THE EFFECTS OF RUBBER MATTING AND A NOVEL GAIT ANALYSIS ON GROWTH PERFORMANCE AND MOBILITY OF CATTLE IN INDOOR FEEDING FACILITIES

BY

CODY RYAN DAWSON

THESIS

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Master's Committee:

Assistant Professor Joshua C. McCann, Chair
Associate Professor Daniel W. Shike
Assistant Professor Isabella C. F. S. Condotta

ABSTRACT

The objective for Chapter 2 was to determine effects of old and new rubber matting in a slatted, indoor cattle feeding facility on cattle growth performance, locomotion, and carcass characteristics. In experiment 1, fall-born Angus × Simmental steers ($N = 207$; $BW = 222 \pm 38$ kg) were blocked by weight and assigned to 32 pens. Pens were randomly assigned to 1 of 4 treatments: no matting/concrete (**CONC1**), 12-year-old Animat Pebble matting (**OLD1**), new Animat Maxgrip matting (**MG**), and new Animat Pebble matting (**PEB1**). Steers were fed a common diet for 209 d with a minimum stocking density of 3.40 m^2 per animal. Final body weight (**BW**) and average daily gain (**ADG**) were affected ($P \leq 0.02$) by treatment with steers on PEB1 finishing heaviest with the greatest growth, MG and CONC1 intermediate, and OLD1 finishing at the lightest final BW with the least growth. Flooring treatment did not affect overall dry matter intake (**DMI**, $P = 0.16$) or gain to feed ratio (**G:F**, $P = 0.94$). Flooring treatment did not affect ($P \geq 0.19$) any carcass traits. Locomotion scores (**LS**) were affected ($P < 0.01$) by flooring treatment with CONC1 having the worst mobility while OLD1, MG, and PEB1 were similar ($P \geq 0.24$). Locomotion score had a day effect ($P < 0.01$) where cattle gait and mobility worsened as days on feed increased. In experiment 2, fall-born Angus × Simmental steers ($N = 189$; $BW = 352 \pm 43$ kg) were blocked by weight and assigned to 21 pens. Pens were randomly assigned to 1 of 3 treatments: no matting/concrete (**CONC2**), 15-year-old Animat Pebble matting (**OLD2**), and new Animat Pebble matting (**PEB2**). Steers were fed a common diet for 112 d with a stocking density of 2.65 m^2 per steer. After 112 days on feed, flooring treatment did not affect ($P \geq 0.30$) BW, ADG, or DMI nor did treatment affect ($P \geq 0.17$) carcass traits. However, steers housed on OLD2 or PEB2 had improved locomotion scores ($P = 0.02$) compared to steers housed on CONC2. Locomotion score had a day effect ($P < 0.01$) as cattle gait and mobility worsened with greater number of days on feed, regardless of treatment.

Overall, results suggest new rubber matting increased ADG and HCW during a 209 d trial when cattle were stocked at 3.4 m^2 and that rubber matting regardless of age improved cattle locomotion scores in slatted indoor feeding facilities.

The objective for Chapter 3 was to determine the variance of locomotion score (**LS**) and growth performance attributable to flooring treatment, hind leg angle and step length (**SL**) measured by 3-D image analysis for cattle in slatted feeding facilities. Inherent individual differences in structural conformation may be related to cattle mobility and growth performance in indoor slatted facilities. Angus × Simmental steers (N = 189; BW = 352 ± 43 kg) were blocked by initial BW and assigned to 21 pens. Pens were randomly assigned to 1 of 3 treatments (**TRT**): concrete slats with no matting (**CONC**), 15-year-old Animat Pebble matting (**OLD**), and new Animat Pebble matting (**PEB**). Steers were fed for 152 days. Individual steers videos were recorded on d 0 using an Intel RealSense depth camera and processed using MATLAB to estimate hind leg angle, SL, and body length (**BL**). Locomotion scores were assigned using a 0 to 3 scale (Zinpro Step-Up® Locomotion Scoring System) throughout the finishing phase. The CORR procedure of SAS 9.4 was utilized to measure correlation of structural conformation traits to average LS, overall ADG, and final BW. Average LS had the greatest correlated (r = -0.23) to SL/BL during the finishing phase. The greatest correlation (r = -0.49) to overall ADG was average LS. Final BW had the strongest correlation (r = 0.51) to BL. The MIVQUE0 option of the MIXED procedure of SAS 9.4 was utilized to estimate the proportion of variance in average LS, overall ADG, and final BW. Variance of average LS was attributed to SL and SL × BL × TRT at 64% and 28%, respectively. For overall ADG, variance was attributable to SL × BL, SL × BL × TRT, and TRT at 38%, 35%, and 25%, respectively. Variables of SL, BL, SL × BL × TRT, and TRT accounted for 38%, 23%, 23%, and 15% of the variance in final BW, respectively. Overall, variance of average LS, overall ADG, and final BW were primarily attributed to SL, BL, TRT, and their interactions. Individual animal differences in structural conformation are related to cattle mobility and growth performance in slatted indoor facilities.

