are not a reason to discount choice tests. Rather, this potential for uncoupling implies that preference results should be viewed in the context of additional measures of animal welfare.
7. Is there a link between preference and subjective states? Earlier, I describe preference testing as a research technique that has arisen out of concern for the subjective states of animals. However, the link between preference and subjective states is not clear. We assume that some subjective experience underlies a given preference, but we know neither the sign of this state (positive or negative) nor its magnitude. However, I believe 'costless' preference testing provides insight into the choices animals make between the options presented, but provides little information about the sign or the strength of subjective states.
8. Finally, there is the obvious need to avoid confounding treatments with other variables as the method of presenting the choices can affect results. Experiments must balance for positional effects and take into consideration possible confounding factors within the experimental design. For example, Natzke et al. (1982) compared dairy cattle preferences for several freestall surfaces. However, each surface was available only in one area of the barn, and this

makes it difficult to conclude that any preferences were for the stall surface rather than for the area where the option was available.

1.2.2 Criticism of Measures of Biological Functioning

A wide range of measures of biological function have been used in animal welfare assessment. Duncan and Fraser (1997 p. 25) summarize these methods:

> "Studies of veterinary epidemiology and pathology identify injuries and potential threats to health arising from how animals are kept. Studies of animal productivity quantify rates of growth and reproduction on the assumption that impaired welfare will reduce commercial productivity. Measures based on disturbed physiology or behavior include changes in the endocrine system, suppression of immune competence, and performance of abnormal behavior. Longer-term measures include longevity and reproductive success."

Criticisms of the biological functioning approach are often directed at specific measures.

1. *Pathology.* There is general agreement that an animal that is injured or diseased has a reduced quality of life (e.g. Fraser, 1995). However, injury is considered a conservative measure; welfare may be compromised well before differences in health are detected.
2. *Production.* Like injuries, production losses can signal welfare problems, for example, if they result from disease, malnutrition, or disturbed social behavior. However, it is questionable whether a reduction in productivity (e.g. milk production or growth rate) necessarily implies

that welfare is impaired (Duncan and Fraser, 1997). Dawkins (1999) uses the following example. A broody hen will give priority to egg incubation over feeding and drinking and can lose up to 17% of her body weight (Sherry et al., 1980). Weight loss could be interpreted as a sign of reduced welfare, but an incubating hen will not eat even if food is provided at the nest. Dawkins (1999) concludes that this type of maternal care has been shaped by natural selection and in no way indicates reduced animal well-being. In addition, many health problems have been created or exacerbated by intense genetic selection for high levels of production (reviewed by Rauw et al., 1998).

3. *Disturbance to Physiology.* Physiological measures can provide insight into underlying mechanisms (e.g. suppressed immune system), that may precede clinical disease. However, specific physiological measures, such as changes in the hypothalamus-pituitary-adrenal (HPA) axis, are criticized for lack of consistency and lack of understanding of basic biological mechanisms at work (Rushen, 1991). For example, many experiments use plasma cortisol as indicator of distress. However, increased cortisol levels are down-stream of a long series of central nervous system (CNS) and neuroendocrine events, and this makes it difficult to understand the underlying cause of the increase in cortisol (e.g. injury, exercise, exploration etc.).

4. *Disturbance to Behavior.* Behavioral measures are often a logical starting point for assessing a subject's response to an environment. Rushen (2000) argues that the main problems with using behavioral indicators as a measure of welfare are related to interpretation and

understanding biological significance of observed changes. These problems make it difficult to judge the severity of the welfare compromise. For example, abnormal behaviors such as repetitive tongue rolling are reported in adult dairy cattle, and Krohn (1994) demonstrated that tethered cattle perform more abnormal behaviors than their pastured counterparts. However, the relationship between abnormal behavior and subjective states is unclear except in cases where the abnormal behavior results in injury directly (reviewed by Mason, 1991). This makes it difficult to conclude that tethered animals suffer more or less than animals on pasture based on the amount of abnormal behavior performed.

5. *Longevity and Reproductive Success.* Longevity and reproductive success, like measures of production, can clearly signal welfare problems. A technical difficulty with using longevity as a measure of welfare is that animals tend either to die early or late in life. Thus factors that influence longevity during either of these life stages may be extremely important at these times, but may not be important during the rest of the animal's life. Moreover, relatively few animals in intensive agriculture die without human intervention, so full use of longevity requires data that are not normally available. Like longevity, reproduction is often under human control in intensive agriculture, and management (like heat detection) is likely to heavily influence this measure. In addition, factors that lengthen life or improve reproductive success may not always be those that are important to the quality of life (Fraser, 1995).

Finally, in addition to the specific criticisms of preference testing and measures of biological function, there has been much discussion about the dangers of using a single measure to assess animal welfare. Some authors have claimed that certain indicators are definitive (reviewed by Mason and Mendl, 1993). As Dawkins (1999) has argued, there are at least three misleading assumptions associated with using a single indicator of welfare: 1) it would apply to all situations 2) that good and compromised welfare are distinguishable from one another using a single method of assessment (e.g. cortisol levels; for further discussion about problems with cut-off points, see Mendl, 1991) and 3) changes in the indicator always reflect a change in animal well-being. Proposals for addressing these criticisms center on using multiple measures of welfare to assess environments (e.g. Dawkins, 1983; Duncan, 1992; Rushen, 2000). Indeed, the most satisfying approach is using multiple measures to assess welfare, particularly when these measures correspond. In this thesis I used several measures, namely preference testing and changes in behavior and production to assess the surfaces and geometry of freestalls used for dairy cattle. I also used stall cleanliness as potentially important variable for animal health and farm management; it too may be linked to animal welfare, but not in a straightforward way.

1.3 Dairy cattle housing

Modern day dairy cattle (*Bos taurus*) are believed to be domesticated from the now extinct aurochs (*Bos primigenius*) (e.g. Loftus et al., 1999). According to Grzimek (1972) the original habitat of aurochsen was open forest and meadows, and the diet included grass, leaves and acorns. Activity was thought to be mainly diurnal. Domestication is thought to have occurred in more than one event, about 10,000 years ago (Bradley et al., 1998).

Dairy production has become increasingly industrialized over the last 50 years. Hand in hand with this industrialization, increasing demands for milk production and growth have been placed on dairy cattle. For example, between 1991 and 2001, the average milk production per cow per year increased by 23% (Canadian Milk Recording Board, 2002). Feeding plays a large role in the increase in milk production because, along with selective breeding, a highly concentrated diet (50% grain: 50% forage) is crucial to maximizing milk production. This has implications for housing because in order for animals to consume this type of diet throughout the day, they are typically housed indoors with limited or no access to pasture.

There are two main types of indoor housing for dairy cattle: loose housing and tie stalls. Animals that are loose housed are usually kept in groups determined by the level of production and dietary need. In contrast, animals housed in tie stalls are tethered to their lying place and can be fed individually. Animals usually have *ad libitum* access to water and feed, and are milked two or three times a day. In loose housing animals are walked to a parlor for milking, while animals housed in tie stalls are often milked in their stalls.

Loose housing may also be divided into two categories based on the area provided for lying: freestalls and bedded packs. In a freestall system, the area provided for lying is partitioned into individual spaces with partitions between stalls. The partitions are used to control where and how cattle lie down, and to direct fecal material into the alleyway. When compared to those on bedded packs (or strawyards), cattle housed in freestalls have a higher incidence of claw lesions (Livesey et al., 1998; Rowlands et al., 1983; Webster, 2001) and lameness (e.g.Rowlands et al., 1983; Whitaker et al., 2000), but lower incidence of mastitis (Faye et al., 1997; Whitaker et al., 2000). Freestall partitions differ in shape, size and installation, as discussed in Chapters 4 and 5. Both systems use a variety of bedding substrates (sawdust, straw, sand, etc.) as discussed in Chapters 2 and 3. Freestall housing is common in North America, and will be the focus of this thesis. Indeed, recent surveys indicate the number of operations using freestalls has risen from 24.4% of all operations in 1996 to 30.8% in 2002 (USDA, 1996; 2002). Not surprisingly, the number of operations using tie stalls declined from 60.1 in 1996 to 52.5% in 2002 (USDA, 1996; 2002). Unfortunately, these surveys do not report the average number of animals housed in these operations. In general, however, older, smaller units tend to use tie stalls and newer, large units tend to use loose housing. Hence, the percentage of animals in loose housing would be considerably higher than those housed in tie stalls.

1.4 Response variables and objectives

To assess the impact of these housing features on dairy cattle, I measured changes in behavior, with special emphasis on the predominate behavior performed in the housing area: lying. There have been a range of studies carried out on lying behavior in cattle and these results are summarized in Table 1.1. Total lying time per day is made up of a series of lying bouts over time. Relatively infrequent lying events may reflect discomfort associated with changing positions between lying and standing. In contrast, longer lying bouts, paired with longer total lying times, may indicate comfort while the animal is in a recumbent position. Average lying times ranged between 9.4 and 14.7 h per 24 h across experiments. Dairy cattle divide this time into an average of 8.2-14.1 lying bouts per day, with average bout duration ranging from 0.9 to 1.4 h.

Lying time is thought to be important to dairy cattle based on several lines of evidence. A 3-h deprivation of the opportunity to lie down is sufficient to cause cows to forego eating in order to lie down (Metz, 1985). Additionally, several physiological changes are associated with reduced lying time; these include a decrease in circulating levels of growth hormone (Munksgaard and Løvendahl, 1993), a short-term increase in plasma cortisol levels (e.g. Fisher et al., 2002) and increased incidence of lameness (Leonard et al., 1994, Singh et al., 1993).

Obviously, when animals are not lying down, they are standing, and cattle also spend time standing in the areas provided for lying, like freestalls. However, the standing behavior performed in the freestall has not been documented to the same extent as lying behavior. Previous research has identified two broad categories of standing in freestalls based on the number of hooves in the stall at one time. For example, Stefanowska et al. (2001) reported that their experimental animals spent between 35 and 60 minutes standing with all four hooves in the freestall, and between 91 and 174 minutes per day standing with only the front hooves in the stall and the back hooves in the alley. These values are similar to those of Galindo et al. (2000), who report mean values of 81 and 89 min standing with only the front hooves in the stall per day.

Standing inside the stall is thought to be important because the flooring surface outside the freestall is often concrete. Concrete flooring is far from ideal for cows, and is known to cause hoof injuries. For example, Frankena et al. (1992) found that housing animals on straw flooring reduced the risk of claw lesions compared to concrete. Furthermore, standing entirely in the stall reduces contact with slurry in the alley, and this reduced exposure to moisture is associated with a lower incidence of hoof injuries (Fitzgerald et al., 2000) and higher sole dry matter content (Bergsten and Pettersson, 1992). In addition, the amount of time spent standing with the front hooves in the stall is positively related to the total number of claw lesions (e.g. Flower and Weary, 2002), but it is not clear if the injuries result in the change in behavior, or vice-versa.

In addition to other measures, I have used preference tests to compare freestall surfaces and geometry. In these studies I attempted to address the criticisms of preference tests mentioned previously. Firstly, I have limited my comparisons to specific aspects of freestall design, either surfaces or geometry. Secondly, to address the issue of motivational states changing over time, animals were always monitored over a 24-h period. However, I was not able to monitor animals during different physiological states over a longer period of time (e.g. lactation versus pregnancy). The third and fourth criticisms, about animals having the sensory capacity to evaluate the options presented and the use of motivational testing, are discussed in Chapter 6. To address the issue of previous experience, I ensured that all the cows had at least short-term (several days) exposure to all treatments before the final assessment of preference, and in one case (Chapter 2) also examined long-term rearing experience. The sixth point, that preference does not always predict long-term welfare, was addressed by measuring changes in behavior associated with access to each treatment; discussion about the relationship between the measures of preferences and short-term changes in behaviors can be found in Chapter 6. In response to the seventh criticism, I acknowledge that there is no straightforward way to infer the magnitude or the sign (postive or negative) of subjective states from preferences. However, preference testing can be an useful starting point to understand what type of housing features are likely important to animals. The eighth criticism, that the method of presenting the choices can affect the results of preference tests, was addressed by balancing treatments across locations within the experimental testing facility.

Finally, I measured freestall cleanliness and milk production as dependent variables in several experiments. I included these variables primarily because they are important practical considerations for farmers. In addition, contact with feces in the stall is anecdotally linked to health problems like mastitis, and farmers often cite milk production as a measure of health, although these links are tenuous as discussed in later chapters. Exposure to treatments was too short to detect longer-term effects on animal health such as injuries or disease.

My objectives were four-fold: 1) to assess dairy cattle preferences for freestall surfaces and geometry, 2) to assess how behavior changes when the animals have access to a single housing option, 3) to measure practical considerations for farmers such as milk production and freestall cleanliness, 4) to understand the relationship between these measures.

In Chapter 2, I compare dairy cattle preferences and behavioral responses to three types of freestall surfaces common in the Fraser Valley: deep-bedded sand, sawdust and geotextile mattresses. In Chapter 3, I compare the response to three levels of sawdust bedding on geotextile mattresses. In Chapter 4, I examine both the width and the length of the freestall using preference testing, changes in behavior, stall cleanliness and milk production. Finally, in Chapter 5, I examine the effect of neck rail placement on dairy cattle behavior, in preference tests as well as with access to a single option.

REFERENCES

Bergsten, C. and B. Pettersson. 1992. The cleanliness of cows tied in stalls and the health of their hooves as influenced by the use of electric trainers. Prev. Vet. Med. 13:229-238.

Bradley, D.G., R.T. Loftus, P. Cunningham, and D.E. Machugh. 1998. Genetics and domestic cattle origins. Evol. Anthropol. 6:79-86.

Canadian Milk Recording Board. 2002. Subject: milk production of dairy cattle. http://www.dairyinfo.agr.ca/cdicfpmilkr.htm. Accessed on June 17, 2002.

Dawkins, M.S. 1980. Animal Suffering. Chapman and Hall Ltd. London, UK.

Dawkins, M.S. 1983. The current status of preference tests in the assessment of animal welfare. Pages 20-26 *in* Farm Animal Housing and Welfare. S.H. Baxter, M.R. Baxter, and J.A.D. MacCormack (eds.) Martinus Nijhoff Publishers. Boston, USA.

Dawkins, M.S. 1999. The role of behaviour in the assessment of poultry welfare. World's Poultry Sci. J. 55:295-303.

Dawkins, M.S. 2000. Who needs consciousness? Anim. Welfare 10:S19-S29.

Dechamps, P., B. Nicks, B. Canart, M. Gielen, and L. Istasse. 1989. A note on resting behaviour of cows before and after calving in two different housing systems. Appl. Anim. Behav. Sci. 23:99-105.

Duncan, I.J.H. 1992. Measuring preferences and the strength of preferences. Poultry Sci. 71:658-663.

Duncan, I.J.H., G.S. Slee, P. Kettlewell, P. Berry, and A.J. Carlisle. 1986. Comparison of the stressfulness of harvesting broiler chickens by machine and by hand. Brit. Poultry Sci. 27:109-114.

Duncan, I.J.H. and D. Fraser. 1997. Understanding animal welfare. Pages 19-31 *in* Animal Welfare. M.C. Appleby and B. O. Hughes (eds.) CAB International. Wallingford, UK.

Faulkner, P.M. and D.M. Weary. 2000. Reducing pain after dehorning in calves. J. Dairy Sci. 83:2037-2041.

Faye, B., F. Lescourret, N. Dorr, E. Tillard, B. MacDermott, and J. McDermott. 1997. Interrelationships between herd management practices and udder health status using canonical correspondence analysis. Prev. Vet. Med. 32:171-192

Fisher, A.D., G.A. Verkerk, C.J. Morrow, and L.R. Matthews. 2002. The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. Livest. Prod. Sci. 73:255-263.

Fitzgerald, T., W. Norton, R. Elliott, H. Podlich, and O.L. Svendsen. 2000. The influence of long-term supplementation with biotin on the prevention of lameness in pasture fed dairy cows. J. Dairy Sci. 83:338-344.

Flower, F. and D.M. Weary. 2002. Testing measures of lameness: using behaviour to predict presence and severity of hoof lesions in dairy cattle. J. Dairy Sci. 85 (suppl. 1):247.

Frankena, K., K.A.S. Van Keulen, J.P. Noordhuizen, E.N. Noordhuizen-Stassen, J. Undelach, D.J. De Jong, and I. Saedt. 1992. A cross-sectional study into prevalence and risk indicators of digital hemorrhages in female dairy calves. Prev. Vet. Med. 14:1-12.

Fraser, D. 1995. Science, values and animal welfare: exploring the 'inextricable connection.' Anim. Welfare 4:103-117.

Fraser, D. and L.R. Matthews. 1997. Preference and motivation testing. Pages 159-173 *in* Animal Welfare. M.C. Appleby and B.O. Hughes (eds.) CAB International. Wallingford, UK.

Fraser, D., P.A. Phillips, and B.K. Thompson. 1993. Environmental preference testing to assess the well-being of animals- an evolving paradigm. J. Agric. Environ. Ethics 6 (suppl. 2):104-114.

Fregonesi, J.A. and J.D. Leaver. 2001. Behaviour, performance, and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livest. Prod. Sci. 68:205-216.

Galindo, F., D.M. Broom, and P.G.G. Jackson. 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. Appl. Anim. Behav. Sci. 67:335-341.

Grzimek, B. 1972. The wild and domestic oxen. Pages 331-373 *in* Grzimek's Animal Life Encyclopedia. Grzimek, B. (ed.) Van Nostrand Reinhold Company. New York, USA.

Haley, D.B., J. Rushen, and A.M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Haley, D. B., A.M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Appl. Anim. Behav. Sci. 71:105-117.

Hultgren, J. 2001. Effects of two stall flooring systems on the behaviour of tied dairy cows. Appl. Anim. Behav. Sci. 73:167-177.

Krohn, C.C. 1994. Behavior of dairy cows kept in extensive (loose housing pasture) or intensive (tie stall) environments. III. Grooming, exploration and abnormal-behavior. Appl. Anim. Behav. Sci. 42:73-86.

Krohn, C.C. and L. Munksgaard. 1993. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments II. Lying and lying-down behaviour. Appl. Anim. Behav. Sci. 37:1-16.

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

Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

Livesey, C.T., T. Harrington, A.M. Johnston, S.A. May, and J.A. Metcalf. 1998. The effect of diet and housing on the development of sole haemorrhages, white line heamorrhages, and heel erosions in Holstein heifers. Anim. Sci. 67:9-16.

Loftus, R.T., O. Ertygrul, A.H. Harba, M.A.A. El-Barodys, D.E. Machugh, S.D.E. Park, and D.G. Bradley. 1999. A microsatellite survey of cattle from a centre of origin: the near east. Mol. Ecol. 8:2015-2022.

Manninen, E., A.M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kind of cubicle flooring. Appl. Anim. Behav. Sci. 75:281-292.

Manske, T., J. Hulgren, and C. Bergsten. 2002. Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. Prev. Vet. Med. 54:247-263.

Mason, G. 1991. Stereotypies: a critical review. Anim. Behav. 41:1015-1037.

Mason, G. and M. Mendl. 1993. Why is there no simple way of measuring animal welfare? Anim. Welfare 2:301-319.

Mendl, M. 1991. Some problems with the concept of a cut-off point for determining when an animal's welfare is at risk. Appl. Anim. Behav. Sci. 31:139-146.

Metz, J.H.M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301-307.

Mogensen, L., L.H. Nielsen, J. Hindhede, J.T. Sørensen, and C.C. Krohn. 1996. Effects of space allowance in deep bedding systems on resting behaviour, production, and health of dairy heifers. Acta Agric. Scand., Sect. A, Anim. Sci. 47:178-186.

Müller, C., J. Ladewig, H.H. Thielscher, and D. Smidt. 1989. Behaviour and heart rate of heifers housed in tether stanchions without straw. Physio. Behav. 46:751-754.

Munksgaard, L. and P. Løvendahl. 1993. Effects of social and physical stressors on growth hormone levels in dairy cows. Can. J. Anim. Sci. 73:847-853.

Natzke, R. P., D. R. Bray, and R. W. Everett. 1982. Cow preferences for free stall material. J. Dairy Sci. 65:146-153.

Pajor, E.A., J. Rushen, and A.M.B. de Passillé. 2003. Dairy cattle's choice of handling treatments in a y-maze. Appl. Anim. Behav. Sci. 80:93-107.

Phillips, P.A., D. Fraser, and B. Pawluczuk. 2000. Floor temperature preference of sows at farrowing. Appl. Anim. Behav. Sci. 67:59-65.

Rauw, W.M., E. Kanis, E.N. Noordhuizen-Stassen, and F.J. Grommers. 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livest. Prod. Sci. 56:15-33.

Rowlands, G.J., A.M. Russell, and L.A. Williams. 1983. Effects of season, herd size, management system and veterinary practice on the lameness incidence in dairy cattle. Vet. Rec. 113:441-445.

Rushen, J. 1991. Problems associated with the interpretation of physiological data in the assessment of animal welfare. Appl. Anim. Behav. Sci. 28:381-386.

Rushen, J. 2000. Some issues in the interpretation of behavioural responses to stress. Pages 23-42 *in* The Biology of Animal Stress. G.P. Moberg and J.A. Mench (eds.) CAB International. Wallingford, UK.

Schrader, L. 2002. Consistency of individual behavioural characteristics of dairy cows in their home pen. Appl. Anim. Behav. Sci. 77:255-266.

Sherry, D.F., N. Mrosovsky, and J.A. Hogan. 1980. Weight loss and anorexia incubation in birds. J. Comp. Physiol. Psych. 94:89-98.

Singh, S.S., W.R. Ward, K. Lautenbach, J.W. Hughes, and R.D. Murray. 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. Vet. Rec. 133:469-474.

Singh, S.S., W.R. Ward, J.W. Hughes, K. Lautenbach, and R.D. Murray. 1994. Behaviour of dairy cows in a straw yard in relation to lameness. Vet. Rec. 135:251-253.

Stefanowska, J., D. Swierstra, C.R. Braam, and M.M.W.B. Hendriks. 2001. Cow behaviour on a new grooved floor in comparison with a slatted floor, taking claw health and floor properties into account. Appl. Anim. Behav. Sci. 71:87-103.

Stolba, A. and D.G.M. Wood-Gush. 1984. The identification of behavioural key features and their incorporation into a housing design for pigs. Ann. Rech. Vet. 15:287-298.

USDA. 1996. Part I: Reference of 1996 dairy management. USDA:APHIS:VS, CEAH, National Animal Health Monitoring System, Fort Collins, USA.

USDA. 2002. Part I: Reference of dairy health and management in the United States. USDA:APHIS:VS, CEAH, National Animal Health Monitoring System, Fort Collins, USA.

Webster, A.J.F. 2001. Effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and first lactation. Vet. J. 162:56-65.

Wechsler, B., J. Schaub, K. Friedli, and R. Hauser. 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. Appl. Anim. Behav. Sci. 69:189-197.

Whitaker, D.A., J.M. Kelly, and S. Smith. 2000. Disposal and disease rates in 340 British dairy herds. Vet. Rec. 46:363-367

Table 1.1. Summary of mean values for lying behavior (lying time, number of lying events, and duration of lying bouts) across different housing systems (tie stall, loose housing, freestall, and pasture) with various surface materials. The dash (-) indicates that the paper did not include this measure over a 24-h period, if at all.

