

**Investigation of Dairy Cattle Ease of Movement on New Methyl Methacrylate Resin  
Aggregate Floorings**

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## **ABSTRACT**

### **INVESTIGATION OF CATTLE EASE OF MOVEMENT ON NEW METHYL METHACRYLATE RESIN AGGREGATE FLOORINGS**

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The objective of this dissertation was to determine the impact of four new methyl methacrylate (MMA) resin aggregate flooring types (1-4) compared to rubber and concrete controls, on dairy cow ease of movement when walking on straight and right angled corridors. Cattle ease of movement was measured using kinematics, accelerometers and visual observation of gait and associated behaviours. Stride length, swing time, stance time and hoof height for each passage were obtained from kinematic evaluation. Acceleration and asymmetry of variance were measured for each passage with accelerometers. Locomotion score and behaviours associated with lameness, such as arch back, head bob, tracking up, step asymmetry and reluctance to bear weight were visually observed. Stride length, swing time, stance time and the number of steps taken were the only variables affected by flooring type. Stride length was longer (better) on rubber when compared to concrete and MMA 1 and 2. On MMA 3 and 4, it did not differ from either rubber or concrete. Swing time was shorter (worse) on MMA 1 than on rubber, but did not differ from any other flooring. Stance time was longer (worse) on MMA 2 when compared to rubber and MMA 3, but it did not differ from any other treatment. The number of steps was higher on MMA 4 compared to rubber, but did not differ from any other treatment. Of all the MMA floors tested, MMA 3 was the only one that was consistently as good as rubber, the positive control, at promoting ease of movement.

## FORWARD

This thesis is composed of 3 chapters. The first chapter is a literature review of lameness in dairy cattle, which discusses its economic importance, some risk factors, cattle ease of movement and the effect of flooring types on cattle ease of movement. The second chapter presents the experiment of this thesis, investigating the effect of methyl methacrylate resin aggregate floorings on cattle ease of movement, in comparison to rubber and traction milled concrete. The third chapter is a general discussion, including experimental limitations and future work.

Nancy Franco-Gendron was in charge of developing the experimental protocol, setting-up, and collecting data for the experiment reported in chapter 2. She was also responsible for the statistical analysis of the data and preparation of this thesis. Dr. Renée Bergeron and Dr. Elsa Vasseur, advisor and co-advisor, supervised all steps of this work. Dr. Trevor DeVries served on Nancy Franco-Gendron's advisory committee.

Due to the labour intensity of the study, many students were hired. Hugo Racine, Jean-Michel Beaudoin and Maureen O'Brien helped with animal handling, experiment set-up during test days and video recording of the animals. Sabrina Plante helped with data analysis by gait scoring the animals. The passages scored were already preselected by Nancy Franco-Gendron and the flooring types were coded with numbers, so that the observer was unaware of treatments while gait scoring. Sabrina Plante also helped calculate the final results for the acceleration and asymmetry of variance acceleration of pre-selected passages, according to the formulas found in chapter 2.

## **DEDICATION**

To my parents,  
Manuela Franco and Michel Gendron,  
And to my grandparents,  
Iria Amaral and Manuel Franco,  
Without whom none of my success would be possible.

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## LIST OF ABBREVIATIONS

BCS – body condition score  
CI – confidence interval  
cm – centimetre  
d – day  
DCOF – dynamic coefficient of friction  
DIM – days in milk  
g – acceleration unit  
kg – kilogram  
m – metres  
mm – millimetre  
MMA - Methyl Methacrylate  
mo – month  
N – Newton  
n – number  
NRS – numerical rating score  
OD – odds ratio  
s – seconds  
SE – standard error  
SEM – standard error of mean  
VAS – visual analogue scale  
wk – week

## CHAPTER 1: GENERAL INTRODUCTION

Lameness is an abnormal and painful condition which affects cattle movement and posture (Flower et al., 2005; Huxley and Whay, 2006; Weber et al., 2013). It is a major concern affecting the welfare, health and productivity of dairy cattle. Lameness prevalence continues to be of concern, especially in intensive farming facilities, where cattle are more prone to have issues with gait, hoof health and lameness than on pasture based systems (Somers et al., 2003; Hernandez-Mendo et al., 2007; Navarro et al., 2013). Difficulties in controlling lameness seem to be related to a lack of awareness, which leads to an underestimation of the severity of the problem by dairy farmers (Higginson Cutler et al., 2015).

Lameness can be very costly to dairy producers as it reduces the longevity of the herd, milk production, and reproductive performance (Booth et al., 2004; Cha et al., 2010; Weber et al., 2013). There are many well-known risk factors that can lead to lameness. However, a major risk factor is the type of walking surface installed in free-stall farms. Floor cleanliness may be difficult to maintain on dairy farms due to constant animal movement, and manure accumulation can cause them to slip and fall as they walk within their facility (Phillips and Morris, 2000; 2001). Falls can cause limb or hoof injuries, which can lead to lameness (Phillips and Morris, 2001; Rushen and de Passillé, 2006).

There are several types of flooring available on farm, but identifying the best options may be very complex. It is important that the flooring installed brings comfort as well as traction, to ensure that it does not compromise cattle ease of movement or inflicts hoof or limb issues (Rushen and de Passillé, 2009).

This review will document the current state of research on cattle lameness by looking at its definition, causes and methods of detection. The prevalence of lameness on dairy herds and its economic impact will also be addressed. The review will then focus on one of the major risk factor for lameness, flooring type, and discuss how it affects ease of movement.

## **1.1 Lameness**

Lameness is an abnormal condition that upsets the limbs and gait of affected cattle (Flower et al., 2005). Lameness has been described as the incapability of an animal to move in a sound and continuous pace on all four limbs, with an arched back posture and impaired head carriage (Sprecher et al., 1997). Lameness has also been linked to pain, as animal posture may be altered due to the presence of hoof issues such as sole ulcers, digital dermatitis or even white line disease (O’Callaghan et al., 2003; Weber et al., 2013). Since affected cows are known to suffer with this condition, lameness has become a serious dairy welfare concern (Whay et al., 2003).

### **1.1.1. Herd Prevalence and Producer’s Perception**

In North America, it is estimated that the prevalence of lameness in free-stall facilities ranges from 24.6 % to 28.5 % (Espejo et al., 2006; Ito et al., 2010). Furthermore, there are nearly 46.4 % of the cows with hoof lesions that may be causing issues like lameness (Cramer et al., 2008). These prevalence ranges are similar to the ones found in the United States and Europe where the reported prevalence of lameness is between 22 % and 36 % (Whay et al., 2003; Klass et al., 2003; Espejo et al., 2006; Ito et al., 2010; Higginson Cutler et al., 2015).

A recent epidemiological study conducted across Canada has shown that the prevalence of lameness is high and changes depending on the type of dairy facility. Out of 237 farms evaluated, it was found that lameness prevalence was 21 % in free-stall barns with milking parlour, 25 % in tie-stalls, and 15 % in automatic milking systems (Higginson Cutler et al., 2015).

Although there are several strategies put in place to reduce the occurrence of lameness, most recommendations are not always followed, for various reasons including a lack of awareness of the problem, ignorance of the cause, or even underestimation of the severity of the issue (Leach et al., 2010b; Higginson Cutler et al., 2015). Indeed, in the Canadian survey, lameness scores estimated by producers were 1.6 to 4.1 times lower than those estimated by researchers (Higginson Cutler et al., 2015), meaning that producers appear to have difficulties estimating lameness in their herds. However, even though producers do not fully perceive the severity of the lameness problem in their herd, almost half of the producers agree that it is a moderate or a major problem (Higginson Cutler et al., 2015). In fact, 29 % of the surveyed producers selected lameness as the third highest ranked health problem they were trying to control for in their herd behind mastitis and reproduction

issues (Higginson Cutler et al., 2015). In addition, a majority of those producers considered lameness as a painful condition and were aware that their cattle may not be comfortable with such a condition (Higginson Cutler et al., 2015). A study done on the perception of producers about lameness in the UK showed that 94 % of those surveyed put a lot of emphasis on making sure that their cattle experienced no pain or suffering, and 70 % felt guilty about having lame cows in their herd (Leach et al., 2010b). This may be due to the fact that 83 % of producers ranked pride and having a healthy herd as very important to extremely important (Leach et al., 2010b). Leach et al. (2010b) reported that one of the biggest motivator triggering management or environmental changes by producers was maintaining proper public image followed by certain farm accreditations. The economic impact and negative effect of lameness on production were mentioned the most often by producers, but it was found that cost alone was not enough to motivate producers to change their facility. Although producers are knowledgeable about the causes or issues which may arise due to lameness, the lack of time and limited skilled workers make it hard for them to rapidly treat lameness (Leach et al., 2010a; Higginson Cutler et al., 2015).

### **1.1.2. Economic Importance**

Lameness can have a drastic impact on the animal itself, but also on the farm's profitability. For example, a study conducted in the United States found that the cost to treat one case of sole ulcer may be approximately \$216.07 USD, \$132.96 USD for digital dermatitis and around \$120.70 USD for foot rot (Cha et al., 2010). Greenough and Weaver (1997), have reported a total cost of \$400 USD per case. Lameness also increases the culling rate of the herd (Enting et al., 1997), which will in turn decrease its longevity (Booth et al., 2004).

There are many economic impacts associated with lameness, which may be of great concern for the producers. For instance, lameness may affect the normal functioning of the cow by impairing its reproductive ability (Weber et al., 2013). It was found that it can take up to 40 extra days to get lame cows pregnant in comparison to healthy ones (Dobson et al., 2008). Furthermore, the intensity of oestrus may be decreased by 50 % in severely lame cows, which may result in fewer ovulations (Dobson et al., 2008). In addition there was a weak interaction between lameness and reproductive performance found by Chapinal et al. (2013b) illustrating that cattle herds with higher lameness prevalence tend to have longer calving to conception intervals ( $R^2=0.09$ ) and calving intervals ( $R^2=0.07$ ).

Lameness can also affect cow production by reducing milk yield (Cha et al., 2010). Indeed, Blackie et al. (2011) found that moderately lame cows (locomotion score of 3) (Table 1.1) tend to produce 8 L less milk per day compared to non-lame ones (locomotion score of 1). Another study found that lame cows produced 0.8 to 1.5 kg/day less milk just in the first and second week following lameness diagnosis (Warnick et al., 2001). Extended over a lactation, these results suggest that lameness may have a tremendous impact on the production of cattle. However, milk loss is only 38 % of the contributor to the total cost associated with lameness; 42 % will come from the cost of treatment for digital dermatitis and 50 % from decreased fertility caused by foot rot (Cha et al., 2010). Although the economic loss caused by lameness may be drastic, it has been reported that 90 % of the cases are treatable with early detection (Cha et al., 2010).

### **1.1.3. Lameness Detection**

Normal behaviours, such as posture or gait, may be altered when animals are experiencing discomfort or pain (Anil et al., 2002). Visual scoring systems have been developed to evaluate cow lameness in free-stall (Sprecher et al., 1997; Thomsen et al., 2008; Flower and Weary, 2006; 2009) and tie-stall facilities (Leach et al., 2009; Gibbons et al., 2014). Most systems are based on a scale ranging from mild to severe (Thomsen et al., 2008).

#### *Visual Evaluation Methods*

Visual evaluation methods, such as locomotion scoring of an animal, are the most common types of lameness scoring. There are two types of visual evaluations for gait assessment: a numerical rating score (NRS) (Table 1.1) and a visual analogue scale (VAS) (Table 1.2), the latter being less commonly used in research today (Flower and Weary, 2009). Most NRS systems are based on a scale of 1 to 5, where a score of 1 indicates a sound cow and a score of 5 corresponds to a severely lame one as seen in Table 1.1 (Sprecher et al., 1997; Flower and Weary, 2006; 2009). The first NRS was developed by Manson and Leaver (1988a) using a 5 point ranking system with 0.5 intervals for each category. However, many researchers no longer use this system to rank lame cattle because it uses vague terms such as “slight”, “some” and “obvious” to describe specific behaviours, and this may lead to differences in interpretation among observers (Flower and Weary, 2009). To improve objectivity, a similar and simpler NRS system assessing only one or two behaviours has been developed. For instance, Sprecher et al. (1997) created an easy to use 5 point

scale NRS system, which consists of evaluating cattle by observing if they have an arched back while walking or standing. Another NRS system, developed by Flower and Weary (2006), combines behavioural indicators from the last two systems but includes 6 behaviours specific to lameness as detailed in Table 1.1 and 1.2. This system is the reference system used in research today, specifically in North America (Flower et al., 2005; 2007; Chapinal et al., 2011). A more complex scoring method involves video recording cows in movement and scoring them for NRS and behaviours associated with lameness. The evaluator watches the video recording twice, the first time to score each behaviour associated with lameness and the second time to give a general NRS score (Flower and Weary, 2006). This method allows for higher reliability (Flower and Weary, 2009), but is not feasible at the farm level. A simplified version of this system has already been used on farms (Ito et al., 2010; Vasseur et al., 2015), which makes it feasible to evaluate cattle in their environment (NFACC, 2009).