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Dedication

To my family and friends, without your support I would not be the person I am today.

TABLE OF CONTENTS

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Feeding cattle in the Midwest is an expanding segment of the grower and finisher phase of cattle production. Compared with more aired western and southern states, greater rainfall in the Midwest can results in poor pen conditions in outdoor feedlot facilities. The weather conditions and limited land availability for feedlots have led to the rise in the number of indoor cattle feeding facilities. Depending on the operation's resources, the facility setup could vary greatly. Deep-bedded facilities are widely used because of their versatility to house not only feedlot cattle but breeding stock as well. This flexibility comes with the need for bedding and manure storage that is not required for slatted floor systems. The pit system in slatted floor facilities does add convenience for manure storage, but animal welfare may become more of a concern. Regardless of the facility style, locomotion alterations and lameness have several risk factors. Disease, environment, and inherent defects can alter the ability of cattle to move. Lameness can account for up to 70% of cattle sold prematurely before reaching a finished weight, which equates to roughly $53,000,000 in total annual loss for the cattle industry (Griffin et al., 1993; USDA, 2018). The relationship between locomotion and lameness from flooring type affects cattle growth performance and carcass characteristics is still uncertain. Despite a lack of data in U.S. cattle feeding systems, the use of rubber matting has become a common choice for slatted facilities.

There is a drive for livestock production to become more sustainable to meet the demand of a growing population. High-throughput phenotyping is the next step to access data for more efficient livestock production (Koltes et al., 2019). The use of digital technology in feedlot cattle is helping to better understand changes in locomotion and lameness along with creating better detection methods. Automatic detection of gait change can have an important role in animal welfare and ultimately profitability but developing practical methods needs to come first. In general, research focused on facility design, locomotion, and digital technology has been limited in addition to being challenging to conduct.

INDOOR CATTLE FEEDING FACILITIES

Indoor cattle feeding facilities are defined as cattle housing systems that are enclosed and under-roof (Grooms et al., 2015). Ventilation can be through open sides or ridge vents. The structure and flooring type can vary greatly prepending on land availability, price, regulations, and preference. These structures can have different types of flooring such as deep-bedded, solid concrete, or slatted floors. Deep-bedded facilities typically have a solid or partial solid concrete foundation for cattle pens with bedding added on top (Euken et al., 2015). A 3.6 to 6.1 m concrete apron along the feed bunk is normally added in this highly traveled area. Deep-bedded facilities should have a minimum stocking density of 3.7 m^2 per animal (Euken et al., 2015). If the same pens stocked at 3.7 m^2 per animal have a standard 3.7 m wide apron added, then the minimum stocking rate for the bedded area would be 2.6 m^2 per animal (Euken et al., 2015). These facilities require bedding to be cleaned or refreshed regularly. Bedding can be removed between groups of cattle or every three to four weeks. Bedding type depends heavily on the availability of options in an operation's location. Traditional bedding materials are corn, wheat, barley, and soybean residue materials. This material is more readily available because of the large area of land that produces those crops. Some alternative bedding materials are sand, peat moss, gypsum, and wood-based products (Niraula et al., 2018). Gypsum bedding can be purchased in a bag but often it is in the form of recycled material like drywall from a construction site. Gypsum bedding should be used with caution because it increases hydrogen sulfide (H_2S) production to a dangerous level in deep-bedding manure storage (Hile et al., 2018). Wood-based products can be either recycled or by-product materials. Paper, cardboard, and wood products such as pallets are easily recycled and shredded for use as livestock bedding. Wood by-products like filtered paper sludge, pulping fiber, and sawdust are potential bedding options when available. The bedding absorbency is important because cattle tend to lay in dry areas that are more comfortable and also help reduce the occurrence of other negative outcomes from added moisture (Camiloti et al., 2012). Traditional bedding and alternative bedding materials do not absorb moisture similarly at the same initial dry matter content (Voyles and Honeyman, 2006; Niraula et al., 2018). Cornstalks are recommended because it has the best absorption for traditional bedding and is easily available in most areas. Alternative bedding like sand does not absorb but drains well and peat moss absorbs almost five times more moisture per unit of bedding compared with all other bedding types. Nutrient composition and gas emissions from manure can differ based on the bedding type included. Soybean stover, corn stover, wheat straw, and wood chips manure-bedding mixes were tested for ammonia (NH_3), H_2S, and greenhouse gas emissions in a controlled setting (Jaderborg et al., 2021). Corn stover produced the least NH_3 emissions, wheat straw produced the least H_2S, and wood chips produced the least methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) gas emissions. Based on this study, no one type of bedding produces the lowest all-around gas emissions. Regardless, it was recommended to remove manure storage between shipping finished cattle and receiving a new group to limit gas emissions. Comparing a traditional bedding, barley straw, with an alternative option, wood chips, resulted in differences in K, C, available P, pH, C:N ratio, and NH_4–N

(Miller et al., 2003). Barley straw had higher K while wood chips had high C, available P, C to N ratio, NH_4–N, and lower pH. These differences can be used for crop production strategies to improve soil composition based on the manure-bedding mix added.