Source	Surface	Lying time (h/24h)	# of lying events/24 h	Lying bout duration (h/bout)
Tie stalls				
Dechamps et al., 1989	Concrete: System A[1]	10.5	10.6	-
Dechamps et al., 1989	Concrete: System B[2]	11.5	13.4	-
Haley et al., 2001	Concrete	10.4	9.0	1.3
Haley et al., 2001	Mattress	12.3	13.1	1.0
Hultgren, 2001	Rubber slatted floor	12.2	-	0.9
Hultgren, 2001	Solid floor	12.2	-	1.0
Krohn and Munksgaard, 1993	Mat & straw	13.0	-	-
Loose housing: bedded areas				
Fregonesi and Leaver, 2001	Straw yard: Experiment 1:HS[3]	13.2	-	-
Haley et al., 2000	Pen with mattresses	14.7	13.6	1.1
Krohn and Munksgaard, 1993	Deep bedding (unspecified)	10.1	-	-
Mogensen et al., 1996	Straw pen: average of herds with 1.8 m^2	13.1	11.0	-
Singh et al., 1994	Straw yard	9.7	-	-
Loose housing: Freestalls				
Fregonesi and Leaver, 2001	Straw: Experiment 1:HC[4]	11.9	-	-
Manninen et al., 2002	Straw: winter	12.9	11.9	1.1
Manninen et al., 2002	Rubber mat: winter	12.5	10.7	1.2
Manninen et al., 2002	Sand: winter	7.5	6.8	1.1
Schrader, 2002	Straw	-	-	1.4
Wechsler et al., 2000	Kraiburg mat[5]	11.4	13	1.1

Wechsler et al., 2000	Straw mattress	11.6	13	1.1
Pasture				
Singh et al., 1993	Pasture: first observation period	9.6	-	-
Krohn et al., 1992	Choice between Pasture/indoor bedded area	10.1	-	-

[1] Tethered with American central yoke

[2] Cubicle closed at rear with metal bar

[3] High-yielding cows housed in strawyard

[4] High-yielding cows housed in cubicles

[5] Conventional 18-mm rubber mat underlain with foam

CHAPTER 2: Effects of three types of freestall surfaces on preferences and stall usage by dairy cows[1]

C.B. Tucker, D.M. Weary, and D. Fraser

INTRODUCTION

Dairy cattle spend approximately 8-16 hours lying down per day (e.g. Dechamps et al., 1989; Haley et al., 2000; 2001; Webster, 1994). The lying surface is known to affect dairy cows in several ways, including behavior, and leg, hoof, and udder health.

Previous work has shown that cows tend to spend more time lying on softer surfaces (for review see Tucker and Weary, 2001). Lying times are lower and standing times higher when dairy cattle are forced to use hard surfaces, specifically concrete (Haley et al., 2001; 2000; O'Connell and Meaney, 1997). Cows also have longer lying times on rubber mats than on concrete (Chaplin et al., 2000; Rushen et al., 1998), but the use of large amounts of bedding on concrete minimizes this difference (Manninen et al., 2002).

The lying surface in the stall also appears to affect leg injuries. Fewer leg injuries are reported on mattresses than concrete (Haley et al., 1999), with rubber as an intermediate (Rodenburg et al., 1994). Cows have fewer injuries on deep-bedded stalls than on mattresses (Weary and Taszkun

[1] A version of this manuscript has been published in the Journal of Dairy Science 86:521-529.

2000; Wechsler et al., 2000). In addition, Nilsson (1992) found a positive relationship between lying surface penetration (i.e. hardness) and hock injuries. Hoof health may also be improved by increased amounts of bedding (Colam-Ainsworth et al., 1989), and by use of rubber mats instead of concrete (Leonard et al., 1994; but see also Chaplin et al., 2000).

Lying surface may also influence udder health. Organic bedding, such as sawdust, has higher bacteria counts than non-organic bedding such as sand (e.g. Fairchild et al., 1982; Hogan et al., 1989), and these higher counts in the bedding lead to higher counts on teat ends (e.g. Bishop et al., 1981; Natzke and Le Clair, 1975; Rendos et al., 1975; but see also Hogan and Smith, 1997). Although there is evidence that high bacteria counts on teat ends are related to udder infection (DeHart et al., 1975; McDonald and Packer, 1968), there is only limited evidence that higher counts in bedding increase the risk of udder infection (Hogan et al., 1989; Natzke and Le Clair, 1975). Nonetheless, the potential relationship between organic bedding and mastitis, combined with the costs of maintaining deep-bedded systems, have led to increased use of geotextile mattresses.

Environmental preference testing, a technique that allows animals to choose between alternative options, has been used since the 1970's to identify housing features that are important to the animals (Fraser and Matthews, 1997). Preferences often correspond with other measures of biological functioning such as injury and they can provide insight into which option (in this case, stall surface) is likely to be most comfortable (e.g. longest lying times, minimize injury). Preference testing for dairy cattle lying surfaces has involved a variety of substrates because different bedding materials are available in different geographic regions. Several patterns have emerged from this literature. Cows tend to prefer mattresses ahead of concrete stalls (Herlin, 1997; O'Connell and Meaney, 1997). Solid rubber mats are preferred to concrete but are less preferred than mattresses (Herlin, 1997; Natzke et al., 1982). The amount of bedding also influences preference. For example, Jensen et al. (1988) showed that cows preferred concrete when bedded with 4-5 kg of straw, but choose mattresses when little bedding remained (see also Gebremedhin et al., 1985; Manninen et al., 2002).

In the present study, we compared three stall surfaces commonly used in British Columbia: deep-bedded sawdust, deep-bedded sand, and geotextile mattresses covered with 2-3 cm of sawdust. Our objectives were to determine: 1) the preferences for stall surface, 2) how the different surfaces affect stall usage when animals are restricted to a single option for a few days and, 3) the relationship between these two measures.

MATERIALS AND METHODS

Experiment 1

Twelve Holstein cows served as subjects. All cows were not pregnant and non-lactating, had been housed in soil-based, sawdust-bedded stalls for the previous lactation. During the experiment each cow was housed alone in a test pen containing a feed trough, a waterer, alley space, and three freestalls side by side, all accessible from the alley (Figure 2.1). All flooring outside the freestall area was concrete. Cows only had access to these three stalls; all others in the facility were blocked off. Each stall in a test pen was bedded with a different material: sand, sawdust, or a rubber-filled geotextile mattress (Pasture Mat® of Promat Ltd.) covered with 2-3 cm of sawdust. Three similar test pens were used for the experiment and the three types of bedding were balanced over the three stall locations (right, center, left) in the three pens. The stalls were 1.14 m wide and 2.34 m long, with no neck rail or brisket board. The sawdust used for the bedding was green hemlock sawdust (not wood chips) with an average particle size of approximately 7 mm by 2 mm. The sand was washed river sand and was a mix of grains with a diameter of 2 mm or less and very few small pebbles averaging 4 mm in diameter. The sand and sawdust was between 30 and 40 cm deep. Feces were removed and bedding leveled to the curb (with new bedding added if necessary) each day during the morning and afternoon feedings (8:00 and 15:00). The animals were fed grass hay *ad libitum*. The average temperature in Vancouver during the experiment was 11.2°C, with a minimum of –1.0°C and a maximum of 25.2°C.

Trios of animals were tested simultaneously, one in each test pen. During the first 7 days (first free-choice phase), cows had free access to all three stalls. During the next 6 days (restriction phase), cows were allowed access to only one of the three stalls for a 2-day period, then another stall for the next 2 days, then the third, with the order of access to the three stalls assigned randomly without replacement. Access to a single stall was achieved by blocking the other stalls with a 5 by 10-cm wooden board hung across the stall entrance. During the final 2 days (second free-choice phase), cows were again allowed free access to all three stalls.

Behavior of the cows was video recorded during the last 24 h of both free-choice phases and of each restriction period for a total of 5 days of recording for each cow. Each pen was recorded at three frames per second using a Panasonic AG-6720 VHS time-lapse video cassette recorder, a Panasonic WJ-FS 10 digital-frame switcher, and three Panasonic WV-BP330 CCTV cameras. These recordings were watched continuously and the following behaviors were measured: 1) time spent lying in the stall 2) time spent standing in the stall, and 3) the number of lying events. Standing was scored when the front two or all four hooves were in the stall, and was scored before, after, between or independent of lying events. Lying outside the stall was not recorded.

Experiment 2

In this experiment twelve pregnant, non-lactating Holstein cows were used, but these cows had all been housed in sand-bedded freestalls during at least two lactations, as well as immediately before the start of the experiment. Their previous exposure to sawdust was limited to the 2 months before each calving, when they were housed on a sawdust pack. All other aspects of this experiment were identical to those in Experiment 1 with two exceptions: 1) the restriction period in each stall and the second free-choice phase lasted for 3 days instead of just 2, and 2) behavioral recording took place in the last 48 h of each restriction period and free-choice phase, instead of 24 h. The average temperature in the city of Vancouver during this experiment was 15.2°C, with a minimum of 1.7°C and a maximum of 27.0°C.

Statistical Analysis

In both experiments, during the free-choice phases lying times in the three stalls were compared using Friedman's rank test. For data from the restriction phase, preferred surfaces (Experiment 1: sawdust, Experiment 2: sand and sawdust) were compared with non-preferred surfaces in paired tests. For these comparisons, all behaviors with a normal distribution (lying behavior except on sand in Experiment 1; number of lying events), were analyzed using paired t-tests. Response variables with non-normal distributions or unequal variances (all standing behavior and lying behavior on sand in Experiment 1) were analyzed using the non-parametric Wilcoxan rank sum test. In Experiment 1 the analysis was based on 24 h of information for each phase. In Experiment 2, the analysis was based on 48 h of information per phase. Video recordings were lost due to equipment malfunction for one cow in the restriction phase (sawdust) and for 24 h for two cows in the free-choice phase of Experiment 2.

RESULTS

Experiment 1

In the first free-choice phase there was a significant difference among surfaces in lying time, with ten of the twelve cows choosing deep-bedded sawdust (Friedman's rank statistic: 11.79; $P < 0.01$), and two choosing mattresses (Table 2.1). In the restriction phase, lying times and the number of lying events were significantly lower on sand than on the preferred sawdust and non-preferred mattresses (Table 2.2; Wilcoxan sign rank statistic ≥ 23; $P \leq 0.05$). This difference was driven partly by two animals with extremely low lying times on sand (Figure 2.2). The cows spent more time standing on the mattresses than on sawdust (Wilcoxan sign rank statistic ≥ 25; $P \leq 0.05$, Table 2.2 and Figure 2.3). In the final stage, after the cows had been restricted to each surface, there was still an overall preference for sawdust (Friedman's rank statistic: 7.04; $P < 0.05$); nine animals ranked sawdust as their first choice in this phase, one animal continued to prefer the mattress, and two converted to sand as their first choice.

Experiment 2

In the first free-choice phase, eight cows chose sawdust as their first choice, four chose sand, and none chose the mattress (Table 2.1). Ten of the twelve cows (seven choosing sand, three choosing sawdust) spent over 90% of their time lying on their first choice. In the restriction phase, lying times and number of lying events were lower on the mattresses than on the sawdust or sand (Table 2.2; $T \geq 2.82$; $P \leq 0.01$). Variance was similar for all three surfaces, and most animals experienced lower lying times and fewer lying events when restricted to mattresses (Figure 2.2). In addition, standing time was higher on the mattresses than on the sawdust or sand (Figure 2.3; Wilcoxan sign rank statistic ≥ 44.0; $P \leq 0.05$), due to several animals with high standing times on mattresses and fewer animals with low standing times. After the restriction phase there was still no overall preference for one substrate (Friedman's rank statistic: 3.13; $P >$

0.2); five of the twelve cows ranked sawdust as their first choice and six chose sand, and one chose the mattress.

DISCUSSION

Preference experiments require attention to several methodological issues that we have attempted to address in our experimental design (Fraser and Matthews, 1997). Firstly, preference results can be affected by the animals' previous experience either as long-term exposure (e.g. during rearing) or as short-term exposure to the various options in the course of the preference test (e.g. Dawkins, 1976; 1983; Petherick et al., 1990). Many studies do not describe the lying surfaces the animals experienced during rearing, nor do they ensure that the animals have some exposure to the surfaces they are asked to choose between (e.g. Sonck et al., 1999). In our studies, we used animals that had substantial experience with both sawdust (Experiment 1) and sand (Experiment 2) and we ensured that all the cows were exposed to all three surfaces during the restriction phase, before the final determination of preference. Secondly, social factors may influence bedding choices; for example, subordinate animals may avoid certain stalls because of proximity to dominant animals. To avoid this problem, each animal was housed individually in our experiments. Thirdly, it is important in preference testing to ensure that the different surfaces are not confounded with location; in our studies, bedding treatments were presented in a different order in each test pen. Finally, preferences are relative - that is, a non-preferred option may nevertheless be acceptable. By measuring lying and standing times when the animals were restricted to a single surface, we were able to assess whether the forced use of a less preferred substrate would affect the animals' behavior.

In Experiment 1, cows showed an overwhelming preference for sawdust and this preference persisted even after the animals had short-term exposure to both sand and mattresses. In Experiment 2, most individual animals had clear preferences with ten of the twelve cows spending over 90% of their time lying on their first choice in the first free-choice phase. In this experiment most animals ranked either sand or sawdust first. Mattresses were rarely preferred in either experiment.

Based on the results of Haley et al. (2000; 2001), we had expected that restricting animals to less preferred surfaces would result in a reduction in lying time, fewer lying events and an increase in standing time. This was largely born out in Experiment 2, where mattresses were the non-preferred surface and, during restriction to mattresses, lying times and number of lying events were lower and standing times higher.

In Experiment 1, the lying and standing behavior painted different pictures of how cows respond to non-preferred surfaces. Because the number of lying events followed the same pattern as lying time, we will discuss only the results for the latter variable. In this experiment sawdust was the preferred surface, but cows did not reduce their lying times when restricted to mattresses, suggesting that these cows also found this surface acceptable for lying. Interestingly, cows actually spent more time standing in the stall when restricted to the stalls with mattresses, perhaps because these cows found this surface especially suitable for standing. The amount of standing on all surfaces was much higher in Experiment 1 than in Experiment 2 perhaps due to variety of reasons including differences in hoof health that are known to affect standing times (Fregonesi et al., 2002), differences in environmental conditions between the two experiments, and differences between the two herds sampled for each experiment.

The response in lying behavior to restriction to sand was more variable than to mattresses in Experiment 1. Some animals maintained high lying times on sand but two animals completely rejected this less preferred surface, lying not at all or in the concrete alley. The rejection of the lying surface raises concerns about the suitability of sand for some individuals. However, in Experiment 1, confining animals to sand for 2 days was sufficient for two animals to switch their first choice from sawdust to sand; and previous exposure to sand for cows in Experiment 2 made sand roughly as desirable as sawdust for lying. Manninen et al. (2002) also reported lower lying times on sand, and also found that additional experience with sand improved acceptance of this surface for most animals. In combination, these results suggest that at least some cows will require a period of adjustment when switching to sand bedding, but after a period of exposure this bedding is acceptable for dairy cows. The question of how long an adjustment period is required is still open. From these experiments, it appears that restriction of just a few days (to different surfaces) has little effect on preferences of most animals, but housing animals for several lactations on a surface may improve acceptance.

In Experiment 1, cows showed good acceptance of mattresses for lying in the restriction phase, but in Experiment 2, lying time was significantly lower on mattresses than on either of the deep-bedded surface. This discrepancy may be explained by the cows in Experiment 1 being familiar with sawdust and thus finding any sawdust-bedded surface acceptable (i.e. either the deep-bedded sawdust or mattresses bedded with sawdust). The general trend in the literature is more consistent with the findings in Experiment 2, with animals showing preferences for deep-bedded surfaces over those covered with wood, mats or concrete (Lowe et al., 2001; Muller and Botha, 1997; except see Manninen et al., 2002). In addition, mattresses are associated with higher incidence and more severe hock lesions compared to deep bedding with either sand or sawdust (Weary and Taszkun, 2000). More work is required to determine if alternative methods of managing mattresses (such as use of more bedding) could reduce injuries and increase acceptance.

More work is required on how differences between cows, such as stage of lactation, age, social status and health, could affect their requirements for lying and standing in the stall. For example, time constraints, such as time spent in the parlor and time spent feeding, would likely differ with stage of lactation, and animals during peak lactation would have less time to spend performing other behaviors (e.g. lying). In addition to cow factors, physical aspects of bedding could influence preference including thermal properties, texture, and footing. Indeed, it is possible that surface characteristics that are desirable for lying (e.g. softness) may not be the properties of surfaces most suitable for standing (e.g. stability). An analytical approach that examines how specific surface characteristics affect both lying and standing in freestalls is needed.

In conclusion, certain surfaces can cause reduced lying times for some animals, as seen with sand in Experiment 1 and mattresses in Experiment 2. Dairy producers should use caution when switching bedding types, as previous experience may influence the behavioral response to new surfaces. Overall, there was a preference for softer surfaces, either sawdust or sand compared to mattresses, among animals that were accustomed to these materials. These results agree with other preference findings and correspond with the reduced incidence and severity of leg injuries found in animals housed on soft surfaces.

ACKNOWLEDGEMENTS

We wish to thank Dave Davis for his cooperation and the use of his animals; Amanda Zimmerman, Dominique Falconer, and Fay Wan for their excellent work in running segments of this study; Jeff Rushen for insightful comments on a previous draft of this manuscript; and members of the UBC South Campus Research and Teaching Complex, especially Ted Cathcart, Chris Shingara, Derek Masselink, Megan Atwood and Barb DeCook, for their help in maintaining the experimental facilities. This research was supported by the Natural Sciences and

Engineering Research Council of Canada through the Industrial Research Chair in Animal Welfare, and by contributions from the Dairy Farmers of Canada, the Beef Cattle Industry Development Fund, the BC Dairy Foundation, the BC SPCA, members of the BC Veterinary Medical Association and many other donors listed on our web site at www.agsci.ubc.ca/animalwelfare.

REFERENCES

Bishop, J. R., J. J. Janzen, A. B. Bodine, C. A. Caldwell, and D. W. Johnson. 1981. Dairy waste solids as a possible source of bedding. J. Dairy Sci. 64:706-711.

Chaplin, S. J., G. Tierney, C. Stockwell, D. N. Logue, and M. Kelly. 2000. An evaluation of mattresses and mats in two dairy units. Appl. Anim. Behav. Sci. 66:263-272.

Colam-Ainsworth, P., G. A. Lunn, R. C. Thomas, and R. G. Eddy. 1989. Behaviour of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. Vet. Rec. 125:573-575.

Dawkins, M. 1976. Towards an objective method of assessing welfare in domestic fowl. Appl. Anim. Ethol. 2:245-254.

Dawkins, M. S. 1983. Cage size and flooring preferences in litter-reared and cage-reared hens. Br. Poult. Sci. 24:177-182.

Dechamps, P., B. Nicks, B. Canart, M. Gielen, and L. Istasse. 1989. A note on resting behaviour of cows before and after calving in two different housing systems. Appl. Anim. Behav. Sci. 23:99-105.

DeHart, D. A., R. P. Natzke, and P. A. Oltenacu. 1975. Effect of coliform challenge at milking time on new udder infections. J. Dairy Sci. 59:1124-1130.

Fairchild, T. P., B. J. McArthur, J. H. Moore, and W. E. Hylton. 1982. Coliform counts in various bedding materials. J. Dairy Sci. 65:1029-1035.

Fraser, D. and L. R. Matthews. 1997. Preference and motivation testing. Pages 159-173 *in* Animal Welfare. M. C. Appleby and B. O. Hughes (eds.) CAB International. Wallingford, UK.

Fregonesi, J., F. Flower, T. Vittie, C.B. Tucker, and D.M. Weary. 2002. Rubber flooring affects behaviour of dairy cows, especially animals with hoof injuries. J. Dairy Sci. 85 (suppl. 1):28.

Gebremedhin, K. G., C. O. Cramer, and H. J. Larsen. 1985. Preference of dairy cattle for stall options in free stall housing. Trans. Am. Soc. Agric. Engin. 28:1637-1640.

Haley, D.B., J. Rushen, and A.M. de Passillé. 1999. Effects of softer flooring on behaviour, health and productivity of dairy cows in tie stall housing. Page 127 *in* Proceedings of the 33rd International Society for Applied Ethology. K.M. Bøe, M. Bakken, and B.O. Braastad (eds.) Agricultural University of Norway. Lillehammer, NR.

Haley, D. B., J. Rushen, and A. M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Haley, D. B., A. M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Appl. Anim. Behav. Sci. 71:105-117.

Herlin, A. H. 1997. Comparison of lying area surfaces for dairy cows by preference, hygiene, and lying down behaviour. Swed. J. Agric. Res. 27:189-196.

Hogan, J. S., K. L. Smith, K. H. Hoblet, D. A. Todhunter, P. S. Schoenberger, W. D. Hueston, D. E. Pritchard, G. L. Bowman, L. E. Heider, B. L. Brockett, and H. R. Conrad. 1989. Bacterial counts in bedding materials used on nine commercial dairies. J. Dairy Sci. 72:250-258.

Hogan, J. S. and K. L. Smith. 1997. Bacteria counts in sawdust bedding. J. Dairy Sci. 80:1600-1605.

Jensen, P., B. Recén, and I. Ekesbo. 1988. Preference of loose housed dairy cows for two different cubicle floor coverings. Swed. J. Agric. Res. 18:141-146.

Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

Lowe, D. E., R. W. J. Steen, and V. E. Beattie. 2001. Preferences of housed finishing beef cattle for different floor types. Anim. Welfare. 10:395-404.

Manninen, E., A. M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kind of cubicle flooring. Appl. Anim. Behav. Sci. 75:281-292.

McDonald, J. S. and R. A. Packer. 1968. Incidence of intramammary infections during lactation in dairy cattle repeatedly exposed to *Streptococcus agalactiae* and *Aerobacter aerogenes*. Am. J. Vet. Res. 29:1525-1532.

Muller, C. J. C. and J. A. Botha. 1997. Cow behaviour in relation to different free-stall surfaces during winter temperate climate. Pages 1069-1076 *in* Livestock Environment 5 Vol. 2. American Society of Agricultural Engineers. St. Joseph, USA.

Natzke, R. P. and B. J. Le Clair. 1975. Coliform contaminated bedding and new infections. J. Dairy Sci. 59:2152-2154.

Natzke, R. P., D. R. Bray, and R. W. Everett. 1982. Cow preferences for free stall material. J. Dairy Sci. 65:146-153.

Nilsson, C. 1992. Walking and lying surfaces in livestock houses. Pages 93-110 *in* Farm Animals and the Environment. C. Phillips and D. Piggins (eds.) CAB International. Wallingford, UK.

O'Connell, J. M. and W. J. Meaney. 1997. Comparison of shredded newspaper and sawdust as bedding for dairy cows: behavioural, clinical and economic parameters. Irish Vet. J. 50:167-170.

Petherick, J. C., I. J. H. Duncan, and D. Waddington. 1990. Previous experience with different floors influences choice of peat in a Y-maze by domestic fowl. Appl. Anim. Behav. Sci. 27:177-182.

Rendos, J. J., R. J. Eberhart, and E. M. Kesler. 1975. Microbial populations of teat ends of dairy cows, and bedding materials. J. Dairy Sci. 58:1492-1500.

Rodenburg, J. H., H. K. House, and N. G. Anderson. 1994. Free stall base and bedding materials: effect on cow comfort. Pages 159-164 *in* Dairy Systems for the 21st Century. American Society of Agricultural Engineers. St. Joseph, USA.

Rushen, J., de Passillé, A. M., and Haley, D. B. 1998. The effects on productivity, health, and behaviour of housing lactating dairy cows in NRI "Cloud 9" rubber mats. Report to NRI Cloud 9 Mats.

Sonck, B., J. Daelemans, and J. Langenakens. 1999. Preference test for free stall surface material for dairy cows. Pages 1-9 *in* Emerging Technologies for the 21st Century. American Society of Agricultural Engineers. St. Joseph, USA.

Tucker, C.B. and D.M. Weary. 2001. Stall design: enhancing cow comfort. Pages 155-168 *in* Advances in Dairy Technology, Vol. 13 (Proceedings of the 2001 Western Canadian Dairy Seminar). J. Kennelly (ed.), University of Alberta. Edmonton, Canada.

Weary, D. M. and I. Taszkun. 2000. Hock lesions and free-stall design. J. Dairy Sci. 83:697-702.

Webster, J. 1994. Comfort and injury. Pages 49-68 *in* Livestock Housing. C.M. Wathes and D.R. Charles (eds.) CAB International. Wallingford, UK.

Wechsler, B., J. Schaub, K. Friedli, and R. Hauser. 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. Appl. Anim. Behav. Sci. 69:189-197.

Table 2.1. Lying times (h per 24-h period) for the three experimental surfaces during first and second free-choice phases shown individually for the twenty-four cows used in Experiments 1 and 2.