The VAS was originally developed for humans, allowing them to rank their pain on a horizontal continuous scale (Scott and Huskisson, 1976). This method has been modified to score lameness in animals on a continuous scale. One research team used the VAS to assess foot rot condition of sheep while they were trotting (Welsh et al., 1993). These authors argued that VAS was a more accurate method than NRS to score lameness because it uses a continuous scale instead of restricting scores to specific categories (Welsh et al., 1993). Similar VAS have been used with cows to measure behaviours associated with lameness like arch back, head bob, tracking-up, joint flexion, asymmetric gait and reluctance to bear weight (Flower and Weary, 2006) (Table 1.2). With this system, it is possible to measure the behaviours associated with lameness on a continuous scale ranging from 0 to 100 points as shown in Table 1.2.

To validate these visual evaluation methods, it is important to evaluate different gaits by comparing cows experiencing lameness pain with sound cows. Flower and Weary (2006) compared the gait of healthy cows with that of cows with sole hemorrhages and sole ulcers. They found no differences in NRS and VAS scores between healthy and sole hemorrhage cows. However, there was a difference between healthy cows (mean  $\pm$  SEM; NRS:  $3.1 \pm 0.08$ ; VAS:  $46 \pm 2$ ) and the ones suffering from sole ulcers (NRS:  $4.0 \pm 0.13$ ; VAS:  $59 \pm 3$ ). The authors also looked at behaviours associated with lameness and found no differences between healthy and sole hemorrhage cows, but found a difference between cows with sole ulcers (arch back:  $28 \pm 3$ ; head

bob  $10 \pm 2$ ; tracking up:  $26 \pm 2$ ; joint flexion:  $32 \pm 2$ ; asymmetric gait:  $27 \pm 2$  and reluctance to bear weight:  $32 \pm 2$ ) and healthy cows (arch back:  $12 \pm 3$ ; head bob  $2 \pm 2$ ; tracking up:  $7 \pm 2$ ; joint flexion:  $21 \pm 2$ ; asymmetric gait:  $18 \pm 2$  and reluctance to bear weight:  $16 \pm 2$ ). Of all the measures taken, the NRS was found to be the most effective to identify healthy cows and cows with sole ulcers, as it classified 92 % of the animals correctly (Flower and Weary, 2006).

Another way to validate a lameness scoring systems and to illustrate that lameness is in fact painful is to observe the gait of a lame cow prior to and after injection with an analgesic. Flower et al. (2008) injected various doses of ketoprofen to dairy cattle showing variation in gait. These authors found that the higher dose of ketoprofen improved the NRS score of cattle by  $0.25 \pm 0.05$  (mean  $\pm$  SEM), but not the VAS score for behaviours associated with lameness (Flower et al., 2008), suggesting that NRS is a more sensitive method to detect gait changes compared to the VAS for behaviours associated with lameness (Flower et al., 2008).

For these visual evaluation scoring systems to be useful, it is important for them to have good reliability. Reliability is defined as the extent to which a particular variable remains precise and consistent throughout scoring (Martin and Bateson, 1998). There are two types of observer reliability: inter and intra-observer reliability. Inter-observer reliability measures the score consistency between many observers, whereas intra-observer reliability measures the score consistency of one observer (Higginson Cutler, 2012; Gibbons et al., 2014). In the case of subjective measurements, it is important to verify that both inter and intra observer reliability remains constant or within acceptable range. According to Gibbons et al. (2012) inter and intra-observer reliability correlations above 70 % are considered good. However, these values may change depending on the training the observers received. For instance, Main et al. (2000), found that the inter-observer reliability of the inexperienced observers were 26 to 53 % in agreement, whereas the inter-observer reliability of experienced observers were 94 % in agreement. Furthermore, it has been shown that observer scores have a tendency to change over time (Hollenbeck, 1978). To prevent “observer drifts”, which are scoring changes due to time while live scoring animals, it may be preferable to assess certain behaviours by filming the cattle and then viewing the videos (Flower and Weary, 2009). By doing so, it is possible for researchers to quantify these drifts by re-scoring the videos at different times to better understand any inconsistencies which may have occurred during the scoring (Flower and Weary, 2009). Although

this method is suitable for research purposes, it may not be applicable in commercial situations. Simplified assessing methods have been developed to facilitate training or develop models to better detect lameness on farms (Vasseur et al., 2013; Charlton et al., 2015). With proper staff training and constant monitoring, these modified methods provide producers with an accurate tool to identify problematic cattle.

### *Kinematics*

Kinematics is the study of positional changes of certain body segments over time and does not take into consideration any forces involved in the motion (Barrey, 1999; Flower and Weary, 2009). To assess cattle gait, small reflective markers may be attached directly to the skin or to a fabric band attached around anatomical locations of the animal. The animals are filmed while walking using a high-speed video camera, which captures animal movements with the visible markers. The videos may be analyzed with a motion analysis software capable of digitizing cattle movements and calculating linear and angular displacements, velocity and acceleration for each marker (Flower and Weary, 2009). The software measures the following variables: stride length, swing time, stance time, hoof height, hoof speed, and stride duration, as defined in Table 1.3.

Stride length is the distance between two consecutive hoof strikes for the same hoof (Flower et al., 2005). A long stride length usually indicates that cow ease of movement is not compromised or has improved (Flower et al., 2005). The stride length of healthy cattle may range from 1.40 to 1.71 m, but it may vary due to cow conformation (Table 1.4). On the other hand, a cow that is lame or has poor ease of movement may have a shorter stride length ranging from 1.40 to 1.64 m, or 1.30 to 1.40 m if she suffers from sole ulcers or lesions (Table 1.4).

Swing time and stance time (Table 1.3) refer to the periods of time when a cow's hoof is respectively off and on the ground during a stride (Flower et al., 2005). In most cases, a long swing time and a short stance time are indicators of good cattle ease of movement (Flower et al., 2005; 2007). Some studies have found that healthy cow's swing time may range from 0.42 to 0.57 s (Table 1.4). Cows with impaired gait due to sole ulcer showed a higher swing time on rubber compared to concrete (Table 1.4). The stance time of healthy cattle may vary from 0.69 to 0.86 s, while the stance time of cows suffering from sole ulcers or lesions tends to be longer, ranging from 0.75 to 0.91 s, which indicates poor ease of movement while walking (Table 1.4).

Hoof height refers to the vertical distance to which the hoof is lifted while the cow is walking (Table 1.3). When a cow has no issue with her movement, her hoof will be lifted high (Flower et al., 2007). A healthy cow can lift her hoof at a height of 0.090 to 0.101 m (Table 1.4). However, a cow that is lame or suffers from sole ulcers or lesions may only reach a height of 0.070 to 0.097 m (Table 1.4).

Passage time is the time that it takes for a cow to complete a pathway, steps taken is the number of steps during each passage (Rushen and de Passillé, 2006), and stride duration is the passage time divided by the number of steps (Flower et al., 2005; 2007). The passage time of a cow walking in a pathway should be short, with few steps taken and a short stride duration (Flower et al., 2005; Rushen and de Passillé, 2006; Flower et al., 2007). It is impossible to give a specific range for passage time or number of steps taken for healthy dairy cows since very few studies have reported values for these variables so far. When calculating the speed and steps per meter taken from data obtained by Rushen and de Passillé (2006), it was found that healthy cattle took on average 0.86 to 0.93 s/m to complete a corridor measuring approximately 27 m long. Cattle also took on average 1.22 to 1.27 steps/m when walking in the corridor. However, the stride duration of healthy cattle may vary from 1.12 to 1.28 s (Table 1.4). Cows that have impaired gait or that suffer from sole ulcers or lesion will have longer stride duration, which can range from 1.09 to 1.48 s (Table 1.4).

### *Accelerometers*

Accelerometers have been validated by Chapinal et al. (2011), by placing one on each limb of dairy cows, and measuring the acceleration and the asymmetry of variance for each limb while walking. The acceleration (g) is expressed as the rate of change of velocity across limbs for a particular passage per unit of time (Chapinal et al., 2011). The asymmetry of variance is the irregular stepping pattern expressed as a percentage obtained from the accelerometers across cattle limb (Chapinal et al., 2011). Using accelerometers to observe asymmetric patterns across limbs is reliable, since Chapinal et al. (2011) found that cow asymmetry assessed by NRS and VAS was positively correlated to asymmetry of variance obtained from the accelerometer ( $r = > 0.6$ ).

It was found by Chapinal et al. (2011) that healthy cattle may have an acceleration of 1.62 to 1.67 g when walking on rubber and concrete. Many other studies have looked at cattle speed

(m/s). A healthy cow will tend to walk at a faster speed, which can range from 1.11 to 1.24 m/s, compared to a cow with an impaired gait or that suffers from sole ulcer or lesions (0.99 to 1.20 m/s) (Table 1.5). As for the asymmetry of variance, due to lack of studies, it is not possible to provide a proper range for this variable. However, cows that walk with proper symmetry among limbs will tend to have better ease of movement in comparison to cows with higher asymmetric scores (Flower et al., 2005; 2007; Chapinal et al., 2011).

#### *Locomotion Scores and Behaviours Associated with Lameness*

Based on the many studies reporting locomotion scores in cows (Table 1.6), healthy experimental animals that are not considered lame (score < 3) at the start of a trial may have a locomotion score of 2.45 to 3.0 measured on a scale of 5 points (Table 1.6). In addition, experimental cows that suffer from sole ulcers or lesions may have locomotion scores of 2.9 to 3.1 (Flower et al. 2007). Thus, cattle with a good ease of movement will tend to have lower locomotion scores.

As mentioned in the NRS section, looking at behaviours associated with lameness can be another way to assess cattle ease of movement (Table 1.2). The overlap or tracking up is measured by the gap left between the imprint of the front hoof and the new imprint formed by the rear hoof (Flower and Weary, 2006; Flower et al., 2007). Usually, a short gap distance or score indicates that a cow is walking with ease (Telezhenko and Bergsten, 2005; Flower et al., 2007; Blackie et al., 2013). Some studies found that the overlap of healthy cows may be close to 0.02 m while the tracking up score may vary from 11 to 19 (scored from a 100-unit scale) (Table 1.6). In the case where a cow has impaired gait or suffers from sole ulcers or lesions, the overlap (-0.02 to 0.05 m) and tracking up (19 to 24) may worsen (Table 1.6). Thus, shorter gap distance or lower tracking up score indicate that the cow is walking with ease.

Joint flexion, asymmetric steps and reluctance to bear weight (Table 1.2) are other variables that are easily detectable on cows with locomotion scores higher than 3 (Flower and Weary, 2006). Joint flexion is related to the flexes and extensions of the limbs while cows are walking (Flower and Weary, 2006; Flower et al., 2007). The asymmetric steps, similar to asymmetry of variance, measures the evenness of the stepping pattern of a cow (Flower and Weary, 2006; Flower et al., 2007). The reluctance to bear weight variable scores how evenly the cow distributes her weight as

she walks (Flower and Weary, 2006; Flower et al., 2007). Because very few studies measured these variables, it is not possible to give a proper range of scores for healthy and unhealthy cows. However, lower scores are desirable for these variables (Flower and Weary, 2006; Flower et al., 2007).

#### **1.1.4. Causes or Risk Factors for Lameness**

Lameness can be caused by internal and external risk factors. Internal risk factors are factors which are linked to the cow itself and external risk factors are due to management procedures or the housing environment.

##### *Internal Risk Factors*

When it comes to lameness, some cows are more susceptible than others. For instance, a recent study conducted on 141 Canadian free-stall dairies by Solano et al. (2015) found that there was a 10 % increase in lameness prevalence for cows that were in their second to third parity. These authors also found that the lowest lameness prevalence was observed when cows were in their first (< 14 %) to second (< 18 %) parity.

Another internal risk factor associated with lameness is the body condition score (BCS). Solano et al. (2015) found that 46 % of the cattle investigated with a  $BCS \leq 2$  were lame. A reason behind this association could be a reduction of feed intake, which leads to body weight loss (Espejo et al., 2006). In addition, as the cow is losing weight, the thickness of her digital cushion may decrease and make the cow more susceptible to foot lesions like sole ulcers or white line disease (Bicalho et al., 2009), which may in turn lead to lameness issues.