Deep-bedding facilities offer cattle performance advantages over traditional open lot housing in harsh conditions with cattle having an increased growth performance and feed conversion (Pastoor et al., 2012). These results are attributed to the more consistent and less extreme environmental conditions. Particularly in the Midwest region, the summer and winter months create added stress on cattle initiating poorer performance when exposed to long-term environmental challenges (Mader, 2003; Anderson et al., 2006). Heat stress from solar radiation is reduced and cattle efficiency increased in indoor cattle feeding facilities with proper ventilation (Brown-Brandl, 2018). Cold stress occurs in open lot systems because of low temperatures, wind exposure, and wet conditions, but deep-bedding facilities can reduce wind vulnerability, mud, and moisture exposure. When cattle are wet, muddy, or covered with tag, the hair insulation is poorer and net energy for maintenance is increased up to 17.6% (Delfino and Mathison, 1991; Euken et al., 2015).

In general, indoor slatted facilities are 5 to 8 times more expensive to construct than open lot facilities (Fulhage and Pfost, 2003). Of the indoor cattle feeding facilities, deep-bedded feedlots are the most conservative in the construction cost. However, they also require the most labor to bed regularly (Euken et al., 2015). Deep-bedded indoor facilities should have 2.3 to 2.7 kg of bedding per animal per day (Boyles et al., 2015; Peters, 2020). When considering a large feedlot system, the daily needs for bedding become a cost and time issue. The extra labor requirements are not only from the effort of cleaning the facility but more labor is needed in the land application of the manure-bedding mix. Applying waste from deep-bedded facilities takes

0.10 hours per head space per year more compared with an open lot system (Euken et al., 2015). For example, a 1,000 animal deep-bedded facility would need an additional 100 hours per year to apply waste to the land. Solid and liquid manure should be separated for more efficient use and handling but is not realistic for most operations. The solid manure can be spread on land for nutrient value or composted for use as bedding. Liquid manure should be applied subterranean to reduce odor and NH_3 emissions (Lau et al., 2003; Webb et al., 2010). Total labors costs are $2.95 per animal per year more for open lot systems and deep-bedded facilities (Euken et al., 2015). Additionally, total bedding costs are around two and a half times higher for deep-bedded facilities due to the added bedding needs (Euken et al., 2015).

Regardless of the added labor and cost, cow-calf operations tend to utilize a deep-bedded design to limit the prevalence of lameness in the herd (Bergsten et al., 2015). Cows housed in a deep-bedded facility, typically in winter months, maintain better hoof and locomotion integrity compared with bare concrete slatted floors (Bergsten et al., 2015). For operations that have both a cow-calf and feedlot enterprise, deep-bedded facilities allow for versatility where both groups of cattle could be housed in the same location throughout different times of the year. A spring calving herd could house fall-born feedlot cattle and vice versa without having crossover. Solid concrete flooring without bedding is not often practiced in the United States but is more common in the Eastern hemisphere in countries such as India. This style of facility design is used in dairy operations and not in open lot housing or feedlots. The stocking density for indoor cattle feeding facilities with solid flooring should be 3.25 m^2 to 4.65 m^2 per animal (Boyles et al., 2015). The major concern with solid concrete flooring without bedding is the slipperiness resulting in decreased locomotion and injuries (Sadharakiya et al., 2019). Concrete surfaces alone do not offer enough friction to foster a comfortable environment for cattle to exhibit normal gait without slipping (Phillips and Morris, 2001).

Slatted floor facilities have a concrete surface with 3.18 to 5.08 centimeter wide openings that are 12.70 to 15.24 centimeter apart for manure to drain into a 1.8 or 3.7 m deep concrete pit underneath (Gooch, 2001; Euken et al., 2015). The underfloor pit system in a slatted floor facility has less nutrient loss from manure (Euken et al., 2015). Slatted floor cattle feeding facilities require the least amount of labor for manure handling and are effective in manure nutrient conservation (Harrison and Smith, 2004; Euken et al., 2015). Slatted floor facilities have an advantage compared with deep-bedded and solid floor options because more cattle can be housed in the same area with a stocking density of 2.0 m^2 to 2.3 m^2 per animal (Euken et al., 2015**).** The manure from this system is stored in a sealed concrete pit that is less likely to have nutrient leaching when compared with deep-bedded or solid concrete storage. Deep-bedded and solid concrete feedlots must have additional storage for 365 days of manure that tend to have lower nitrogen retention while slatted floor facilities tend to store manure for 180 days. The manure from a slatted floor pit system is considered slurry that contains the liquid and solid portions that go through a chopper pump to create a finer texture that flows more consistently when being injected into the soil (Pfost et al., 2000).

