HOOF PAIN CHANGES HOW DAIRY CATTLE DISTRIBUTE THEIR BODY WEIGHT

by

SOPHIE NEVEUX

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Abstract

Behavioural changes associated with lameness in dairy cattle are often subtle, making lameness detection difficult. Objective and reliable methods of assessing weight distribution among the four limbs may be useful in the early detection of hoof injuries. To determine how cows redistribute their body weight among the four limbs in response to discomfort, I used a standing force platform with uncomfortable surfaces under either a single hoof (Exp. 1, n = 13 cows) or two hooves (Exp. 2, n = 15 cows). In control sessions, when all four hooves were on comfortable surfaces, cows in both experiments kept more weight on the front hooves than on the back hooves. In Experiment 1, when one of the back hooves was on an uncomfortable surface, cows removed weight from this hoof and redistributed the majority of this weight onto the contralateral back hoof but did not change the distribution of weight among the front hooves. When the uncomfortable surface was under a front hoof, cows placed less weight on that hoof and placed more weight on the contralateral front hoof and the ipsilateral back hoof. The variation in weight placed by the cows on both contralateral hooves increased when one of the hooves was on the uncomfortable surface. Cows in Experiment 2 placed more weight on the back hooves when both front hooves were on uncomfortable surfaces, though there was no change in weight distribution when both back hooves were on uncomfortable surfaces. This study demonstrates that dairy cows can alter their weight distribution to accommodate discomfort and that they adopt different standing behaviours depending on the location of discomfort. These results will help in the interpretation of data from force platforms for on-farm detection of lameness in dairy cattle.

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List of Abbreviations

NRS = Numerical Rating Scale

VAS = Visual Analog Scale

RF = Right Front

LF = Left Front

RB = Right Back

LB = Left Back

DIM = Days In Milk

BW = Body Weight

SD = Standard Deviation

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General Introduction

Lameness in dairy cattle

Lameness has an important influence on cattle welfare (Bennett et al. 2004). It has been defined as the clinical exhibition of an abnormality of the musculo-skeletal system in one or more limbs, with most cases in dairy cattle resulting from hoof injuries (Phillips, 2002b). The associated changes in locomotion are a result of biomechanical restriction in movement, usually thought as an attempt to alleviate pain (Scott, 1989; Greenough, 1996), as well as a response to the animals' hyperalgesic state (Whay et al., 1997). The pain or discomfort is created by digital lesions or abnormal weight bearing that stresses joints, tendons, and ligaments (Rebhun, 1995).

In addition to causing pain and suffering in afflicted dairy cattle (Scott, 1989; Rebhun, 1995; Greenough, 1996), lameness has been shown to result in economic loss to producers due to poor reproduction, treatment costs, reduced milk production (Green et al., 2002; Juarez et al. (2003)) and increased likelihood of culling (Booth et al. 2004). The causes for lameness are numerous and likely multi-factorial, including environment, nutrition, and herd management.

Behavioural changes associated with lameness are the focus of an emerging field of research. Juarez et al. (2003) reported that lame cows had longer lying times and took longer to return from the milking parlour and remained closer to the pen entrance than cows that were not lame. Although no difference in total time standing between lame and non-lame cows was detected by Galindo et al. (2000), this study found that lame cows spent a greater amount of time standing with only their front hooves in the lying cubicles. Moreover, these authors observed that lame cows had a lower index of displacement, measured by agonistic interaction, implying that lameness influences social ranking. O'Callaghan et al. (2003) reported that activity level in lame animals, as measured by steps per hour, was significantly reduced as compared to non-lame cows. These authors concluded that changes in daily activity are a useful indication of pain associated with lameness. In combination, these results indicate that cows adopt different behavioural strategies to lessen the pain associated with lameness.

The average annual incidence of lameness in herds visited in the UK in 1977 was 5.6 % with a range of 3.6 to 11.8 % (Rowlands et al., 1983). A decade later, another UK survey of 37 farms reported that the prevalence of lameness was 20.6 % (Clarkson et al., 1996). Moreover, these authors reported that the mean annual incidence of new cases was 54.6 per 100 cows with a range of 10.7 to 170.1 cases. Wells et al. (1993) investigated 17 dairy herds in Minnesota and Wisconsin and found the prevalence of clinical lameness cases to be 13.7% and 16.7% in the summer and spring, respectively. Leach et al. (1998) evaluated the hooves of 31 first calf heifers and found that all had at least one hoof injury. Similarly Manske et al. (2002) found that 72 % of animals investigated on Swedish herds had at least one hoof lesion. Somers et al. (2003) surveyed herds in The Netherlands and found that 80% of the cows exposed to concrete flooring had at least one hoof disorder at the time of observation. Similarly, Bell (2004) found that 85.7% of 624 dairy cows in British Columbia had at least one hoof injury.

Lameness is associated with many risk factors including stockmanship, environment, nutrition and genetics. The demands of intensive farming have likely imposed increased stresses on dairy cows (Greenough, 1996). Larger farms favour cubicle ("free stall") housing, often with concrete flooring throughout. Both cubicle housing and increased exposure to concrete flooring are risks for lameness. Moreover, the concrete is often covered in slurry, and this moisture softens the horn increasing both the risk of injury and slipping (Greenough, 1996; Phillips, 2002a).

Differences in the incidence of lameness among studies may be due to geographical factors or to differences in the way lameness was assessed. A cow considered lame in one study that uses one behaviour as criteria (e.g. back arch) may not fall within the criteria of lameness in another study that uses several behaviours (e.g. back arch, tracking up, reluctance to bear weight). Further, the apparent increased reported incidence of lameness over the last decade may be due in part to an improved ability to identify abnormalities in cow gait. Regardless, successful prevention and treatment is clearly dependent on our ability to correctly identify lame cows.