Injuries of all sorts are other risk factors which may cause lameness in cattle. Solano et al. (2015) found that the odds of lameness were four times higher for cows that had hock injuries than for cows without. The association between hock injury and lameness was described by Zaffino Heyerhoff et al. (2014), who reported that lame cows have difficulties lying down or standing up, which results in abrasion on hock areas. Limb injuries are very painful, and may cause cows to change the way they walk, thus making them lame (Solano et al., 2015). In addition, claw condition may also have an impact on lameness (Solano et al., 2015). For instance Manske (2002), who investigated claw length and foot lesions, found that lame cows tended to have longer, shallower

and more concave claws when compared to healthy cows. However, the conformation of the claw may vary depending on the foot lesion and individual animal (Manske, 2002). Furthermore, other studies demonstrated that 20 to 70 % of cattle gait variation was due to sole lesions (Whay et al., 1997; van Eerdenburg et al., 2003; Flower and Weary, 2006; 2009).

An additional internal risk factor for lameness in cows is milk production (Barkema et al., 1994; Hansen et al., 1979; Lucey et al., 1986), although results are not consistent across studies. Green et al. (2002) found that cows producing more milk ( $1.12 \pm 0.34$  kg/d) were more likely to become lame throughout their lactation than lower producing cows. Furthermore, a study conducted by Amory et al. (2008) found that higher producing animals were more susceptible to develop sole ulcers and white line disease. The increased risk of lameness for high producing animals may be due to nutritional demands that are not met (Green et al., 2002). In cases where there is adequate amount of high quality feed, high producing animals must stand for a long period to eat, which may increase their risk of lameness (Green et al., 2002). However, Haskell et al. (2006) did not find that higher producing animal were more likely to become lame or have leg issues, but instead suggested that lameness issues may arise from poor facility management.

#### *External Risk Factors*

Nutrition is another risk factor that can contribute to lameness. Manson and Leaver (1988a) and Bramley et al. (2008) have shown that diets with high grain levels may make dairy cattle susceptible to lameness due to acidosis problems. In addition, diets containing high levels of sugars, especially oligofructose, may also increase the risk of lameness (Danscher et al., 2009; Milinovich et al., 2006; 2008; Danscher et al., 2010). Furthermore, diets containing high protein levels may increase the risk of lameness in a herd (Manson and Leaver, 1988b). However, Bramley et al. (2008) found that diets with lower non-digestible fibre levels could reduce the risk of lameness in a herd. Thus, it is important that producers remain aware of the risk involved with a poor diet formulation (Lean et al., 2013).

Stall comfort and bedding type are factors to consider when attempting to reduce lameness incidence in the herd. For instance, when stalls are too short, head lunge space may be reduced, which affects the lying behaviour of cattle (Dippel et al., 2009). Dippel et al. (2009) found that cattle with abnormal lying behaviour were twice as likely to develop lameness due to poor stall

configuration compared to cows with no impairment in lying behaviour. Chapinal et al. (2013a) found that lameness cases were more frequent on farms using sawdust bedding (odds ratio (OD) = 1.71; confidence interval at 95 % (CI) = 1.06-2.76) and less frequent on farms that used deep bedding (OD = 0.48; CI = 0.29-0.79) or sand bedding (OD = 0.32; CI = (0.19-0.53) as these two surfaces are more comfortable to lay on, which results in increased lying time of cattle and diminishes the progression of clinical lameness (Cook and Nordlund, 2009; Ito et al., 2010). It is also important to keep the stalls clean, as stall fecal contamination has been shown to increase the risk of lameness in dairy cattle (OD = 1.15; CI = 1.06-1.25) since high bacterial load in the bedding may increase the risk of infectious disease like digital dermatitis, which can further cause lameness (Chapinal et al, 2013a).

Factors that affect cow behaviour and how they occupy space in the barn may increase the risk of lameness. Typically, the time budget of freestall cows is split between milking periods, feeding time, standing time, resting time and other activities (e.g. grooming, interacting with pen mates, etc.). On average, a cow spends 2.7 hours a day standing while waiting to be milked, 4.3 hours eating, 2.5 hours standing in the alleys, 2.7 hours standing in their stalls and 11.9 hours resting in their stalls (Gomez and Cook, 2010). Cows that spend more time standing up are more likely to become lame compared to other cows that rest more or stand up less (Bergsten and Frank, 1996) since standing on a hard surface may create stiffness in the limbs and joints of cattle (van der Tol et al., 2005; Hernandez-Mendo et al., 2007). Espejo et al. (2006) reported that cows observed in the last third of the milking order are more at risk of becoming lame since they will be standing for a longer period of time. In addition, these cows will have less time available for crucial activities like eating, drinking, socializing with pen mates and resting (Gomez and Cook, 2010). Conversely, cow time budget may be affected by lameness. For instance, some studies found that lame cows lay down more frequently and for a longer duration compared to healthy cattle (Ito et al., 2010; Gomez and Cook, 2010). In addition, lame cows may avoid standing in alleys to prevent any confrontation with other dominant cows (Proudfoot et al., 2009).

Cows that spend too much time on hard surfaces like concrete are more at risk of lameness (Telezhenko and Bergsten, 2005; Vanegas et al., 2006). In contrast, giving cows access to pasture reduces the occurrence of lameness in the herd (Navarro et al., 2013). Research has shown that cows restricted to the outdoors benefit from pasture as it is a comfortable surface to walk, stand

and lay on (Hernandez-Mendo et al., 2007). Cows on pasture improve their gait (Hernandez-Mendo et al., 2007), have better hoof health (Somers et al., 2003), and show reduced lameness (Navarro et al., 2013). Cattle with access to pasture exercise more, but also get a chance to walk on a softer surface, which releases pressure on their joints (van der Tol et al., 2005; Hernandez-Mendo et al., 2007). In North America, only organic farms are required to give cows access to pasture (Mongeon and Summerhayes, 2012), but those represent a small proportion (5.7% in 2008) of farms (AAFC, 2011). A majority of producers keep their cows inside and must make sure that they choose the flooring type that will best suit their cow's needs.

### **1.1.5. Characteristics of Good Flooring**

When installing a flooring within a facility, it is crucial to ensure that it promotes proper health and vigor, and allows cows to walk at their own pace, without fear of slipping and/or falling (Rushen and de Passillé, 2009). The flooring should be soft enough and possess compressible attributes, but should also offer good traction (Rushen and de Passillé, 2009). Soft compressible surface will allow the hooves of the cows to sink into the material, which may also provide a little traction while the cow is walking (Platz et al., 2008). In addition, adding grooving or small particles (aggregates), which can adhere to the floor surface, can increase its coefficient of friction and improve traction. Increasing floor friction may result in a reduction in slips and falls (Phillips and Morris, 2001). Clean and dry floors will also help reduce slipperiness and potential leg injuries resulting from falls (Phillips and Morris, 2001). Floor cleanliness is also essential to minimise claw health issues and reduce the transmission of infectious diseases (Hinterhofer et al., 2006). When the hooves of cattle are constantly exposed to moisture and manure, this causes the hooves to become soft, which may result in heel or sole crack, and further degrade into ulcers, abscesses or other hoof infections (Ishler et al., 1999).

### **1.1.6. Flooring Types Available on Farms**

There are many flooring options offered to producers, and those can be installed in specific locations of their free-stall dairy facility, such as alleys, milking parlour and waiting areas. One of the most commonly found flooring options in Canadian free-stall dairies is concrete (found mostly in parlours at 67 %, holding pens at 65 %; Solano et al., 2015). Concrete flooring may have a tendency to become too slippery when wet or when it has been worn due to scrapers or animal

movements (Philips and Morris, 2000; 2001; van der Tol et al., 2005). This could be fixed by adding some texture (via aggregates) or grooving on it; however some textures may be too slippery (low friction) or too rough (high friction), and therefore it is important to select a texture or grooving that will best suit the desired flooring function (Barnes, 1989; Gooch, 2003).

Concrete may be given various textures once it has been poured on the ground. A producer may choose to have a tamped finish (Figure 1.1 A), which is done once concrete has been compacted (Gooch, 2003). A notched tamper is lifted and dropped at intervals of 20 to 40 mm from the length of the slab (Barnes, 1989). This flooring texture is very suitable in areas frequently used by cattle (Gooch, 2003). Producers may also choose to have grooved concrete (Figure 1.1 C) in their facility. Grooves may be created on the surface of the concrete using a large wooden float (Figure 1.1 B), which has different length of V-belting on it (Barnes, 1989). The spacing, depth and the width of the grooves created may change, but it is preferable to make the grooving in the travel direction of the cleaning scrapers to improve flooring drainage and to reduce wear (Barnes, 1989). Producers may also choose to have concrete flooring with a brush finish (Figure 1.1 D), which is created with a bass broom (Barnes, 1989). However, this texture is not recommended in areas where cows will frequently walk on as it may be too smooth (Barnes, 1989). Despite this, it is ideal in alleys for wheeled vehicles or even to install in cow cubicles and other resting areas (Barnes, 1989). Sprinkling small particles of silicon carbide or aluminium oxide onto concrete, or mixing them in can make this surface more slip-resistant (Barnes, 1989; Gooch, 2003).

Another flooring option is slatted concrete. Some producers like to install this type of flooring in their facility because of its self-cleaning property, making it easier to manage floor cleanliness (Platz et al., 2008). However, slatted concrete floors may put too much strain on cow claws (van der Tol et al., 2003) when walking, which could in turn increase the risk of laminitis or claw horn lesions (Cook et al., 2004a). This flooring may be improved by the addition of rubber slatted mats, which are more comfortable while maintaining the self-cleaning property (Platz et al., 2008). A study conducted by Platz et al. (2008) found that cows walking on rubber slats were expressing more natural behaviours like mounting (112 observations) compared to cows walking on slatted concrete (23 observations). The cows were also more confident on this flooring type, as shown by their increased incidence of grooming on three legs on the rubber slatted floor (511 observations) compared to slatted concrete (105 observations) (Platz et al., 2008). Although slatted

floors help to improve hygiene due to their self-cleaning attributes, solid floors tend to be better over slatted floors as they evenly distribute the stress on the claws when cows are walking, which may improve locomotion (Hinterhofer et al., 2006; Platz et al., 2008).

Solid rubber flooring has become a common alternative option over bare concrete, since there has been an increase of this floor type in the last twenty years (found in parlours at 33 %, holding pen at 27 %, Solano et al., 2015) (USDA, 2009). Rubber may improve dairy cattle comfort (Rajapaksha et al., 2015) due to its compressible attribute, which tends to provide cattle with a more secure footing (Platz et al., 2008). Cow hooves are also able to sink in this surface, which also provides traction while walking (Platz et al., 2008). In addition, it was found by Vanegas et al. (2006) that softer surfaces, like rubber, may reduce the pressure on the claws and potentially improve cow comfort, and thus reduce the incidence of lameness. Furthermore, cows have less claw wear on rubber mats (2.80 mm/month) in comparison to concrete (3.21 mm/months) (Vanegas et al., 2006). Thus, rubber may be a better flooring choice to minimize hoof wear. However, rubber mats in combination with manure slurry or improper scraping management may increase slips and/or falls as the surface becomes slippery (Phillips and Morris, 2000; 2001). It is very difficult to maintain a dry floor even with the best cleaning practices due to the constant movement of cattle leading to manure accumulation in free-stall alleys (Magnusson et al., 2008).

#### **1.1.7. Flooring and its Impact on Cattle Ease of Movement**

Cattle ease of movement is related to the ability of the animal to walk around on a particular floor surface without any fear of slips and/or fall and without having to change its normal gait (Boyle et al., 2007). Compressible (Rushen and de Passillé, 2006) and slip resistant flooring (Phillips and Morris, 2001) may improve certain gait attributes in contrast to slippery floors, which may worsen cattle ease of movement (Philipot et al., 1994; Jungbluth et al., 2003; Telezhenko and Bergsten, 2005). Many studies have been conducted to investigate the impact of flooring type, such as rubber and concrete, on cattle gait, using both sound and lame animals to look at interactions between flooring and foot health.

To investigate cattle movement and how it is influenced by flooring, many of the same methods and variables commonly used to assess lameness have been applied to cows walking on

various floor surfaces. Most studies looked at the difference between rubber and concrete, which are the most common flooring types installed on farms (Table 1.4).

### *Kinematics*

Telezhenko and Bergsten (2005), investigated the impact of rubber and concrete flooring (slatted and continuous), on the stride length of sound cattle (Table 1.4). These authors found that sound cows had longer stride length on slatted rubber (1.48 m) compared to slatted concrete (1.33 m) (Telezhenko and Bergsten, 2005). For solid rubber and concrete, a study found that stride length of cattle was longer on rubber (1.57 m) compared to concrete (1.52 m) indicating that cattle were more at ease walking on a compressible surface like rubber (Flower et al., 2007) (Table 1.4). Phillips and Morris (2001), investigated cow's ease of movement on floors with different coefficients of friction, and found that cows walking on aggregated flooring surfaces tended to have longer stride length (1.37, 1.35 and 1.36 vs. 1.30 m) and a lower stepping rate (0.61, 0.60, 0.59 vs. 0.65 step/s) in comparison to cattle walking on a smooth surface.