	First free-choice phase			Second free-choice phase		
Cow	Sawdust	Sand	Mattress	Sawdust	Sand	Mattress
Experiment 1 [1]						
1	14.2	0.0	0.0	0.0	16.7	0.0
2	14.3	0.0	0.0	15.1	0.0	0.0
3	15.3	0.0	0.0	15.1	0.0	0.0
4	13.4	0.0	0.0	7.8	0.0	7.3
5	15.8	0.0	0.0	14.5	0.0	0.0
6	10.7	0.0	0.0	13.3	0.0	0.0
7	0.0	0.0	11.3	2.5	0.0	11.2
8	12.0	0.0	0.0	13.8	0.0	0.0
9	12.2	0.0	0.0	14.3	0.0	0.0
10	7.8	0.0	7.9	16.9	0.0	0.0
11	14.6	0.0	0.0	17.1	0.0	0.0
12	17.0	0.0	0.0	0.0	14.6	1.7
Experiment 2 [2]						
1	15.9	1.0	0.0	16.0	0.0	0.0
2	14.7	0.0	0.0	0.0	16.8	0.0
3	14.6	0.0	0.0	0.0	15.0	0.0
4	0.0	15.0	0.0	3.0	6.5	1.8
5	0.6	11.4	1.8	0.0	16.4	0.0
6	12.7	0.0	0.0	14.6	0.0	0.0
7	0.0	15.9	0.0	1.1	13.4	1.1
8	14.6	0.0	0.0	10.4	5.2	0.0
9	18.8	0.0	0.0	18.6	0.0	0.0
10	11.8	1.1	2.8	10.5	0.0	0.0
11	0.0	17.6	0.0	0.0	15.9	0.0
12	13.9	0.0	0.0	0.1	5.4	7.8

[1] based on 24 h of recording

[2] based on 48 h of recording, except for cows 9 and 10 which were recorded for only 24 h due to a technical difficulty

Table 2.2. Mean ± S.E.M. for lying behavior (lying time, number of lying events and duration of lying bouts) and standing behavior (standing with front two hooves, four hooves or total standing in the stall) for three bedding surfaces during the restriction phase.

	Surface		
	Sawdust	Sand	Mattress
Experiment 1 [1,2]			
Lying behavior			
Lying (h)	14.3 ± 0.83	10.9 ± 1.57[a]	14.3 ± 0.54
Number of lying events	9.1 ± 0.73	6.7 ± 1.06[a]	9.3 ± 0.68
Duration of lying bouts (h)	1.6 ± 0.10	1.4 ± 0.23	1.6 ± 0.10
Standing behavior			
Front hooves in the stall (min)	12 ± 10.2	6 ± 5.4	30 ± 10.8
Four hooves in the stall (min)	54 ± 13.2	30 ± 4.8	72 ± 19.8
Total standing (min)	66 ± 21.0	42 ± 6.6	102 ± 24.0[a]
Experiment 2 [1,2]			
Lying behavior			
Lying (h)	15.0 ± 0.40	14.9 ± 0.62	13.3 ± 0.54[a]
Number of lying events	10.5 ± 0.57	10.0 ± 0.48	8.5 ± 0.55[a]
Duration of lying bouts (h)	1.4 ± 0.05	1.5 ± 0.06	1.6 ± 0.10
Standing behavior			
Front hooves in the stall (min)	0 ± 1.2	6 ± 2.4	6 ± 4.2
Four hooves in the stall (min)	24 ± 3.6	18 ± 5.4	24 ± 4.8
Total standing (min)	24 ± 4.8	24 ± 6.0	36 ± 4.8[a]

[a] indicates a significantly different from the preferred material (sawdust in Experiment 1; sawdust and sand in Experiment 2).

[1]based on twelve cows per experiment, but only eleven cows were included in sawdust restriction information in Experiment 2

[2] based on 24 h recording in Experiment 1 and 48 h in Experiment 2. Results for Experiment 2 are presented as per 24 h.

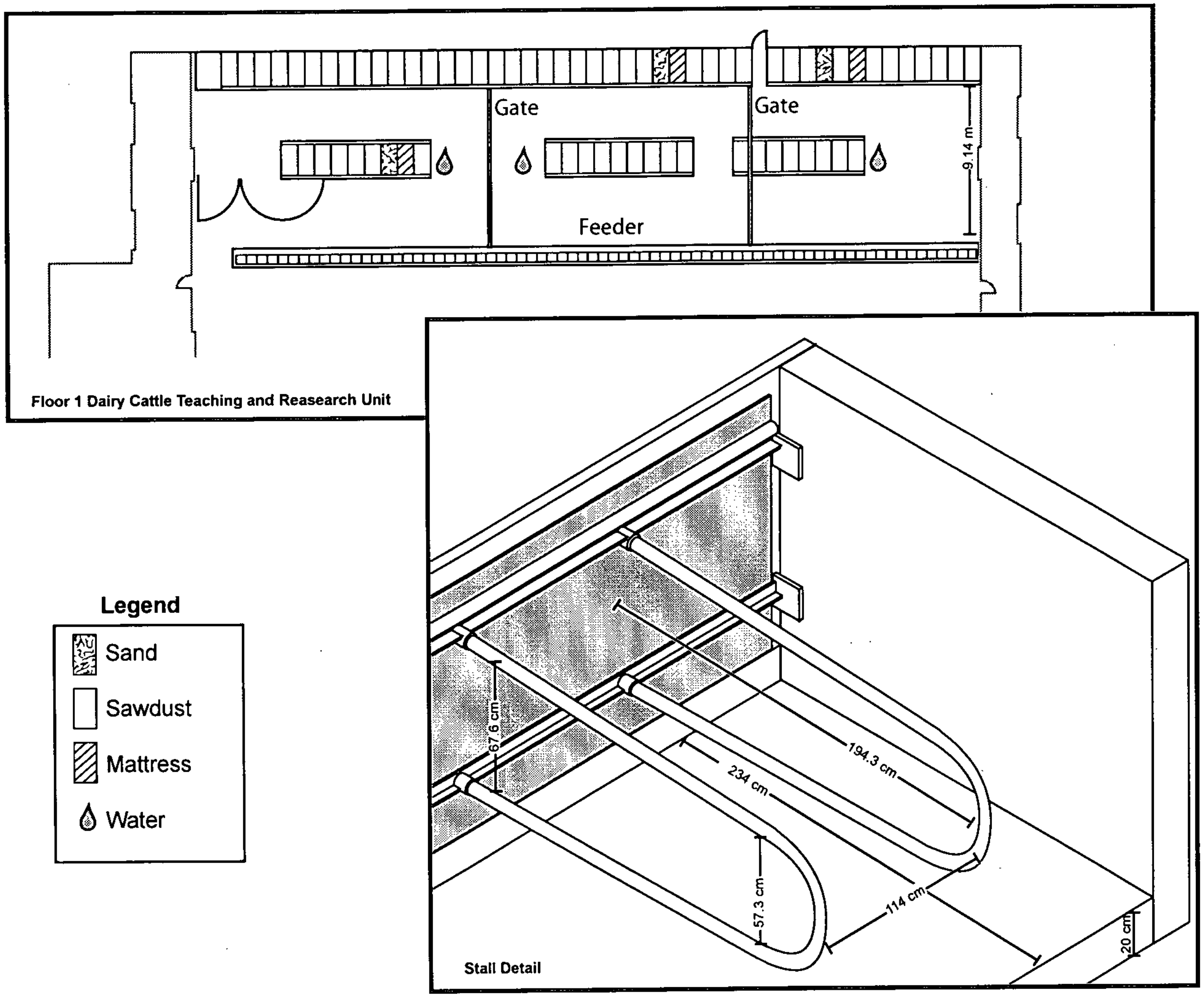

Figure 2.1. Layout of test pens used in Experiments 1 and 2.

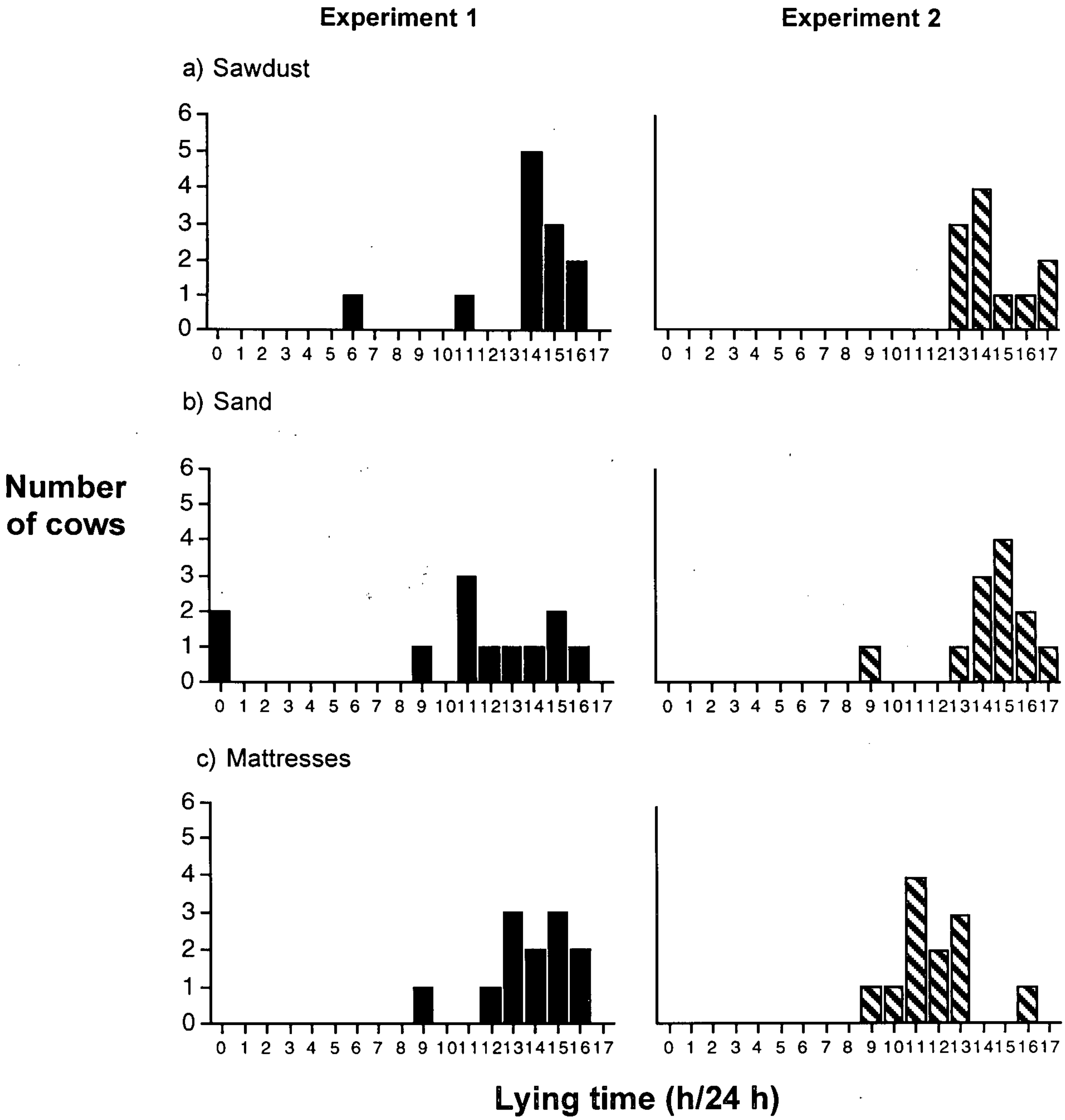

Figure 2.2. Frequency distributions of lying times during the restriction phase in Experiment 1 (left-hand panel, solid bars[1]) and Experiment 2 (right-hand panel, striped bars[2]). In Experiment 1 the distribution for sand (b) was noticeably flatter than that for sawdust (a) or mattresses (c), reflecting the variability in response to sand. In Experiment 2, the distributions for all three

surfaces were very similar; however, for most animals, lying times were lower on mattresses compared to sand or sawdust.

[1]based on twelve cows per experiment, but only eleven cows were included in sawdust restriction information in Experiment 2

[2]based on 24-h recording in Experiment 1 and 48-h in Experiment 2. Results for Experiment 2 are presented as per 24 h.

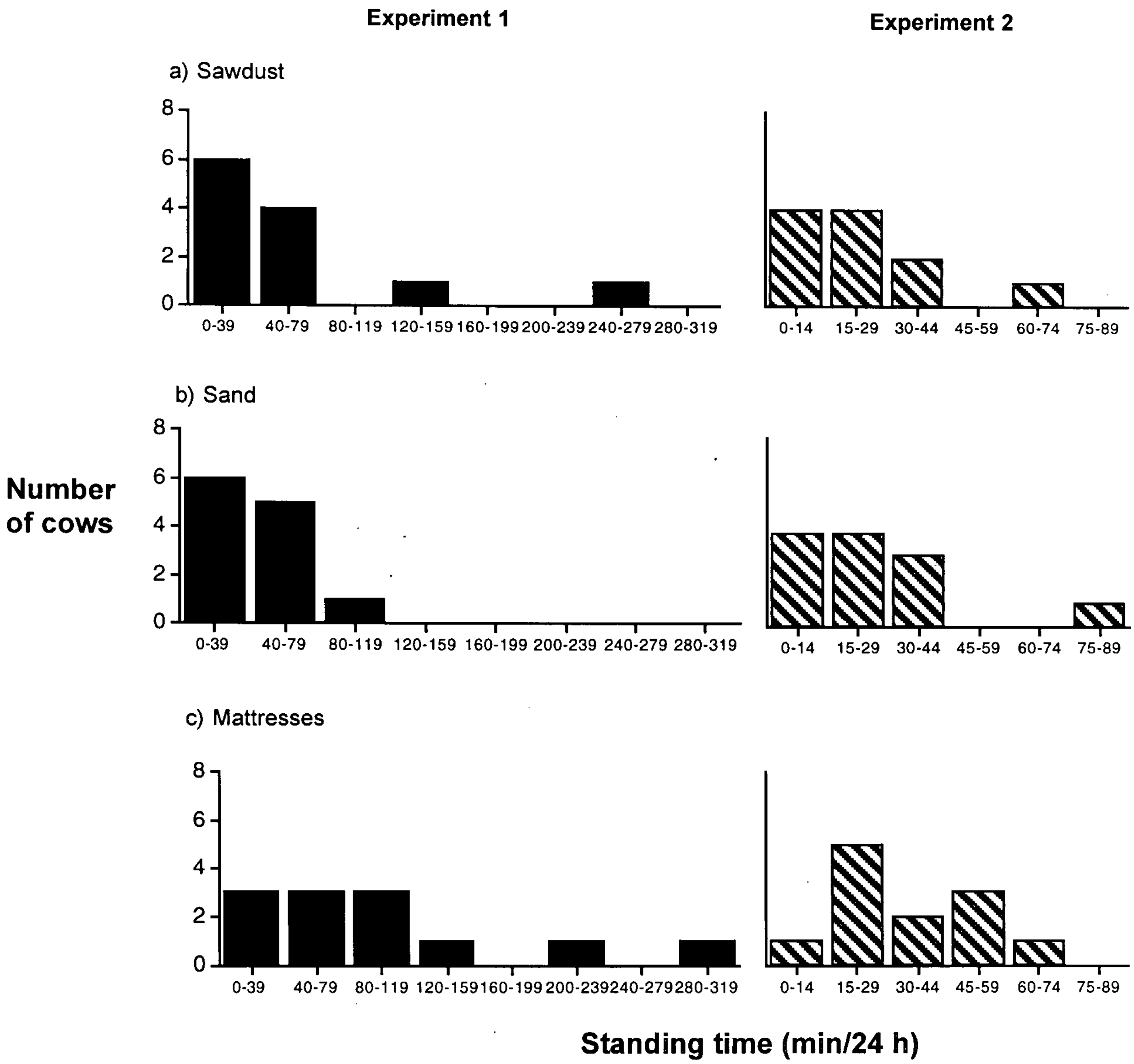

Figure 2.3. Frequency distributions of standing times during the restriction phase in Experiment 1 (left-hand panel, solid bars[1]) and Experiment 2 (right-hand panel, striped bars[2]). Standing was more variable on mattresses (c) than on sawdust (a) or sand (b) in both Experiments 1 and 2. Standing times were higher in Experiment 1 than Experiment 2.

[1]based on twelve cows per experiment, but only eleven cows were included in sawdust restriction information in Experiment 2

[2]based on 24-h recording in Experiment 1 and 48-h in Experiment 2. Results for Experiment 2 are presented as per 24 h.

CHAPTER 3: Bedding on geotextile mattresses: how much is needed to improve cow comfort?

C.B. Tucker and D.M. Weary

INTRODUCTION

Dairy cattle spend approximately 8-16 hours lying down per day (e.g. Dechamps et al., 1989; Haley et al., 2000; 2001) and between 35 and 175 min standing in freestalls (e.g. Stefanowska et al., 2001). The design of the freestall is thought to be important to dairy cattle well being, in part because of the large amount of time they spend in the stalls. This paper will discuss one aspect of freestall design, the surface. Specifically, geotextile mattresses are becoming an increasingly popular stall surface in dairy barns, in part because this surface is marketed as being suitable for use with little or no bedding. The impact of freestall surface quality on dairy cattle has been assessed using several approaches including measures of preference, measures of behavior in non-choice situations, and measures of injury.

Previous work has studied the preferences of dairy cows for a variety of freestall surfaces. Several patterns emerge from this literature (Tucker and Weary, 2001). Cows tend to prefer lying on mattresses (rubber-filled substrate) rather than concrete (Herlin,1997; O'Connell and Meaney, 1997). Solid rubber mats tend to be preferred to concrete, but are chosen less than mattresses (Herlin, 1997; Natzke et al., 1982). Cows prefer heavily bedded concrete stalls to lightly bedded mats (Jensen et al., 1988; Manninen et al., 2002), and deep-bedded stalls, usually soil based, are preferred to stalls with geotextile mattresses covered with 2-3 of sawdust or concrete (Muller and Botha, 1997; Tucker et al., 2003).

Time spent lying and standing is also influenced by substrates in stalls. Lying times are reduced and standing times increased when dairy cattle are housed with non-preferred lying surfaces like concrete (Haley et al., 2000; 2001; O'Connell and Meaney, 1997; Rushen et al., 2001). However, when concrete is covered with bedding, lying times are similar to those seen with soft mats (Manninen et al., 2002; Wechsler et al., 2000). Lying times also tend to be longer for deep-bedded stalls compared to wood-covered stalls or mattresses (Muller and Botha, 1997; Tucker et al., 2003). However, cattle also spend more time standing on mattresses than on deep-bedding surfaces (Tucker et al., 2003).

In general, preferred lying surfaces are also those associated with fewer leg injuries. Consistent with preference results, cows show fewer injuries on mattresses than concrete (Rushen et al., 2001), with rubber as an intermediate (Rodenburg et al., 1994); there are fewer injuries in deep-bedded stalls compared to mattresses (Weary and Taszkun, 2000; Wechsler et al., 2000); and more bedding reduces injuries in stalls with mattresses (Mowbray et al., 2003). Hoof health may also relate to lying surface: increased amounts of bedding (Colam-Ainsworth et al., 1989), and rubber mats instead of concrete (Leonard et al., 1994), reduce these problems.

Geotextile mattresses are gaining popularity, in part because this surface is marketed as being suitable for use with little or no bedding thus decreasing labor and other expenses associated with maintaining stall bedding. However, given the evidence outlined above, zero or low-bedding management for mattresses may reduce lying times and be less preferred than well-bedded mattresses. Thus, the objective of our study was to evaluate how the amount of bedding on mattresses influences dairy cattle behavior. Specifically, we tested how the quantity of sawdust bedding affects which stall cows chose to lie in (preference) and lying and standing behavior when they are restricted to a single option (stall usage).

MATERIALS AND METHODS

Fifteen pregnant and non-lactating Holstein cows were used in this experiment. These cows had spent their previous lactation in a barn where 25% of the stalls were fitted with geotextile mattresses bedding with sawdust (similar to the 1-kg treatment described below) and the remaining were deep-bedded stalls, with either sand or sawdust over a soil base. During the experiment, each cow was housed alone in a test pen containing a feed trough, a waterer, and three freestalls accessible from the alley. All flooring outside the freestall area was concrete. The three stalls were either adjacent to each other, or separated by a blocked stall between each available stall. Cows had access to only these three stalls; all others in the facility were blocked off. The stalls were 1.2 m wide and 2.7 m long, the neck rail was 1.25 m high, and the brisket board was 10 cm high and 2.25 m from the curb of the stall. The animals were fed grass hay *ad* *libitum*. The average temperature in the city of Vancouver during the experiment was 8.4°C, with a minimum of –6.2°C and maximum of 12.0°C.

Each stall was fitted with a Promat geotextile mattress, and bedded with one of three levels of kiln-dried sawdust, a common bedding substrate in the Fraser Valley: 0, 1, and 7.5 kg. The lower two levels of bedding (0 and 1 kg) reflected the use of sawdust in common commercial practice. The highest value (7.5 kg) was chosen to provide an extremely well-bedded option, more similar to that found in deep-bedded stalls. The weight of the bedding was used to describe the treatments because the height of the sawdust could not be quantified consistently. The 1-kg treatment covered the entire stall surface, but small sections of the mattresses were visible through the bedding. Bedding was removed and reapplied and pens cleaned twice each day during the morning and afternoon feedings (8:00 and 15:00) in order to maintain the appropriate amount of bedding on the surface as there was no bedding retainer.

Three similar test pens, each with three freestalls, were used for the experiment. Trios of animals were tested simultaneously, one in each pen. The location of the bedding treatments was allocated randomly without replacement and balanced for each pen, across trials. Five trios (fifteen animals) were used in the experiment, but information from four animals was lost due to technical malfunction, all from one pen.

Each test consisted of three stages. For the first 7 days (adjustment phase), cows had free access to all three stalls. During the next 9 days (restriction phase), cows were allowed access to only a single stall at a time, each for a 3-day period, and the order of access to each treatment was assigned randomly without replacement and balanced across cows. Access to the other treatments/stalls was blocked with a wooden barrier hung across the entrance to the stall. During the last 3 days, or the free-choice phase, cows were again allowed free access to all three stalls.

The behavior of the cows was video recorded during the last 48-h period of the free-choice phase and of each restriction period for a total of 8 days of recording for each cow. Each pen was recorded at three frames per second using a Panasonic AG-6720 VHS time-lapse video cassette recorder, a Panasonic WJ-FS 10 digital-frame switcher, and three Panasonic WV-BP330 CCTV cameras. Cameras were located with a full view of all three stalls, and a 100-watt white light was hung above each set of stalls to facilitate recording at night. These recordings were watched continuously to measure: 1) time spent lying in the stall, 2) time spent standing in the stall (with the front two or all four hooves in the stall) and 3) the number of times the animal lay down in the stall (number of lying events), and 4) the number of times the animal entered the stall (number of visits). In addition, we looked at a specific subset of standing behavior: standing that took place before a lying event; this analysis excluded standing that took place during a visit when the animal did not lie down at all or that occurred after a lying event. Lying outside the stall was not recorded.

Statistical Analysis

The time spent lying and standing and the number of lying events and visits during the restriction phase were analyzed using a general linear model. This model included a term for cows (10 df) and order of exposure to each treatment (2 df), and tested the linear and quadratic effects of the amount of sawdust (1 df each) against the residual error (18 df). The quadratic effect was never found to be significant and is not reported further. Preference during the free-choice phase was based on duration of lying and standing in each stall and compared using Friedman's rank test.

RESULTS

During the restriction phase, lying time increased with amount of sawdust; lying times were lowest on bare mattresses and highest in stalls with 7.5 kg of bedding (Table 3.1 and Figure 3.1; $P = 0.02$). The number of lying events followed the same pattern ($P = 0.08$), and there was no difference in the average duration of lying bouts ($P = 0.51$). The number of visits to the stall were similar across the three levels of bedding: 6.3, 6.5, and 6.6 for 0, 1, and 7.5 kg of sawdust, respectively (LS S.E.: 0.42, $F= 0.24$; $P = 0.63$). There were large individual differences between cows in the amount of time spent standing in the stalls (range of 21 to 364 min/ 24 h); cows also differed in whether they stood with only two or four hooves in the stall. For example, averaging across treatments, one cow spent 93% of her total standing time with only her front hooves in the stall. In contrast, another individual spent 86% of her total standing time (averaged across treatments) with all four hooves in the stall. There was no difference in the amount of time spent standing in stalls with 0, 1 or 7.5 kg bedding ($P = 0.22$). However, the time spent standing before lying down tended to differ between treatments and was lowest in the 7.5-kg option (total standing: $P = 0.06$; standing with front hooves in stall: $P = 0.08$).

In the free-choice phase, all eleven animals chose, for both lying and standing, the stall bedded with 7.5 kg of sawdust (Table 3.2; Friedman's rank statistic: 7.08; $P < 0.05$). All eleven cows showed a clear preference for lying on the deepest bedding, with five of the eleven cows never standing or lying on the other surfaces during the preference stage of the study.