Lameness detection

Dairy cattle producers have had limited success in detecting lame cows, as illustrated most recently by Whay et al. (2003), who found that farmers failed to identify three lameness cases out of four. Traditionally lameness assessment has relied on subjective methods of identification including the evaluation of hoof health and gait. These have been used on their own or in combination in several studies and both have advantages and disadvantages.

Hoof health evaluation

Hoof health evaluation typically records the presence, severity and location of hoof injuries (Greenough and Vermunt, 1991). Leach et al. (1998) used digital photography of hooves to determine the presence and severity of lesions. Hoof surfaces were divided into different zones to distinguish between toe, sole, bulb and heel areas.

The sizes of the injuries were compared to a circle of known diameter affixed to injury-free areas of the hoof when the photographs were taken. Although this increases the objectivity of the measurements, allocating severity scores to injuries remains subjective.

Common injuries and hoof pathologies reported in two UK farm surveys include solar ulcers, white line lesions (Clarkson et al., 1996), foul in the foot, white line abscesses and sole ulcers (Rowlands et al., 1983). Interestingly, sole ulcers appeared to be more predominant in cattle housed on concrete (Rowlands et al., 1983). Manske et al. (2002) reported that heel-horn erosion, sole haemorrhages and dermatitis were the most observed injury in Swedish herds. Further, the majority of the hoof injuries were found in the hind hooves (Toussaint Raven et al., 1985; Leach et al., 1998; Manske et al., 2002).

Results from several studies (e.g. Scott, 1989; Winckler and Willen, 2001; O'Callaghan et al., 2003) show discrepancies between hoof health and gait scores; namely, injured cows do not always show alterations in their gait, and cows with high gait scores do not always have injuries. O'Callaghan et al. (2003) evaluated the relationship between hoof health and gait in 345 lactating dairy cattle. They found that chronic foot lesions were usually associated with higher scores than acute lesions. Although severe lesions were usually associated with high scores, some cows with severe foot lesions did not show obvious lameness. Moreover, other work has shown that gait responses likely differ depending on the type of injury (Scott, 1989; Flower et al., 2005), and bilateral injuries may cause no changes in gait due to the reluctance of cattle to transfer weight onto already lame limbs (Whay et al., 1998).

Gait scoring

Lameness in walking dairy cattle is normally assessed using subjective locomotion scoring systems such as those developed by Manson and Leaver (1988) and Sprecher et al. (1997). These scoring systems are based on various behaviours exhibited by cows while walking, e.g. back arch, tracking and reluctance to bear weight on injured limbs (Whay et al. 1998; O'Callaghan et al., 2003). Examples of two methods used when scoring gait are illustrated: The first (Table 1) is based on the use of a numerical rating scale (NRS), which allocates a single score to the cow's overall locomotion (ability to move). The second (Table 2) is a visual analog scale (VAS) that allows a trained observer to score along a scale within the two extremes possible (e.g. sound and could not be more lame). Visual analogue scales provide a continuous method of subjective measurement and remove the constraints placed on observers by the numerical rating scale (Welsh et al., 1993).

Although these gait scoring systems provide an easy and inexpensive method of assessment (Colborne, 2004), the subjective nature of these systems puts into question their reliability (Hood et al., 2001; Winckler and Willen, 2001). Further, the ability of these scoring systems to detect subtle pain related behavioural changes associated with subclinical lameness has also been questioned (Winckler and Willen, 2001; O'Callaghan et al., 2003). Welsh et al. (1993) found greater variation in the reproducibility (a measure of between-observer variability) and repeatability (a measure of within-observer variability) of scores when NRS or VAS systems were employed, when sheep were perceived to be moderately lame, rather than having mild or severe lameness. Similarly, Keegan et al. (1998) found that even for experienced clinicians, subjective scoring of mild to moderate lameness of horses trotting on a treadmill was not repeatable. Lameness scoring of pigs using subjective systems has also been criticized. Main et al. (2000) suggested that these scoring systems were unreliable due to their low sensitivity when used by unfamiliar observers. These concerns, combined with the fact that dairy producers often fail to detect lame cows in their herd (Wells et al., 1993; Whay et al., 2003), suggests that valid and reliable methods of assessing lameness in dairy cattle are needed. Developing automated lameness detection tools for use on-farm may be particularly helpful for producers.

Kinetics and Kinematics

Equine biomechanists have capitalized on the work done with humans in developing objective lameness identification tools (Colborne, 2004). Merkens et al. (1988) evaluated the forces applied to limbs while horses walked normally and was able to differentiate between hardly lame and sound animals that were otherwise undetectable through subjective observation of gait. With some recent exceptions (e.g. Flower et al., 2005), research on the use of objective methods to evaluate cattle motor mechanics has tended to lag behind.

Force platform assisted kinetic and kinematics analyses have been used in previous studies on mammals (e.g. Macpherson et al., 1987; Schott et al., 1994; Hood et al. 2001). Kinematic analysis measures the geometry of movement without considering the forces that cause the movement, while kinetics is the study of the forces that are responsible for the movements (Clayton and Schamhardt, 2001). The quantitative nature of force platform data provides the opportunity for unbiased evaluation of load distribution (Budsberg et al., 1988; Anderson and Mann, 1994) and are frequently used as a gold standard against which other systems are evaluated (Hurkmans et al., 2003). Weight distribution analysis can provide valuable information by quantifying the effects of drugs, lesions or disease on the motor system (Macpherson et al., 1987).