Swing time and stance time are variables for which it may be harder to find differences strictly due to flooring. For instance, it was found that neither swing time (0.42 s) nor stance time (0.85 s) of healthy cattle differed between cows walking on rubber and concrete (Flower et al. 2007) (Table 1.4). However, when cattle were lame due to sole ulcer, their stance time was longer (0.91 s) in comparison to healthy cattle (0.69 s) (Flower et al., 2005). Thus, it is possible that these variables only change depending on the health condition of the animal. Phillips and Morris (2001) reported that as the flooring coefficient of friction increases above 0.5, cattle swing time may be larger at the expense of the stance time.

Few studies have looked at hoof height in dairy cattle. For example, Flower et al. (2007), found that healthy cows lift their hooves 0.014 meters higher on rubber mats compared to concrete (Table 1.4). When they compared the two floors using cows with hoof issues, they found no differences between flooring types, although cows with sole ulcer tended to show higher hoof height on rubber (Flower et al., 2007). However, an earlier study conducted by Flower et al. (2005) found that cows suffering from sole ulcers lifted their hoof 0.09 meters lower when walking in comparison to healthy cattle (Table 1.4). Blackie et al., (2013) compared this variable among cows with different locomotion scores (Table 1.4) and found no differences in hoof height between cows

with locomotion scores varying from 1 to 3. Due to the lack of a clear association between foot height and cattle movement, this may be another variable that is more influenced by lameness than flooring type.

The time taken by a cow to walk on a corridor, or passage time, and the number of steps taken have been used by Rushen and de Passillé (2006) to assess ease of movement and lameness. These authors investigated cattle gait by observing how cows would walk in a corridor with turns and obstacles, and found that cows took 1.3 fewer steps and 1.8 less seconds to complete a corridor when walking on rubber in comparison to concrete (Table 1.4). They also observed cow gait on PastureMats (compressibility: 10.11 N/cm<sup>2</sup>) and felt (5.23 N/cm<sup>2</sup>), two materials more compressible than rubber (2.05 N/cm<sup>2</sup>). Cows walking on PastureMats, took 1.4 fewer steps and 2.8 less seconds to complete the passage when compared to concrete. Cows took 9 more seconds to turn on felt when compared to concrete. Although there were more positive effects on cattle ease of movement when cattle were walking on the PastureMat, cattle locomotion was not compromised or worsened when walking on rubber mats. This suggests that the compressibility offered by rubber mats may be enough to promote cattle ease of movement.

Concerning stride duration, a study completed by Flower et al. (2007) observed healthy and unhealthy cows walk on rubber and concrete flooring. These authors could not conclude anything with their results for stride duration as there were no change due to flooring type or health condition of cattle (Flower et al., 2007) (Table 1.4).

### *Accelerometers*

Chapinal et al. (2011) used accelerometers to determine changes in acceleration and asymmetry of variance of cattle walking on rubber and concrete surfaces. These researchers found that cows' acceleration and speed was higher (0.05 g and 0.06 m/s more) when walking on rubber compared to concrete flooring (Chapinal et al., 2011) (Table 1.5). However, when looking at the asymmetry, they were unable to find any differences between flooring surfaces (Table 1.5). Telezhenko and Bergsten (2005) conducted a similar study where they were looking at the speed (m/s) of healthy and unhealthy cattle when walking on slatted and continuous rubber and concrete floors (Table 1.5). These authors found that cattle walking on slatted rubber were walking at a faster pace (0.09 m/s more) in comparison to slatted concrete, and they obtained similar results for

the continuous surface (Table 1.5). When looking at gait score differences, they found that cows with a gait score of 2 were walking at a slower rate (0.12 m/s less) compared to cows with normal gait (score of 0) (Table 1.5). Flower et al. (2007) also compared the speed of healthy and unhealthy cattle on rubber and concrete floorings and reported that cows had higher acceleration walking on the rubberized surface (0.05 m/s more) in comparison to concrete, which is similar to the findings of other studies (Table 1.5). However, when looking at cows with sole ulcers and cows without, the speed was not affected (Flower et al., 2007).

### *Locomotion Scores and Behaviours Associated with Lameness*

When scoring the locomotion of cattle or their behaviours associated with lameness, either by using a 5 point or 100 point scale (Table 1.1 or 1.2), higher scores indicate that cows have issues with their ease of movement (Flower et al., 2007; Chapinal et al., 2011). Cows walking on rubber had a better locomotion score (0.1 to 0.3 points of improvement) compared to when walking on concrete (Flower et al., 2007; Chapinal et al., 2011) (Table 1.6). However, rubber flooring did not improve the locomotion score of cows with sole ulcers (Flower et al., 2007). Differences in behaviours associated with lameness are not easily detectable when cattle are not severely lame. For instance, posture of the back or the carriage of the head while walking are most pronounced when a cow has a locomotion score above 3 (Table 1.1) (Flower and Weary, 2006). This may explain why Flower et al. (2007) did not find any difference in arch back and head bob for both healthy cows and cows with sole ulcers when walking on rubber compared to concrete flooring (Table 1.6).

The overlap distance and tracking up score may also fluctuate depending on what flooring type the cows are walking on. For instance, a study done by Telezhenko and Bergsten (2005), evaluated the overlap of cows walking on rubber and concrete flooring, either slatted or solid. They found that cows had a better overlap length when walking on the slatted rubber surface (-0.017 m) in comparison to the slatted concrete (-0.11 m) (Table 1.6). The overlap distance was also improved on the continuous rubber (0.002 m) in comparison to solid concrete (-0.04 m) (Table 1.6). When comparing the overlap distance to the tracking up score, Flower et al. (2007), found that cattle had better tracking up scores on rubber compared to concrete (score of 15.0 vs. 19.5), which supports Telezhenko and Bergsten's (2005) finding. When comparing healthy cows to the

ones with sole ulcers, Flower et al. (2007) found that healthy cows had better tracking up than unhealthy animals (13.0 vs. 21.5) (Table 1.6).

Flower et al. (2007) also found that cows had a better joint flexion (improvement of 4 points) and asymmetric steps (improvement of 3.5 points) when walking on rubber flooring compared to concrete (Table 1.6). Similarly, Chapinal et al. (2013a) observed that cows obtained lower scores for asymmetry of steps (18.0 vs. 23.1; measured on a 100-unit scale) on rubber compared to concrete. When Flower et al. (2007) compared these results with cows who suffered from sole ulcers, they found that cows had a better joint flexion on rubber than concrete (score of 29 vs. 33). Furthermore, the authors also noticed that healthier animals had better step asymmetry and less reluctance to bear weight scores on rubber and concrete when compared to compromised animals (Table 1.6).

### **1.1.8. Flooring and its Impact on Hoof Health**

Given that 90 % of lameness cases are caused by hoof issues such as sole ulcers or lesions (Bergsten, 2001), and that approximately 300 kg of milk is lost per year per cow because of hoof injuries (Warnick et al., 2001), it is important to ensure good hoof health in dairy cattle.

A flooring that is too rough for cattle hooves can lead to excessive wear, creating issues such as sole ulcers or lesions (Vermunt and Greenough, 1996; Hultgren and Bergsten, 2001; Somers et al., 2003). It has been shown that concrete flooring may increase the incidence of hoof lesions and hoof wear compared to softer surfaces like rubber, dirt or straw (Vermunt and Greenough, 1996; Hultgren and Bergsten, 2001; Somers et al., 2003). Vanegas et al. (2006) observed heel erosion rate of cattle during three experimental periods and found that cows on concrete were more likely to see no improvements or have a worse condition in follow-up examination, especially when comparing the first period (odds ratio of 3.6; 95 % CI = 1.45 to 9.14) with the third (3.9; 95 % CI = 1.53 to 10.2). Similarly, Boyle et al. (2007) found that cattle housed on concrete had higher heel erosion scores 7 weeks post-partum compared to cattle that were placed on rubber ( $5.7 \pm 0.31$  vs.  $4.6 \pm 0.31$ ).

Barker et al. (2009) found that the odds of white line disease and digital dermatitis increased respectively from 1.00 to 2.94 (95 % CI = 0.88 to 9.78) and 1.00 to 1.32 (95 % CI = 0.19 to 9.39) when cattle were housed on solid grooved concrete in comparison to slatted concrete. The

increase of white line disease and digital dermatitis on slatted flooring may be due to uneven pressure and force distribution on the claw capsule, meaning that the claw is partially supported when cattle walk (Hinterhofer et al., 2006). However, Ahrens et al. (2011) found that the score for white line disease increased on slatted rubber compared to slatted concrete ( $2.5 \pm 0.4$  vs.  $1.0 \pm 0.3$ ) 10 months after a flooring transition was made. It is thought that rubber's higher deformability, and increased cow activity and mobility on rubber compared to concrete may have aggravated the white line disease (Platz et al., 2008; Ahrens et al., 2011).

Some flooring options, like rubber for instance, may help cows suffering from sole ulcers improve their ease of movement. For instance, it was shown by Flower et al. (2007) that cows with sole ulcers improved their gait when walking on rubber compared to concrete. They walked at a faster pace ( $1.22 \pm 0.04$  vs.  $1.17 \pm 0.04$  m/s), had longer stride length ( $1.57 \pm 0.026$  vs.  $1.50 \pm 0.026$  m) and had higher hoof height ( $0.097 \pm 0.3$  vs.  $0.088 \pm 0.3$  m). Furthermore, unlike concrete ( $3.21$  mm/mo), soft surfaces like rubber, may decrease claw wear ( $2.80$  mm/mo), which may be beneficial for proper claw health (Vanegas et al., 2006). However, as mentioned earlier, the benefits of rubber or even concrete, are easily offset once the flooring is wet due to slurry.

### **1.1.9 Conclusions**

In conclusion, lameness is a prevalent condition, which has a tremendous impact on the production and welfare of cows. To control lameness, it is crucial to better understand the major causing factors. This will help provide producers with more specific and suitable solutions to reduce lameness on farms. Among the many risk factors for lameness, poor flooring seems to be a main concern in free stall facilities. More research is needed to test new flooring types with the potential to address issues of slips and falls on farm, by providing the right combination of aggregate and comfort properties.

### **1.1.10. Thesis Objectives**

The main objective of this thesis was to investigate the effect of a new flooring technology on cattle ease of movement. The specific objectives were:

1. Develop a protocol to evaluate ease of movement based on kinematics, accelerometers, and visual observation
2. Compare the influence on cow ease of movement of four MMA floors with different degrees of abrasiveness with that of two control floors (rubber and concrete) in both a straight and a right angle turn configuration

It was hypothesized that cows walking on the MMA surfaces will have a better ease of movement than when walking on the traction milled concrete, but show an ease of movement similar to when walking on rubber.

Franco-Gendron, Table 1.1

**Table 1.1.** Numerical rating score (NRS) for dairy cattle locomotion: score (ranging from 1 to 5), category, description and associated behaviours.

Score	Category <sup>2</sup>	Description <sup>1</sup>	Associated behaviours <sup>1</sup>
1.0	Normal/Sound	Smooth and fluid movement	Flat back Steady head carriage Hind hooves track up with front hooves Joints flex freely Symmetrical gait All legs bear weight equally
2.0	Mildly lame	Imperfect locomotion but ability to move freely not diminished	Flat or mildly arched back Steady head carriage Hind hooves do not track up perfectly Joints slightly stiff Slightly asymmetric gait All legs bear weight equally
3.0	Moderately lame	Capable of locomotion but ability to move freely is compromised	Arched back Steady head carriage Hind hooves do not track-up Joints show signs of stiffness Asymmetric gait Slight limp can be discerned
4.0	Lame	Ability to move freely is obviously diminished	Obvious arched back Head bobs slightly Hind hooves do not track-up Joints are stiff and strides are hesitant Asymmetric gait Reluctant to bear weight on at least one limb but still uses that limb in locomotion
5.0	Severely lame	Ability to move is severely restricted and must be vigorously encouraged to move	Extremely arched back Obvious head bob Poor tracking-up with short strides Obvious joint stiffness characterized by lack of joint flexion with very hesitant and deliberate strides Asymmetric gait Inability to bear weight on one or more limbs

<sup>1</sup> Description and associated behaviours based on Sprecher et al. (1997); Flower and Weary (2006, 2009).

<sup>2</sup> These categories can be further grouped into sound (score 1 to 2), intermediate (score 3) and lame (4 to 5).

**Table 1.2.** Visual analogue scale (VAS) for dairy cattle locomotion: behaviour, definition and endpoints (ranging from 0 to 100).