Slatted floor housing can be bare concrete or have rubber matting added to the surface. The rubber matting type and quality vary by the manufacturer due to manufacturing processes, rubber source, and chemical components (Lafrance, 2013). Some of the prominent brands used are Easyfix USA (Tea, SD, US), Animat (Sherbrooke, QC, CA), Kraiburg (Waldkraiburg, DE) and Durapak Agri LTD (Ballincollig, Co. Cork, IE). Easyfix USA and Durapak Agri LTD rubber matting are designed with wedges that grip the slatted holes to keep in place while Animat and

Kraiburg rubber matting uses a clamp system. The use of rubber matting derives mainly from an animal welfare concern. Cattle are more active and lie less in an open lot pen design compared with bare concrete slatted floors (Brscic et al., 2015a; Earley et al., 2017). Adding rubber matting helps mitigate those concerns by decreasing lying down attempts, slipping events, and laying duration while decreasing morbidity and mortality rates (Cozzi et al., 2013; Dewell et al., 2018). Aside from resting behavior, the addition of rubber matting keeps cattle cleaner, decreases skin lesions, and decreases the occurrence of joint swelling which improves food safety at an abattoir by reducing pathogenic presence on the hide (Lowe et al., 2001; Schulze Westerath et al., 2007; Carlson et al., 2008; Elmore et al., 2015; Murphy et al., 2018). Despite bare concrete slatted flooring negatively affecting resting behavior and joints, the rougher surface texture does minimize excess hoof growth compared with rubber matting (Brscic et al., 2015b). With limited research, it has been reported that a breed and flooring type interaction may influence the intensity of differences in growth performance and carcass characteristics (Magrin et al., 2019a).

LOCOMOTION AND LAMENESS

Locomotion in cattle has been defined as the voluntary movement of an animal (Phillips, 2002). Locomotion can easily be affected by a variety of outside variables but is most commonly changed by lameness and environmental factors. Lameness is categorized by abnormal movement of at least one limb caused by disease, environment, or inherent defects (Phillips, 2002; Olechnowicz and Jaskowski, 2011). The abnormal movement of a limb in beef cattle results in reduced load-bearing, side-to-side sway, shortened stride, or conformational flaws.

Risk Factors

Beef cattle research on the cause of lameness and locomotion changes in feedlots is limited due to the practicality of investigation but has increased in recent years. Some contagious diseases like foot rot and bovine digital dermatitis (**DD**) cause lameness in beef cattle (Anderson, 2001). Foot rot is present because of a systematic infection of *Fusobacterium necrophorum* or *Bacteroides* (Anderson, 2001). Cases of DD cause inflammation of cells and lesions at the hoof line between claws from an infection of *Treponema* bacteria (Wilson-Welder et al., 2015). Seasonal changes are a major contributor to foot rot and DD as a result of excess surface moisture (Davis-Unger et al., 2019).

Some of the common non-infectious hoof afflictions in feedlot cattle are sole ulcers, sole hemorrhages, and white line abscesses (Magrin et al., 2018). A sole ulcer is defined as disruption or penetration of the sole with or without exposure to the corium potentially with granulation tissue (Miguel-Pacheco et al., 2017). A sole hemorrhage has red to yellow discoloration on the sole or white line typically from bruising (Egger-Danner et al., 2020). Sole hemorrhaging is more prevalent with cattle housed on bare concrete slatted floors (Magrin et al., 2020). White line abscesses cause the white line to separate with necrotic inflammation of the corium due to trauma, hemorrhaging, or swelling (Magrin et al., 2018). Unlike dairy cattle or some cow-calf production systems, hooves of finishing cattle are not regularly trimmed as a result of the quick turnover rate, so most claw disorders go undetected until lameness or further physical ailments arise. Cattle that appeared with normal locomotion and lameness free had feet inspected post-slaughter (Magrin et al., 2018). Based on claw disorder at the abattoir, 0.7% to 96.1% of the slaughter groups were affected. The total number of feet affected by disorder was 0.0% to 50.2% within slaughter groups. The differences is hoof health within slaughter groups could be attributed to animal management if cattle within a slaughter group came from similar origins. Dairy cattle have been noted to have a heritability of sole ulcers, sole hemorrhage, and white line abscesses at 0.03 to 0.39, 0.21, and 0.08-0.17 respectfully (Greenough and Weaver, 1997). If beef cattle have similar heritability rates, some finishing animals may be genetically predisposed to non-infectious hoof afflictions.

Environmental factors that cause lameness are difficult to compare because each operation is unique. Overstocking of pens can lead to limbs being stepped on if other animals are laying down. Animals housed on bare concrete slatted floors would have a greater likelihood of being stepped on compared with animals on rubber matting because they spend more time with limbs extended while laying down from lack of comfort (Cozzi et al., 2013.) Also, tails are commonly stepped on causing injury or tail removal that can lead to a systemic infection (Schrader et al., 2001; Kroll et al., 2014). The prevalence of tail alterations is higher in slatted floor facilities than in open lot design while also increasing as individual animal space is decreased.

Not only are slatted floor facilities stocked denser, but the area of the pen is typically smaller. Smaller overall pen dimensions may limit cattle movement and alter lying behavior which can lead to stiffness, injuries from being stepped on, and lesions (Gygax et al., 2007; Tessitore et al., 2009). Cattle travel longer distances in larger pen designs which allows the animal to stretch and take a full stride reducing stiffness. The identification of lameness created from stiffer joints and muscles compared across different pen sizes has not been documented. More research should evaluate how combinations of pen size and stocking density affect mobility.