The effectiveness of surgical treatments of lameness in dogs has been evaluated by analysing the forces associated with walking on a platform (Jevens et al., 1996). Corr et al. (2003) used platforms to evaluate locomotor health of chickens while walking although they found high variability in ground reaction forces, attributed mainly to fluctuations in speed. Van der Tol et al. (2003) used both force and pressure plates to evaluate the forces applied to bovine claws while walking. Results show uneven loading and possible overloading of hind claws, increasing the risk of injuries.

A platform system for identifying lameness in cattle when walking was designed by Rajkondawar et al. (2002). The Reaction Force Detection (RFD) system had a walk-through layout with left and right floor plates equipped with load cells on four corners of each plate which measured vertical ground reaction forces components and positions of the loads applied. Although the RFD system detected changes to individual limb loads when cows were sound versus lame in one limb, the study did not describe changes to gait when cows were afflicted with hoof injuries on multiple limbs. Further developments should focus on easier methods of measuring single limb load and identifying cows with multiple injuries.

Van der Tol et al. (2002) evaluated the pressure distribution over the bovine hoof while standing and found differences between and within hooves, which may explain susceptibility of some hoof regions to injury. Further, when cows are lame relief is gained by reducing the weight loaded on the diseased hoof while standing (Phillips, 2002b).

Postural adjustments are required when one limb is raised, resulting in weight transfer to the other limbs to maintain balance (Coulmance et al., 1979; Gahéry and Nieoullon, 1978). Changes in weight distribution in osteoarthritic rats were also used by Bove et al. (2003) as an index of joint discomfort. Hood et al. (2001) reported that lame horses increase the shifting of weight among their limbs, as measured by the increased variation in the weight loaded on each limb. Interestingly, this weight shifting behaviour was significantly reduced with the administration of a non-steroidal anti-inflammatory drug. The magnitude and variability of weight bearing of limbs can thus be used as a measure of pain associated with lameness (Rietmann et al., 2004).

Studies have investigated the weight distribution while standing in several species. Posture and stance behaviour recorded using platforms, have been used in conjunction with muscle activity records to better understand motor control in cats (Macpherson et al., 1987). Weight bearing during standing has been used to assess pain in rats. Rats injected with an inflammatory agent in one hind paw removed weight from this paw and significantly increased the weight load on the contralateral limb (Schott et al., 1994). Changes to weight distribution in laminitic horses have also provided information on how animals are affected by lameness (Hood et al. 2001). Horses responded to the presence of laminitis in one fore limb by increasing the load to the contralateral limb and also shifted more weight among the forelimbs, as measured by variation of weight applied.

Standing behaviour

Studies have identified two types of weight distribution changes resulting from interference during normal, quiet standing. When one limb is lifted in healthy quadrupeds, the remaining weight is redistributed in either a diagonal or non-diagonal pattern of support (Figure 1). Two forms of non-diagonal postural adjustments have been identified; one where weight transfer occurs only to the contralateral (i.e. opposite side of the body) limb and the other where weight is shifted to all other limbs (Di Fabio 1983).

The advantage to the diagonal posture is that there is minimal displacement of the center of gravity (Gahéry and Nieoullon, 1978; Coulmance et al., 1979; Dufossé et al., 1982) and orientation of the body axis remains unchanged (Dufossé et al., 1982). The weight of the cow is loaded onto the contralateral and ipsilateral (i.e. same side of the body) limbs. The disadvantage to this bipedal pattern is that this results in very narrow limits of stability for the quadruped since only two limbs are supporting the animal (Dufossé et al., 1982; Gahéry and Massion, 1981).

Non-diagonal postures, on the other hand, are characterized by a lateral shift in the position of the center of gravity. The force changes often occur in contralateral limb pairs (front or back) while the remaining limb loads remain unchanged (Dufossé et al., 1982). In contrast to the diagonal pattern, this tripedal stance, with the center of pressure shifted to the triangle created by the three limbs supporting the animal, is very stable (Dufossé et al., 1982). Moreover, this stance may be energy-efficient since the sum of the weight changes on all four limbs is less and the muscles activated are restricted to one half of the body (Dufossé et al., 1982).

One important factor that influences the type of postural change is the context in which the animal is removing weight from a limb. Dufossé et al. (1982) found that the diagonal pattern of support was observed when the limb movement was elicited by an unexpected external perturbation, while the non-diagonal pattern accompanied a learned limb movement elicited by an auditory cue. Gahéry et al. (1980) also found that diagonality of stance depended on whether the movement was elicited unexpectedly or if it was a conditioned, learned response.

Objectives

The Rajkondawar et al. (2002) study examined forces when cows were walking, but little is known about how cows change weight distribution in response to discomfort or pain while standing. Evaluating standing behaviour may provide information on weight distribution of sound cows (e.g. non-lame), changes in limb loading associated with hoof injuries and provide insight into the high incidence and recurrent nature of hoof injuries in the hindlimbs of cows (Clarkson et al., 1996; Greenough and Vermunt, 1991). The integration of kinetic platforms on-farm may be a practical option for many dairy producers. For example, it could be implemented in conjunction with robotic milking systems, integrated within weighing scales or even the standing surface of the milking parlour. Thus, the objectives of this study were to evaluate how sound cows distribute their weight while standing and how they change this distribution in response to hoof discomfort. Since it is not clear how much pain is caused by existing injuries, we experimentally varied standing surfaces that we judged to be comfortable and uncomfortable. Studies have evaluated the comfort associated with various stall and standing surfaces, typically comparing concrete to rubber mats similar to what was used in this study. Results show that cows have a preference for softer materials, as measured by the time spent lying in stalls with this material (Jensen et al., 1988; Herlin 1997; Haley et al. 2000). I recorded the weight applied to limbs when standing on a comfortable surface and evaluated changes to weight distribution when one or more limbs were placed on an uncomfortable surface. I predicted that cows would remove weight from the limb standing on the uncomfortable surface, transfer the weight to the contralateral limb and increase the shifting of weight among these limbs. I also tested whether there were differences in the way cows redistribute their weight when a single limb (front or back) or pair of contralateral limbs were on an uncomfortable surface.