Behaviour	Definition <sup>1</sup>	Endpoints <sup>1,2</sup>	
		0	100
Arch back	The shape of the spine when the cattle walks where a score of 0 is a flat spine and a score of 5 demonstrates a convex arch between the withers and tailbone	Flat spine	Convex arch between the withers and tailbone
Head bob	The movement of the head when the cattle walks where a score of 0 illustrates a steady and even head carriage and a score of 5 is a pronounced and uneven head movement	Steady and even head carriage	Pronounced, uneven head movement
Tracking-up / Overlap	It is the gap between the imprint left behind the front hoof and the new imprint formed from the rear hoof	Hind hoof falls in imprint left by the front hoof	Hind hoof falls short of imprint left by the front hoof
Joint flexion	Related to the flexes and extensions of the limb while the cow is moving	Flexes and extends limbs through the normal range of motion	Limited flexion and extension resulting normal range of motion in stiffness
Asymmetric gait	How even the stepping pattern of a cow is	Rhythmic 4-beat hoof placement	Arrhythmic hoof placement
Reluctance to bear weight	How evenly the cow distributes her weight when walking	Bears weight equally over all legs	Uneven weight bearing among legs

<sup>1</sup> Description and endpoints based on Flower and Weary, 2006.

<sup>2</sup> These are scored on a 100-unit continuous scale where a score of 0 represents a sound behaviour and a score of 100 is severely impaired behaviour.

**Table 1.3.** Definition of kinematic variables obtained from hoof movement of dairy cattle.

<b>Variable</b>	<b>Definition<sup>1</sup></b>
Stride length, m	Horizontal displacement of two consecutive hoof strikes for the same hoof
Hoof height, m	Maximum vertical displacement of two consecutive hoof strikes for the same hoof
Stride duration, s	Time interval between two consecutive hoof strikes for the same hoof
Stance time, s	Duration the hoof is in contact with the ground
Swing time, s	Duration the hoof is in the air
Hoof speed, m/s	Stride length/stride duration
Passage time, s	Time taken to complete a passage
Steps taken, steps	Number of steps taken to complete a passage

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<sup>1</sup> Definitions based on Flower et al., 2005

Franco-Gendron, Table 1.4

**Table 1.4.** Summary table of impact of flooring type and health condition on kinematic variables in dairy cattle.

Variable <sup>3</sup>	Health Condition <sup>1</sup>			Flooring Type <sup>2</sup>			Reference	
	Healthy	Unhealthy	P	Rubber (R)	Concrete (C)	P <sup>4</sup>		
Stride Length (m)	Gait score of 0: 1.55	Gait score of 1: 1.52 Gait score of 2: 1.40	n.s. < 0.05	Slatted: 1.48 Continuous: 1.54	Slatted: 1.33 Continuous: 1.49	< 0.05 < 0.05	Telezhenko and Bergsten, 2005	
	1.40	Sole ulcer: 1.30 Sole lesions: 1.40	< 0.05 n.s.	Floor comparison not made			N/A	Flower et al., 2005
	1.54	1.53	n.s.	1.51	1.57	0.001	Flower et al., 2007	
	Gait score of 1: 1.71	Gait score of 2: 1.64 Gait score of 3: 1.54	n.s. < 0.05	Floor comparison not made			N/A	Blackie et al., 2013
Swing Time (s)	0.57	Sole lesions: 0.55 Sole ulcer : 0.57	n.s. n.s.	Floor comparison not made			N/A	Flower et al., 2005
	Healthy on R: 0.42 Healthy on C: 0.42 Sole ulcer on R: 0.43 Sole ulcer on C: 0.41			P = 0.037			Flower et al., 2007 <sup>5</sup>	
Stance Time (s)	0.69	Sole lesions: 0.75 Sole ulcer: 0.91	n.s. 0.001	Floor comparison not made			N/A	Flower et al., 2005
	0.86	0.88	n.s.	0.87	0.86	n.s.	Flower et al., 2007	

Foot Height (m)	0.096	Sole lesions: 0.097	n.s.	Floor comparison not made		N/A	Flower et al., 2005
		Sole ulcer: 0.087	< 0.05				
	0.101	0.093	0.019	0.102	0.092	0.001	Flower et al., 2007
Gait score of 1: 0.09		Gait score of 2: 0.08	n.s.	Floor comparison not made		N/A	Blackie et al., 2013
		Gait score of 3: 0.07	n.s.				
Steps Taken (no.)	Health comparison not made		N/A	33.0	34.3	< 0.001	Rushen and de Passillé, 2006
Passage Time (s)	Health comparison not made		N/A	23.2	25.0	< 0.001	Rushen and de Passillé, 2006
Time/Step or Stride Duration (s)	1.26	Sole lesions: 1.30	n.s.	Floor comparison not made		N/A	Flower et al., 2005
		Sole ulcers: 1.48	< 0.001				
	1.28	1.30	n.s.	1.29	1.29	n.s.	Flower et al., 2007
Gait score of 1: 1.12		Gait score of 2: 1.09	n.s.	Floor comparison not made		N/A	Blackie et al., 2013
		Gait score of 3: 1.31	n.s.				

<sup>1</sup> Cows with different gait scores were measured on a 5 point scale. Cattle with a score of 1 to 2 were classified as sound, 3 as intermediate, 4 and 5 as lame. Telezhenko and Bergsten (2005) used a different scoring system which ranged from 0 to 4.

<sup>2</sup> Flooring was a continuous type unless specified otherwise.

<sup>3</sup> Units of each variable are included in the brackets.

<sup>4</sup> Significance of the differences between treatment on left and treatment on the right, within the same cell and the same line.

<sup>5</sup> Reported differently due to significant interaction.

Franco-Gendron, Table 1.5

**Table 1.5.** Summary table of impact of flooring type and health condition on acceleration variables in dairy cattle.

Variable <sup>3</sup>	Health Condition <sup>1</sup>			Flooring Type <sup>2</sup>			Reference
	Healthy	Unhealthy	<i>P</i>	Rubber (R)	Concrete (C)	<i>P</i> <sup>4</sup>	
Speed (m/s)	Gait scores of 0: 1.11	Gait score of 1: 1.05 Gait score of 2: 0.99	n.s. < 0.05	Slatted: 1.06 Continuous: 1.01	Slatted: 0.97 Continuous: 1.08	< 0.05 < 0.05	Telezhenko and Bergsten, 2005
	1.24	1.20	n.s.	1.24	1.19	0.004	Flower et al., 2007
	Health comparison not made			1.28	1.22	0.03	Chapinal et al., 2011
Acceleration (g)	Health comparison not made			1.62	1.67	0.01	Chapinal et al., 2011
Asymmetry of Variance Acceleration (%)	Health comparison not made			14.0	13.5	n.s.	Chapinal et al., 2011

<sup>1</sup> Cows with different gait scores were measured on a 5 point scale. Cattle with a score of 1 to 2 were classified as sound, 3 as intermediate, 4 and 5 as lame. Telezhenko and Bergsten (2005) used a different scoring system which ranged from 0 to 4.

<sup>2</sup> Flooring was solid unless specified otherwise.

<sup>3</sup> Units of each variable are included in the brackets.

<sup>4</sup> Significance of the differences between treatment on left and treatment on the right, within the same cell and the same line.

Franco-Gendron, Table 1.6

**Table 1.6.** Summary table of impact of flooring type and health condition on gait and associated behaviours in dairy cattle.

Variable <sup>3</sup>	Health Condition <sup>1</sup>			Flooring Type <sup>2</sup>			Reference
	Healthy	Unhealthy	<i>P</i>	Rubber (R)	Concrete (C)	<i>P</i> <sup>5</sup>	
Locomotion Scores <sup>4</sup>	2.45	3.00	0.003	2.65	2.80	0.010	Flower et al., 2007
	Health comparison not made			2.3	2.6	< 0.001	Chapinal et al., 2011
Arch Back	10.0	12.5	n.s.	11.5	11.0	n.s.	Flower et al., 2007
Head Bob	5	5	n.s.	5.5	4.5	n.s.	Flower et al., 2007
Overlap (m)	Gait score of 0: 0.02	Gait score of 1: 0.05	< 0.05	Slatted: -0.017	Slatted: -0.11	< 0.05	Telezhenko and Bergsten, 2005
		Gait score of 2: -0.11	< 0.05	Continuous: 0.002	Continuous: -0.04	< 0.05	
	Gait score of 1: 0.02	Gait score of 2: -0.02	n.s.	Floor comparison not made			N/A
		Gait score of 3: -0.03	n.s.				
Tracking Up	13.0	21.5	0.008	15.0	19.5	0.001	Flower et al., 2007
Joint Flexion	25	31	0.23	26	30	0.003	Flower et al., 2007
Asymmetric Steps	24.0	33.5	0.006	27.0	30.5	0.016	Flower et al., 2007
	N/A	N/A	N/A	18.0	23.1	0.02	Chapinal et al., 2011
Reluctance to Bear Weight	6.5	14.0	0.009	9.0	11.5	0.022	Flower et al., 2007

<sup>1</sup> Cows with different gait scores were measured on a scoring system with 5 categories. Cattle with a score of 1 to 2 were classified as sound, 3 as intermediate, 4 and 5 as lame. Telezhenko and Bergsten (2005) used a different scoring system which ranged from 0 to 4.

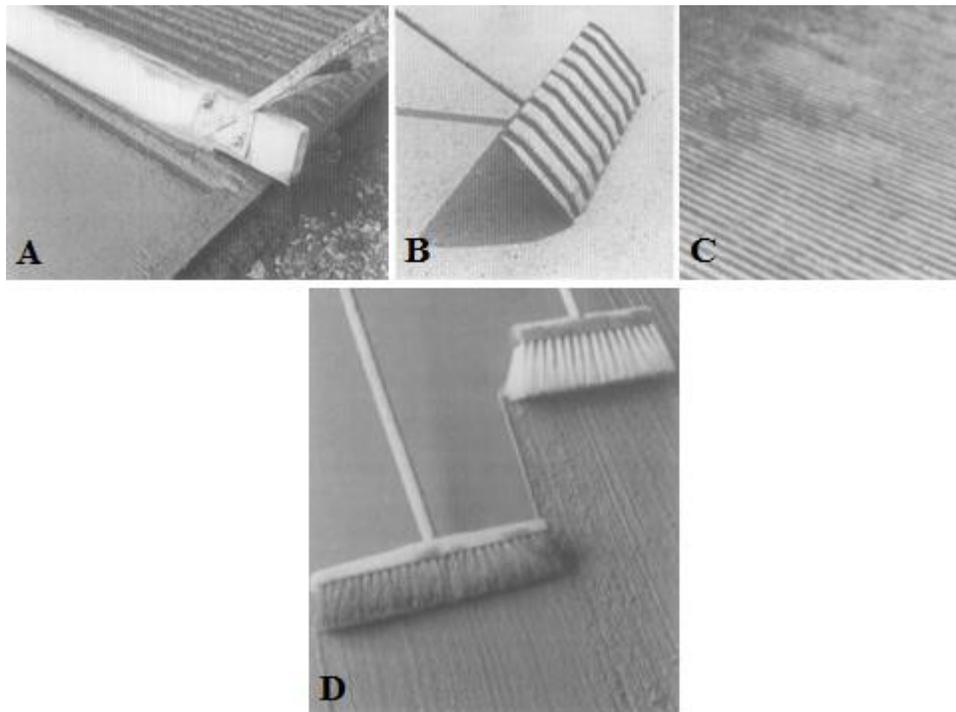
<sup>2</sup> Flooring was solid unless specified otherwise.

<sup>3</sup> Units of each variable are included in the brackets.

<sup>4</sup> Significance of the differences between treatment on left and treatment on the right, within the same cell and the same line.

Franco-Gendron, Figure 1.1

**Figure 1.1.** Examples of concrete texture or grooving available on free-stall dairies.<sup>1</sup>



<sup>1</sup> Pictures obtained from Barnes, 1989; tamped texture (A), tool used to groove concrete (B), grooved concrete (C) and floor texture obtained from brushes (D)

## **CHAPTER 2: INVESTIGATION OF DAIRY CATTLE EASE OF MOVEMENT ON NEW METHYL METHACRYLATE RESIN AGGREGATE FLOORINGS**

### **2.1 Introduction**

Lameness is a major concern in dairy cattle, affecting between 24.6 and 28.5 % of animals in free-stall facilities (Espejo et al., 2006; Ito et al., 2010). Lameness is known to be a painful condition that affects animal welfare and causes significant economic losses for producers (Warnick et al., 2001; Vermunt, 2007). It is the second most costly health condition, following mastitis (Kossaibati and Esslemont, 1997; Greenough and Weaver, 1997; Cha et al., 2010). Cows that are lame have a tendency for a reduction in milk yield (Cha et al., 2010), a lower body condition score (Peake et al. 2011), and impaired reproductive abilities (Weber et al., 2013). Lameness also increases the culling rate of the herd (Enting et al., 1997), which will in turn decrease its longevity (Booth et al., 2004).

Many environmental factors can have an impact on the incidence of lameness on farms. Possible risk factors include stall comfort and dimensions (Charlton et al., 2015), bedding type (Chapinal et al., 2013a), infrequent exercise (Popescu et al., 2013) and flooring type (Cook et al., 2004b; Rushen and de Passillé, 2006). The most common type of flooring found on Canadian free-stall dairies is concrete (Solano et al., 2015). However, rubber has become an increasingly popular alternative over the last 20 years (USDA, 2009).