Cattle handling and facilities can also negatively affect locomotion and increase lameness prevalence. If handlers are untrained or poorly trained, cattle may injure themselves in a natural instinct of fight or flight behavior. Cattle facilities should be free of sharp turns and uneven surfaces to avoid injury (Grandin, 1980). Animals could injure a limb at a sharp turn or protruding obstacle so designs should follow cattle's instinct to follow curves. Uneven surfaces could result in toe and heel bruising, injured carpal joint, or other limb injuries. Recommendations for facility design and spacing should be followed on an individual operation basis for best animal safety and efficient handling.

Lameness can be a result of poor nutrition in the feedlot. Selenium deficiency has been noted to cause the serratus ventralis muscle to rupture causing scapula displacement (Buergelt et al., 1996). Copper and manganese deficiencies could result in carpal-metacarpal swelling while low zinc levels can cause a stiffer gait from swelling of distal limbs (Graham, 1991). Excess fluorine and selenium at a toxic level can cause general lameness, stiffness, and irregular hoof growth (Koller and Exon, 1986; Jubb et al., 1993). Animal nutrition should meet the intended goal of the animal while maintaining safe nutrient levels (Samuelson et al., 2016).

Animal conformation is most commonly a selection criterion in dairy and cow-calf operations for its role in production and longevity within the herd. In dairy cattle, physical foot and leg abnormalities occur 28% more times in lame cattle than in non-lame cattle (Mahin et al., 1986). Physical abnormalities such as claw deformations can be used to identify potential lameness cases. In dairy herds, lameness decreases milk production, reproductive performance, and longevity which increases the culling rate (Booth et al., 2004). Heritability of feet and leg conformation in dairy cattle was reported from 0.16 to 0.41 (Van Dorp et al., 1998). Inaccuracy and inconsistency in scoring methods may have reduced the validity of the estimates. Although the heritability rate can be moderate to low, the author inferred decisive conclusions on how conformation affects lameness. Cattle with shallower foot and more set to the hind leg angle were more likely to develop lameness (Van Dorp et al., 1998). As a whole, Angus cattle feet and leg conformation traits have a heritability range of 0.10 to 0.33 using a Linear Animal Model and

0.12 to 0.50 using the Threshold Animal Model (Jeyaruban et al., 2012; Giess, 2017). Structural conformation was evaluated by feet angle, claw set, rear leg side view angle, and rear leg hind view. Little research has been conducted on animal conformation and its effects in a beef feedlot setting. In beef feedlots, a longer claw and greater heel depth may be associated with an underlying lameness issue (Magrin et al., 2020). The most correct conformation and least likelihood of lameness should result from pairing genotypic and phenotypic selection. Using recommendations from dairy production, beef production, and the limited research from beef feedlots suggest that cattle with long claws, more angular hind limbs, and longer heels have the greatest likelihood of lameness and should be examined often. More precise tools are needed to accurately evaluate conformational differences. The American Simmental Association has created feet and leg scoring recommendations to improve claw shape, foot angle, and hind leg side view angle in the breed through genetic selection over time (Giess, 2021).

Using animal conformation to identify potential causes of lameness can be crucial in reducing the prevalence of severe lameness that could lead to culling and mortality. In a large group study of 6 commercial feedlots, 9% of the cattle determined lame were realized due to severe status (Terrell et al., 2017). Flooring type can influence culling rate with cattle housed on bare concrete slatted floor being 6.7 times more likely to be culled than deep-bedded at an occurrence of 2.53% and 0.38%, respectively (Brscic et al., 2015 Welfare). Realizer cattle are typically culled on average 30 to 54 days before their contemporaries (Magrin et al., 2019b). While culling is rarely reported in beef cattle research, culling rates in dairy herds are well documented. Voluntary and involuntary combined culling rate from lameness in dairy herds increases as lactation number increases, ranging from 4.0% to 13.1% with an overall average of 8.3% (Esslemont and Kossaibati, 1997). More beef cattle feedlot research should be conducted to determine not only the realizer or culling rate from lameness but also the source of the affliction. Commercial feedlots had 22% of cattle that were diagnosed lame became critical around 16 days after identification resulting in euthanasia or death (Terrell et al., 2017). Mortality rate, by either euthanasia or death, increases as locomotion scores assigned increase. Detecting lameness quickly can reduce lameness morbidity and mortality rates.

Prevalence

The prevalence of lameness is based on a variety of factors. The average days on feed for lameness detection for 2,532 affected cattle was 57 days (Terrell et al., 2017). Including all lameness causes and management types of feedlots with a capacity of greater than 1,000 animals, lameness can affect 1.8% of cattle (USDA, 2013). In 2015, lameness accounted for 1.7% of death loss in the U. S. beef cattle inventory under 228 kg and 4.6% of death loss in beef cattle over 228 kg (USDA, 2017).