DISCUSSION

Cows increased the time spent lying down in stalls by more than 2 h per day when 7.5 kg of sawdust was provided, compared to a bare mattress. Indeed, for one animal the restriction to the bare mattress elicited an extremely short lying time in the stall (3 h /24 h). When this individual was restricted to stalls with either 1 or 7.5 kg of sawdust, her lying time was at least 9 h higher. These results agree with limited evidence from Wander (1976) that greater depth of sawdust is associated with higher lying times. The number of lying events followed a pattern similar to lying time, but there was no difference in the average duration of lying bouts for the three amounts of sawdust. Similarly, Manninen et al. (2002) reported lower lying times and fewer lying events on sand compared to straw and rubber mats, but no difference in duration of lying bouts. These authors found that the percentage change in both duration and frequency of lying was very similar (approximately 75% increase), and concluded that it is no more difficult to get up and down on sand compared to straw or rubber mats. In contrast, according to Haley et al.

(2001), fewer lying events, shorter lying times per day *and* longer lying bouts are symptoms of discomfort associated with changing position on concrete compared to geotextile mattresses. However, the results from this experiment are more consistent with Manninen et al. (2002); there were fewer lying events and shorter lying times per day on bare and lightly bedded mattresses compared to the well-bedded option, but no difference in average bout duration. This indicates that the additional sawdust may improve the comfort of the mattresses for changing positions between lying and standing. Indeed, given that the number of visits to the freestall was similar among the three levels of sawdust, the additional bedding may influence the decision to lie down, but not to enter the stall. However, average duration of lying bouts did not differ between treatments and this suggests that the amount of sawdust may not have affected the comfort of the surface while the cow was recumbent. It remains unclear which physical characteristic of the sawdust is important to dairy cattle, as sawdust may change the softness and the thermal properties of the surface.

Lying time is thought be important to dairy cattle for several reasons. Cows spend a large portion of their time lying; even 3 h deprivation of lying is sufficient to cause cows to forego eating in order to lie down (Metz, 1985). Additionally, several physiological changes are associated with reduced lying time; these include a decrease in circulating levels of growth hormone (Munksgaard and Løvendahl, 1993), a short-term increase in plasma cortisol levels (e.g. Fisher et al., 2002) and increased incidence of lameness (Leonard et al., 1994, Singh et al., 1993).

However, it is unclear whether the average lying time on the worst option in this experiment (11.5 h on bare mattresses), would be detrimental to dairy cattle welfare because this time falls well within the range of lying times reported in previous studies including those when cattle were housed on pasture (e.g. Dechamps et al., 1989; Krohn and Munksgaard, 1993; Singh et al., 1993). However, the cows in this experiment may have shown longer lying times compared to other experiments because this comparison was carried out using non-lactating animals. Lactating dairy cattle usually spend at least 2 h away at milking and may spend more time eating, leaving less time for lying down than their non-lactating counterparts (e.g. Fregonesi and Leaver, 2001). In addition, the animals in our study were housed individually. Under normal freestall conditions cows must compete for access to stalls, especially when there are fewer stalls available than cows, likely further reducing lying times (e.g. Friend et al., 1976). This experiment would need to be repeated to determine if bare mattresses combined with the time constraints of lactation and social competition push the average lying time below averages reported in other studies.

Although the results of the current experiment are most likely due to differences in the perceived comfort of the lying surface, previous experience of cows can also affect the results of such experiments. For example, Manninen et al. (2002) concluded that additional experience with sand across experiments increased lying duration on this novel surface by several hours. The cows used in the current experiment came from a barn with both deep-bedded stalls and mattresses covered with some sawdust (similar to the 1 kg/day treatment); hence, limited previous experience with bare mattresses may have been a factor. Indeed, if the animals choose to avoid mattresses in the original home pen, their experience with mattresses would be limited to the time during the experiment. In addition to duration of lying, preference can also be affected by previous experience. However, Tucker et al. (2003) found that two days experience was sufficient time for some cows to switch their preference from a familiar surface to a novel surface. In this experiment, three days of restriction to each treatment was insufficient experience for any cows to prefer either the 0 or 1 kg treatment, indicating that short-term experience is unlikely to influence preference for amount of bedding on mattresses. Indeed, all eleven cows preferred the stall bedded with 7.5 kg of sawdust and spent 85% or more of their lying time on their first choice.

In addition, during the free-choice phase, all cows chose the stall with 7.5 kg of bedding, regardless if preference was based on lying or standing duration. Only one cow (number 2, Table 3.2) stood in a stall that she did not use for lying (1 kg of sawdust). Based on this evidence, it appears that animals were not seeking out different surfaces solely to stand upon. However, standing in the stall, particularly standing with only the front hooves in the stall, is not well understood. Galindo et al. (2000) speculate that dairy cattle perform this behavior to avoid dominant cattle within the group; however, this is clearly not the motivation for the animals in this experiment, which were housed individually. Alternatively, animals could be investigating the lying space, and cases of prolonged standing could indicate a reluctance to lie down on the surface. Tucker et al. (2003), found that cows spent more time standing on mattresses covered with 2-3 cm of sawdust compared to deep-bedded surfaces, suggesting that mattresses may be more comfortable to stand on. Alternatively, standing in the stall may indicate a reluctance to lie down. In the current experiment, there was no difference in the total time spent standing on each treatment, however, the results suggest that cows spend more time standing before they lie down when the stall contained either 1 or 0 kg of sawdust. The differences in standing time before lying down may indicate a reluctance to lie down in these stalls with less sawdust bedding. Indeed, previous work has shown that cattle spend more time assessing lying areas without bedding than bedded areas (e.g. Müller et al., 1989). In addition, cattle spend more time examining confined lying spaces, like tie-stalls, than deep-bedded areas or pasture before lying down (Krohn and Munksgaard, 1993; Müller et al., 1989).

In addition to the reduction in lying time observed in the current study, previous work has found that mattresses with little bedding are associated with a higher incidence and more severe hock lesions compared to deep-bedded surfaces (Mowbray et al., 2003; Weary and Taszkun, 2000). Indeed, Nilsson (1992) found more hock injuries on surfaces with less penetration (or harder surfaces). By covering mattresses with a thick layer of bedding (as in 7.5 kg of sawdust treatment), the surface will be softer and is likely to reduce the incidence of injury. However, more work is needed to understand the importance of various physical properties of stall surfaces (e.g. thermal conductance, visual appearance, coefficient of friction) to dairy cattle.

In conclusion, increased amounts of sawdust bedding on geotextile mattresses appear to increase the suitability of the surface for lying, both in terms of lying duration and number of lying events, as well as reduce the time spent standing in the stall before lying down. Moreover, all cows showed a clear preference for stalls with more sawdust. Thus, to promote both comfort, geotextile mattresses are best managed with copious bedding.

ACKNOWLEDGMENTS

We would like to thank Barb DeCook, Karen Vickers and Tyler Vittie for their excellent work weighing bedding and watching video tapes, members of the UBC South Campus Research and Teaching Complex, especially Ted Cathcart, Chris Shingara, and Derek Masselink for their help in maintaining the experimental facilities, and Jeff Rushen and David Fraser for input throughout this study. This research was supported by the Natural Sciences and Engineering Research Council of Canada through the Industrial Research Chair in Animal Welfare, and by contributions from the Dairy Farmers of Canada, the Beef Cattle Industry Development Fund, the BC Dairy Foundation, the BC SPCA, members of the BC Veterinary Medical Association and many other donors listed on our web site at www.agsci.ubc.ca/animalwelfare.

REFERENCES

Colam-Ainsworth, P., G. A. Lunn, R. C. Thomas, and R. G. Eddy. 1989. Behaviour of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. Vet. Rec. 125:573-575.

Dechamps, P., B. Nicks, B. Canart, M. Gielen, and L. Istasse. 1989. A note on resting behaviour of cows before and after calving in two different housing systems. Appl. Anim. Behav. Sci. 23:99-105.

Fisher, A.D., G.A. Verkerk, C.J. Morrow, and L.R. Matthews. 2002. The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. Livest. Prod. Sci. 73:255-263.

Fregonesi, J.A. and J.D. Leaver. 2001. Behaviour, performance, and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livest. Prod. Sci. 68:205-216.

Friend, T.H., C.E. Polan, and M.L. McGilliard. 1976. Free stall and feed bunk requirements relative to behavior, production, and individual feed intake in dairy cows. J. Dairy Sci. 60:108-116.

Galindo, F., D.M. Broom, and P.G.G. Jackson. 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. Appl. Anim. Behav. Sci. 67:335-341.

Haley, D. B., J. Rushen, and A. M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Haley, D. B., A. M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Appl. Anim. Behav. Sci. 71:105-117.

Herlin, A. H. 1997. Comparison of lying area surfaces for dairy cows by preference, hygiene, and lying down behaviour. Swed. J. Agric. Res. 27:189-196.

Jensen, P., B. Recén, and I. Ekesbo. 1988. Preference of loose housed dairy cows for two different cubicle floor coverings. Swed. J. Agric. Res. 18:141-146.

Krohn, C.C. and L. Munksgaard. 1993. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments II. Lying and lying-down behaviour. Appl. Anim. Behav. Sci. 37:1-16.

Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

Manninen, E., A.M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kind of cubicle flooring. Appl. Anim. Behav. Sci. 75:281-292.

Metz, J.H.M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301-307.

Mowbray, L., T. Vittie, and D.M. Weary. 2003. Hock lesions and free-stall design: effects of stall surface. Pages 288-295 *in* Proceedings of the 5th International Dairy Housing Conference. American Society of Agricultural Engineers. St. Joseph, USA.

Müller, C., J. Ladewig, H.H. Thielscher, and D. Smidt. 1989. Behaviour and heart rate of heifers housed in tether stanchions without straw. Physio. Behav. 46:751-754.

Muller, C. J. C. and J. A. Botha. 1997. Cow behaviour in relation to different free-stall surfaces during winter temperate climate. Pages 1069-1076 *in* Livestock Environment 5 Vol. 2. American Society of Agricultural Engineers. St. Joseph, USA.

Munksgaard, L. and P. Løvendahl. 1993. Effects of social and physical stressors on growth hormone levels in dairy cows. Can. J. Anim. Sci. 73:847-853.

Natzke, R. P., D. R. Bray, and R. W. Everett. 1982. Cow preferences for free stall material. J. Dairy Sci. 65:146-153.

Nilsson, C. 1992. Walking and lying surfaces in livestock houses. Pages 93-110 *in* Farm Animals and the Environment. C. Phillips and D. Piggins (eds.) CAB International. Wallingford, UK.

O'Connell, J. M. and W. J. Meaney. 1997. Comparison of shredded newspaper and sawdust as bedding for dairy cows: behavioural, clinical and economic parameters. Irish Vet. J. 50:167-170.

Rodenburg, J. H., H. K. House, and N. G. Anderson. 1994. Free stall base and bedding materials: effect on cow comfort. Pages 159-164 *in* Dairy Systems for the 21st Century. American Society of Agricultural Engineers. St. Joseph, USA.

Rushen, J., A.M. de Passillé, D. Haley, E. Manninen, and H. Saloniemi. 2001. Using behavioral indicators and injury scores to assess the effect of stall flooring on cow comfort. Pages 716-723 *in* Livestock Environment 6 Vol. 2. R. Stowell, R. Bucklin and R. W. Bottcher (eds.) American Society of Agricultural Engineers. St. Joseph, USA.

Singh, S.S., W.R. Ward, K. Lautenbach, J.W. Hughes, and R.D. Murray. 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. Vet. Rec. 133:469-474.

Stefanowska, J., D. Swierstra, C.R. Braam, and M.M.W.B. Hendriks. 2001. Cow behaviour on a new grooved floor in comparison with a slatted floor, taking claw health and floor properties into account. Appl. Anim. Behav. Sci. 71:87-103.

Singh, S.S., W.R. Ward, K. Lautenbach, J.W. Hughes, and R.D. Murray. 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. Vet. Rec. 133:469-474.

Tucker, C.B. and D.M. Weary. 2001. Stall design: enhancing cow comfort. Pages 155-168 *in* Advances in Dairy Technology, Vol. 13 (Proceedings of the 2001 Western Canadian Dairy Seminar). J. Kennelly (ed.), University of Alberta. Edmonton, Canada.

Tucker, C.B., D. M. Weary and D. Fraser. 2003. Effects of three types of free stall surfaces on preferences and stall usage by dairy cows. J. Dairy Sci. 86:521-529.

Wander, J.F. 1976. Haltungs- und verfahrenstechnisch orientierte Verhaltensforschung. Zuchtungskunde. 48:447-459.

Weary, D. M. and I. Taszkun. 2000. Hock lesions and free-stall design. J. Dairy Sci. 83:697-702.

Wechsler, B., J. Schaub, K. Friedli, and R. Hauser. 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. Appl. Anim. Behav. Sci. 69:189-197.

Table 3.1. Stall usage (mean and least-square S.E.) for three levels of sawdust bedding in the restriction phase (n = 11). P values are for the linear term.

	Amount of sawdust (kg)					
	0	1	7.5	LS S.E.	F-value	P-value
Lying behavior						
Lying events (number/24 h)	7.9	9.8	10.3	0.69	3.41	0.08
Duration of lying bouts (h/bout)	1.5	1.3	1.4	0.05	0.46	0.51
Lying (h/24 h)	11.5	12.5	13.7	0.54	6.83	0.02
Standing behavior						
Front hooves in stall (min/24 h)	85	83	71	8.6	1.56	0.23
Four hooves in stall (min/24 h)	33	40	31	8.0	0.28	0.60
Total standing (min/24 h)	118	123	102	11.9	1.60	0.22
Subset of standing behavior: before lying down						
Front hooves in stall (min/24 h)	43	44	33	4.6	3.41	0.08
Four hooves in stall (min/24 h)	24	26	19	5.0	0.87	0.36
Total standing (min/24 h)	67	70	52	6.6	4.02	0.06

Table 3.2. Time spent lying (h/24 h) and standing duration (min/24 h) for the three experimental surfaces during the free-choice phase, shown separately for all 11 animals.

	Amount of bedding (kg)			
Cow	0	1	7.5	% time on # 1 choice
Lying time				
1	0.6	0.0	14.0	96%
2	1.9	0.0	10.5	85%
3	0.0	1.3	11.8	90%
4	0.0	0.0	15.0	100%
5	0.0	0.0	14.3	100%
6	0.0	0.0	13.9	100%
7	0.0	1.2	14.5	92%
8	0.0	0.0	15.1	100%
9	0.0	0.0	11.8	100%
10	0.0	1.0	13.9	93%
11	0.0	0.0	11.1	100%
Standing time				
1	18	0	132	89%
2	12	12	90	81%
3	0	6	30	88%
4	0	0	36	100%
5	0	0	60	100%
6	0	0	114	100%
7	0	6	66	91%
8	0	0	54	96%
9	0	0	132	100%
10	0	48	66	59%
11	0	0	216	100%

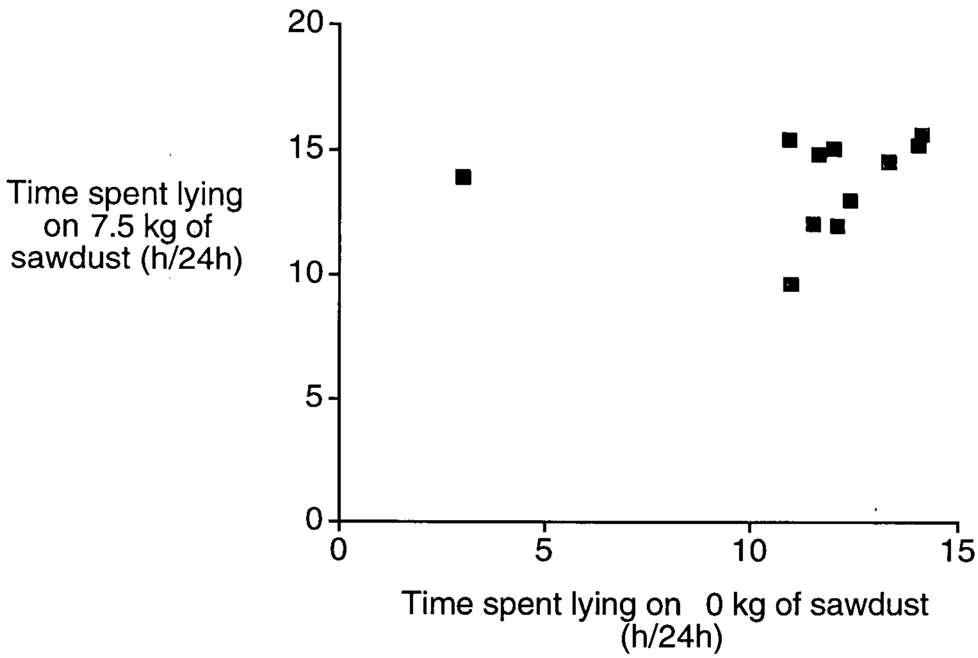

Figure 3.1. Scatter plot of mean lying times (h per 24 h) during the restriction phase for two levels of sawdust on geotextile mattresses: 0 kg (x-axis) and 7.5 kg (y-axis). One of the eleven animals tested had an extremely low lying time (3 h) on the 0-kg treatment.

CHAPTER 4: Freestall Dimensions: Effects on Preference and Stall Usage

C.B. Tucker, D.M. Weary, and D. Fraser

INTRODUCTION

Dairy producers are faced with a range of recommendations concerning suitable dimensions for freestalls. For example, recommendations for overall stall bed length range from 200 – 240 cm, but if there is space for a lateral head lunge, bed length recommendations can be as small as 185 cm (Bickert, 2000; Irish and Martin, 1983; McFarland and Gamroth, 1994). Recommendations for stall width are generally given in terms of the size of the animals. Common recommendations are about twice the hip width, which often translates into approximately 100-120 cm (Bickert, 2000; Irish and Martin, 1983; McFarland and Gamroth, 1994). Little is known about the range of stall sizes found on farms in North America, but a recent survey of 37 farms in the UK found that 87% of stalls measured were less than 230 cm and 50% were between 115 and 122 cm in width (Faull et al., 1996). The variation in recommendations reflects the lack of formal research on freestall design and dimensions, and how these dimensions affect cow behavior.

Indeed, what is known about the space requirements for dairy cattle comes from the literature examining the standing up and lying down movements (reviewed by Lidfors, 1989). The lunge space, or the space taken up by the head of the animal as it moves forward in order to stand up is often thought of as the optimal length requirement. However, until recently, there were few reliable estimates of the space requirements for dairy cattle. One exception is the results of kinematic analysis of the standing up movements, which indicate that dairy cattle use between 260 to 280 cm total longitudinal space (from the nose to the most caudal point of the cow) and that lateral displacements during this movement ranges from 60 to 110 cm at the hips (Ceballos, 2003).

The size of the lying area may affect the behavior of dairy cattle. Comparisons of the results of Haley et al. (2000) and Haley et al. (2001) suggest that lying time were 1.5- 2 h lower in tie stalls (180 cm by 130 cm or 2.3 m^2 per cow) than in larger pens (420 cm by 390 cm or 16.4 m^2 per cow). In addition, in one study heifers were housed in straw bedded pens providing 1.8, 2.7, or 3.6 m^2 of lying area (Mogensen et al., 1997), and in another, cows were housed with either 9 or 4.5 m^2 of bedded area per cow (Fregonesi and Leaver, 2002). In both experiments, the animals showed no differences in lying time associated with space allowance. These previous studies can provide some insight into the effect, or lack of effect, of the size of the lying area. However, they are inadequate as a basis for recommendations for freestall design, as neither of these studies have examined how animals interact with the freestall infrastructure without constraints such as tethers.

The objective of the two experiments described in this paper was to assess the impact of freestall size on dairy cattle behavior, specifically stall usage and preference. Preference testing, or allowing an animal to choose between alternative housing designs, can provide insights into aspects of housing design that may be important to the cow. Results from preference tests can correspond with the behavioral response to an option when the animal has no choice. Time spent in the stall is an important response variable because it can provide information about how comfortable cows find a given stall design (see Haley et al., 2000 example above). Together, the combination of information about changes in stall usage and preferences can provide a more comprehensive evaluation of which housing features affect cattle. The first experiment evaluated how the width and length of freestalls affected cow preference and stall usage. The second experiment also examined the effect of freestall width on stall usage, and also assessed other considerations such as milk production and stall cleanliness. The dimensions tested in both experiments represented the range seen in the industry.

MATERIALS AND METHODS

Experiment 1: Freestall width and length

Fifteen Holstein cows, all pregnant and non-lactating, were used as subjects (average weight ± S.D.: 720 ± 69 kg). Before this experiment, the subjects had been housed in a freestall barn where stalls measured 116 cm between stall partitions and either 229 or 274 cm in length. During this study, each animal was housed alone in a test pen containing a row of four freestalls. In each stall, the neck rail was positioned 125 cm above the geotextile mattress base and 160 cm from the curb. A 10-cm-high plastic brisket pillow was positioned 165 cm from the curb (Figure 4.1).

Stalls were bedded with 2-3 cm of sawdust and were cleaned each day during the morning and afternoon feedings (08:00 and 15:00). The animals were fed grass hay *ad libitum*.

Trios of animals were tested simultaneously in the three identical test pens at the South Campus Large Animal Research Facility, located in Vancouver, British Columbia. During the experiment, each animal was housed alone in a test pen containing a feed trough, a waterer, and four freestalls accessible from the alley. All flooring outside the freestall area was concrete. The four freestalls in each pen varied in width and length according to a 2X2 design. Stall length (short or long: 229 or 274 cm) was altered by adjusting the lunge space available in front of the brisket board, as this is often the space eliminated in smaller stalls in commercial conditions. Stall width (narrow or wide: 112 cm or 132 cm) was altered by adjusting the space between stall partitions. The four stalls thus varied in total area available from 2.48 m^2 to 3.51 m^2. Treatments were balanced and allocated randomly without replacement to the four positions in each pen. For each animal, treatments were assigned randomly to the four positions in a pen.

Each test consisted of three consecutive phases: adjustment, restriction, and free choice. During the adjustment phase, animals had free access to all four stalls for 7 days. This allowed animals to settle into the facilities, as they were normally housed at a different location. During the restriction phase, the animals were allowed access to only a single stall at a time, each for a 2-day period, with the order of access assigned randomly without replacement. A preliminary experiment in our facility had shown that restricting animals for 2 days yields the same behavioral results (e.g. lying time) as a longer (10-day) period of restriction. The restriction phase ensured that animals had short-term experience with each option before testing preferences and allowed us to measure stall usage. During the free-choice phase, animals were again allowed free access to all four stalls for 2 days.

Each animal was video recorded during the last 24-h period of the adjustment, free choice, and of each restriction phase for a total of 6 days of recording. Recordings were at three frames per second using a Panasonic AG-6720 time-lapse VCR, a Panasonic WJ-FS 10 digital-frame switcher, and a Panasonic WV-BP330 CCTV camera. Cameras were located with a full view of all four stalls, and 100-watt white light was hung above each set of stalls to facilitate recording at night. Video tapes were watched continuously and the following behaviors recorded: 1) lying in the stall, 2) standing with four hooves in the stall, 3) standing with the front two hooves in the stall, and 4) the number of lying events. Lying down outside the stall was not recorded. Mean lying bout duration was calculated by dividing total lying time by the number of lying events in each 24-h period. Due to technical malfunction, preference data (free-choice phase) were recorded for only twelve of the fifteen animals.

Statistical analysis

Analysis of preferences was based on lying time, as this behavior provides a clear indicator that the animals are willing to use the stall. Specifically, lying time was used to rank each option to assess which option a given animal preferred. The probability of a given number of animals choosing either the wide or long stalls was compared using a binomial test. For the preference information, the interaction between width and lunge space was compared using the Fisher's exact test. In addition, as the animals did not spend all of their time in one stall, a value was calculated representing the composite size of freestall used during this phase (proportion of lying time in the stall multiplied by the area of that stall). The relationship between this variable (composite size of freestall used during preference phase) and animal weight was tested using Pearson correlation. A general linear model (GLM) was used to analyze differences in the dependent variables during the restriction phase. This model included a term for animals (14 df), and terms for width (1 df), length (1df) and the width by length interaction (1df) tested against the residual error term (42 df). For behaviors where the analysis showed effects of both width and length, a similar model was used to test the linear, quadratic, and cubic effect of total stall area (1 df each). The higher order effects (quadratic and cubic) were never found to be significant and are not reported further.