Both rubber and concrete, when covered in manure slurry or not properly scraped, may become slippery, which may increase the risk of slips and/or falls and cause injuries (Phillips and Morris, 2001; Rushen and de Passillé, 2006). Slippery floors may also alter cattle ease of movement (Flower et al., 2005; Flower and Weary, 2006; Flower et al., 2007; Flower and Weary, 2009) making it more difficult for cattle to move around within their facility (Aland and Banhazi, 2013). Kinematic variables like stride length, swing time, stance time, and hoof height, may differ when healthy or compromised cattle walk on either rubber or concrete flooring (Flower et al., 2005; 2007; Blackie et al., 2013). These measures may thus indicate whether or not a surface is adequate for cattle to walk on. Furthermore, inadequate flooring may reduce walking speed, and negatively affect

locomotion scores and behaviours associated with lameness (Telezhenko and Bergsten, 2005; Flower et al., 2007; Chapinal et al., 2011). Adding small particles (aggregates), which adhere to floor surface provides animals with better traction due to an increased coefficient of friction, and can improve stride length, speed, swing time, stance time and overall cattle locomotion (Phillips and Morris, 2001; Rushen and de Passillé, 2006).

The purpose of the study was to investigate cattle ease of movement on four new types of methyl methacrylate (MMA) floorings to see how they would compare to a positive and a negative control flooring. Rubber was chosen as the positive control because it is a much more compressible surface (Rushen and de Passillé, 2006), which brings more comfort to cattle by reducing pressure on the limbs and joints (van der Tol et al., 2005; Hernandez-Mendo et al., 2007). Concrete on the other hand, is a harder surface with little compressibility (Rushen and de Passillé, 2006), and thus was considered as a negative control. However, depending on its finish, concrete may offer more friction than rubber, which may decrease the incidence of slips on wet flooring (Telezhenko and Bergsten, 2005). Our hypothesis is that cow ease of movement when walking on the MMA surfaces will be better than when walking on traction milled concrete, and at least as good as when walking on rubber.

## **2.2 Materials and Methods**

### *2.2.1 Animals*

A total of 18 Holstein cows were selected from the Organic Dairy Research Farm at the University of Guelph - Alfred Campus (Alfred, Ontario, Canada). The cows were housed in a free-stall facility and were cared for according to the standards and guidelines of the Canadian Council on Animal Care (2009). The experimental protocol was approved by the University of Guelph Animal Care Committee. Only sound and healthy animals were enrolled in the study. The 2 most recent hoof trimming reports (2 and 9 months prior to the study) were consulted to select cows without any hoof disease or hoof injury, and a visual gait scoring was done by one trained observer while cows were walking on a sand path, to make sure none were clinically lame (none with numerical rating system (NRS)  $\geq$  4 as described by Flower and Weary (2006)). The selected cows had a parity range of 1 to

6 (parity 1: n = 6 cows; parity 2: n = 5; parity 3: n = 3; parity  $\geq$  4: n = 4) to maximize the chance that cows had different gait scores, since parity influences gait as observed by Chapinal et al. (2009). The experimental cows were all  $\geq$  122 DIM (mid lactation: 122-198 DIM, n = 6 cows; late lactation: 208-291 DIM, n = 7; and dry  $\geq$  305 DIM n = 5) at the beginning of the trial.

### *2.2.2 Flooring Types*

Two control flooring types, rubber mats, 1.9 cm thick (Animat Inc., Saint-Élie d'Orford, QC, Canada), and traction milled concrete (Agri-Trac, Woodstock, ON, Canada) were chosen, as they are the common types of flooring found in dairies in North America (concrete found mostly in parlours at 67 %, holding pens at 65 % and rubber found in parlours at 33 %, holding pens at 27 %) (USDA, 2009; Solano et al., 2015). These controls were compared with 4 concrete based aggregated methyl methacrylate (MMA) coated floorings with high degrees of friction: MMA 1 (0.7-1.2 mm quartz, 1 seal coat), MMA 2 (0.7-1.2 mm quartz, 2 seal coats), MMA 3 (0.4-0.8 mm quartz, 1 seal coat) and MMA 4 (0.4-0.8 mm quartz, 2 seal coats) (SureBond Safe Floors, Calgary, AB, Canada). The dynamic coefficients of friction (DFCO) provided by the manufacturer decreased from MMA 1 to 4 and were all higher than the coefficients of friction reported in the literature for the two controls (Table 2.1).

### *2.2.3 Flooring Configurations*

Test corridors were built with concrete paving slabs (61  $\times$  61 cm), traction milled or covered with the various MMA resin aggregate surfaces. Rubber mats were laid directly on the floor of the test arena. Two corridor configurations were tested for each flooring type: straight (1.2 m wide  $\times$  9.1 m long) and right-angled with a 90° angle (1.2  $\times$  5.5 m entering and 1.8  $\times$  4.9 m in the angle) (Figure 2.1). Two corridors (corridor 1 and 2) were installed side by side allowing tests on 2 different flooring types each day (Figure 2.1). Corridors were outlined with fencing tape (12.5 mm Turbo Tape, Gallagher, Owen Sound, ON, Canada) and pigtail fence posts (Gallagher, Owen Sound, ON, Canada) fixed in buckets filled with sand.

#### *2.2.4 Training and Tests*

Cows were taken from the barn after the morning milking (0800 h) and were led to the experimental building, enticed with grain buckets. Cows were individually trained by walking 5 times on each flooring and configuration, while the 5 other cows were kept in a waiting pen within visual and auditory range (Figure 2.1). Cows were randomly introduced to 2 new flooring types per week during a 3-wk habituation period. They walked on both corridors in straight configuration on wk 1, on both corridors in a right angled configuration on wk 2, and on both corridors in the 2 configurations on wk 3. Once trained, cows were randomly allocated to groups of 6 individuals, which were changed every week, to make sure there were no influences of groups on cow behaviour.

Due to space and time constraints, only 2 flooring types in both configurations were tested each day. Tests were done on Mondays, Wednesdays and Fridays, to allow for flooring reconfiguration between test days. All 6 floorings were tested each week in a randomized order. A new group of 6 cows was tested on each of the 3 d, and the 18 cows were tested each week on a maximum of one flooring type. Therefore, 6 wk were necessary to test all cows on each flooring type.

Cows walked on the same flooring type for at least 5 walking passages in each configuration (10 passages/cow/d), to ensure that at least one passage with a steady pace could be obtained. Passages where cows ran, defecated, or stopped were not utilized for analysis. When cows defecated on the corridor, the excess manure was removed to ensure that only a thin coat remained on the floor. Cows were lured by a handler walking backwards at a distance of approximately 1 m in front of them and holding a bucket of grain. Another handler also walked to the side of the cows, behind the point of balance (Grandin, 2010), and tapped the floor in a rhythmic manner with a stick to encourage walking. The handler located next to the cows would never touch them while walking, but would gently pat the cows with their hand if they stopped.

Each day, once corridor configurations were set up, and before tests were started, flooring surfaces were covered with a thin coat of manure slurry (equal volumes of manure and water) using a paint roller. Once the cows were done walking on the straight corridor

or right-angled turn corridor, cows were sent outside on pasture with access to water and shade, giving the handlers time to change corridor configurations.

### 2.2.5 Acceleration

Every test day immediately before walking, cows were equipped with two 3-D accelerometers (Hobo Pendant G Acceleration Data Logger, Onset Computer Corp., Bourne, MA, US), which were placed in custom made pouches attached with Velcro to both rear legs above the fetlock. The accelerometers were set to sample 33 readings/s (de Passillé et al., 2010; Chapinal et al., 2011). The time clocks on the video camera and the accelerometers were synchronized to be able to match data recorded by both devices. Acceleration was measured as the rate of change of velocity across rear limbs for a particular passage per unit of time (Chapinal et al., 2011). The overall acceleration was calculated for the 3 axes as the magnitude of the 3-D acceleration vector for each limb using the following formula (Chapinal et al., 2011):

$$Acceleration (g) = \sqrt{acc_x^2 + acc_y^2 + acc_z^2},$$

Where the  $acc_x$  is the acceleration for the x-axis,  $acc_y$  is the acceleration for the y-axis and  $acc_z$  is the acceleration for the z-axis. To find the mean acceleration for each limb, the acceleration was averaged, and the variance was calculated over a selected time period for a passage based on the calculated vector. The acceleration and variances for each limb were averaged together resulting in a single mean and variance of acceleration for the selected passage per flooring type. From the calculated variances per limb, the asymmetry of variance (%) was obtained using the formula (Chapinal et al., 2011):

$$Asymmetry\ of\ variance\ (\%) = \left[ 1 - \left( \frac{Variance_{min}}{Variance_{max}} \right) \right] \times 100,$$

where the  $Variance_{min}$  was the lowest variance of acceleration and  $Variance_{max}$  was the highest variance within each pair of limbs. The asymmetry of variance calculated for the rear limbs was averaged across passages to get a single asymmetry of variance value for each cow per flooring type (Chapinal et al., 2011). The asymmetry of variance represents

how irregular the stepping patterns were for both rear limbs based on the accelerometer (Chapinal et al., 2011).

### *2.2.6 Steps Taken and Passage Time*

Cows were video recorded on the right side while walking on the right-angled corridors. The camcorder (JVC AVCHD 40X Optical Zoom, Konica Minolta HD Lens 116mm 1:1.8, Mississauga, ON, Canada), was placed diagonally from the first straight section of each corridor at a distance of 11.8 m and 9.7 m from corridor 1 and 2 (Figure 2.1). The same method as in the straight corridor configuration was used to encourage cows to walk. A total of 108 video recordings were analyzed for the number of steps taken, passage time (s), and time per step (s/step) for a chosen passage of each cow walking on all flooring types. Passage time refers to the amount of time taken to complete a passage, the steps taken refers to the number of steps taken in order to complete a passage and the time per step is the amount of time elapsed between each step or stride. Count started when the hind right hoof stepped on the tested flooring and ended when it left the flooring at the end of the passage. Passage time was calculated from the same start and finish points as those used to count the number of steps. Time taken per step was obtained by dividing passage time by number of steps.

### *2.2.7 Kinematics*

Kinematic measurements were only taken in the straight configuration. Cows were filmed on their right side following Flower et al. (2007) and Grégoire et al. (2013). Two reflective plastic ball markers measuring 3.18 cm (B &L Engineering, Santa Ana, CA, USA) were sewn on a 12 cm wide black elastic band, adjustable with Velcro, and long enough to be placed on the metatarsal and metacarpal regions of the right limbs before the cows walked on each corridor. Two reflective plastic balls were also placed on the floor (8.57 m apart) as reference markers. A digital video camera (uEye UI-1225LE-C, Imaging Development Systems GmbH, Obersulm, Germany) with lens (Pentax CCTV C418DX, 4.8 mm, 1:1.8, Pentax Ricoh Imaging Americas Corporation, Denver, CO, USA) was used to video record the right side of the cows while walking. Two spot lights (Pro light w/Lamp P2-101, 250 W, Lowel, Hauppauge, NY, USA) were placed 0.5 m away from both sides

of the camera to light up the reflective markers. The camera was placed perpendicular to the center of the corridors (9.7 m away from corridor 1 and 11.8 m from corridor 2; Figure 2.1). The walking passages of the cows were recorded and digitalized for 3 or 4 strides at 30 frames/s. A total of 108 video recordings were then analyzed using an automatic tracking program (MoviAs Pro, version 1.63g: 3D, NAC Image Technology, Simi Valley, CA, USA). Once the recordings were processed, the stride length (m), swing time (s), stance time (s) and hoof height (m) were calculated for both the front and rear right hoof. Stride length corresponds to the distance between two consecutive hoof strikes for the same hoof. Swing time and stance time refer to the periods of time when a cow's hoof is respectively off and on the ground during a stride, and hoof height refers to the maximal vertical distance at which the hoof is lifted while the cow is walking (Flower et al., 2005; Flower et al., 2007). The mean and SE for stride 2 and 3 were calculated for each variable.

#### *2.2.8 Gait Scoring and Behaviours Associated with Lameness*

The videos used for the kinematic analysis were also used to evaluate the gait of the cows while walking on different flooring types on the straight corridors. Scoring was done by one observer, previously trained by scoring video recordings of cows that had been scored beforehand by an expert. The flooring types were coded with numbers so that the observer was unaware of experimental treatments. Cow gait was scored using the NRS procedure, as described by Flowers and Weary (2009) (1 to 5 scale where 1 is sound and 5 is severely lame, scored at 0.5 intervals) and 6 behaviours associated with lameness; arch back, head bob, tracking up, joint flexion, asymmetric steps and reluctance to bear weight (0 to 5 scale where 0 is sound and 5 bad, scored at 0.1 intervals) as defined by Flower and Weary (2006). The outcomes of each variable were recorded by averaging the scores obtained using a visual analogue scale template developed in Microsoft Excel (Microsoft Corp., Redmond, WA). The training process took one week and the observer started scoring the video recordings once a target level of agreement of 90 % for intra and inter-observer reliability was reached for the NRS scoring, and 80 % for the behaviours associated with lameness. A total of 108 recordings were watched 13 times (twice per behaviour and once for NRS score) to score each variable. Once half of the video recordings were analyzed, the observer re-scored the first 10 videos of the trial and also re-

scored 10 random videos from the expert to ensure that intra and inter-observer reliability levels were maintained.