Flooring type influences the occurrence of lameness. Animals in deep-bedding are less lame than those on concrete surfaces (Schültz et al., 2014). Cattle housed on bare concrete slatted floors developed lameness 2.6 times more often than cattle on rubber matting (Dewell et al., 2018). As the stocking rate increased, the number of lame animals increases in deep-bedded and bare concrete slatted housing (Magrin et al., 2019b). In deep-bedding pens, 1.1% of cattle stocked at 5.5 m^2 of space per steer were lame while 3.7% of cattle housed at 5.0 m^2 of space per steer were lame. Although at a higher proportion, cattle housed on bare concrete slatted floors at a stocking density of 4.0 m^2 had 3.0% lame cattle and pens at a 3.5 m^2 stocking density had 6.7% lame cattle. In a smaller study, cattle housed at a low stocking density of 4.7 m^2 on bare concrete slatted floor facilities had lameness occur in 12.7% of animals while a high stocking density of 3.5 m^2 had lameness occur in 18.7% of animals (Cortese et al., 2020).

In a 10-year collection of 28 feedlots' treatment records, lameness was categorized as foot rot, joint infection, lameness with no apparent cause, and injuries accounting for 74.5%, 16.1%, 6.1%, and 3.1%, respectively, for all lameness causes (Davis-Unger et al., 2019). Death rates causes by lameness identified as joint infections, foot rot, injuries, and lameness with no apparent reason were 6.4%, 3.9%, 1.3%, and 1.2%, respectively. A slaughter facility used the North American Meat Institute's Mobility Scoring System (NAMI) of 1 to 4 to evaluate 65,600 animals. Six different slaughter facility evaluating mobility over an 8-hour shift for five days reported 1.68% of cattle had general stiffness and 0.23% of cattle were lame (Lee et al., 2018). Regardless of the factors that influenced the lameness, the prevalence of lameness can start shortly after arrival in a feedlot setting and continue to increase until slaughter.

Detection

Lameness and locomotion alterations can be assessed with visual inspection or scoring systems. Animals should be visually inspected during routine health checks of a group for hoof, limb, and gait abnormalities that are causing altered locomotion or could in the future (Desrochers et al., 2001). Trained and educated evaluators should inspect animals daily while following operation protocols and veterinarian directives when problems with animals occur.

Lameness scoring systems identify the overall health of a hoof through different categories of scales with the potential to clarify reasons for gait change (Manske et al., 2002). Lameness scoring is typically done in dairy cattle at the time of hoof trimming which is not common or practical in most feedlot operations. Non-infectious lesion score (NILS) accounts for the number of lesions on a single hoof by disorder and zone affected with a score ranging from 0 to 40 caused from non-infectious sources (Magrin et al., 2018). Infectious lesion score (ILS) accounts for the number of lesions on a single hoof by disorder and zone affected with a score ranging from 0 to 10 caused from infectious sources (Magrin et al., 2018).

Locomotion scoring systems rely on stride length, speed of movement, weight-bearing, and head movement to detect problems with cattle (Edwards-Callaway et al., 2017). Since 2013, abattoirs have seen an increase in cattle identified with Fatigue Cattle Syndrome (FCS). Stiff gait, reluctance to move, and labored breathing are all signs of FCS (Thomas et al., 2015). This syndrome is recorded at the abattoir to help identify options to increase animal welfare prior to arrival. Abattoir staff use the NAMI mobility scoring 1 to 4 scale to evaluate mobility focusing on change in gait, stiffness, and ability to travel. A score of 1 represents no change in any of the previously listed areas. A score of 4 represents cattle that have no desire for movement even with encouragement. Locomotion scoring systems developed by Kansas State University and Zinpro Corporation can be used for onsite evaluation. The Kansas State University system uses a 0 to 3 scale to evaluate changes in gait, vertical head movement, and weight-bearing of limbs (Terrell, 2016). A score of 0 represents normal behavior. A score of 3 represents cattle that have severe restriction to their gait, drastic head movement, or inability to travel. The Step-Up Locomotion Scoring System® developed by the Zinpro Corporation was adapted from the Kansas State University system. It uses a 0 to 3 scale to evaluate changes in gait, stride length, vertical head movement, and weight-bearing of limbs (Step-Up Locomotion Scoring System®). A score of 0 represents normal behavior. A score of 3 represents cattle that have severe restriction to their gait or stride, drastic head movement, or inability to travel.

Visual identification systems for lameness and locomotion problems are easy to understand with simple instructions to train individuals to use. They have a wide application that can universally be understood. Unfortunately, these types of visual identifications are not reliable and rarely predict future issues. When assessing the same animal twice, the probability of perfect agreement ranges from 60% to 72% within a group of trained observers with varying levels of experience in dairy cattle (Garcia et al., 2015). Similar results were found in beef cattle with different experience level observers having agreement values ranging from 81% to 84% (Tunstall et al., 2020). This type of subjective technique should not be the sole identification factor for locomotion impairments. Automatic detection of impaired gait or conformation concerns is not documented in finishing beef cattle. In contrast, automatic detection of impaired gait or conformation concerns in dairy cattle is well reported because cattle travel to the parlor multiple times each day providing ample opportunities for the use of this system. Finish beef cattle are rarely removed from their pen which makes regularly monitoring cattle in a routine location challenging.