Experiment 2: Freestall width

One objective of this experiment was to re-assess the effect of stall width on stall usage, as the results from Experiment 1 indicated that this was an important factor influencing lying time. However, in this experiment we tested lactating cattle managed under commercial conditions, and thus could also assess how stall width affected milk production and stall cleanliness. We used twenty-seven Holstein cattle divided into three groups of nine, balanced for lactation number (mean ± S.D. = 2.75±1.34) and days in milk (DIM) (71.5±20.5). Each group of nine animals was housed in one of three pens, each with nine stalls, at the University of British Columbia's Dairy Research and Education Centre in Agassiz, British Columbia. In a given pen, the nine stalls were configured in three rows. Two rows faced one another, were open at the front ('head-to-head') and had a bed length of 240 cm. The back row of stalls faced a cement wall, so these stalls were 30 cm longer to allow more space for the cow to lunge forward when getting up and lying down. Stalls were bedded with 40 cm of washed river sand. Animals were fed a total mixed ration and milked twice a day at approximately 6:00 and 16:00. All flooring outside the freestall area was grooved concrete.

Freestall partitions (Figure 4.1) were adjusted to give three stall widths of 106, 116, and 126 cm, all measured as the space between the partitions. All stalls within a pen were adjusted to the same width for a 3-week period and then switched, such that treatments were assigned according to a Latin-square design so that each width was tested once in each of the three periods, and once in each of the three pens.

The animals were videotaped using one video camera (Panasonic WV-BP330) per pen, a time-lapse videocassette recorder (Panasonic AG-6540) and a video multiplexer (Panasonic WJ-FS 216). To facilitate recording during the dark period we suspended two red lights (100 W, < 5 lx) approximately 8 m over each pen (same height as cameras). Observations began after the evening milking on Saturday and ended immediately before the evening milking on Sunday on the first and third week of each treatment. Observations were suspended while animals were absent from the pens during milking, which ranged from 29 min to 170 min/24 h. Video tapes were watched continuously and the following behaviors recorded: 1) lying in the stall, 2) standing with four hooves in the stall, 3) standing with the front two hooves in the stall, and 4) the number of lying events. Individual animals were identified with markings made with Clairol's Nice and Easy # 122, Natural Black, or Clairol's L'image Maxiblonde, depending on hair color on the back.

Stall cleanliness and milk production

Fecal matter from each pen was collected and weighed during the Saturday morning, Saturday afternoon and Sunday morning milkings of weeks 1 and 3 of each treatment. We attempted to minimize the amount of sand mixed in with the fecal material, but the weights reported likely overestimate the amount of fecal material because of the bedding still present in the samples. After removing feces from each stall, the stall surface was leveled with a rake, in accordance with normal farm practice. Milk production was recorded at each milking and averaged across each three-week treatment period.

Statistical analysis

To test the effect of stall width, these data were analyzed as a change-over experiment as described by Morris (1999). The individual animal served as the observational unit as each animal was tested under each condition. Observations from weeks 1 and 3 on each treatment were averaged for each cow. A GLM was used to analyze differences in time spent lying, standing with two or four hooves in the stall, and the number of lying events, and mean duration of lying bouts (lying time divided by number of lying events), and milk production. This model included a term for cows (26 df) and order of exposure to each treatment (2 df), and tested the linear and quadratic effects of total stall width (1 df each) against the residual error (52 df). The quadratic effect was never statistically significant and is not reported further. For the analysis of stall cleanliness, pens served as the experimental unit, because fecal material could not be identified based on individual animals. Fecal weights were log-transformed prior to analysis (because of unequal variances), and differences in stall cleanliness were analyzed using a GLM that included a term for pen (2 df) and order of exposure to each treatment (2 df) and tested the linear and quadratic effects of stall width (1 df each) against the residual error (2 df).

RESULTS

Experiment 1: Freestall width and length

During the restriction phase, animals spent more time lying in the wide stalls than the narrow (Table 4.1; $P = 0.01$), but length did not affect lying times ($P = 0.29$). The longer lying times can be explained by longer average lying bouts in wide stalls ($P = 0.01$). Both length and width influenced the amount of time spent standing with the front hooves in the stall. As a result, this behavior was better explained by comparing the different stalls on the basis of total area available. Time spent standing with the front two hooves in the stall was explained by the total area of the freestall (Figure 4.2; $P < 0.01$). Standing with all four hooves in the stall and the number of lying events did not vary in relation to stall width or length ($P > 0.1$). Total time spent standing (with either two or four hooves in the stall) tended to be higher in the narrow stalls ($P = 0.06$), a difference driven primarily by standing with only front hooves in the stall. There were no significant interactions between width and length for any measure.

There was no consistent preference lying in stalls of a given size: six cows ranked the wide-short stall as their first choice, two chose wide-long, three chose narrow-long, and one chose narrow-short (Table 4.2). Eight out of twelve animals choose wide stalls ($P = 0.19$) and seven out of twelve animals choose stalls with more forward lunge space ($P = 0.39$). There was no interaction between width and lunge space ($P = 0.22$). The amount of time cows spent lying on their first choice ranged from 38%- 100%. There was no clear relationship between the weight of the animal and size of stalls used in the preference phase ($r = 0.38$; $P = 0.22$), although the two lightest animals did prefer the smaller stalls (animals 2 and 7 in Table 4.2).

Experiment 2: Freestall width

The linear effect of stall width was statistically significant for the total lying time and the duration of lying bouts ($P < 0.05$, Table 4.3), with the greatest difference between stalls measuring 106 and 116 cm. There was no effect of stall width on the number of lying events, total time spent standing in the stall, or milk production ($P > 0.3$). Time spent standing with front two hooves in the stall was reduced with increasing stall width; the least amount of time (58 min) was spent in stalls measuring 126 cm and the most (85 min) was spent in stalls measuring 106 cm ($P \leq 0.01$). The amount of time spent standing with all four hooves in the stall tended to increase with stall width, with the most standing taking place in the stall measuring 126 cm (68 min; $P = 0.06$). There was also a linear, positive relationship between stall width and amount of fecal material in the pen ($P = 0.04$).

DISCUSSION

In both experiments, the animals spent more time lying down, and had longer lying bouts, in wider stalls, at least within the range tested in Experiments 1 and 2. In Experiment 2, lying times in stalls measuring 106 cm averaged 0.7 h less than in stalls measuring 116 or 126 cm. In Experiment 1, the difference between lying times in stalls measuring 112 cm and 132 cm was 1.2 h. These results are consistent with the limited research available on the effect of stall size on behavior: Wander (1976) reported decreased lying times in smaller stalls (although it is unclear how the stalls were smaller); also, narrow tie stalls (1 m) were found to reduce lying time compared to stalls of 1.1 and 1.2 meters in width (Maton et al., 1978). However, animals differed in the magnitude of the response between experiments (Experiment 1: 1.2 h, Experiment 2: 0.7 h), and in their average lying time between the two experiments (Experiment 1: 10.2 h, Experiment 2: 12.8 h). These differences may have been due to differences in freestall widths tested or to differences between the two groups of animals including stage of lactation/parturition. Despite the difference in the magnitude of the responses, in both experiments the animals spent more total time lying down, and exhibited longer lying bouts, when using wider stalls.

The difference in the duration of lying bouts was not accompanied by a difference in the number of lying events. Other authors have hypothesized that a reduced number of lying events is associated with discomfort during rising and lying down (e.g. Haley et al., 2001); for example, more lying events were observed in stalls with softer surfaces that allow the knees to sink into the flooring material (Dumelow, 1995). These results suggest that the range of freestall widths tested did not the affect the ease with which cows got up and down.

One possible explanation for the longer lying bouts in wider stalls it that cows are less likely to contact the stall partitions in these stalls. Blom et al. (1984) placed pressure sensors on various parts of the freestall and found that cows contact stall partitions over 100 times per day, but it was unclear whether the contact occurs while the animals were in a recumbent position or during the rising/lying movements. However, given that the frequency of lying events is well below 100, it seems likely that some of the contact with the stall partitions was occurring while lying in the stall. Haley et al. (2000) found cows spent more time lying down when housed in large pens with mattress flooring compared to concrete tie stalls, but this difference was driven by a greater number of lying events rather than a change in the average duration of lying bouts as reported in the current study. However, the width of the tie stall in the Haley et al. experiment was 130 cm, a value close to the upper range of those tested in Experiments 1 and 2, and the pen tested had no equivalent to freestall partitions. Perhaps contact with the partitions only influences the duration of lying bouts at smaller widths.

The length of the freestalls did not affect lying behavior, despite the fact that the 229 cm treatments were at least 30 cm less than the 260-280 cm used by dairy cattle when rising (Ceballos, 2003). However, this type of precise kinematic analysis has not been carried out with recumbent cattle. It seems likely that amount of space required while resting would be less than the 260-280 cm used when lunging forward. Future work should evaluate the effects of lunge space on the difficulty of standing up.

Interestingly, when given a choice among freestalls with different dimensions, cattle showed no clear preferences, although there was a trend for animals to choose stalls of intermediate size (wide-short and narrow-long). It is possible that cattle are strongly focussed on the evaluation of the lying surface, rather than stall size, when lying down. Dairy cattle are descendents of plains-dwelling animals, who would rarely have to consider spatial constraints about where to lie down. Stall width affects behavior while animals have contact with the stall surface and partitions (as described above), but it is unclear if animals evaluate or remember this aspect of the lying space when deciding where to lie down.

Recommendations for stall sizes are normally provided separately for different weight classes of animals (e.g. Agriculture Canada, 1990). The experiments reported here were not specifically designed to test the effects animal size, but as a secondary aim of Experiment 1 we examined the effect of animal weight on preferences for stalls of various sizes. There was no clear relationship between composite size of freestall used and body weight, but the two smallest animals tended to use the smaller stalls. Further work is likely needed to evaluate how stall usage changes with body size. One approach would be to hold stall size constant and monitor the behavior of a large number of animals varying in size.

Lying time may be important to cows for several reasons. Cows spend a large portion of their time lying, and even a 3-h deprivation of lying is sufficient to cause animals to forego eating in order to lie down (Metz, 1985). Additionally, several physiological changes are associated with reduced lying time in cattle; these include a decrease in circulating levels of growth hormone (Munksgaard and Løvendahl, 1993), a short-term increase in plasma cortisol levels (Ladewig and Smidt, 1989; Fisher et al., 2002) and increased incidence of lameness (Leonard et al., 1994, Singh et al., 1993). More blood circulates to the udder while the animal is lying down compared to when standing (Metcalf et al., 1992). However, no study to date has found differences in milk production clearly linked to duration of lying. For example, Rushen et al. (2001) found no difference in milk production when cows were housed in stalls with concrete versus rubber mat surfaces over a 16-week experiment, despite a difference between treatments of 1.5 h per day in lying time. Similarly, we found no differences in milk production associated with stall width in Experiment 2. It is possible that changes in lying time are not associated with milk production, because feed intake, a limiting factor for milk production, may not be affected by the treatments tested. Although we did not measure the amount of feed consumed, other work has shown that deprivation of the opportunity to lie down does not affect feed intake (Ingvartsen et al., 1999). Indeed, Fregonesi and Leaver (2001) have shown that high-producing cows spend more time feeding and less time lying down than low-producing cows, and high milk production is correlated with high dry matter intake (e.g. Dado and Allen, 1994).

In addition to longer lying times in wider stalls, the increase in time spent standing with all four hooves in the stall may also benefit cows. The wider space between stall partitions provided more room for cows, possibly making it more comfortable for the animals to stand entirely in the stall without contacting the partitions or neck rail. Indeed, in both experiments, the amount of time spent standing with four hooves tended to be higher in the wider stalls, although this result was only statistically significant in Experiment 2. Cows may stand in the stall to avoid the relatively uncomfortable standing surface available in the alley, as suggested by Stefanowska et al. (2001). We found marked individual differences in the time cows spent standing in this way, perhaps because the increase in stall size was especially important for certain animals. For example, animals with hoof injuries may particularly benefit from the more comfortable standing surface available in the stall, and the lactating cattle in Experiment 2 were more likely to be experiencing hoof injuries than the dry animals in Experiment 1 (e.g. Chaplin et al., 2000). Future experiments should consider the incidence of claw lesions/other hoof injuries and animal size as covariates to better understand the effect of stall size has on standing behavior.

Standing with the two front hooves in the stall occupied almost 2 h more time in the smaller stalls relative to the largest in Experiment 1. Similarly, in Experiment 2 animals spent 27 min more time standing with front hooves in the stall when tested with the narrowest width relative to the widest. As with standing entirely in the stall, there was considerable individual variation in this behavior. Some authors have suggested that standing in the stall in this manner may be used to hide from more socially dominant animals (e.g. Galindo et al., 2000). However, this was clearly not the case in Experiment 1 because animals were housed individually. An alternative explanation for standing with the only the front hooves in the stall may be a reluctance to lie down, perhaps because of cow size, but additional work is required to determine how cow size influences the expression of this behavior. There may also be health consequences associated with excessive standing with only the front hooves in the stall. Two previous studies have indicated that increased standing with the front two hooves in the stall predisposed cattle to claw lesions (Colam-Ainsworth et al., 1989; Galindo and Broom, 2000). This may be because increased exposure to moisture is highly correlated with lameness (Fitzgerald et al., 2000), and cattle standing in this position have their back hooves in the relatively moist environment of the alley. In addition, increased exposure to fecal material and concrete surfaces is associated with increased prevalence of hoof diseases (e.g. Bergsten and Pettersson, 1992). Thus, in addition to providing a comfortable area to lie down, the design of freestalls should also allow cattle access to a suitable standing surface.

As a potential disadvantage, larger stalls can increase the frequency with which animals defecate and urinate in the stall as opposed to the alley. We found that wider stalls in Experiment 2 contained 1.5 times more fecal material than narrow ones. The increase in fecal material was likely due to animals spending more time lying and standing with all four hooves in the stall – positions where fecal material was likely to come in contact with the stall surface. More defecation in the stall may increase the exposure of teat ends to bacteria and lead to an increased rate of clinical mastitis. However, it may be possible to reduce such negative effects by cleaning stalls more often. Indeed, improved stall maintenance may be one way to minimize the impact of additional stall soiling associated with wider stalls, while allowing animals to spent more time lying down and less time spent standing with only the front hooves in larger stalls.

ACKNOWLEDGEMENTS

We would like to thank Fay Wan, Sylvia Huang, and Tamiko Thomas for their help in running segments of this study. We also wish to thank members of the UBC South Campus Research and Teaching Complex, especially Chris Shingara, the staff of the UBC Dairy Research and Education Center, and the staff and students of UBC's Animal Welfare Program for their help and cooperation. We thank Jeff Rushen for his insightful comments on previous drafts of this document and The William and Charlotte Parks Foundation for Animal Welfare for funding the first author while she wrote this manuscript. This research was supported by the National Sciences and Engineering Research Council of Canada through the Industrial Research Chair in Animal Welfare, and by contributions from the Dairy Farmers of Canada, the Cattle Industry Development Fund, the BC Dairy Foundation, the BC SPCA, members of the BC VMA and many other donors listed on our web site at www.agsci.ubc.ca/animalwelfare.

REFERENCES

Agriculture Canada. 1990. Housing. Pages 9-14 *in* Recommended code of practice for the care and handling of dairy cattle. Agriculture Canada Publication. Ottawa, ONT.

Bergsten, C. and B. Pettersson. 1992. The cleanliness of cows tied in stalls and the health of their hooves as influenced by the use of electric trainers. Prev. Vet. Med. 13:229-238.

Bickert, W.G. 2000. Freestall design. Pages 205-213 *in* Proceedings of "Dairy Housing and Equipment Systems: Managing and Planning for Profitability." Natural Resources Agriculture and Engineering Service. Ithaca, NY.

Blom, J.Y., S.P. Konggaard, J.G. Larsson, K. Nielsen, A. Northeved, and P. Solfjeld. 1984. Electronic recording of pressure exerted by cows against structures in free-stall housing. Appl. Anim. Behav. Sci. 13:41-46.

Ceballos, A. 2003. Kinematic analysis of dairy cow lying movements. M.Sc. thesis. University of British Columbia. Vancouver, Canada.

Chaplin, S.J., H.E. Ternet, J.E. Offer, D.N. Logue, and C.H. Knight. 2000. A comparison of hoof lesions and behaviour in pregnant and early lactation heifers at housing. Vet. J. 159:147-153.

Colam-Ainsworth, P., G.A. Lunn, R.C. Thomas, and R.G. Eddy. 1989. Behaviour of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. Vet. Rec. 125:573-575.

Dado, R.G. and M.S. Allen. 1994. Variation in and relationships among feeding, chewing, and drinking variables for lactating dairy cows. J. Dairy Sci. 77:132-144.

Dumelow, J. 1995. Testing cubicle mats for dairy cows. Agric. Eng. Winter: 17-21.

Faull, W.B., J.W. Hughes, M.J. Clarkson, D.Y. Downham, F.J. Manson, J.B. Merritt, R.D. Murray, W.B. Russell, J.E. Sutherst, and W.R. Ward. 1996. Epidemiology of lameness in dairy cattle: influence of cubicles and indoor and outdoor walking surfaces. Vet. Rec. 139:130-136.

Fisher, A.D., G.A. Verkerk, C.J. Morrow, and L.R. Matthews. 2002. The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. Livest. Prod. Sci. 73:255-263.

Fitzgerald, T., W. Norton, R. Elliott, H. Podlich, and O.L. Svendsen. 2000. The influence of long-term supplementation with biotin on the prevention of lameness in pasture fed dairy cows. J. Dairy Sci. 83:338-344.

Fregonesi, J.A. and J.D. Leaver. 2001. Behaviour, performance, and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livest. Prod. Sci. 68:205-216.

Fregonesi, J.A. and J.D. Leaver. 2002. Influence of space allowance and milk yield on behaviour, performance, and health of dairy cows housed in strawyard and cubicle systems. Livest.. Prod. Sci. 78:245-257.

Galindo, F. and D.M. Broom. 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Res. Vet. Sci. 69:75-79.

Galindo, F., D.M. Broom, and P.G.G. Jackson. 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. Appl. Anim. Behav. Sci. 67:335-341.

Haley, D.B., J. Rushen, and A.M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Haley, D. B., A.M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Appl. Anim. Behav. Sci. 71:105-117.

Ingvartsen, K.L., L. Munksgaard, L., V.K.M. Nielsen, and L.J. Pedersen. 1999. Responses to repeated deprivation of lying down on feed intake, performance, and blood hormone concentration in growing bulls. Acta. Agric. Scand., Sect. A, Anim. Sci. 49:260-265.

Irish, W.W. and R.O. Martin. 1983. Design considerations for free stalls. Pages 108-121 *in* the 2nd Proceedings of Dairy Housing II, National Dairy Housing Conference. American Society of Agricultural Engineers. St. Joseph, USA.

Ladewig, J. and D. Smidt. 1989. Behavior, episodic secretion of cortisol, and adrenocortical reactivity in bulls subjected to tethering. Horm. and Behav. 23:344-360.

Leonard, F.C., J.M. O'Connell and K.J. O'Farrell. 1994. Effects of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

Lidfors, L. 1989. The use of getting up and lying down movements in the evaluation of cattle environments. Vet. Res. Commun. 13: 307-324.

McFarland, D.F. and M.J. Gamroth. 1994. Freestall designs with cow comfort in mind. Pages 145-158 *in* Dairy Systems for the 21st Century, (Proceedings of the 3rd International Dairy Housing Conference). R. Bucklin (ed.), American Society of Agricultural Engineers. St. Joseph, USA.

Maton, A., J. Daelemans, and J. Lambrecht. 1978. Le comportement des vaches laitières en stabulation entravée à litière pailée, en fonction de la largeur du bati. Revue de l'Agriculture. 31:827-835.

Metcalf, J.A., S.J. Roberts, and J.D. Sutton. 1992. Variations in blood flow to and from the bovine mammary gland measured using transit time ultrasound and dye dilution. Res. Vet. Sci. 53:59-63.

Metz, J.H.M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301-307.

Mogensen, L., L.H. Nielsen, J. Hindhede, J.T. Sørensen, and C.C. Krohn. 1997. Effect of space allowance in deep bedding systems on resting behaviour, production, and health of dairy heifers. Acta Agric. Scand., Sect. A, Anim. Sci. 47:178-186.

Morris, T.R. 1999. Experimental Design and Analysis in Animal Sciences. CAB International. Wallingford, UK.

Munksgaard, L. and P. Løvendahl. 1993. Effects of social and physical stressors on growth hormone levels in dairy cows. Can. J. Anim. Sci. 73:847-853.

Rushen, J., A.M. de Passillé, D. Haley, E. Manninen, and H. Saloniemi. 2001. Using behavioral indicators and injury scores to assess the effect of stall flooring on cow comfort. Pages 716-723 *in* Livestock Environment 6 Vol. 2. R. Stowell, R. Bucklin and R. W. Bottcher (eds.) American Society of Agricultural Engineers. St. Joseph, USA.

Singh, S.S., W.R. Ward, K. Lautenbach, J.W. Hughes, and R.D. Murray. 1993. Behaviour of first lactation and adult dairy cows while housed and at pasture and its relationship with sole lesions. Vet. Rec. 133:469-474.

Stefanowska, J., D. Swierstra, C.R. Braam, and M.M.W.B. Hendriks. 2001. Cow behaviour on a new grooved floor in comparison with a slatted floor, taking claw health and floor properties into account. Appl. Anim. Behav. Sci. 71:87-103.

Wander, J.F. 1976. Haltungs- und verfahrenstechnisch orientierte Verhaltensforschung. Zuchtungskunde 48:447-459.

Table 4.1. Response measures (mean and least-square S.E.) for cows in Experiment 1 (n = 15) shown in relation to stall length and width.

	Width (cm)				Length (cm)				
	112	132	F	P	229	274	F	P	LS S.E.
Lying behavior									
Lying events (number/24 h)	8.5	8.0	0.96	0.33	8.2	8.4	1.53	0.22	0.36
Duration of lying bouts (h/bout)	1.3	1.5	7.52	0.01	1.4	1.4	0.10	0.76	0.05
Lying time (h/24 h)	9.6	10.8	7.64	0.01	9.9	10.5	1.72	0.20	0.29
Standing behavior									
Front hooves in stall (min/ 24 h)	169	135	3.54	0.07	171	133	4.61	0.04	12.7
Four hooves in stall (min/24 h)	104	95	0.35	0.56	90	109	1.75	0.19	9.8
Total standing (min/24 h)	272	230	3.81	0.06	261	241	0.88	0.35	15.2

Table 4.2. Duration of lying (h per 24 h) for the four stall sizes during the free-choice phase, shown for twelve individual animals in Experiment 1, together with weight (kg) and "composite size of freestall" (calculated by summing the proportion of time spent lying in a given stall multiplied by the area of that stall).

			Stall size			
Animal	Weight (kg)	Composite size of freestall (m^2)	Narrow Short (112 x 229)	Narrow Long (112 x 274)	Wide Short (132 x 229)	Wide Long (132 x 274)
1	760	3.05	1.8	4.0*	0.0	3.3
2	608	2.77	4.3*	2.8	4.3	0.0
3	734	3.35	0.0	0.0	4.2	10.0*
4	758	3.07	0.0	0.0	6.5*	1.4
5	742	2.95	0.5	0.0	9.8*	0.0
6	766	2.97	0.0	0.0	12.7*	0.0
7	618	2.81	4.1	0.0	6.8*	0.4
8	630	2.97	0.0	0.0	12.5*	0.0
9	624	2.90	1.6	11.1*	6.0	0.0
10	799	2.94	0.5	2.7	10.5*	0.0
11	743	2.89	0.7	7.7*	0.0	0.0
12	686	3.20	0.0	5.7	1.4	5.9*
median	738	2.96	0.5	1.4	6.2	0.0

* indicates stall size ranked first, based on lying time

Table 4.3. Lying and standing behavior and milk production (mean and least-square S.E.; P values for linear term) for three stall widths in Experiment 2 (n = 27). Values for weight of fecal material are back transformed, hence least-square S.E. are unequal.