Table 1. Numerical Rating Scale for gait scoring.

Gait score	Clinical description	Assessment Criteria
1.0	Sound	*Smooth and fluid movement*. Flat back posture when standing and walking. Symmetrical gait without swinging out. All limbs bear weight equally and joints flex freely. Back hooves land on or in front of fore hoof prints (tracking up). Head carriage remains steady as the animal moves.
2.0	Imperfect Locomotion	*Ability to move freely not diminished*. When standing and walking, back posture is flat or mildly convex – in the absence of other gait abnormalities this stance is likely attributed to normal posture. Gait slightly asymmetrical due to minimal swinging out. All limbs bear weight equally but joints show slight stiffness. Back hooves do not track up perfectly but shortened strides are uniform. Head carriage remains steady.
3.0	Lame	*Capable of locomotion but ability to move freely is compromised*. Flat or mildly convex back posture when standing, but obviously arched when walking. Gait is asymmetrical due to swinging out. All limbs bear weight equally but a slight limp can be discerned in one limb. Joints show signs of stiffness but do not impede freedom of movement. Back hooves do not track up and strides may be shortened. Head carriage remains steady.
4.0	Moderately Lame	*Ability to move freely is obviously diminished*. Obvious arched back posture when standing and walking. Gait is asymmetrical due to swinging out and one or more strides obviously shortened. Reluctant to bear weight on at least one limb but still uses that limb in locomotion. Strides are hesitant and deliberate and joints are stiff. Head bobs slightly as animal moves in accordance with the sore hoof making contact with the ground.
5.0	Severely Lame	*Ability to move is severely restricted*. Animal must be vigorously encouraged to stand and/or move. Extreme arched back posture when standing and walking. Gait is asymmetrical due to swinging out, one or more strides obviously shortened and/or inability to bear weight on one or more limbs. Obvious joint stiffness characterized by lack of joint flexion with very hesitant and deliberate strides. Head obviously bobs as sore hoof makes contact with the ground.

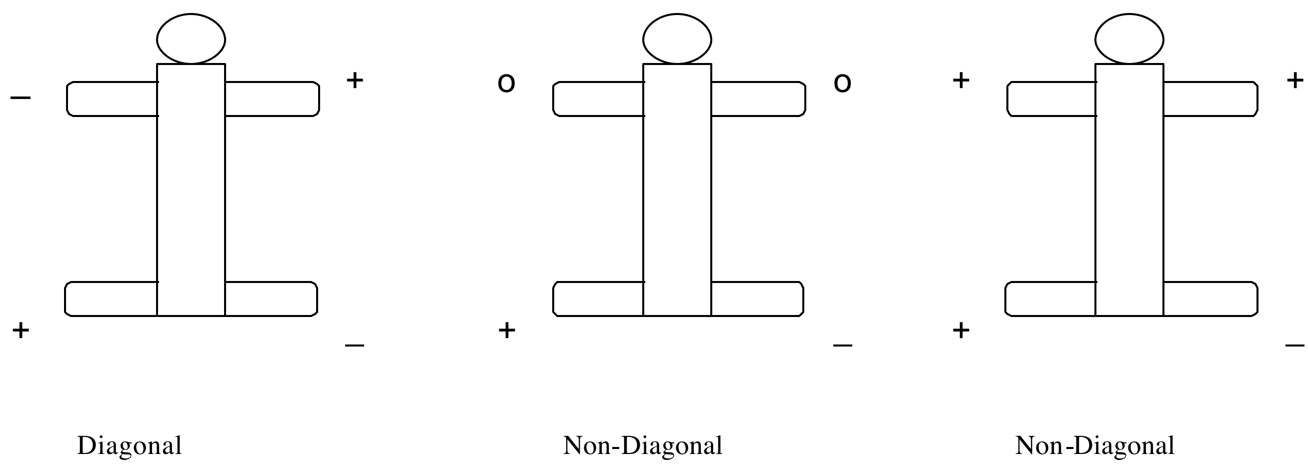
Adapted from Zimmerman, 2001.

Table 2. Visual Analog Scale for gait scoring.

Behaviour	Description	Scale
Swinging in/out	Abduction/adduction of the back limbs from the sagittal plane	Straight — Circular movement
Back Arch	Deviation of the back from a 180° angle.	Straight back — Severely arched back
Head Bob	Head movement associated with the movement of limb(s)	No head movement — Head bob
Tracking	The position of the back limbs in reference to the imprints left from the front limbs	Limbs track up — Limbs do not track up
Joint Flexibility	Joint flexion and extension through the range of motion	Joints flex freely — Joints are stiff
Stepping rhythm	The balanced rhythm of the steps	Steps in rythym — Steps out of rythym
Bear Weight	The weight bearing of each limb	Limbs bear equal weight — Limb(s) limp

Adapted from Zimmerman, 2001

Figure 1. Diagram showing the postural patterns of support during standing. This example illustrates both the diagonal and non-diagonal weight redistribution response of a quadruped when the right back limb is lifted. (Weight removed (-); weight added (+); weight unchanged (o)).