Treatment

Treatment methods for lameness depend on the source of the affliction. Generally, lameness is treated with injectable antibiotics, corticosteroids, and nonsteroidal anti-inflammatory medications (USDA, 2013). Foot rot can be treated with antibiotics. The most commonly used treatments are tilmicosin, oxytetracycline, and tulathromycin (Feedlot). The addition of zinc methionine in diet could potentially improve hoof condition and reduce foot rot infections but results are not conclusive (Anderson et al., 2001). Additional, vaccinations for the prevention of foot rot are available. Cases of DD can be treated using topically or group treatment can be done with foot baths. Topical treatments can be antibiotics or alternatives. The alternative treatment methods tend to be less effective aside from acidified sodium chlorite (Laven and Logue, 2006). Foot baths also use antibiotics or alternatives but treatments such as formalin sodium hydroxide mix, high zinc sulfate concentrations, and peracetic acid have similar response rates (Laven and Logue, 2006).

Treatments for locomotion problems caused by environment or conformation are not available. Some corticosteroids and nonsteroidal anti-inflammatory medications can be given to help alleviate pain and swelling based on operation protocols and veterinary directives but it is only a temporary solution. Best cattle stewardship, facility design, and handling practices should be used to limit risk factors resulting in locomotion alterations.

Associated Cost of Lameness and Poor Locomotion

Lameness and poor locomotion can affect the profitability of cattle through treatment costs, early culling, and trim loss at the slaughter. Treatment cost for lame cattle affected from any source averaged \$14.40 per treatment for operations with more than 1,000 animals (Feedlot). Others have reported lameness treatment costs when swelling is not observed to average \$17.10 per treatment (Davis-Unger et al., 2017). Early culling resulting from lameness and locomotion problems can attribute to around 36 kg lost at slaughter weight compared to healthy animals (Magrin et al., 2019b). Cattle that are realized prior to optimal slaughter weight, around 453 kg or less, due to unrecovered lameness had a net return of \$265 less than cattle that were able to recover and reach a finishing weight (Davis-Unger et al., 2017). Arthritic joints can be associated with lameness or locomotion problems which cause an average of 17.9 kg of trim loss in processing plants. In 1999, an estimated seventeen million kilograms of trim loss from arthritic joints occurred in 701,946 cattle (Feedlot). Cattle that had foot rot but recovered had an average range of net return of around \$500 (Davis-Unger et al., 2017). Cattle that had foot rot but did not recover and were realized had an average range of net return around \$45 (Davis-Unger et al., 2017). Cattle with lameness caused by a non-contagious infection that recovered from the infection had an average net return of -$227 (Davis-Unger et al., 2017). Cattle with lameness caused by a non-contagious infection that did not recover from the infection were realized and had an average net return of -$270 (Davis-Unger et al., 2017). Lame cattle with no swelling that recovered, were realized, or died had an average net return of -$450 or greater. Lameness and locomotion problems can lead to financial loss which can affect the profitability of an operation regardless of size but does become more of a concern in larger feedlots.

IMPACT OF FLOORING TYPE ON PERFORMANCE AND CARCASS CHARACTERISTICS

Although bare concrete slatted floors potentially cause lameness, the addition of rubber matting may mitigate lameness and joint swelling (Graunke et al., 2011). Rubber matting improved gait score and comfort for dairy cattle compared with bare concrete floors which increased feed intake up to 5 kg per head per day (Flower et al., 2007; Norring et al., 2014). While the use of rubber matting in indoor feedlot facilities is a common practice, most rubber matting research has not been conducted in US feedlot systems where growth promotants are commonly used. Additionally, rubber matting is a consumable product with a variable lifespan. However, its effect on cattle growth performance and locomotion after long-term use has not been evaluated to determine the length of positive impact.

Growth Performance

Final body weight (BW) and average daily gain (ADG) directly determines the days on feed needed to reach a finished weight. A greater ADG will reduce days on feed which will increase profit by reducing opportunity costs (Fuez, 2002). Cattle housed for 132 days in outside lots have been reported to have a 38 kg heavier final BW and gained 0.38 kg more per day than cattle housed on bare concrete slatted floors but are similar to deep-bedded facilities (Dunne et al., 2008). This study used a limited number of steers and had an average initial BW of 527 kg which is heavier than most studies. Almost five times more cattle per treatment were assigned to a similar 150-day study but reported no difference in final BW and ADG between outside pens, bare concrete slatted facilities, and rubber slatted facilities (Early et al., 2017). The study conducted by Early et al. (2017) had greater power and replication for analysis because of more animals that allowed for a more accurate report of effects of flooring type. It is not definitive whether cattle housed on rubber matting and bare concrete slatted floors are different in final BW and ADG. Cattle on rubber matting have been reported to have up to 22.4 kg heavier final BW and gain 0.07 kg more per day than cattle housed on bare concrete slatted floors (Brscic et al., 2015; Magrin et al., 2019a). However, other studies have reported differences in ADG but not final BW (Cozzi et al., 2013; Keane et al., 2015). In contrast, no difference in final BW and ADG were documented (Elmore et al., 2015). Some studies do not report both values making it challenging to interpret the results (Dewell et al., 2018). Based on current research it is not clear if flooring type affects final BW and ADG, therefore further studies should be conducted.