	Stall width (cm)					
	106	116	126	LS S.E.	F	P
Lying behavior						
Lying events (number/24 h)	12.3	11.9	11.9	0.38	0.59	0.45
Duration of lying bouts (h/bout)	1.1	1.2	1.2	0.03	4.83	0.04
Lying time (h/24 h)	12.3	13.0	13.0	0.21	5.47	0.02
Standing Behavior						
Front hooves in stall (min/24 h)	85	66	58	7.0	7.26	0.01
Four hooves in stall (min/24 h)	53	50	68	5.8	3.68	0.06
Total standing (min/24 h)	138	116	126	8.0	0.96	0.33
Milk Production						
Amount of milk (kg/24 h)	47.0	45.8	46.2	0.77	0.25	0.62
Weight of fecal material (kg per pen/ 24 h); n=3	22.5	33.3	53.9	+1.13/ -0.89	26.6	0.04

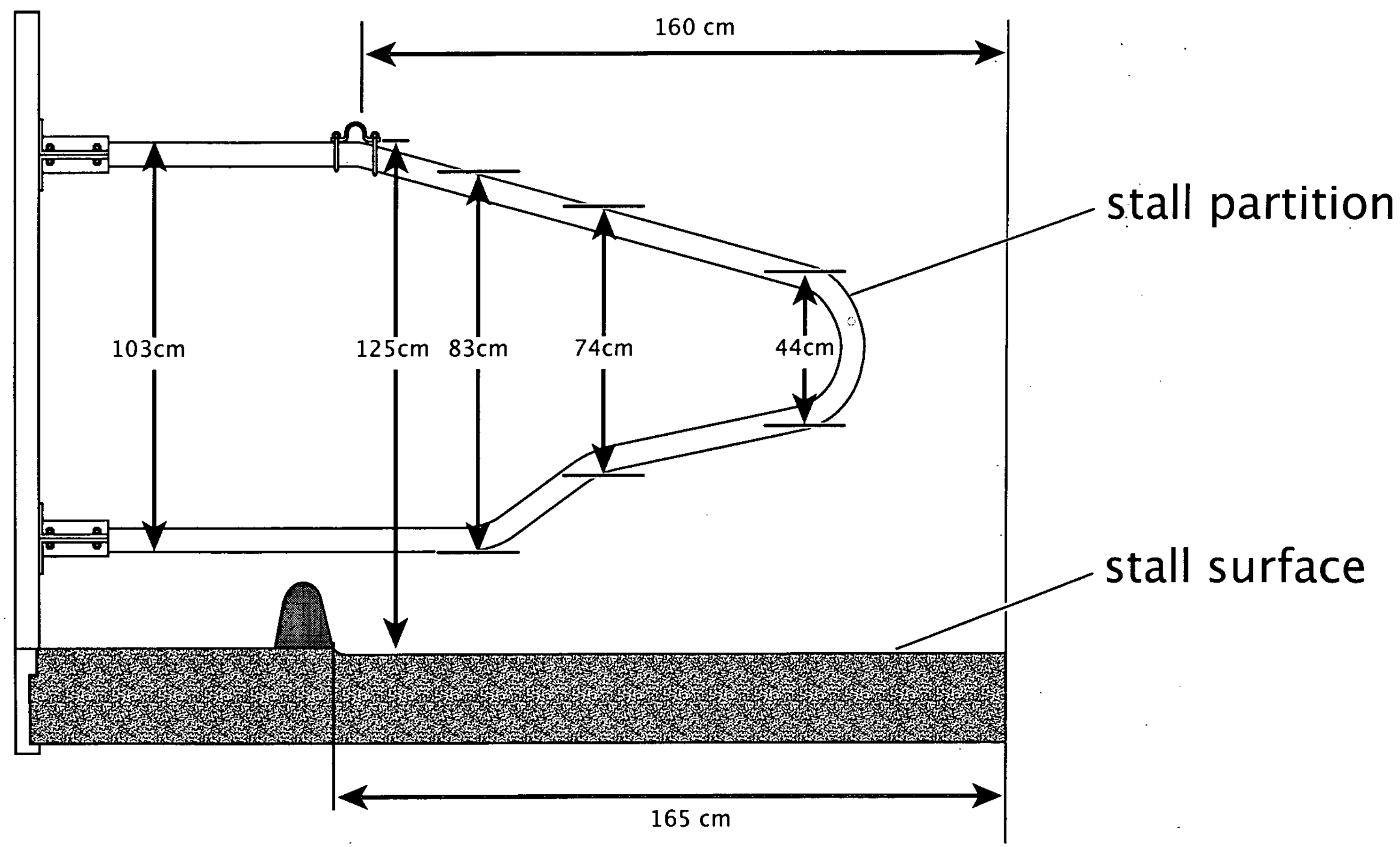

Figure 4.1. Design of freestall partition used in Experiments 1 and 2.

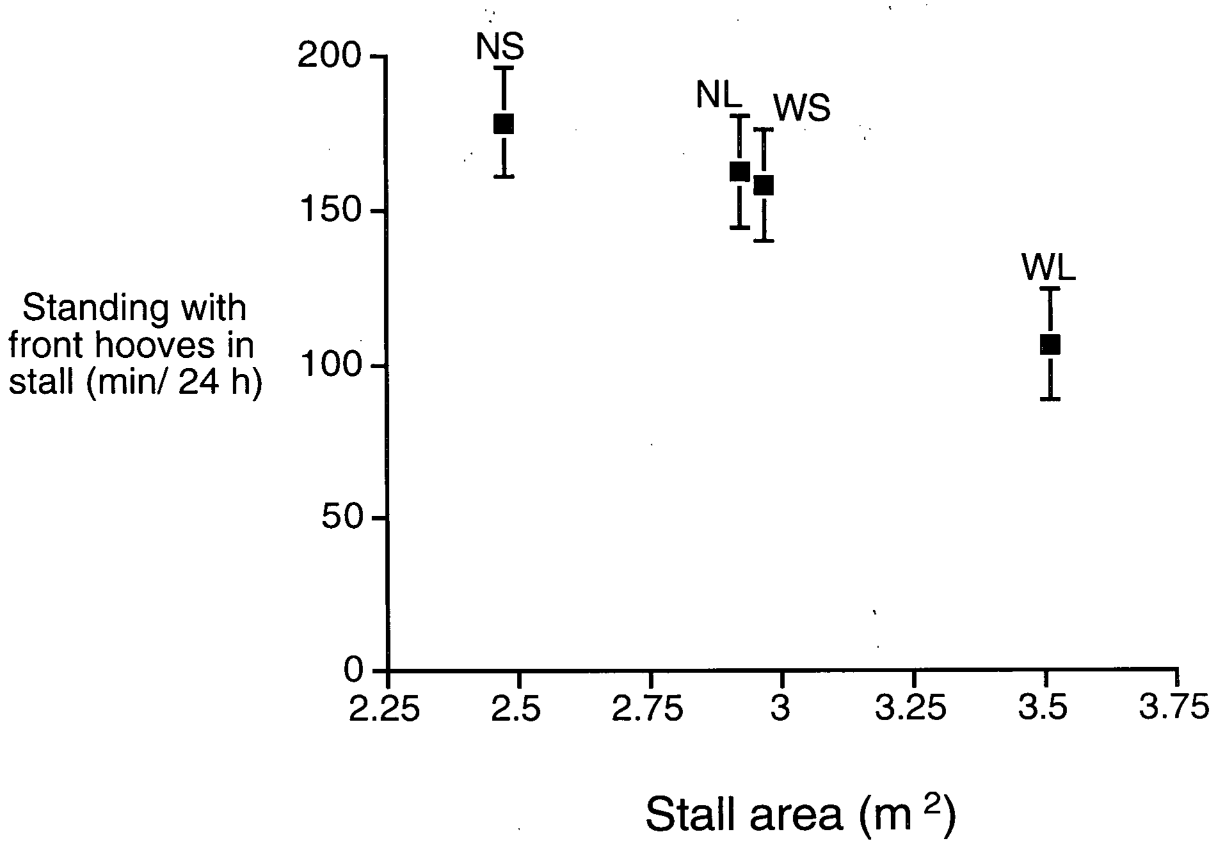

Figure 4.2. Mean time spent standing with the front two hooves in the stall (min/24 h ± least-square S.E.) are shown in relation to total stall area (m^2) in each of the four stalls in Experiment 1 (n = 15). Each stall is labeled as its designation in the 2x2 design (e.g. NS indicates Narrow Short or 112 x 229 cm).

CHAPTER 5: Neck rail placement: effect on freestall preference, usage, and cleanliness

C.B. Tucker, D.M. Weary, and D. Fraser

INTRODUCTION

A hallmark of good housing design for animals is that the design features make the system easier for the animals to use. However, in some cases housing features are designed to prevent certain types of use by the animals, such as defecating in areas intended for lying or eating. Freestalls commonly have a bar positioned above the stall partitions. This 'neck rail' is designed to help maintain a clean lying surface, by allowing dairy cattle to enter the stall, but forcing them to back out of the freestall while defecating or urinating. However, we are aware of little or no research on the effect of neck rails on dairy cattle behavior or freestall cleanliness.

Electric cow-trainers (ECTs) are commonly used in tie stalls and are designed to serve a similar function to the neck rail in the freestall. The effectiveness of ECTs has been studied, and this research may provide some useful insights into the potential benefits of the neck rail. For example, Bergsten and Pettersson (1992) showed that use of ECTs resulted in cleaner stalls, cleaner cows, and a lower incidence of heel-horn erosion in the hind hooves. While the reduction in the incidence of heel erosion is desirable, it is unclear that cleaner stalls provide udder health benefits as commonly assumed. Feces and urine contamination are thought to play an important role in bacterial growth in dairy bedding (Carroll and Jasper, 1978; Zehner et al., 1986).

However, Bakken (1982) reported a higher risk of mastitis on farms using ECTs, despite that these farms likely had cleaner stalls. In addition, Oltenacu and others (1998), also found that the incidence of mastitis did not differ among farms prior to the installation of ECTs, but was higher on the half of the farms that had subsequently installed ECTs.

Although this research on ECTs is informative, the electric current used in ECTs may affect behavior and health very differently than the neck rail. To our knowledge, the scientific literature to date contains no information on of the effects of neck rail placement (including the height of the neck rail above the base of the stall and its distance from the curb) on dairy cattle use of the stall for lying and standing and stall cleanliness. Anecdotally, it is thought that lower neck rails or those closer to the entrance of the stall (or the curb) are more likely to encourage animals to back out of the freestall when defecating or urinating. However, in addition to the ideal outcome (that animals use the stalls freely, but back out before defecating or urinating), neck rail installation may result in one of three problems. (1) In some instances neck rail placement may actually discourage cattle from entering and using the stall for lying and standing. These unused stalls will stay clean, but can hardly be considered an instance of appropriate design. Indeed, Gaworski et al. (2003) reported a positive relationship between time spent standing and lying in the stall and the amount of fecal material in the freestall (R^2=0.30), indicating that one way the neck rail may keep the stall clean is by preventing the cattle from using the stall. (2) In other cases, the neck rail may allow animals to enter the stall and lie down, but will not allow them to stand fully in the stall. These stalls may remain cleaner (as long as little defecation or urination occurs while the animal is lying), but may disadvantage cattle if standing in the stall is an important behavior. For example, standing in the stall (i.e. a non-concrete surface) may be important for hoof health, as concrete has been linked to hoof-related diseases (e.g. Bergsten, 1994). (3) Finally, it is also possible that neck rails may be placed in such a way that they have no effect on behavior and provide no improvement in stall cleanliness.

The objective of the three experiments described in this paper was to assess the impact of neck rail placement or presence on dairy cattle behavior, specifically stall usage, preference, and eliminative behavior. Time spent in the stall is an important response variable because it provides information about how comfortable cows find a given stall design (see Haley et al., 2000). Preference tests can provide insight into aspects of housing design perceived to be important to dairy cattle. Together, the combination of information about changes in stall usage and preferences can provide a more comprehensive evaluation the impact of neck rail placement on dairy cattle. The first experiment evaluated how neck rail height and distance from the curb affected cow preference and stall usage. The second experiment examined only the effect neck rail distance from the curb on stall usage. The third experiment examined the effect of neck rail presence on eliminative behavior and stall cleanliness. The dimensions tested in these experiments represented the range seen in the industry, with recommendations for neck rail height ranging from 94 to 127 cm and distance from the curb ranging from 152 to 196 cm (Gaworski et al., 2003).

MATERIALS AND METHODS

Experiment 1: Effect of neck-rail height and location on freestall preference and usage

Ten Holstein non-pregnant and non-lactating cows were used as subjects. All cows had been housed previously in freestalls with neck rails ranging from 113 cm to 126 cm above the base of the stall. Each cow was housed individually in a test pen containing a feed trough, a waterer, alley space, and a row of four freestalls, all accessible from the alley. All flooring outside the freestall area was concrete. Cows had access only to these four stalls; all others in the facility were blocked off. Each stall was fitted with a rubber-filled geotextile mattress (Pasture Mat® of Promat Ltd.) and bedded with 2-3 cm of sawdust. Stalls measured 121 cm wide, 272 cm long, with an 10 cm brisket board (PolyPillow® of Promat Ltd.) 227 cm from the curb. The sawdust used for the bedding was green hemlock sawdust (not wood chips) with an average particle size of approximately 7 mm by 2 mm. Feces were removed and bedding leveled (adding bedding if necessary) each day during the morning and afternoon feedings (8:00 and 15:00). The animals were fed grass hay to *ad libitum* intake.

Trios of animals were tested simultaneously in three identical test pens, in the same barn. In each test pen, each of the four stalls was equipped with one of four neck rail heights: 0 (neck rail absent), 102 cm (40 in), 114 cm (45 in), or 127 cm (50 in). Treatments were presented to the cows in a split-block design, blocked by distance of the neck rail from the curb, either 180 cm (72 in, n=4) or 160 cm (63 in, n= 6). Treatments were balanced and allocated randomly without replacement to the four positions in each pen. For each animal, treatments were assigned randomly to the four positions in a pen.

Each test consisted of three stages. During the first or adjustment phase, cows had free access to all four stalls for 7 days. During the second or restriction phase, cows were allowed access to only a single stall at a time, each for a 2-day period, with the order of access assigned randomly without replacement. During the final or free-choice phase, cows were again allowed free access to all four stalls for 3 days.

The behavior of the cows was video recorded during the last 24 h of each of the four treatments in the restriction phase and of the free-choice phase for a total of 5 days of recording for each cow. Each pen was recorded at three frames per second using a Panasonic AG-6720 VHS time-lapse video cassette recorder, a Panasonic WJ-FS 10 digital-frame switcher, and three Panasonic WV-BP330 CCTV cameras. These recordings were watched continuously and the time spent in the following behaviors was measured: 1) lying in the stall, 2) standing with the front two hooves in the stall, 3) standing with four hooves in the stall and 4) the number of lying events. Mean lying bout duration was calculated for each cow in each 24-h period by dividing the total lying time by the number of lying events. Lying events outside the stall were not recorded.

Statistical Analysis

The information from the restriction phase was used to address two questions: 1) how does the distance of the neck rail from the curb affect stall usage, and 2) how does stall usage change as the neck rail is raised and removed? To answer the first question, a general linear model (GLM) was used to analyze differences between the two distances from the curb, as well as any interactions with the three neck rail heights tested, in time spent lying, standing with two or four hooves in the stall, the number of lying events, and average bout duration. The model statement included a term for distance from the curb (1 df), cow (8 df), order of exposure to each treatment (3 df), linear and quadratic terms for neck rail height (1 df each), and two terms for the interaction between neck rail height (both linear and quadratic) and distance from the curb (1 df each). The interaction terms were tested against the residual error from the model described above (24 df). The effect of distance was tested against the mean square for cows (8 df), as this was a between-subject test. To answer the second question, Page's test was used to test for a linear trend in the behavior in the stall with the four ordered levels of neck rail tested (102, 114, 127, and none; for a description of Page's test, see Hollander and Wolfe, 1973). Distance from the curb was excluded because neither it nor its interaction was significant in the first analysis. Analysis by ranks was admittedly conservative, but unknown value of the 'none' treatment four treatments tested required the use of non-parametric statistics. Preference during the free-choice phase was calculated separately for lying time and standing time in each stall; these data were compared using Page's test for ordered alternatives.

Experiment 2: Effect of neck-rail location on stall usage

Twenty-four lactating Holstein cattle were divided into two equal groups, balanced for lactation number (mean ± S.D.; 2.9 ± 1.2) and days in milk (135 ± 23). All animals were housed in one of two pens, each of which contained twelve stalls, at the University of British Columbia's Dairy Research and Education Centre in Agassiz, British Columbia. Stalls were bedded with 5-12 cm of washed sand over a geotextile mattress base (PackMat® of Promat Ltd.) and measured 118 cm wide, with 10 cm brisket boards (PolyPillow® of Promat Ltd.) set 227 cm from the curb. Neck rails were 126 cm high, as measured from the base of the stall. In a given pen, the twelve stalls were configured in three rows. Two rows faced one another, were open at the front ('head-to-head') and had a bed length of 240 cm. The back row of stalls faced a cement wall, so these stalls were 30 cm longer to allow more space for the cow to lunge forward when getting up and lying down. Cows were fed a total mixed ration (TMR) and milked twice a day at approximately 5:00 and 14:00. Bedding was leveled to the curb and stalls cleaned during both milking periods. All flooring outside the freestall area was grooved concrete.

Neck rails were positioned either 152 cm or 170 cm from the curb in a crossover design, with the two groups balanced for order of exposure to the two treatments. All neck rails within a pen were placed at one location for a 1-week period and then switched to the other location for the second week. Each group of cows remained in the same pen for the entire experiment. Neck rail distance was measured from the inside of the curb to the front of the neck rail.

The cows were videotaped using two video cameras (Panasonic WV-BP330) per pen, a time-lapse videocassette recorder (Panasonic AG-6540) and a video multiplexer (Panasonic WJ-FS 216). Two red lights (100 W, < 5 lx) were suspended over each pen to facilitate recording during the dark period. Observations began 3 days after treatment was applied and lasted 24 h. Observations were suspended while cows were absent from the pens during milking. These recordings were watched continuously and the same dependent variables were measured as described in Experiment 1. Individual animals were used as the observational unit and identified with markings made with Clairol's Nice and Easy # 122, Natural Black, or Clairol's L'image Maxiblonde, depending on hair color on the back.

Statistical Analysis

To test the effect of neck rail distance from the curb, individual animals served as the observational unit as each animal was tested under each condition (cross-over design). The effect of neck rail location was tested with a GLM that included terms for animal (23 df), order of exposure to each treatment (1 df), and treatment (1 df), and tested the effects of order and treatment against the residual error (22 df).

Experiment 3: Effect of neck-rail presence on stall cleanliness

Fourteen lactating Holstein primiparous cattle were housed in a single group in a single pen with fourteen stalls (seven facing the north wall and seven facing south wall with an alley between). Stalls were fitted with geotextile mattresses (Pasture Mat® of Promat Ltd.), measured 126 cm wide by 272 cm long, and had an 10 cm brisket board (PolyPillow® of Promat Ltd.) 227 cm from the curb. All flooring outside the freestall area was concrete. Animals were fed a total mixed ration (TMR) and milked twice a day at approximately 5:00 and 14:00. Stalls were cleaned and a small amount of sawdust bedding was added to the stalls during both milking periods.

In a switchback design consisting of three stages, animals were monitored with or without a neck rail placed 124.5 cm high and 160 cm from the curb. The neck rail was present in the first and third stage and removed in between. Each stage lasted 3 days. A single Panasonic WV-BP330 CCTV camera and a Panasonic AG-6720 VHS time lapse video cassette recorder, were used to record elimination events performed by each animal. Recordings were watched continuously to score the posture of the animal and the location of feces or urine. Postures during elimination included 1) lying in the stall, 2) standing with front two hooves in the stall, 3) standing with four hooves in the stall and, 4) standing with four hooves in the alley. If any of the fecal material or urine contacted the mattress, it was categorized as soiling the stall. Otherwise it was recorded as falling in the alley.

Statistical Analysis

This comparison was intended as a case study, and the data are not suitable for inferential statistical analysis. The values from the two stages with the neck rail were averaged, as they did not appear to differ.

RESULTS

Experiment 1: Effect of neck-rail height and location on freestall preference and usage

During the restriction phase, animals spent the least time standing with all four hooves in the stall with the lowest (102 cm) rail, (mean of 22 min), and the most in the stall with no neck rail, (mean of 83 min; Table 5.1; $P < 0.001$). The total amount of time standing in freestalls was also higher as the neck rail was raised and removed ($P < 0.01$). Time spent lying in the stall, number of lying events, average duration of lying bouts, and standing with two hooves in the stall did not differ among the four neck rail positions tested ($P > 0.05$). There was no effect of neck rail distance from the curb or interaction between the three neck rail heights tested and distance from the curb for any response variable ($P > 0.3$).

Overall, animals showed no clear preference for certain stalls in the free-choice phase, based on either time spent lying or standing with all four hooves in the stall (Table 5.2; Page's test statistic, $L \geq 244$; $P > 0.05$). Two animals ranked the stall with the 102-cm neck rail as their first choice, five animals chose 114 cm, two chose 127 cm, and one chose the stall with no neck rail based on either time spent lying or standing with all four hooves in the stall. The amount of time animals spent lying on their first choice ranged from 52%-100%.

Experiment 2: Effect of neck-rail distance on stall usage

None of the measures of lying behavior differed between the two neck rail locations (Table 5.3; $P \geq 0.1$). The total time spent standing in the stall also did not differ between treatments (P =

0.74), but the distance of the neck rail from the curb changed the type of standing performed in the stall. Animals spent 15 min more per day standing with four hooves in the stall, and 17 min less standing with two hooves in the stall when the neck rail was 170 cm from the curb, compared to 152 cm ($P < 0.04$).

Experiment 3: Effect of neck-rail presence on stall cleanliness

There was no apparent difference between the two stages when the neck rail was present for any of the response variables (Table 5.4), and the average value for the two stages is presented throughout (Table 5.5). The number of times the animals defecated while in the stall was similar when the neck rail was present and absent (Table 5.5). However, the presence of the neck did affect where the fecal material landed: fecal matter was more likely to contact the stall surface when the neck rail was absent (7.6/72 h) than when it was present (4.9/72 h). There was no clear difference in the number of defecation events occurring while lying down, but feces were more than twice as likely to contact the stall surface when animals stood with all four hooves in a stall without a neck rail than with a neck rail. There was no clear difference in the number of urination events that contacted the stall surface associated with the presence of the neck rail.

DISCUSSION

Experiments 1 and 2 showed that neck rail placement can affect standing in the freestall. When the neck rail was lower (Experiment 1) or closer to the curb (Experiment 2), animals spent less time standing with all four hooves in the stall. Experiment 1 was designed primarily to test neck rail height, and provided only a weak between-subject test of location relative to the curb. Thus it is not surprising that an effect of distance from the curb was detected only in Experiment 2 which used a more powerful within-cow design.

Both experiments demonstrated that when the neck rail was less of a barrier (either higher/ removed or farther from the curb), animals spent more time standing in the stall. Animals may choose to spend time standing in the stall because of the comfort of the stall surface compared to the concrete flooring outside the stall. There has been little work on the comfort of standing surfaces for dairy cattle. One recent experiment compared flooring surfaces outside the stall, and found that cows spent more time standing with four hooves in the stall when housed on slatted concrete floors, compared to solid, grooved concrete (Stefanowska et al., 2001). Indeed, slatted floors likely provide less surface area of support for the hoof, and this difference may affect the comfort of the standing surface. In addition to differences in comfort, solid concrete flooring is known to cause hoof injuries. For example, Frankena et al. (1992) found that housing animals on straw flooring reduced the risk of claw lesions compared to concrete. Furthermore, standing entirely in the stall reduces contact with slurry in the alley, and this reduced exposure to moisture is associated with a lower incidence of hoof injuries (Fitzgerald et al., 2000) and higher sole dry matter content (Bergsten and Pettersson, 1992).

Although standing behavior was affected by neck rail position when animals were restricted to a single design, the animals did not show any clear preference for stalls when they could choose among alternative designs. It is possible that cattle have little ability to choose stalls based on neck rail height (Fraser et al., 1993). Dairy cattle are descendents of open forest/meadow-dwelling animals, and may not have evolved the capacity to use overhead spatial constraints in selecting bedding sites, but this idea is difficult to evaluate. Alternatively, perhaps the animals were sufficiently focused on the assessment of the suitability of the lying surface that they did not take notice of the overhead spatial constraints. Indeed, dairy cattle are thought to spend time assessing lying space before lying down, namely by swinging their head from side to side with the nose/head close to the ground (e.g. Krohn and Munksgaard, 1993). Regardless of the reason, the animals do not change their choices based on these dimensions, which may indicate that all options were acceptable.