### *2.2.9 Statistical Analysis*

The data underwent analysis to find extreme outliers (3 times the interquartile range outside of the interquartile limits) using Excel but no outliers were found. The residuals for each variable were examined to verify normality and homogeneity of variances. Only stride length, stance time and swing time were found to follow a normal distribution. The number of steps taken, passage time and time/step were transformed using a square root transformation. The normal and transformed variables were analysed using the MIXED procedure of SAS (version 9.2, SAS Institute Inc., Cary, NC). The differences between flooring types for these variables were tested using a generalized linear mixed model with cow as a random effect, week as a random block factor, and flooring type as a fixed effect. Multiple-comparisons with a Scheffé adjustment were done to analyze differences among flooring types. Hoof height, acceleration, asymmetry of variance acceleration, NRS and behaviours associated with lameness were analysed using a Kruskal-Wallis test with the NPAR1WAY procedure, in order to find difference between flooring types. Any significance was report at a probability of less than 5 %. Within each treatment, regression analysis were made between parity, DIM and each variable, to rule out any effect of these variables (Vasseur et al., 2012).

## **2.3 Results and Discussion**

### *2.3.1. Kinematics in a Straight Configuration*

Cows walking on rubber showed improved ease of movement compared to concrete, but the only difference was for stride length, which was 0.144 m longer on rubber (Table 2.2). This is consistent with the previously reported longer stride length of non-lame cows on rubber compared to concrete (Telezhenko and Bergsten, 2005; Flower et al., 2007). Furthermore, the result obtained was within the range of 1.54 to 1.57 m previously reported for non-lame cows walking on rubber (Telezhenko and Bergsten, 2005; Flower et al., 2007). Stride length was respectively 0.114 and 0.169 m shorter on MMA 1 and 2

compared to rubber. On MMA 4, it did not differ from any other flooring, but it was longer on MMA 3 compared to MMA 2.

Swing time was 0.037 s shorter on MMA 1 than on rubber, indicating a better ease of movement on rubber (Flower et al., 2005; 2007). However, no differences were found between MMA 1 and any other flooring. Few researchers have looked at the impact of flooring surfaces on the swing time of cattle. Flower et al. (2007) compared the effect of flooring and hoof health on swing time and found that flooring differences were only apparent in cows with sole ulcers, which had a shorter swing time on concrete than on rubber. The values reported for swing time in the present study were outside the range of 0.42 to 0.57 s reported for healthy cows (Flower et al., 2005; Flower et al., 2007). Although cattle that have an impaired gait due to sole ulcers or lesions have been reported to have longer swing time, which may range between 0.55 to 0.57 s (Flower et al., 2005), the higher values in the present study may reflect differences in environment and animal factors, such as housing, herd management, or genetics, between experimental sites. In a study with sows, Conte et al. (2014) also observed herd differences in kinematic variables, which were independent of lameness scores.

Stance time on MMA 2 was 0.178 and 0.168 s longer than on rubber and MMA 3, respectively, but it did not differ from any other flooring surfaces. Shorter stance time indicate a better ease of movement (Flower et al., 2005; 2007). This difference could potentially be explained by the fact that MMA 2 and 3 differed in both quartz size and number of seal coats. MMA 2 had larger particle size and 2 seal coats, while MMA 3 had smaller particle size with only one seal coat. Since cows walking on MMA 3 showed improved stance duration compared to MMA 2, it is possible that cows were more at ease walking on a surface with smaller granulation, but with just enough seal coats to provide sufficient grip to walk at a steady pace. Once again, very few researchers have analyzed the effect of flooring type on stance time in cattle. Flower et al. (2007) reported no differences in stance time between cows walking on rubber and concrete flooring.

### 2.3.2. Kinematics in a Right Angle Turn Configuration

Rushen and de Passillé (2006) compared the number of steps taken by cattle walking on a rubber and concrete flooring and found that cows took fewer steps on rubber compared to concrete (averages of 33.0 vs. 34.3 steps) indicating that they were more at ease walking on rubber. In our study, the number of steps taken on rubber was not significantly lower than on concrete. However, cows took more frequent steps on MMA 4 than on rubber, indicating that they may have been less at ease walking on this surface, especially in a turn configuration. Differences between studies may be explained by the degree of difficulty of the experimental corridor. In Rushen and de Passillé (2006), cows had to walk on a corridor with one obstacle (gutter), in addition to a turn. This suggests that as the course becomes more challenging, cows are more at ease walking on rubber than on concrete.

The passage of a cow walking in a pathway should be short, with few steps taken and with short stride duration (Flower et al., 2005; 2007; Rushen and de Passillé, 2006). There were no differences in passage time among flooring types in the present study (Table 2.3), which does not support the shorter passage time for cows walking on rubber (23.2 s) compared to concrete (25.0 s) reported by Rushen and de Passillé (2006). These authors also found that cattle took on average 23.2 to 25.0 s to complete a 27 m course (0.86 to 0.93 s/m), while cows in the present study took on average 6.01 to 7.05 s to complete their 11.6 m course (0.52 to 0.61 s/m). Differences in speed between studies may again be explained by the presence of an obstacle in the former study. Other studies investigated the speed (m/s) of cattle walking on rubber and concrete and found opposite results. For instance, Telezhenko and Bergsten (2005) found that cattle walking on rubber floors walked at a faster speed (1.01 m/s) in comparison to concrete (1.08 m/s). This was also seen by Flower et al. (2007) and Chapinal et al. (2011) who both found that cattle walking on rubber floors walked at a faster speed (1.26 and 1.28 m/s) than when walking on concrete (1.21 and 1.22 m/s).

There were no differences between flooring types in the time/step, or stride duration, which is consistent with the findings of Flower et al. (2007). Blackie et al. (2013) also reported no differences in stride duration between cattle with a gait score of 1, 2 and

3. Flower et al. (2005) on the other hand found that cattle with sole ulcers had a longer stride duration than healthy cows (1.48 vs. 1.26 s). These results suggest that stride duration is more susceptible to change with hoof health status than flooring type.

#### *2.3.3. Accelerometer Variables*

No differences between flooring types in any configuration were found for acceleration or asymmetry of variance (Table 2.2 and 2.3). This is not consistent with the lower acceleration reported by Chapinal et al. (2011) on rubber in comparison to concrete (1.62 vs. 1.67 g), which was explained by a greater absorption of the hoof impact by rubber. As for the asymmetry of variance, Chapinal et al. (2011) also found no differences in asymmetry of variance between cattle walking on rubber versus concrete, which is consistent with our results.

#### *2.3.4. Locomotion and Behaviours Associated with Lameness*

Healthy experimental animals that are not considered lame at the start of a trial may have a locomotion score of 2.4 to 2.5 on a total of 5 points (Flower et al., 2007) which matches the range obtained in the present study for NRS scores (Table 2.2). However, no differences were found between flooring types for NRS scores, which is not consistent with the improved locomotion scores reported by Flower et al. (2007) and Chapinal et al. (2011) for cows walking on rubber in comparison to concrete.

The lack of differences in arched back, reluctance to bear weight, and head bob between flooring types (Table 2.2) was expected since these variables only become apparent when cattle are moderately lame (Score > 3) (Flower and Weary, 2009). Flower et al. (2007), found that cattle suffering from sole ulcers had poor weight bearing (14 on a 100-unit scale) on all four limbs in comparison to cows without hoof issues (6.5 on a 100-unit scale), regardless of flooring type. This is an indicator that their hoof condition was painful enough to trigger a change in their weight distribution between limbs. However, since our cattle had low NRS and no sole ulcers, the flooring type they were walking on did not have any effect on their head movement, back posture, or weight distribution while walking.

Tracking up scores of healthy cattle may vary from 11 to 15 (scored with a 100-unit scale) (Flower et al., 2007). Although we did not use the same scale as Flower et al. (2007), our cows also had very low scores (Table 2.2). No difference in tracking up was observed in the current study. In contrast to the study by Flower et al. (2007), who reported that healthy cattle walking on rubber mats had better tracking up scores compared to concrete (11 vs. 15 on a 100-unit scale).

Joint flexion scores did not change with flooring type either (Table 2.2). Again, these results contrast with the reported improvements when cows walk on rubber (23 on a 100-unit scale) compared to concrete (27 on a 100-unit scale) (Flower et al., 2007). The discrepancy between the two studies may be explained by the type of concrete used. Flower et al. (2007) tested their cows on smooth concrete, providing less traction than rubber. Phillips and Morris (2001) reported that cattle have better joint angulation on higher friction floors than on smooth surfaces. In contrast, concrete in the present experiment was traction milled, resulting in a coefficient of friction similar to that of rubber (Table 2.1).

Finally, no differences between flooring types were found for asymmetric step scores, which is consistent with the data obtained with the accelerometers. However, this contrasts with the reported improvement in symmetry on rubber (23 on a 100-unit scale) in comparison to concrete (25 on a 100-unit scale) (Flower et al., 2007). A similar improvement (5 points on a 100-unit scale) was also observed by Chapinal et al. (2011). Once again, it is possible that a more precise 100-unit scale was more suitable for the detection of differences between flooring types.

## **2.4 Conclusions**

Cows walking on rubber had longer stride length, suggesting better ease of movement, than when walking on traction milled concrete. However, rubber did not differ from concrete in any other measured variable. When comparing the MMA floorings to the controls, MMA 3 was consistently similar to rubber, whereas the other MMA floors showed inconsistent resemblance to rubber. It should be noted that all four MMA floors never differed from concrete in any of the ease of movement variables measured. These

results suggest that MMA 3 may improve cow ease of movement, compared to the other MMA floors, but more research is required to confirm these findings.

## **2.5 Acknowledgements**

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Franco-Gendron, Table 2.1

**Table 2.1.** Dynamic Coefficient of Friction (DCOF) reported in literature for rubber mats and concrete or measured in laboratory for MMA 1 to 4.

Flooring Types	DCOF	Test Method	Surface Condition	References
Rubber Mats <sup>1</sup>	0.48	Tribometer, 100 kg weight	Dry	Penev et al., 2013
	0.47	Standard ASTM D1894	Dry	Rushen and de Passillé, 2006
	0.46	Portable friction tester	Manure slurry	Telezhenko and Bergsten, 2005
Concrete <sup>1</sup>	0.58	Portable friction tester	Manure slurry	Telezhenko and Bergsten, 2005
	0.43	Tribometer, 150 kg weight	Dry	Phillips and Morris, 2000
	0.30 to 0.45	Skid resistance tester	Wet	Georg, 2011
MMA 1 <sup>2</sup>	0.70	Standard rubber foot	Dry	SureBond Safe Floors, Calgary, AB, Canada
MMA 2 <sup>2</sup>	0.67	Standard rubber foot	Dry	SureBond Safe Floors, Calgary, AB, Canada
MMA 3 <sup>2</sup>	0.66	Standard rubber foot	Dry	SureBond Safe Floors, Calgary, AB, Canada
MMA 4 <sup>2</sup>	0.58	Standard rubber foot	Dry	SureBond Safe Floors, Calgary, AB, Canada

<sup>1</sup> Friction coefficients reported by other researchers.

<sup>2</sup> Friction coefficients obtained from supplier.

Franco-Gendron, Table 2.2.

**Table 2.2.** Dairy cow ease of movement measured with kinematics, acceleration, gait and associated behaviours while walking on various flooring types (rubber, concrete, MMA 1 to 4) in a straight configuration.