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Hoof Discomfort Changes How Dairy Cattle Distribute Their Body Weight

Introduction

Lameness is one of the most widespread and costly problems of intensive dairy production with annual incidences often in excess of 30% (Booth et al., 2004). Economic losses associated with lameness include decreased milk production, weight loss, reduced fertility, treatment costs, and involuntary culling (e.g. Green et al., 2002; Hernandez et al., 2002; Booth et al., 2004; Garbarino et al., 2004). The prevalence of lameness in a herd and the efficacy of control depend on how soon it is detected and treated. However, research has shown that, on average, dairy producers are aware of 25% to 50% of the cows that are lame (Wells et al., 1993; Whay et al., 2003) and most cases of sub-clinical lameness remain undetected and untreated.

Lameness in dairy cattle is normally assessed using subjective gait scoring systems (e.g. Manson and Leaver, 1988, Sprecher et al., 1997). Although these gait scoring systems can provide an easy and inexpensive method of detecting lameness (Colborne, 2004), the subjective nature of the systems puts into question their reliability (Hood et al., 2001; Winckler and Willen, 2001). Further, the ability of these scoring systems to detect subtle behavioural changes related to pain has also been questioned (O'Callaghan et al., 2003). Results from several studies (e.g. Scott, 1989; Winckler and Willen, 2001; O'Callaghan et al., 2003) show discrepancies between hoof health and gait scores; namely, cows with visible hoof lesions do not always show alterations in their gait, and cows with high gait scores do not always have visible injuries. Moreover, gait responses likely differ depending on the type of injury (Scott, 1989; Flower et al. 2005), and bilateral injuries may cause no changes in gait (Whay et al., 1998). Finally, the increasing size of dairy farms and the limited amount of time available to dairy producers to observe cows, has led to an interest in automated means of detecting lameness. Thus, valid, reliable and automated methods of assessing lameness in dairy cattle are needed.

In horses, lameness has often been studied by examining the load applied to each limb using force platforms (e.g. Keegan et al. 1998, Hood et al. 2001). When animals are lame, relief may be gained by reducing the weight loaded on the painful limb by transferring weight to the other limbs to maintain balance (Gahéry and Nieoullon, 1978; Coulmance et al., 1979). In addition to these changes in limb loading, animals may also respond to discomfort by shifting weight among their limbs. This weight shifting in laminitic horses is reduced with the administration of analgesics (Hood et al., 2001). Thus, both the magnitude and variability in limb loading may be used as a measure of pain associated with lameness (Rietmann et al., 2004).

In a key study on dairy cattle, Rajkondawar et al. (2002) described how loads on individual limbs during walking differed between lame and healthy cows, and found that force data could be used to identify lame cows. The Rajkondawar et al. (2002) study examined forces when cows were walking, but a force platform measuring weight distribution between limbs when cows were standing likely would be easier to implement on farms. Neveux et al. (2003) presented preliminary data showing that cows with hoof lesions showed a greater variability in weight distribution among the four limbs when standing, compared to healthy cows. However, there was no simple relation between the presence of visible injuries on a hoof and the weight placed on that limb. One limitation to this approach is that we do not know how cows redistribute their weight among their limbs in response to discomfort in one limb. Thus, the objectives of the current study were to evaluate how sound cows distribute their weight while standing and how they change both the magnitude and variability in limb loading in response to hoof discomfort. Discomfort in both a single hoof and a pair of contralateral hooves were investigated to simulate both types of lameness. Since it is not clear how much pain is caused by existing injuries, we experimentally varied standing surfaces that we judged to be comfortable and uncomfortable, and measured the weight transferred to each hoof in response to these standing surfaces.

Materials and Methods

Animals and housing

In Experiment 1, we used 13 Holstein dairy cows (Mean ± SD; parity of 1.2 ± 0.6; BW 636 ± 75 kg). Two of the cows were not lactating and the remaining 11 averaged 260 ± 94 days in milk (DIM). For Experiment 2, we used 15 lactating Holstein dairy cows (parity 1.2 ± 0.4; BW 617 ± 61 kg; DIM 208 ± 62). All cows were housed in a tie-stall barn at Agriculture and Agri-Food Canada's research herd in Lennoxville, Quebec. Lactating cows were walked to the milking parlour twice daily while non-lactating cows remained in their stalls.

We selected cows that were not lame as judged using measures of gait and hoof health from 4 monthly hoof evaluations and gait scoring sessions. Animals were restrained in a horizontal-trimming chute operated by a professional hoof trimmer. The hoof trimmer pared approximately 1 mm of the sole horn from the hoof, and the presence and severity of injuries (haemorrhage of the wall, haemorrhage of the sole, sole ulcer, dermatitis and heel erosion) were recorded for all hooves (Table 3). All cows were correctively trimmed 1 mo before the start of the study and again at the end of the experiment.

Experiment 1: 24 cows were originally tested although several could not be used in the analysis. Errors in data recording and excessive manipulations while standing on the platform resulted in insufficient stable data for analyses. One cow afflicted with a severe ulcer and with a locomotion score of 4 was also removed from all analysis. Therefore, data from 13 cows were used to analyse weight distribution while standing on the rubber surface. The treatments were reasonably balanced among the retained cows.

Experiment 2: Of the 16 cows tested originally, one was removed due to lameness as indicated by her gait score and hoof health evaluation, which identified an ulcer on the right back hoof.