Not surprisingly, because cattle have no contact with the neck rail while recumbent, placement did not affect the time spent lying. Just as neck rail position or presence did not affect lying time, stall soiling while lying did not appear to be affected by the presence of a neck rail. Experiment 3 indicated that the presence of the neck rail may change elimination behavior, but defecation and urination were affected differently. When the neck rail was absent fecal material contacted the stall surface 55% more often (7.6 vs 4.9/72 h) than when the neck rail was present. This change was driven by a two-fold increase in the number of defecation events that soiled the stall when the heifers were standing with all four hooves in the stall. The change in posture and stall soiling are consistent with the findings in Experiment 1 and 2 in that the neck rail reduces the amount of time spent standing with all four hooves in the stall. In contrast, the neck rail did not alter the position (lying, standing with two or four hooves in the stall) adopted for urinating. In fact, contrary to the expectations, there were slightly more urination events when the neck rail was present, although there was no difference in the number of events that contacted the stall surface. Perhaps other subtle differences in urination and defecation behavior could explain the divergent responses to the treatment (see Aland et al. 2002 for a discussion of eliminative behavior).

In conclusion, the neck rail placement, within the range of measurements tested, influenced standing behavior performed in the stall. Cows spent more time standing with all four hooves in the stall with higher neck rails or no neck rail at all and when the neck rail was moved from 152 cm to 170 cm from the entrance to the stall. In addition, the number of defecation events that resulted in stall soiling was higher when the neck rail was absent.

ACKNOWLEDGEMENTS

We wish to thank Amanda Zimmerman, Fay Wan, Tamiko Thomas, Sylvia Huang, and Laura Mowbray for their help running segments of these experiments. We would also like to thank members of the UBC South Campus Research and Teaching Complex, especially Chris Shingara, the staff of the UBC Dairy Research and Education Centre, and the staff and students of UBC's Animal Welfare Program for their help and cooperation, and Jeff Rushen for helpful comments on a previous draft. The William and Charlotte Parks Foundation for Animal Welfare funded the first author during the writing of this manuscript. This research was supported by the

Natural Sciences and Engineering Research Council of Canada through the Industrial Research Chair in Animal Welfare, and by contributions from the Dairy Farmers of Canada, the Beef Cattle Industry Development Fund, the BC Dairy Foundation, the BC SPCA, members of the BC Veterinary Medical Association and many other donors listed on our web site at www.agsci.ubc.ca/animalwelfare.

REFERENCES

Aland, A., L. Lidfors, and I. Ekesbo. 2002. Diurnal distribution of dairy cow defecation and urination. Appl. Anim. Behav. Sci. 78:43-54.

Bakken, G. 1982. The relationship between environmental conditions and bovine udder diseases in Norwegian dairy herds. Acta Agric. Scand. 32:23-31.

Bergsten, C. 1994. Haemorrhages of the sole horm of dairy cows as a retrospective indicator of laminitis:an epidemiological study. Acta Vet. Scand. 35:55-66.

Bergsten, C. and B. Pettersson. 1992. The cleanliness of cows tied in stalls and the health of their hooves as influenced by the use of electric trainers. Prev. Vet. Med. 13:229-238.

Carroll, E. J. and D. E. Jasper. 1978. Distribution of Enterobacteriaceae in recycled manure bedding on California Dairies. J. Dairy Sci. 61:1498-1508.

Fitzgerald, T., W. Norton, R. Elliott, H. Podlich, and O.L. Svendsen. 2000. The influence of long-term supplementation with biotin on the prevention of lameness in pasture fed dairy cows. J. Dairy Sci. 83:338-344.

Frankena, K., K.A.S. Van Keulen, J.P. Noordhuizen, E.N. Noordhuizen-Stassen, J. Undelach, D.J. De Jong, and I. Saedt. 1992. A cross-sectional study into prevalence and risk indicators of digital hemorrhages in female dairy calves. Prev. Vet. Med. 14:1-12.

Fraser, D., P.A. Phillips, and B.K. Thompson. 1993. Environmental preference testing to assess the well-being of animals - an evolving paradigm. J. Agric. Environ. Ethics 6 (suppl. 2):104-114.

Gaworski, M.A., C.B. Tucker, D.M. Weary, and M.L. Swift. 2003. Effects of stall design on dairy cattle behaviour. Pages 139-146 *in* Proceedings of the 5th International Dairy Housing Conference. American Society of Agricultural Engineers. St. Joseph, USA.

Haley, D. B., J. Rushen, and A. M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Hollander, M. and D.A. Wolfe. 1973. Nonparametric Statistical Methods. John Wiley and Sons, New York, USA.

Krohn, C.C. and L. Munksgaard. 1993. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments II. Lying and lying-down behaviour. Appl. Anim. Behav. Sci. 37:1-16.

Oltenacu, P.A., J. Hultgren and B. Algers. 1998. Associations between use of electric cow-trainers and clinical diseases, reproductive performance, and culling in Swedish dairy cattle. Prev. Vet. Med. 37:77-90.

Stefanowska, J., D. Swierstra, C.R. Braam, and M.M.W.B. Hendriks. 2001. Cow behaviour on a new grooved floor in comparison with a slatted floor, taking claw health and floor properties into account. Appl. Anim. Behav. Sci. 71:87-103.

Zehner, M.M., R.J. Farnsworth, R.D. Appleman, K. Larntz, and J.A. Springer. 1986. Growth of environmental mastitis pathogens in various bedding materials. J. Dairy Sci. 69:1932-1941.

Table 5.1. Lying and standing behavior (mean and least-square S.E.) in freestalls with neck rails or three heights or no neck rail at all (absent) in the restriction phase of Experiment 1 (n = 10). P values and L statistics (Page's test for ordered alternatives) are reported for linear trend of ordered treatments (102 < 114 < 127 < absent).

	Neck rail height						
	102 cm	114 cm	127 cm	absent	LS S.E.	L	P <
Lying Behavior							
Lying events (number/24 h)	8.8	7.7	9.7	9.7	0.47	265	NS
Duration of lying bouts (h/bout)	1.8	2.0	1.7	1.6	0.10	235	NS
Lying time (h/24 h)	14.8	13.9	14.3	13.7	0.42	238	NS
Standing Behavior							
Front hooves in stall (min/24 h)	26	27	26	40	14.59	245	NS
Four hooves in stall (min/24 h)	22	21	40	83	16.77	283	0.001
Total standing (min/24 h)	48	48	66	123	16.54	275	0.01

Table 5.2. Duration of lying (h/24 h) and standing with four hooves in the stall (min/24 h) for the four neck rail positions during the free-choice phase, for each of the ten animals in Experiment 1.

		Neck rail height (cm)			
Animal	Distance from curb (cm)	102	114	127	none
Lying (h)					
1	160	0.0	0.0	14.9*	0.0
2	160	0.0	14.4*	0.0	0.0
3	160	0.0	16.0*	0.0	0.0
4	160	8.1*	0.0	1.7	4.6
5	160	0.0	0.0	8.0*	0.0
6	160	0.0	4.4	0.0	10.0*
7	180	7.2	8.1*	0.0	0.0
8	180	0.0	9.7*	0.0	4.0
9	180	0.0	12.3*	0.0	0.0
10	180	6.2*	5.7	0.0	0.0
	median	0.0	6.9	0.0	0.0
Standing with four hooves in the stall (min)					
1	160	0	0	19*	0
2	160	0	9*	0	0
3	160	0	22*	0	0
4	160	10*	0	3	14
5	160	0	0	94*	0
6	160	0	1	0	11*
7	180	4	8*	0	0
8	180	0	13*	0	6
9	180	5	36*	0	0
10	180	3*	6	0	0
	median	0	7	0	0

* The stall ranked first based on lying time.

Table 5.3. Lying and standing behavior (mean and least-square S.E.) of twenty-four animals in Experiment 2. Animals were observed at two neck rail positions: 152 and 170 cm from the curb.

	Neck rail distance from curb (cm)				
	152	170	LS S.E.	F	P
Lying Behavior					
Lying events (number/24 h)	10.3	11.1	0.33	2.93	0.10
Duration of lying bouts (h/bout)	1.2	1.2	0.04	0.73	0.40
Lying time (h/24 h)	12.0	12.2	0.24	0.12	0.74
Standing Behavior					
Front hooves in the stall (min/24 h)	111	93	5.5	5.08	0.03
Four hooves in the stall(min/24 h)	8	22	4.5	5.04	0.03
Total standing (min/24 h)	118	115	7.0	0.11	0.74

Table 5.4. Number of defecation and urination events per 72 h (mean and least-square S.E.) in Experiment 3, for fourteen animals in stalls with neck rails, in Stages 1 and 3. Presented separately are the total number of defecation and urination events while the animals were in the stall, and the number of these events that contacted the stall surface.

	Neck rail present		
	Stage 1	Stage 3	LS S.E.
Events occurring while heifers were in the stall			
Defecation			
Defecations while in the stall	10.4	11.0	0.81
Defecations that contact the stall surface while:			
Standing with front hooves in the stall	0.0	0.0	-
Standing with four hooves in the stall	1.8	1.5	0.24
Lying in the stall	3.4	3.1	0.35
Total (sum of three postures)	5.1	4.6	0.44
Urination			
Urinations while in the stall	9.1	10.8	0.77
Urinations that contact the stall surface while:			
Standing with front hooves in the stall	0.0	0.0	-
Standing with four hooves in the stall	1.9	2.3	0.33
Lying in the stall	0.0	0.0	-
Total (sum of three postures)	1.9	2.3	0.33

Table 5.5. Number of defecation and urination events per 72 h (mean and least-square S.E.) in Experiment 3, for fourteen animals in stalls with (mean of Stage 1 and 3) and without neck rails. Presented separately are the total number of defecation and urination events while the animals were in the stall, and the number of these events that contacted the stall surface.

	Neck rail		
	Present	Absent	LS S.E.
Events occurring while heifers were in the stall			
Defecation			
Defecations while in the stall	10.7	11.3	0.76
Defecations that contact the stall surface while:			
Standing with front hooves in the stall	0.0	0.0	-
Standing with four hooves in the stall	1.6	3.9	0.57
Lying in the stall	3.3	3.7	0.29
Total (sum of three postures)	4.9	7.6	0.72
Urination			
Urinations while in the stall	9.9	8.6	0.48
Urinations that contact the stall surface while:			
Standing with front hooves in the stall	0.0	0.0	-
Standing with four hooves in the stall	2.1	3.2	0.50
Lying in the stall	0.0	0.1	0.05
Total (sum of three postures)	2.1	3.3	0.50

CHAPTER 6: General Discussion

My overall objective was to assess the implications of different freestall designs for the behavior and practical management of dairy cattle. I had four specific objectives: 1) to assess dairy cattle preferences for freestall surfaces and geometry, 2) to assess how behavior changes when the animals have access to a single housing option, 3) to understand the relationship between these measures, 4) to measure variables with practical implications for farmers such as milk production and freestall cleanliness.

6.1 Preferences for stall surfaces and configuration

Dairy cattle demonstrated clear preferences for freestall surfaces: sawdust and sand were preferred to mattresses with 2-3 cm of sawdust in Chapter 2, and mattresses bedded with 7.5 kg of sawdust bedding were chosen over those with only 1 or 0 kg of sawdust bedding in Chapter 3. Although the range of time spent lying on the first choice was between 52 and 100%, 28 of the 35 animals tested spent more than 90% of their time in stalls rated as the first choice after short-term exposure to each option in the restriction phase.

As discussed in both Chapters 2 and 3, there are several trends in previous work on dairy cattle preferences for stall surfaces. Cows tend to prefer lying on mattresses rather than concrete (Herlin, 1997; O'Connell and Meaney, 1997) and solid rubber mats tend to be preferred to concrete, but are chosen less than mattresses (Herlin, 1997; Natzke et al., 1982). The results from Chapter 3, in which the mattresses bedded with 7.5 kg of sawdust were unanimously preferred to stalls with either 1 or 0 kg, were consistent with other work demonstrating that cows prefer heavily-bedded concrete stalls to lightly-bedded mats (Jensen et al., 1988; Manninen et al., 2002). In addition, in Chapter 2, cows chose deep-bedded stalls (sawdust or sand) over mattresses. These results are consistent with two other papers addressing the issue of deep-bedded lying surfaces, compared with other bases like concrete, mats or wood (Lowe et al., 2001; Muller and Botha, 1997). The resilience of the surface may be a major factor influencing the choice of lying surfaces. However, other correlated factors (e.g. thermal insulation/conductance) could also be involved. Indeed, Manninen et al. (2002) found that cows avoided deep-bedded sand stalls, and preferred either straw-covered concrete or rubber mats instead, in both winter and summer. This discrepancy between Manninen et al. (2002) and the results from Chapter 2 might be due to specific features of sand or the extent of previous exposure to the different stall substrates.

In contrast to the preferences shown for stall surfaces, dairy cattle did not exhibit clear preferences for the freestall configurations tested in Chapters 4 and 5. In Chapter 4, Experiment 1, there was a slight trend for the animals to prefer wide stalls, but this preference disappeared after short-term exposure to each option. Likewise, in Chapter 5, Experiment 1, the animals showed no clear preference for neck rail placement. Perhaps the animals were sufficiently focused on assessing the suitability of the lying surface that they did not take notice of these spatial constraints, or perhaps they do not change their choices based on these dimensions. Indeed, dairy cattle often swing the head from side to side with the nose close to the ground immediately before lying down. Other authors have interpreted this behavior as 'assessment' of the lying area, and during the performance of head-swinging dairy cattle appear focussed on the lying surfaces, rather than what is above it. Previous work has shown that cattle spend more time engaged in this characteristic head-swinging behavior when entering a lying area without bedding than a bedded area (e.g. Müller et al., 1989), and are twice as likely to interrupt the head swinging behavior when the animals were housed in deep-bedded or tie stall systems compared to pasture (e.g. Krohn and Munksgaard, 1993; Ladewig and Smidt, 1989).

Although the cattle in these studies did not exhibit clear preferences for the stall sizes or neck rail placements, the results are limited to the options presented. The relative nature of preference tests raises several issues. Firstly, was the range of choices sufficient, or were animals asked to choose the lesser of two evils? It seems unlikely that all the options presented were severely lacking, given that lying and standing times performed during the restriction phases were within the range reported for animals on pasture and in open pens (see Table 1.1). However, the dimensions tested were within the recommendations given to the industry, and this kept the range relatively narrow. A more useful approach might have been to follow Phillips et al. (1988). They tested different ramp designs by first offering a wide range of options for a single variable (e.g. illumination, width) to see if the animals had any preference for that factor. These experiments were followed by more specific comparisons to identify the most preferred combinations. A second approach that might have proved useful is motivational testing. This technique involves asking what the animal is willing to pay (e.g. energy expenditure, lost foraging opportunities, etc.) to gain access to a specific resource (e.g. a specific freestall design). In this thesis, all preference tests were 'costless.' Future experiments could require cattle to pay a 'fee' in order to gain access to a given freestall configuration or surface. For example, it may be possible to ask dairy cattle to push a weighted door to gain access to a freestall. Indeed, in some instances a few cattle were able to temporarily break down the wooden barriers in front of preferred stalls. In a recent experiment, Mason et al. (2001) monitored the amount of weight that mink were willing to push in order to gain access to a variety of resources. They found that mink would push 1.25 kg (the maximum weight used, or 'reservation price') to gain access to water, but that 0.84 kg was the maximum weight mink would push to gain access to an empty cage. This type of experimental design provides the researcher with a quantitative response that can be compared among resources.

In addition, this 'fee-based' approach could also help address a second problem in my experimental design. In all the preference tests used in this thesis, cattle were asked to choose between three or four options. For example, when I compared the amount of sawdust bedding (Chapter 3), I offered the animals three choices: 0, 1, and 7.5 kg of sawdust. This design allowed me to conclude that the 7.5 kg option was preferred, but does not allow any conclusions about the 1 versus 0 kg treatments. I see two options to address this problem. I could have charged a 'fee' to gain access to each option and compared the price the animals were willing to pay for each option, when presented alone. Alternatively, I could have continued to use 'costless' preference tests, but present each option in a pair-wise manner. This would have allowed me to describe the relative ranking of each level of sawdust bedding. Finally, future work could focus on the factors underlying the animals' preferences. Specifically, future research could investigate which physical properties of lying surfaces are important to dairy cattle, rather than testing options that are specific to one region. For example, we could compare freestall surfaces that differ in only one physical property (e.g. compressibility, thermal conductance, coefficient of friction), rather than using materials like sawdust, where resilience is likely correlated with thermal insulation. This approach would allow the results to be useful to a broader range of farmers, regardless of the bedding types available in their region.

6.2 Changes in behavior associated with freestall surfaces and configuration

Although dairy cattle showed no consistent preferences for freestall geometry and consistent preferences for lying surfaces, both of these features influenced the behavior of the animals when only one option was available.

6.2.1 Lying behavior in the freestall

Dairy cattle have physical contact with both the freestall surface and partitions while recumbent and both lying surface and stall width affect lying behavior. Dairy cattle normally have no contact with the neck rail while lying down, and the placement of this feature had no consistent effect on lying behavior.

Both stall surface and stall width influenced the amount of time animals spent lying down. Changes in lying time can come about by changes in the number of lying events, or the length of the lying bouts, or some combination of both variables. As described below, stall surfaces and size affected number of lying events and average duration of lying bouts differently.

6.2.1.1 Stall surface

With the exception of one experiment (Haley et al., 2001), freestall surface affected lying time by altering the number of lying events, but had no appreciable effect on bout duration (Table 6.1). It has been suggested that fewer lying events may reflect discomfort associated with changing positions between lying and standing or vice versa; more lying events were observed in stalls with softer surfaces that allow the knees to sink into the flooring material (Dumelow, 1995). However, in Chapter 2, both average lying times and number of lying events were lower on either sand (Experiment 1) or mattresses (Experiment 2) compared to the preferred sawdust or sawdust/sand stall surfaces, respectively. These results, particularly fewer lying events on the sand surface, refute the idea that surface resilience is the major factor. However, more information is needed about the physical characteristics of such surfaces, perhaps tested in the manner that Tierney and Thomson (2003) describe. In Chapter 3, animals averaged 2.1 h less time lying down and 2.4 fewer lying events when there was no sawdust bedding on the geotextile mattress compared to when the mattress was bedded with 7.5 kg of sawdust. In both Chapters 2 and 3, there was no difference in the average duration of lying bouts between the stall surfaces tested. This pattern is similar to those reported by Manninen et al. (2002).

The experiment conducted by Haley et al. (2001) compared tie stalls with either concrete or mattress surfaces and has been the only study to find a significant effect of surface on average bout duration (1.3 h on concrete and 1.0 h on mattresses). Haley et al. (2001) interpreted the combination of fewer *and* longer lying bouts as symptoms of discomfort associated with changing position on concrete compared to geotextile mattresses in tie stalls; on concrete surfaces cows lay down less often, and stayed lying for longer periods. However, in the other seven experiments on lying surfaces described in Table 6.1 there were no statistical differences in the average duration of lying bouts, indicating that the cattle were not lengthening lying bouts to avoid the discomfort of changing position. This pattern, along with the average bout duration described across experiments in Table 1.1, indicate that average bout length is fairly stable.

The stability of bout length raises the interesting question: why do most animals lie down for approximately one hour at a time? Several authors have attempted to answer this question by comparing the behavior of animals at different ages, stage of lactation, and in new social groups. Chaplin and Munksgaard (2001) found higher maximum bout duration associated with the stage of lactation (early lactation:1.7 h, late lactation:2.3 h, dry:3.1 h), but no differences among lactation number (1, 2, or 3). It is unclear which factors underlie these findings; perhaps the size of the udder influences discomfort while lying. Interestingly, although Dechamps et al. (1989) did not detect differences in average bout duration between pre- and post-calving periods, they reported that bouts were more likely to last more than 1 h after calving. Finally, Hasegawa et al. (1997) found that when heifers were introduced into a new social group, they performed fewer lying bouts longer than 15 minutes in duration than prior to mixing. These studies have begun to provide some insight into factors that may influence bout length (e.g. metabolic demands of lactation; social factors). To more fully understand what drives bout duration, future work could begin by examining the sequence of events before and after rising. For example, after rising, does the animal go to the feed bunk? Alternatively, is the animal disturbed by a conspecific before rising? This type of descriptive work could provide insight into bout duration and form the basis for future research.

6.2.1.2 Stall size

Although a series of experiments have assessed the effects of stall surface on lying behavior, only the two experiments described in Chapter 4 allow us to evaluate the effects of freestall size. Before conducting the experiments in Chapter 4, it was unclear how stall size would affect lying behavior. It seemed possible that it would be more difficult for animals to change position in smaller stalls, which could have resulted in fewer lying events. However, in these experiments total lying times were higher in wider stalls due to longer lying bouts, possibly because of less contact with stall partitions in wider stalls. There was no difference in the number of lying events in the treatments tested. These results suggest that wider stalls affect comfort while in a recumbent position, but not the comfort associated with changing positions between lying and standing.

Finally, there are two experiments presented in Table 6.1 in which the effects of the lying surface and housing system were purposely confounded. These experiments found that animals spent more time lying down in tie stalls with rubber mats than open pens with slatted concrete floor (Munksgaard and Simonsen, 1995) and more time lying in pens with geotextile mattresses than in tie stalls with concrete floors (Haley et al., 2000). In both cases, the animals spent more time lying on the softer surface regardless of whether it was presented in the more restrictive space (Munksgaard and Simonsen, 1995) or the less restrictive space (Haley et al., 2000). This indicates that lying surface was more important for lying time than the degree of physical enclosure. However, the tie stalls used in the Haley et al. (2000) comparison measured 130 cm, similar to the widest option tested in this thesis. Munksgaard and Simonsen (1995) did not specify the size of the tie stall used. In addition, although I often discuss tie-stall research together with findings from research in freestalls, there are no published studies comparing these two systems and controlling for stall surface. However, it is thought that tethering may affect the animals' behavior, particularly when adapting to tie stalls (e.g. Ladewig and Smidt, 1989).

6.2.1.3 Preferences and lying behavior

The way lying behavior responds to treatment likely relates to preferences for that option. Cattle can evaluate the lying surface while standing on it, and it is thought that they do this by swinging their head from side to side with the nose close to the ground (e.g. Müller et al., 1989). In general, there is a trend in the literature for dairy cattle to spend less time performing head-swinging behavior on surfaces where cattle have more lying events and higher total lying times (e.g. surfaces with more bedding; e.g. Müller et al., 1989). Cattle also show preferences for such stall surfaces. In contrast, cattle may not be able to evaluate the discomfort associated with narrow stalls until already lying down, which might explain why stall size affects the length of the lying bouts and total lying time, but not preferences (a decision that is made while cattle are still standing).

6.2.2 Standing behavior

In addition to lying in the freestall, dairy cattle also use the stall for standing, and the amount of time spent standing in the stall also varied with the stall surfaces and configurations tested. In both experiments in Chapter 2, cattle spent more total time standing on mattresses than on sand or sawdust, but there was no effect of treatment on the type of standing (either with only front hooves or all four hooves in the stall). The difference in total standing time may be related to the suitability of the surface for standing. In addition, there were individual differences in the amount of time spent standing with all four hooves or with only two hooves in the stall.

Stall width, length and neck rail placement all affected the amount time spent standing with front or four hooves in the stall. For example, in Chapter 4, time spent standing with the front hooves in the stall was higher in smaller freestalls. This behavior is not well understood. Some authors have indicated that standing in the stall in this manner may be used to hide from more socially dominant animals (e.g. Galindo et al., 2000). However, this was clearly not the case in this thesis as animals housed individually performed this behavior just as much or more than animals housed in groups. For example, in Chapter 4, animals in Experiment 1 were individually housed and animals in Experiment 2 were housed in groups and yet individually housed animals spent more time standing with the front hooves in the stall. Interestingly, standing with only the front hooves in the stall might reflect a reluctance to enter the stall. For example, in Chapter 5, when the neck rail was 152 cm from the entrance to the stall, cattle spent less time standing with all four hooves in the stall and more time standing with only the front hooves in the lying area than when the neck rail was 170 cm from the entrance. However, the inverse relationship between standing with only two hooves and four hooves in the stall was not found in Chapter 5, Experiment 1 (neck rail height). Further work is required to understand why dairy cattle engage in this behavior, as there is considerable individual variation in the amount of time cows spend standing in this posture. Anecdotally, this posture is not seen on pasture; cattle do not seem to seek out objects 10-20 cm higher than ground level to standing on. Interestingly, the amount of time spent standing with the front hooves in the stall is positively related to the number of claw lesions (Colam-Ainsworth et al., 1989; Flower and Weary, 2002; Galindo and Broom, 2000), but it is not clear if the injuries result in the change in behavior, or vice-versa.