Straight Configuration Variable	Flooring Type <sup>1</sup>						SEM	P
	Rubber	Traction milled Concrete	MMA 1	MMA 2	MMA 3	MMA 4		
<b>Kinematics</b>								
Stride Length, m	1.55 <sup>a</sup>	1.41 <sup>b,c</sup>	1.44 <sup>b,c</sup>	1.38 <sup>c</sup>	1.49 <sup>a,b</sup>	1.47 <sup>a,b,c</sup>	0.035	< 0.0001
Swing Time, s	0.65 <sup>a</sup>	0.63 <sup>a,b</sup>	0.61 <sup>b</sup>	0.62 <sup>a,b</sup>	0.63 <sup>a,b</sup>	0.64 <sup>a,b</sup>	0.010	0.0019
Stance Time, s	0.75 <sup>b</sup>	0.91 <sup>a,b</sup>	0.82 <sup>a,b</sup>	0.93 <sup>a</sup>	0.76 <sup>b</sup>	0.83 <sup>a,b</sup>	0.057	0.0013
Hoof Height, m	0.06	0.06	0.07	0.06	0.06	0.06	0.004	0.6544
<b>Acceleration</b>								
Mean Acceleration, g	1.33	1.25	1.32	1.31	1.29	1.31	0.054	0.8464
Asymmetry of Variance Acceleration, %	22.70	42.44	22.56	30.17	29.43	32.78	6.964	0.0768
<b>Locomotion and Behaviours Associated with Lameness, score 0 to 5</b>								
NRS	2.53	2.56	2.44	2.44	2.50	2.55	0.112	0.9095
Arch Back	1.08	1.14	1.17	1.10	1.09	1.11	0.221	0.9995
Head Bob	0.08	0.04	0.08	0.04	0.08	0.03	0.033	0.7721
Tracking Up	0.11	0.39	0.41	0.40	0.28	0.42	0.138	0.5563
Joint Flexion	1.39	1.32	1.33	1.36	1.37	1.34	0.041	0.8503
Asymmetric Steps	0.74	0.57	0.64	0.60	0.62	0.68	0.105	0.7456
Reluctance to Bear Weight	0.18	0.13	0.14	0.13	0.10	0.13	0.050	0.9025

<sup>a-b</sup> Least squares means within a row with different superscripts are significantly different at  $P < 0.05$ .

<sup>1</sup> MMA 1 (0.7-1.2 mm quartz with 1 seal coat), MMA 2 (0.7-1.2 mm quartz with 2 seal coats), MMA 3 (0.4-0.8 mm quartz with 1 seal coat) and MMA 4 (0.4-0.8 mm quartz with 2 seal coats).

Franco-Gendron, Table 2.3.

**Table 2.3.** Dairy cow ease of movement measured with number of steps, passage time and acceleration while walking on various flooring types (rubber, concrete, MMA 1 to 4) in a right angle turn configuration.

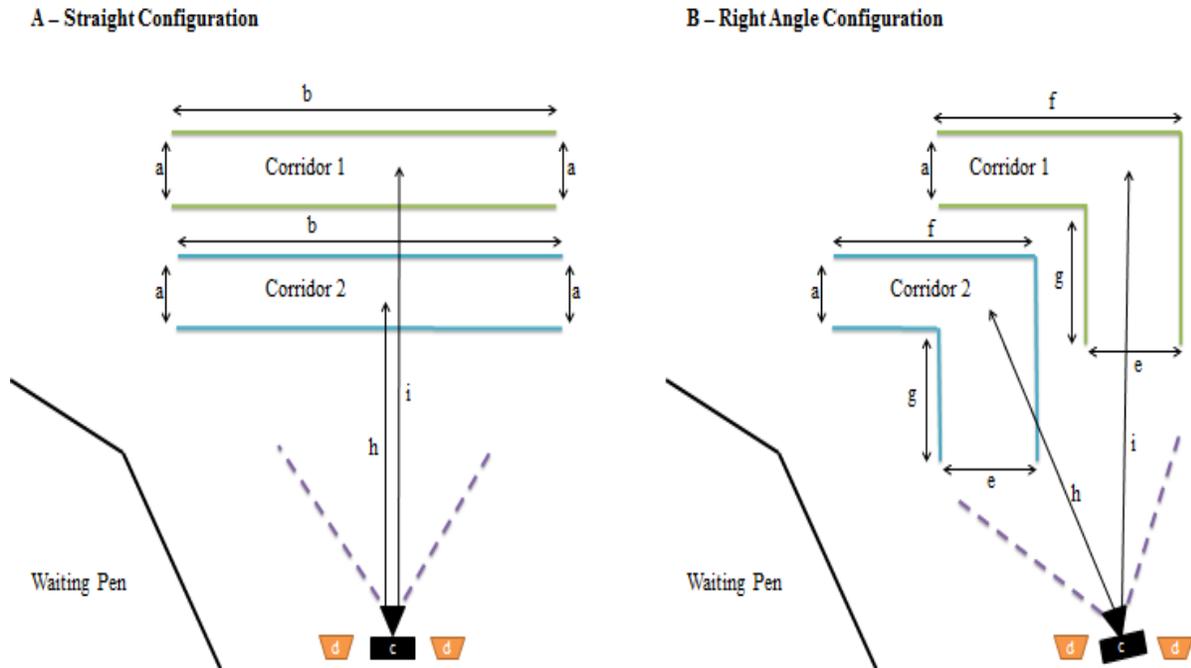
Right Angle Turn Configuration Variable	Flooring Type <sup>1</sup>						SEM	P
	Rubber	Traction milled Concrete	MMA 1	MMA 2	MMA 3	MMA 4		
<b>Kinematics</b>								
Number of steps	3.95 <sup>b</sup>	4.22 <sup>a,b</sup>	4.39 <sup>a,b</sup>	4.39 <sup>a,b</sup>	4.33 <sup>a,b</sup>	4.57 <sup>a</sup>	0.143	0.0081
Passage time, s	6.01	6.33	6.67	6.85	6.43	7.06	0.429	0.1016
Time/Step, s/steps	1.50	1.49	1.50	1.55	1.47	1.54	0.069	0.7777
<b>Acceleration</b>								
Mean Acceleration, g	1.30	1.37	1.38	1.30	1.29	1.31	0.046	0.5090
Asymmetry of Variance Acceleration, %	37.35	26.53	22.44	36.29	25.53	36.29	6.676	0.1145

<sup>a-b</sup> Least squares means within a row with different superscripts are significantly different at  $P < 0.05$ .

<sup>1</sup> MMA 1 (0.7-1.2 mm quartz with 1 seal coat), MMA 2 (0.7-1.2 mm quartz with 2 seal coats), MMA 3 (0.4-0.8 mm quartz with 1 seal coat) and MMA 4 (0.4-0.8 mm quartz with 2 seal coats).

Franco-Gendron, Figure 2.1.

**Figure 2.1.** Corridors and flooring configurations (straight (A) and right angle (B)) showing the waiting pen, corridors, camera and spotlights placement.<sup>1</sup>



<sup>1</sup> Distance a is equal to 1.21 m, b is 9.14 m, c is the camera, d are the spotlights, e is 1.82 m, f is 5.48 m, g is 4.88 m, h is 9.65 m and i is 11.

## CHAPTER 3: GENERAL DISCUSSION

The purpose of this thesis was to investigate new types of surfaces with different coefficients of friction and quartz size and see how they would influence cattle ease of movement compared to a negative and positive control, traction milled concrete and rubber. The present study tested four different floorings, which were MMA 1 (0.7-1.2 mm quartz with 1 seal coat), MMA 2 (0.7-1.2 mm quartz with 2 seal coats), MMA 3 (0.4-0.8 mm quartz with 1 seal coat) and MMA 4 (0.4-0.8 mm quartz with 2 seal coats) (SureBond Safe Floors, Calgary, AB, Canada). Previous research looking at the impact of rubber and concrete on cattle ease of movement concluded that rubber has beneficial attributes on cattle ease of movement due to its compressible surface (Rushen and de Passillé, 2006), which brings more comfort to cattle as they walk by reducing pressure on the limbs and joints (van der Tol et al., 2005; Hernandez-Mendo et al., 2007). Concrete on the other hand, is a harder surface with little compressibility (Rushen and de Passillé, 2006), and thus may compromise cattle ease of movement. However, concrete may offer more friction than rubber, which may decrease the incidence of slips when wet (Telezhenko and Bergsten, 2005). Both flooring surfaces may be considered too slippery when wet (Phillips and Morris, 2000; 2001). Therefore, an alternative flooring with higher friction and particle size may be the solution to reduce incidence of slips and falls on farm, as well as the incidence of lameness.

### 3.1 Overview of Results

In our study (Chapter 2), 18 cows were walking on all flooring surfaces (MMA 1 to 4 and controls) on both a straight and right angle turn corridor. We used kinematics measures to analyze the stride length, swing time, stance time and hoof height of each cow as they were walking on the straight corridor. Locomotion was scored and behaviours associated with lameness were observed as the cows were walking on the straight corridor. Furthermore, cows were equipped with accelerometers, to measure average acceleration and asymmetry of variance of the rear hoof while walking on both corridor configurations. Additionally, passage time, number of steps taken and stride duration of cows walking on the right angle turn corridor were evaluated.

Our main findings were that cattle stride length was longer and thus better on rubber when compared to concrete and MMA 1 and 2. In addition, the stride length of cows walking on MMA 3 and 4 was similar to both controls. Cows' swing time was shorter, hence worse, when walking on MMA 1 compared to rubber, but did not differ from any other flooring types. Furthermore,

cattle's stance time was longer, thus worse, on MMA 2 when compared to rubber and MMA 3, but it did not differ from any other treatments. Cows took more frequent steps walking on MMA 4 compared to rubber, but did not differ from any other flooring. Therefore, of all the alternative floors tested, it seems that MMA 3 was the only MMA treatment that was consistently as good as rubber, the positive control, at promoting cattle ease of movement.

### **3.2 Study Limitations**

The main limitation of our study was the small sample size, which may have reduced the power of the statistical tests. Even though our sample size was bigger compared to the sample from Rushen and de Passillé (2006) (16 cows tested), it was much smaller compared to other studies that used sample sizes above 32 cows (Telezhenko and Bergsten, 2005; Flower et al., 2005; 2006).

Another limitation is the potential bias induced by the selection of one passage for analysis, from a sub sample of five. This was made to ensure that cows walked at a steady pace. Passages where cows stopped, ran or defecated were systematically eliminated, and the final selection was based on a subjective assessment of the most natural walk. Potential differences between treatments may have been masked by this assessment. It may have been preferable to select more than one passage and perform the analysis on average values.

It should also be pointed out that friction coefficients mentioned in this thesis were not calculated during the experiment. The coefficients for rubber and concrete were obtained from the literature reporting values for similar floors, while coefficients for the MMA floorings were calculated by the supplier at the factory. It would have been more accurate to perform on-site measure of friction coefficients for all experimental floorings prior to testing.

### **3.3 Future Research**

The study presented in this thesis brought forward the need for more research comparing alternative floorings with those commonly found on farms like concrete and rubber (USDA, 2009; Solano et al., 2015). Although one MMA floor slightly stood out compared to the others, the lack of significant results for most of the variables characterizing ease of movement, makes it difficult to conclude that it is the best alternative flooring to install on farms in order to improve cattle ease of movement. It would be beneficial to test these types of flooring on commercial free-stall farms to evaluate their real impact on cattle over a long period of time (e.g., 1 lactation). On-farm

monitoring studies could be valuable to determine the short-term effects of these floorings on slips and falls, and longer term effects on cattle lameness and hoof health. Because these MMA surfaces had higher coefficients of friction than concrete or rubber (Chapter 2), it would be important to ensure that no hoof issues like thin sole occur from excessive wear (Vanegas et al., 2006). Phillips and Morris (2001) showed that cattle ease of movement was influenced by floorings with different particle sizes, but did not look at longer term effects in a farm situation.

It would also be beneficial to investigate where certain flooring types should be placed to reduce lameness issues on farm. A single flooring type installed across the farm may not be the key to control lameness problems within the herd. Instead, having a combination of floorings in different locations may be a better approach. For instance, compressible surfaces may be used where cows spend a lot of time standing, e.g. waiting areas or even feed alleys, to remove pressure on the joints (van der Tol et al., 2005; Hernandez-Mendo et al., 2007), whereas MMA surfaces may be more suitable in areas where cows struggle to walk due to slipperiness, such as transfer alleys to the milking parlor where no automated scrapers are installed. Furthermore, the MMA surfaces tested as part of this study are expensive, ranging in price from \$15.50 to \$16.00/ft<sup>2</sup> CAD including installation (SureBond Safe Floors, personal communication) compared to concrete or rubber mats, which cost respectively \$2.00/ft<sup>2</sup> CAD including installation (AgriTrac, personal communication) or approximately \$1.92/ft<sup>2</sup> (Animat, personal communication). Therefore, installing these floors only in problematic areas could significantly reduce the costs of renovating facilities.

Although there are more research results available on the impact of concrete on cattle movement, there is a lack of information with regards to the influence of the type of grooving on cattle ease of movement. Because concrete is a relatively cheaper flooring alternative, it may be beneficial to producers to further look into identifying the best grooving technique.

Finally, more research is needed to measure the impact of MMA floors on animal handling and production efficiency. For example, when being fetched before milking; cows may feel more at ease walking on the new flooring, which could potentially reduce milking time and time spent standing or walking on a hard flooring.

### **3.4 Implications**

Our hypothesis that MMA flooring would provide a better ease of movement than traction milled concrete was not supported by the results of the present study. Of the four MMA floorings tested, MMA 3 most closely resembled rubber, our positive control, and would be the most promising alternative to test in a longer term study.

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