During each gait scoring session a handler walked behind the cows encouraging them to walk in a consistent manner along a 13 m long by 1.3 m wide non-grooved concrete passageway. Each cow was videotaped from her right side. The video camera was placed 6 m from the cow, which allowed us to record at least four complete strides for each cow during each passage. A second video camera was mounted 1.8 m above the floor, pointed towards the rear of the cow, to allow for scoring of abduction and adduction of the back limbs. These videos were used to assign each cow a gait score by an experienced observer using the 5-point scale developed by Zimmerman (2001) (Table 1 and 2). Cows were included only if the gait score was 3 or less (i.e. non-lame) in the scoring session conducted immediately prior to the experiment. Cows in Experiment 1 and 2 had an average gait score (± SD) of 2.69 ± 0.60 and 2.03 ± 0.63, respectively.

Load Cells and Platform

The weight distribution of cows was obtained while they were standing on a platform containing four independent recording units (each 56 x 91 cm) fitted in a 1.9 x 1.3 m enclosure. Each recording unit contained two single point load cells (TEDEA, Model 1250). The load cells were mounted off-centre at either end of each unit. Within each load cell, the internal strain gauges measured deformation from the tension and compression proportional to the vertical load applied. Horizontal forces were not measured. The corresponding change in electrical resistance was transmitted via an electrical signal to the acquisition hardware FieldPoint (National Instruments, Canada) at a rate of one reading every 0.9 s for Experiment 1 and every 0.25 s for Experiment 2. The load cells were validated periodically during the study using dead weight calibration with standard weights. The weight recorded was always the same regardless of position on the unit. LabView (National Instruments, Canada) was used to provide a real time graphical display of the weight applied to each of the four units and data were automatically stored on a computer.

In Experiment 1, the platform stood 16 cm above the floor and had a 2.3 m entrance and exit ramp (sloped approximately 4° from the floor) at the front and back of the enclosure. The side barriers of the platform were 2.1 m high and were made of 6 lateral steel bars. An adjustable rear barrier discouraged cows from reversing and allowed handlers to safely correct the position of the cows. An 81 cm tall door made of solid wood, with a 37 cm wide opening for the cow's head, prevented the animal from moving forward while in the enclosure. Observations of cows during preliminary trials showed that head movement influenced the weight distribution. Therefore, to limit the cow's peripheral view and ability to move their head, the door was equipped with lateral blinders that extended 19 cm from the door.

Individual limb and head positions of the cows while standing on the platform were recorded using two video cameras. These recordings were monitored to ensure that hooves were correctly placed on the platform throughout the period that loads were measured. If a hoof was not placed on the correct load-recording unit, the cow was gently manipulated to encourage repositioning. The timing of each of these manipulations was identified using the video recordings, and 10 s of the load data before and after each event were eliminated from the analysis. The first and last 30 s of each session on the platform were also removed to account for cows adjusting their position while entering and exiting the platform.

The materials and procedures described above were identical in Experiment 2, with the following exceptions: The lateral barriers on the platform were placed closer to the cows to improve the likelihood that the cows correctly placed their hooves on the recording units. Due to improved procedures present in Experiment 2 we only removed 5 s of the load data before and after manipulations to correct cow positioning on the platform.

Standing materials

In both experiments we used a ‘comfortable’ flooring surface of 3.8 cm thick revulcanized rubber mats (Animat, Quebec), and an ‘uncomfortable’ concrete surface, which we intended to cause mild discomfort but not injure the animals. In Experiment 1, we created an uncomfortable standing surface by placing rocks into the standing surface. Rocks were approximately 1.3 cm thick and placed directly into the concrete at the time of manufacturing. The rocks (5 per 15 cm^2) protruded 0.6 cm above the surface of the concrete. Difficulties associated with the inconsistent size and placement of the rocks created spatial variation within and among the units. Thus, to create a more uniform surface in Experiment 2, we used screw heads that we were able to place in a very consistent manner within the standing surface. These screw heads were placed at 5 per 15 cm^2, had smooth concave surfaces 1.8 cm in diameter and protruded 2.0 cm above the concrete surface. In both experiments we followed the hoof health and gait of the cows to ensure that treatments did not cause any injury or evidence of longer-term pain. We also gait scored the cows at the beginning and the end of their respective test days and detected no changes in locomotion.

Experimental procedure

In Experiment 1, we placed the uncomfortable surface under either a single front or back hoof. The cows, tested over 4 d, were walked along a passageway and stood on the platform in a calm and manageable manner. Treatments were imposed at 1 h intervals, and recordings were started immediately after the morning milking. Each cow received each of three treatments, presented in a balanced order: 1) control (4 rubber surfaces), 2) right back (RB) surface was concrete embedded with rocks and the other three surfaces were rubber and, 3) right front (RF) surface was concrete embedded with rocks and the other three surfaces were rubber. Cows stood on the platform for approximately 5 min during each test and were returned to their stalls between tests. Due to time limitations, we evaluated weight distribution changes in response to discomfort on the right side only.

In Experiment 2, we placed uncomfortable surfaces under both front hooves or both back hooves. The cows, tested over 4 d, were walked along the passageway and stood on the platform in a calm and manageable manner. Treatments were imposed at 30 min intervals. Each cow received each of the three treatments: 1) control (4 rubber surfaces), 2) both front units had concrete surfaces embedded with screws and both back units had rubber surfaces, and 3) both back units had concrete surfaces embedded with screws and both front units had rubber surfaces. The two uncomfortable surface treatments were presented in balanced order, between two repetitions of the control condition. To minimize the risk of injury while standing on the uncomfortable units, cows stood only 2 min before being returned to their stalls.

Statistical analysis

Experiment 1: Although 5 of the 13 cows were observed to have one or more hoof injury at the end of the study, they did not show any overt signs of lameness when walking or reluctance to bear weight on the limb while on the platform during the control treatment, and were therefore retained in the study. Subsequent comparisons of the animals with and without injuries indicated no differences and therefore the data were pooled prior to the final analyses.