Cattle also spend time standing with all four hooves in the stall. In Experiments 1 and 2 of Chapter 4 animals tended to spend more time standing with all four hooves in the stall in the wider stalls. This difference was statistically significant only in the second experiment, perhaps because the non-lactating animals used in Experiment 1 were probably less affected by hoof injuries (e.g. Chaplin et al., 2000), and may have been less sensitive to the potential discomfort of concrete flooring outside the freestall. Neck rail placement influenced this behavior in all three experiments in Chapter 5, regardless of lactation status. Cows spent more time standing with all four hooves in the stall as the neck rail was raised/removed or was moved farther from the entrance of the stall. These results indicate that the neck rail was acting as a barrier to standing in the stall.

It seems reasonable that standing entirely in the stall would be desirable for dairy cattle, as the stall provides a refuge from concrete flooring in the rest of the cow's environment. Indeed, in a comparison of sawdust and concrete flooring in front of the feeder, twelve of twelve animals preferred the sawdust flooring and spent, on average, 69% of their feeding time on this surface (DeCook et al., 2002). In addition, concrete flooring is thought to worsen the severity, and increase the prevalence of hoof injuries (Bell and Weary, 2000). Animals spent more time standing with all four hooves in the stalls that were less restrictive (either wider or neck rail placed farther from the curb) in both Chapters 4 and 5. These changes provide some insight into which freestall features influence the amount of time spent standing with all four hooves in the stall (e.g. neck rail height), but it is unclear if the magnitude of the treatment differences reported have implications for the well being of the animals.

Indeed, much remains unclear about standing with four hooves in the freestall. This type of standing may result from discomfort from the flooring outside the freestall, as described above. Alternatively, standing with four hooves in the stall may indicate a reluctance to lie down. As with standing with only the front hooves in the stall, the evidence to demonstrate 'reluctance' is limited and somewhat confusing. In Chapter 2, Experiment 1, cattle spent more time standing with all four hooves in the freestalls bedded with mattresses, but no less time lying down on this surface (although it was not preferred). In Chapter 2, Experiment 2, there was no difference in the amount of time spent standing with all four hooves on the mattress, but animals did spend less time lying down on this surface compared to sawdust. These conflicting results are not convincing evidence that the time spent standing with all four hooves in the stall indicates a reluctance to lie down. Perhaps future work could look at the number of times the lying down process (beginning with head swinging) was interrupted to assess whether the time spent standing with four hooves in the stall is related to a reluctance to lie down.

6.2.3 Interpreting treatment differences

It is clear that the freestall surface and configuration affect both lying and standing behavior. These changes provide insight into how dairy cattle perceive the space provided for these activities and allow us to draw conclusions about which options are relatively more desirable for the cattle. However, the biological importance of the treatment effects on time spent lying and standing in the freestall remains unclear. With the exception of few animals with extremely low lying times in Chapters 2 and 3, the lying times of most animals, even when they had access only to relatively undesirable treatments, were well within the range reported in the literature, even those studies on pasture. In addition, the differences in time spent standing with all four hooves in the stall ranged from an extra 15 min per 24 h (neck rail location: 152 vs. 170 cm in Chapter 5, Experiment 2) to an additional 43 min per 24 h (neck rail height: 127 cm vs. none in Chapter 5, Experiment 1). While these differences in standing times were statistically significant and provide information about these specific comparisons, the biological importance of these relatively small differences in standing times and relatively normal lying times (even on the undesirable options) remains unclear. Indeed, to properly interpret changes in lying and standing behavior we need to more fully understand both the health consequences associated with each behavior, as well as the motivation to perform the behavior.

As stated previously, there are thought to be various physical consequences of reduced lying time; these include decreased levels of circulating growth hormone (Munksgaard and Løvendahl, 1993) or higher levels of plasma cortisol (Fisher et al., 2002) in animals deprived of the opportunity to lie down for 14 h (Munksgaard and Løvendahl, 1993) or 17 h (Fisher et al., 2002) per day. More time spent standing with front hooves in the stall is also associated with physical consequences including higher prevalence of hoof injuries (Colam-Ainsworth et al., 1989; Flower and Weary, 2002; Galindo and Broom, 2000). However, by and large, this evidence does not provide explicit information about the amount of time the animals do spend engaged in the behavior. For example, Munksgaard and Løvendahl (1993) prevented cattle from lying down for 14 h per day and monitored circulating levels of growth hormone, but they failed to measure the amount of time cows spent lying down during the remaining 10 h of the day. Although the authors attribute the differences in circulating levels of growth hormone to deprivation of lying, the reader has no way of assessing the magnitude of difference in lying times between the two groups. In addition to understanding the magnitude of the change in lying time required to affect other physiological parameters, the results of correlation-based research have not been replicated across studies. For example, Chaplin et al. (2000) report that lame cows spend less time lying down, while Hassell et al. (1993) report higher lying times for lame cattle than sound ones, although this particular disagreement may be due to the authors using different definitions of lameness. In addition to the lack of agreement across studies, little is known about the causal nature of the relationship between time spent lying and standing and hoof injuries. A more comprehensive understanding of how lying and standing times relate to health is needed and future research should focus on this issue.

In addition, it remains unclear if there is a minimal threshold for lying time and how motivated cattle are to perform this behavior. Two lines of evidence have attempted to address this issue. As an example of the first line of evidence, Metz (1985) found even a 3-h deprivation of both feed and space for lying was sufficient to cause cows to forgo eating in order to lie down. However, this result is difficult to interpret given the challenges in understanding ruminant satiety. The use of food as 'currency' is problematic in ruminants, like dairy cattle, because regulation of feed intake is not nearly as straightforward as it is in non-ruminants. In non-ruminants, regulation of dietary intake has focussed on glucose absorption, subsequent glycemic rise and stimulation of secretory responses (e.g. insulin;Van Soest, 1983). However, ruminants do not show a post-feeding rise in glucose levels, as most of the sugar and starch in the diet are fermented in the rumen to volatile fatty acids. There are several other theories about the control of feed intake in ruminants including the idea that satiation is controlled by physical limitations, such as rumen fill (e.g. Van Soest, 1983). Uncertainty about the satiety mechanism in ruminants means that food is a confusing currency to assess motivation. After 3 h, depending on rumen fill and other factors, cattle may not be motivated to feed. If this were the case, the choice to lie down rather feed provides no further information about the importance of lying time to dairy cattle. Perhaps, in future research, a more informative approach would be to vary the amount of time required to forage for daily nutritional requirements (over a 24-h period, to minimize problems with satiety in a shorter time frame) and assess at what point the cattle stop foraging in order to lie down. A second approach would be to provide more comfortable environment outside the freestall and monitor how this affects stall usage. For example, Fregonesi et al. (2002) found that when cows were given access to rubber flooring in front of the feeder instead of concrete, cows spent less time lying down in the freestalls. This result indicates that cows may be using the freestall as a refuge from the concrete flooring elsewhere in the pen. In addition, the higher lying times when the all flooring is concrete may indicate that some of the behavior is 'luxury' lying, or lying time that is not important for the sake of lying, but for other reasons. Information about a lower threshold for lying time (to prevent health problems) and the motivation to perform the behavior is essential in order to interpret how various housing systems influence animal welfare.

In order to fully understanding the health implications of lying and standing times and the motivation for lying down, there is a third issue that still needs to be addressed. The experiments conducted in this thesis were relatively short-term and it is unclear if the treatment differences detected in the thesis would persist over time. There is little known about the time course of adaptation to housing treatments in dairy cattle, but this information could help us understand and predict relationships between treatments and health consequences. In Chapter 5, for example, it remains unclear if the behavioral changes associated with neck rail placement will persist beyond the few days tested in these experiments. This information would be important to understand whether neck rail placement (and the changes in standing behavior associated with it) is likely to influence hoof health. Future work could begin by monitoring behavior from the time the treatment is imposed, and following animals over several months.

6.3 Relationship between preference and other measures

The results of this thesis provide an opportunity to explore the relationship between preference and other measures. As mentioned in Chapter 1, the use of multiple measures of welfare has been widely advocated, as cases where multiple measures of welfare agree provide a high level of confidence about the welfare consequences of a given housing feature. To this end, I might expect three possible scenarios for the measures taken in this thesis. In the first scenario, animals may exhibit preferences for a given option, but show no corresponding change in behavior when allowed access to a single option (restriction phase). Preference tests are very sensitive, so in some situations preference tests may detect differences that are not reflected in other measures. However, I did not find this scenario with any of the treatments tested in this thesis.

The second possibility is that animals exhibit preferences for a given option, and they react differently to the preferred and unpreferred options when given only one treatment at a time. This second scenario is largely borne out by how dairy cattle responsed to lying surfaces. For example, in experiments testing different lying surfaces (Chapters 2 and 3), dairy cattle clearly preferred heavily- or deep- bedded stalls, and when they had no choice between treatments, cattle tended to spend more time lying on well-bedded surfaces. One exception was the response to the mattress in Chapter 2, Experiment 1: no preference, but time spent lying down was similar to deep-bedded sawdust). Indeed, other evidence from the literature also indicates that the lying surface affects behavior and health. Animals tend to spend less time swinging the head from side to side before lying down on well-bedded surfaces (e.g. Müller et al., 1989) and experience fewer leg and hoof injuries when they have ample bedding (e.g. Mowbray et al., 2003).

In the third scenario, animals may not exhibit preferences for a given option, although when given no choice, behavior may change in response to the treatment. This third scenario is borne out by how dairy cattle respond to differences in freestall geometry. Cattle did not appear to show preferences for different freestall sizes or neck-rail placement, within the range tested. However, when animals had no choice between treatments, cattle spent less time lying in smaller stalls and more time standing with only the front hooves in the stall and the rear hooves in the alley. When the neck rail was lowered or moved closer to the curb, the hooves of these animals had more contact with concrete and moist environment outside the stall increasing the risk of hoof injuries (e.g. Flower and Weary, 2002). Thus freestall geometry affected the time budgets of dairy cattle, but they seemed not to choose stalls based on this feature, perhaps because they were unable to evaluate this aspect of the stall until already lying down or were sufficiently focussed on evaluation of the stall surface at the time a choice is made. Interestingly, although behavior changed with freestall geometry, milk production, another measure of biological function, did not differ with stall width. Perhaps stall width did not affect the energy balance of the animal (e.g. energy loss or intake- feed intake), and therefore, did not affect milk production, which is closely tied to feed intake.

In this thesis, I found that both agreement and disagreement between multiple measures had interpretative value. Cases where preference and other measures agreed provide a high level of confidence about the welfare consequences of a given housing feature. In addition, cases where these measures disagree can provide insights into how animals evaluate features in their environment.

6.4 Production and management considerations and animal welfare

In addition to understanding how stall design affects standing and lying times, this thesis also examined several issues relevant to dairy producers such as stall cleanliness and milk production. In Chapter 4, wider stalls contained more fecal material. In Chapter 5, the presence of the neck rail influenced elimination behavior. If the neck rail was present, feces were less likely to contact the stall surface when the animal defecated while standing with all four hooves in the stall. These results, together with more time spent standing with all four hooves in stalls when neck rails were placed higher or farther from the curb, are consistent with the idea that stalls that are used more are also more likely to contain fecal material (Gaworski et al., 2003). However, like the treatment differences for lying and standing times, the biological importance of the difference in the amount of fecal material in the stall is unclear. Feces and urine contamination are thought to play an important role in bacterial growth in dairy bedding (Carroll and Jasper, 1978; Zehner et al., 1986), and there is evidence that bacteria counts on teat ends are related to udder infection (DeHart et al., 1976; McDonald and Packer, 1968). However, there is only limited evidence that higher bacterial counts in bedding actually lead to an increased risk of mastitis (Hogan et al., 1989; Natzke and Le Clair, 1975).

When making recommendations to farmers, it remains unclear how to balance the trade-off between higher lying times and a possible risk of mastitis associated with stall soiling. In part, the difficulty in making these recommendations stems from incomplete scientific information needed to interpret results (e.g. the health consequences of feces in bedding or understanding the importance of lying time to dairy cattle). However, other factors, like the variability between farms and farm managers also make it difficult to make recommendations about housing. For example, for some farmers, an increase in stall soiling could be easily managed by cleaning the freestalls more often. On such a farm, widening the freestalls may be advisable. On other farms, however, managers may be less willing to devote more labor toward stall cleanliness. Indeed, research tends to examine factors in some degree of isolation of others (e.g. management factors). Thus final recommendations need to integrate new information with other relevant factors, and may be specific to certain situations.

In addition to stall cleanliness, milk production is also a practical concern for farmers. It is commonly believed that milk production is related to housing design, despite the lack of scientific evidence supporting this claim. Rushen et al. (2001) found no difference in milk production when cows were housed in stalls with concrete vs. rubber mat surfaces over a 16-week experiment, despite a 1.5 h per day difference in duration of lying between treatments. Similarly, I found no differences in milk production associated with stall width in Chapter 4, Experiment 2, despite differences in lying times of 0.7 h per day. Indeed, when cattle were prevented from lying down 14 h per day for 10 weeks, there was no change in feed intake over this period (Ingvartsen et al., 1999). It seems likely in order to detect differences in milk production, a change in housing design would have to influence feeding behavior, specifically feed intake, a driving factor of milk production.

The overall objective of this thesis was to assess the implications of different freestall designs for the behavior and practical management of dairy cattle and this objective has been achieved to a certain extent. For example, we now more fully understand that dairy cattle exhibit preferences for freestall surfaces, such as deep-bedded sawdust and heavily-bedded geotextile mattresses. Dairy cattle also tend to spend more time lying down on these preferred surfaces. These results correspond with other studies showing a lower incidence of hock lesions on deep-bedded surfaces. This combination of evidence provides confidence that housing dairy cattle on surfaces like concrete, compromises the well-being of the animals. In addition, we also more fully understand how freestall geometry affects dairy cattle behavior. Although dairy cattle do not appear to show clear preferences for neck rail placement or freestall size, both of these parameters influence the amount of time spent standing in the stall and stall soiling. In addition, cattle spend more time lying down in wider freestalls, namely by lengthening the average duration of the lying bout. Future work is required to fully understand the welfare implications of housing dairy cattle in smaller freestalls with more neck rail placed in restrictive locations. However, these experiments provide insight into how dairy cattle perceive freestall designs commonly used on today's dairy farms.

REFERENCES

Bell, E. and D.M. Weary. 2000. The effects of farm environment and management on laminitis. Pages 179-189 *in* Proceedings of the Annual Pacific Northwest Animal Nutrition Conference. Spokane, USA.

Carroll, E. J. and D. E. Jasper. 1978. Distribution of Enterobacteriaceae in recycled manure bedding on California Dairies. J. Dairy Sci. 61:1498-1508.

Chaplin, S.J., H.E. Ternet, J.E. Offer, D.N. Logue, and C.H. Knight. 2000. A comparison of hoof lesions and behaviour in pregnant and early lactation heifers at housing. Vet. J. 159:147-153.

Chaplin, S. and L. Munksgaard. 2001. Evaluation of a simple method for assessment of rising behaviour in tethered dairy cows. Anim. Sci. 72:191-197.

Colam-Ainsworth, P., G. A. Lunn, R. C. Thomas, and R. G. Eddy. 1989. Behaviour of cows in cubicles and its possible relationship with laminitis in replacement dairy heifers. Vet. Rec. 125:573-575.

DeCook, B., M.C. Nelson, C.B. Tucker, and D.M. Weary. 2002. Cows discriminate between flooring surfaces in front of the feeder. Page 17 *in* Proceedings of the 5th North American Regional Meeting for the International Society for Applied Ethology. Laval University. Quebec City, Canada.

Dechamps, P., B. Nicks, B. Canart, M. Gielen, and L. Istasse. 1989. A note on resting behaviour of cows before and after calving in two different housing systems. Appl. Anim. Behav. Sci. 23:99-105.

DeHart, D.A., R.P. Natzke, and P.A. Oltenacu. 1976. Effect of coliform (*Escherichia coli*) challenge at milking time on new udder infections. J. Dairy Sci. 59:1124-1130.

Dumelow, J. 1995. Testing cubicle mats for dairy cows. Agric. Eng. Winter: 17-21.

Flower, F. and D.M. Weary. 2002. Testing measures of lameness: using behaviour to predict presence and severity of hoof lesions in dairy cattle. J. Dairy Sci. 85 (suppl. 1):247.

Fisher, A.D., G.A. Verkerk, C.J. Morrow, and L.R. Matthews. 2002. The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. Livest. Prod. Sci. 73:255-263.

Fregonesi, J., F. Flower, T. Vittie, C.B. Tucker, and D.M. Weary. 2002. Rubber flooring affects behaviour of dairy cows, especially animals with hoof injuries. J. Dairy Sci. 85 (suppl. 1):28.

Galindo, F. and D.M. Broom. 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Res. Vet. Sci. 69:75-79.

Galindo, F., D.M. Broom, and P.G.G. Jackson. 2000. A note on possible link between behaviour and the occurrence of lameness in dairy cows. Appl. Anim. Behav. Sci. 67:335-341.

Gaworski, M.A., C.B. Tucker, D.M. Weary, and M.L. Swift. 2003. Effects of stall design on dairy cattle behaviour. Pages 139-146 *in* Proceedings of the 5th International Dairy Housing Conference. American Society of Agricultural Engineers. St. Joseph, USA.

Haley, D. B., J. Rushen, and A. M. de Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci . 80:257-263.

Haley, D. B., A. M. de Passillé, and J. Rushen. 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Appl. Anim. Behav. Sci. 71:105-117.

Hasegawa, N., A. Nishiwaki, K. Sugawara, and I.Ito. 1997. The effects of social exchange between two groups of lactating primiparious heifers on milk production, dominance order, behavior, and adrenocortical response. Appl. Anim. Behav. Sci. 51:15-27.

Hassall, S.A., W.R. Ward, and R.D. Murray. 1993. Effects of lameness on the behaviour of cows during the summer. Vet. Rec. 132:578-580.

Herlin, A. H. 1997. Comparison of lying area surfaces for dairy cows by preference, hygiene, and lying down behaviour. Swed. J. Agric. Res. 27:189-196.

Hogan, J.S., K.L. Smith, K.H. Hoblet, D.A. Todhunter, P.S. Schoenberger, W.O. Hueston, D.E. Pritchard, G.L. Bowman, L.E. Heider, B.L. Brockett, and H.R. Conrad. 1989. Bacteria counts in bedding materials used on nine commercial dairies. J. Dairy Sci. 72:250-258.

Ingvartsen, K.L., L. Munksgaard, L., V.K.M. Nielsen, and L.J. Pedersen. 1999. Responses to repeated deprivation of lying down on feed intake, performance, and blood hormone concentration in growing bulls. Acta. Agric. Scand., Sect. A, Anim. Sci. 49:260-265.

Jensen, P., B. Recén, and I. Ekesbo. 1988. Preference of loose housed dairy cows for two different cubicle floor coverings. Swed. J. Agric. Res. 18:141-146.

Krohn, C.C. and L. Munksgaard. 1993. Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments II. Lying and lying-down behaviour. Appl. Anim. Behav. Sci. 37:1-16.

Ladewig, J. and D. Smidt. 1989. Behavior, episodic secretion of cortisol, and adrenocortical reactivity in bulls subjected to tethering. Horm. Behav. 23:344-360.

Lowe, D. E., R. W. J. Steen, and V. E. Beattie. 2001. Preferences of housed finishing beef cattle for different floor types. Anim. Welfare 10:395-404.

McDonald, J. S. and R. A. Packer. 1968. Incidence of intramammary infections during lactation in dairy cattle repeatedly exposed to *Streptococcus agalactiae* and *Aerobacter aerogenes*. Am. J. Vet. Res. 29:1525-1532.

Manninen, E., A. M. de Passillé, J. Rushen, M. Norring, and H. Saloniemi. 2002. Preferences of dairy cows kept in unheated buildings for different kind of cubicle flooring. Appl. Anim. Behav. Sci. 75:281-292.

Mason, G.J., J. Cooper, and C. Clarebrough. 2001. Frustrations of fur-farmed mink. Nature 410:35-36.

Metz, J.H.M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301-307.

Mowbray, L., T. Vittie, and D.M. Weary. 2003. Hock lesions and free-stall design: effects of stall surface. Pages 288-295 *in* Proceedings of the 5th International Dairy Housing Conference. American Society of Agricultural Engineers. St. Joseph, USA.

Müller, C., J. Ladewig, H.H. Thielscher, and D. Smidt. 1989. Behaviour and heart rate of heifers housed in tether stanchions without straw. Physiol. Behav. 46:751-754.

Muller, C. J. C. and J. A. Botha. 1997. Cow behaviour in relation to different free-stall surfaces during winter temperate climate. Pages 1069-1076 *in* Livestock Environment 5 Vol. 2. American Society of Agricultural Engineers, St. Joseph, USA.

Munksgaard, L. and P. Løvendahl. 1993. Effects of social and physical stressors on growth hormone levels in dairy cows. Can. J. Anim. Sci. 73:847-853

Munksgaard, L. and H.B. Simonsen. 1995. Behavioural and pituitary-adrenal axis responses of tethered cows or cows kept in pens with slatted floors. Acta Agric. Scand., Sect. A, Anim. Sci. 45:132-138.

Natzke, R. P. and B. J. Le Clair. 1975. Coliform contaminated bedding and new infections. J. Dairy Sci. 59:2152-2154.

Natzke, R. P., D. R. Bray, and R. W. Everett. 1982. Cow preferences for free stall material. J. Dairy Sci. 65:146-153.

O'Connell, J. M. and W. J. Meaney. 1997. Comparison of shredded newspaper and sawdust as bedding for dairy cows: behavioural, clinical and economic parameters. Irish Vet. J. 50:167-170.

Phillips, P.A., B.K. Thompson, D. Fraser. 1988. Preference tests of ramp designs for young pigs. Can. J. Anim. Sci. 68:41-48.

Rushen, J., A.M. de Passillé, D. Haley, E. Manninen, and H. Saloniemi. 2001. Using behavioral indicators and injury scores to assess the effect of stall flooring on cow comfort. Pages 716-723 *in* Livestock Environment 6 Vol. 2. R. Stowell, R. Bucklin and R. W. Bottcher (eds.) American Society of Agricultural Engineers. St. Joseph, USA.

Tierney, G. and R. Thomson. 2003. Methods for assessing the cushioning performance of free-stall dairy cow synthetic beds. Trans. ASAE 46:147-153.

Van Soest, P.J. 1983. Nutritional ecology of the ruminant. O & B Books. Oregon, USA.

Zehner, M.M., R.J. Farnsworth, R.D. Appleman, K. Larntz, and J.A. Springer. 1986. Growth of environmental mastitis pathogens in various bedding materials. J. Dairy Sci. 69:1932-1941.

Table 6.1. The difference in lying time, number of lying events, and duration of lying bouts reported across various experiments. Only experiments that reported a statistically significant differences in lying time were included in this table. Differences were calculated by subtracting the option with the lower lying time from the option with the higher lying time.

Experiment	Difference			Citation
	Lying time (h)	Number of lying events	Duration of lying bouts (h)	
Comparisons involving lying surfaces:				
Sawdust vs. sand in freestall	3.4*	2.4*	0.1	Chapter 2, Experiment 1
Sawdust vs. mattress in freestall	1.7*	2.0*	0.0	Chapter 2, Experiment 2
7.5 kg vs. 0 kg of sawdust on mattresses(7.5 kg vs. 1 kg in parentheses) on mattresses	[2.2 (1.2)]*	[2.4 (0.5)]†	-0.1 (0.1)	Chapter 3
Straw vs. sand in freestall (summer)	5.4*	5.1*	-1.9	Manninen et al., 2002
Straw vs. sand in freestall (winter)	9.7*	9.1*	-0.4	Manninen et al., 2002
Rubber mats in tie stall vs. slatted floor in pen(4 w)	3.7*	3.1*	NS[1]	Munksgaard and Simonsen, 1995
Concrete in tie stall vs. mattress in pen	4.2*	5.4*	-0.3	Haley et al., 2000
Concrete vs. mattress in tie stall	1.8*	4.1*	-0.3*	Haley et al., 2001
Comparisons involving the size of the lying area:				
132 cm vs. 112 cm freestall width	1.2*	-0.5	0.2*	Chapter 4, Experiment 1
126 cm vs. 106 cm (116 cm and 126 cm in parentheses) freestall width	[0.7 (0.0)]*	-0.4 (0.0)	[0.1 (0.0)]*	Chapter 4, Experiment 2

[1] no values reported, non-significant result reported in text

* indicates $P \leq 0.05$, † indicates $P \leq 0.08$; statistical significance for values [brackets] are for the linear term, as paired comparisons were not used