Differences in load applied among pairs of hooves (front versus back and left versus right) during control treatments were tested using t-tests. GLM with specified contrasts was used to test differences in weight applied to all four hooves in response to the treatments. We predicted that less weight would be applied to the hooves on the uncomfortable surface and that this weight would be redistributed among the 3 other hooves. In addition, we used the average SD of the load on each limb during the 5 min period for a particular treatment, averaged over of all cows, as the measure of the limb-load variation. We predicted that variation in weight placed on each hoof would increase when the cow was standing on the ‘uncomfortable’ surface.

Experiment 2: No differences were found in the weight distribution between the two control treatments, so an average of the two was used. Analyses were as described in Experiment 1. We predicted that cows would remove weight from the uncomfortable surfaces, and increase the variation in weight loading when standing on these surfaces.

Results

During control sessions in Experiment 1, cows placed more weight on the front hooves than on the back hooves (54.7 vs. 45.3% ± 0.4%; t = 36.2, df = 12, $P < 0.001$). Cows also distributed more weight on their right side than on their left side (52.0 vs. 48.0 ± 1.7%; t = 2.4, df = 12, $P = 0.04$).

The proportion of weight placed on the right back hoof during the RB treatment was less than during the control treatment ($P < 0.001$; Table 4). The weight placed on the left back hoof increased ($P < 0.001$), but there were no significant changes observed in weight placed on the front hooves. During the RF treatment the animals placed less weight on the right front hoof ($P < 0.001$) and more weight on the left front hoof ($P < 0.001$), than during control treatments. Cows also increased the weight placed on the right back hoof ($P = 0.011$), but the change in weight applied to the left back hoof was not significant. The presence of an uncomfortable surface under one hoof also changed the variability in weight distribution over time. The variation in weight applied to the back hooves increased by more than 50% during RB treatment ($P < 0.01$; Table 5) and by more than 100% for the front hooves during the RF treatment ($P < 0.01$).

In Experiment 2, cows again placed more weight on the front than the back hooves (54.0 vs. 46.0 ± 0.5 %; t = 15.7, df = 14, $P < 0.0001$) during control sessions. Cows also showed a lateral difference in weight distribution, again placing more weight on the right side than the left (52.4 versus 47.6 ± 1.7 %; t = 2.8, df = 14, $P = 0.013$). The proportion of weight placed on the front hooves decreased by 1.2 % when the uncomfortable surfaces were placed under the front hooves ($P < 0.0001$; Table 6). However, I found no significant effect on weight distribution when the uncomfortable units were under the back hooves. I also found no effect of either treatment on the variation in weight applied to the hooves.

Discussion

Strong load redistribution relationships were identified between contralateral hooves when a single hoof was on an uncomfortable surface; the unloading of one hoof resulting in an increased load on the contralateral hoof. This shifting of load between limbs may increase the risk of secondary hoof injuries (Hood et al., 2001). In Experiment 1, cows standing with their back hoof on an uncomfortable surface responded by shifting their weight to the contralateral (i.e. opposite side of the body) back hoof. This supports the preliminary findings of Neveux et al. (2004) who found strong negative correlations between the amounts of weight applied to contralateral hooves. No weight was shifted to the front hooves. Similar contralateral shifts in weight have been observed in dogs (Brookhart et al., 1965; Jevens et al., 1996) and cats (Dufossé et al., 1982; Di Fabio, 1983).

When the uncomfortable surface was placed under the front hoof in Experiment 1, cows responded by shifting their weight to the contralateral front and ipsilateral (i.e. same side of the body) back limb. The results of Experiment 1 suggested that cows had difficulty shifting weight from back to front although some weight could be shifted from front to back. The results of Experiment 2 support this. When the two front hooves were on uncomfortable surfaces the cows proved able to transfer some weight from the front to the back hooves. However, the reverse did not occur when the two back hooves were on uncomfortable surfaces. This difference may help explain the higher incidence and recurrent nature of back limb injuries (Clarkson et al., 1996; Greenough and Vermunt, 1991).

The variability over time of the load applied to each limb measured the extent that cows repeatedly shifted their weight while on the platform. Such shifting has previously been suggested to serve as an indicator of lameness (Hood et al., 2001). Variation in loads increased when cows were standing on an uncomfortable surface, during either the front or back limb treatments in Experiment 1. Similar results were found by Hood et al. (2001), who reported that horses afflicted with acute laminitis in one limb shifted weight among the contralateral limbs. These results suggest that an increase in the shifting of weight between contralateral limbs may be used as an indicator of single limb lameness. When both contralateral limbs are affected, however, it appears that cows may not be able to perform similar weight shifting behaviour.

The cows used in both experiments placed more weight on their front hooves than on their back hooves. Previous studies have found similar results in cattle (55-60% front: 45-40% back; Phillips, 2002), as well as other quadrupedal mammals (e.g. 60 : 40% in dogs; Budsberg et al., 1987; and 58 : 42% in horses; Hood et al., 2001). The 10 to 20% increase in weight applied to the forelimbs reflects the anterior position of the centre of gravity in the cow (Gray, 1944; Merkens et al., 1993; van der Tol et al., 2002), and likely other quadrupeds.

In both experiments we found that cows placed more weight on the right limbs, but this has finding has not been reported previously. This difference may have been due to the design of our platform; although we attempted to restrict cow movement they had enough space to move their heads and shift their body off centre. The off-centre location of the rumen may also have influenced weight distribution.

Objective and valid measures of lameness in dairy cattle should help improve the identification of lame cows. The implementation of such tools on-farm has considerable potential for the treatment and prevention of lameness in the dairy industry. This study provides some insight into the standing behaviour of dairy cattle, with more weight placed on the front limbs and contralateral dependent limb loading. Observing cows over longer periods of time can provide a within cow weight distribution profile and may allow identification of changes from normal standing patterns. Further research is needed to validate the use of platforms to detect changes in limb loading associated with painful hoof lesions. Moreover, we need to determine how measures from standing relate to those when animals are walking (Coulmance et al., 1979), and how both measures relate to hoof health.

Table 3. Hoof health evaluation.

Injury	Severity Score	Description
Dermatitis	0	No dermatitis
	1	Light dermatitis
	2	Moderate
	3	Severe dermatitis, dermis is exposed
Heel Erosion	0	No heel erosion
	1	Light heel erosion
	2	Moderate heel erosion
	3	Severe heel erosion, dermis is exposed
Haemorrhage of the sole or white line	0	No haemorrhage
	1	Light haemorrhage, petechia or localized haemorrhage, with altered coloration covering less than 10% of the sole or the white line
	2	Moderate haemorrhage, covering 10 to 25% of the sole of the white line
	3	Severe haemorrhage covering more than 25% of the sole or the white line, or colouring a localized region with a deep red
Ulcer	0	No ulcer
	1	Insult to sole exposing dermis
	2	Like #1, but with exposed corium
	3	Like #2, but with signs of infection

Adapted from Manske et al. 2002.

Table 4. Average proportion of weight (%) distributed on each limb for three treatments: 1) control, 2) uncomfortable rock surface placed on the right back (RB) unit and, 3) uncomfortable rock surface placed on the right front (RF) unit. P values are from the GLM analysis.

	Control Treatment		RB Treatment		RF Treatment	
Limb	Mean Weight (%) N = 13	SD	Mean Weight (%) N = 13	SD	Mean Weight (%) N = 13	SD
Right Front	29.0	2.6	28.7	3.4	21.0***	4.3
Left Front	25.7	2.7	26.4	3.4	32.9***	3.8
Right Back	23.0	2.4	17.7 ***	2.2	25.0*	1.6
Left Back	22.3	2.2	27.2 ***	2.4	21.1	1.1

* $P = 0.05$.

*** $P < 0.001$.

Table 5. Variation of weight (measured as the SD of the proportion of weight load) distributed on each limb for three treatments: 1) control, 2) uncomfortable rock surface placed on the right back (RB) unit and, 3) uncomfortable rock surface placed on the right front (RF) unit. P values are from the GLM analysis.

	Control Treatment		RB Treatment		RF Treatment	
Limb	Variation N = 13	SD	Variation N = 13	SD	Variation N = 13	SD
Right Front	11.22	3.43	18.07	8.50	23.79**	12.87
Left Front	11.33	3.85	17.43	8.28	21.08**	11.17
Right Back	15.36	8.93	27.19**	7.13	17.29	8.78
Left Back	16.02	9.66	24.55**	6.92	15.97	7.78

** $P = 0.01$.

Table 6. Average proportion of weight (%) distributed on the front and back limbs for three treatments: 1) control, 2) uncomfortable surface placed on the front units and, 3) uncomfortable surface placed on the back units. P values are from the GLM analysis.

	Control Treatment		Front Treatment		Back Treatment	
Limbs	Mean Weight (%) N = 15	SD	Mean Weight (%) N = 15	SD	Mean Weight (%) N = 15	SD
Front	54.0	0.98	52.8***	1.47	54.4	1.06
Back	46.0	0.98	47.2***	1.47	45.6	1.06

*** $P < 0.001$.

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Discussion

The objectives of this thesis were to develop a kinetic force platform and simulate hoof pain to understand how cows change their weight distribution while standing in response to lameness. I used uncomfortable standing surfaces to cause hoof discomfort, as this allowed for a carefully controlled within-cow test of sound cows. My results showed how cows change their weight distribution in response to discomfort, validating the use of the platform to detect discomfort. However, more work is now required to identify changes to limb loading resulting from painful hoof injuries. It is possible that the discomfort imposed in our treatments was different from the pain associated with hoof injuries. From our preliminary studies, and other research (Hood et al. 2001; O'Callaghan et al. 2003; Scott 1989), pain associated with hoof lesions is variable among animals and lesion type.

Cows were variable in how they distributed weight among their limbs, as reported previously by Rajkondawar et al. (2002). I therefore urge future researchers to evaluate changes to weight distribution within cows. As suggested by O'Callaghan et al. (2003), repeated measurements over time are likely more useful than single time-point measures. One excellent approach is to monitor a large number of animals over time and retrospectively assess changes in weight distribution in relation to known injuries (e.g. Rajkondawar et al., 2002).

My results indicate that the platform can identify weight distribution changes in response to discomfort in one or two limbs. Cows showed a contralateral relationship in limb loading, where removal of weight from one limb was associated with greater weight placed on the contralateral limb, and showed a greater ability to displace weight onto the back limbs then on the front limbs. These results may help explain the recurrent nature of many hoof injuries and the higher incidence of injuries in the back limbs (Toussaint Raven et al., 1985; Leach et al., 1998; Manske et al., 2002).

Reducing lameness depends on our ability to correctly identify lame animals, preferably during the early stages of development. To date, the methods available to producers have had variable success. Objective, valid and automated lameness identification tools will greatly improve the detection of lame cows. Such systems could be integrated with automatic milking systems, weight scales and into milking parlours. These results indicate that standing force platforms have the potential to provide reliable assessment of dairy cattle weight distribution and the changes due to hoof injuries.

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