Dry matter intake (DMI) is reduced as the severity of lameness increases. The most severely lame dairy cattle will consume about 16% less feed per day (Margerison et al., 2002). Additionally, the number of meals and time spend eating will decrease as locomotion problems occur (González et al., 2008). Cattle will compensate for fewer feeding events by increasing their feeding rate and almost doubling the meal size (Margerison et al., 2002; González et al., 2008). These interactions have not yet been associated with flooring type. Research has reported differences in cattle locomotion by flooring type but there were no differences in DMI (Dewell et al., 2018). More investigation into how locomotion changes based on flooring type affect DMI is needed.

Feed conversion is not typically affected by flooring type. When flooring treatments are evaluated, diets are similar among treatments and thus, feed conversion is not affected. Feed conversion was not affected when feedlot cattle are fed similar diets in outside lots, deep-bedded barns, bare concrete slatted floors, or rubber matted pens (Gottardo et al., 2016; Early et al., 2017; Dewell et al., 2018).

Carcass Characteristics

Similar to differences in growth performance, hot carcass weights (HCW) are not consistent. Additionally, many studies are underpowered to determine HCW differences. Research on if flooring type affects hot carcass weight (HCW) is contradictory. Forty-five Charolais steers housed in outside lots, deep-bedded pens, and bare concrete slatted floor pens were different in HCW (Dunne et al., 2008). Steers housed in outside lots had the great HCW, deep-bedding pens intermediate, and cattle on bare concrete slatted floors had the lightest HCW. Similarly, a study conducted to determine differences between Charolais and Limousin finishing bulls housed on bare concrete slatted floors and rubber matting reported differences in HCW (Magrin et al., 2019a). Cattle housed on rubber matting averaged 10.7 and 14.6 kg heavier HCW than bulls on bare concrete slatted floors for Charolais and Limousin cattle, respectively. A majority of the research on flooring type that reported HCW had no improvements based on treatment (Keane et al., 2015; Gottardo et al., 2016; Early et al., 2017; Lowe et al., 2019). Other carcass values of longissimus muscle area, 12th rib fat thickness, yield grade, marbling score, percent kidney-pelvic-heart fat, and dressing percent are consistently reported to not be affected by flooring type (Lowe et al., 2001; Gottardo et al., 2016; Early et al., 2017; Lowe et al., 2019). Muscle and eating quality factors have been noted by some research which also states that flooring type does not affect color, drip loss, shear force, pH, or percent cooking loss (Lowe et al., 2001; Dunne et al., 2008; Gottardo et al., 2016; Lowe et al., 2019). Overall, differences in HCW should align with any differences observed in final BW and ADG, given a sufficiently large enough sample size that would overcome additional variation from physical fill and dressing percentage.

ANALYZING LOCOMOTION AND LAMENESS WITH DIGITAL TECHNOLOGY

The ability to detect locomotion and lameness problems manually requires trained individuals to evaluate animals every day. In doing so, the individual may not identify an animal that needs extra care because of many factors like the environment, human error, or there is only a slight alternation to the animal that is not detectable. The scoring systems used are subjective and categorical. Often animals may not meet requirements to be scored correctly if they are running or not walking straight which can often bias the case in a group or individual setting. Analyzing animals with digital technology can be used routinely to monitor animal movement allowing for quantitative non-biased measurements. Digital technology for analyzing locomotion has been mostly used in dairy, equine, humans, and dogs. Dairy cattle research uses digital technology to evaluate locomotion and lameness because of the relationship with animal performance and welfare. Equine and canine research is focused on locomotion and gait because they are used from their physical performance. Research with humans on locomotion mainly is used to understand structural problems and to assess rehabilitation needs.

A majority of livestock research that uses digital technology has been with dairy cattle and has focused on lameness detection. Hoof and leg health is important to dairy production because of the role it plays in longevity, performance, and milking ability. An understanding of lameness problems and their effect on dairy cattle has been established but there is little research in relation to conformation. Researchers do not have near the knowledge of beef cattle lameness or locomotion differences as they do for dairy cattle.

2-Dimensional Videos

Cattle movement can be captured using 2-dimensional (2-D) videos that rely on kinematic data to provide a spatial and temporal measurement of the animal's gait (Carvalho et al., 2007). A digital video camera can be positioned perpendicular to the median plane of an animal to capture locomotion. Multiple natural strides are required to capture the full range of motion for the animal. Cattle stride length, step length, stride speed, angularity of limbs and joints, and displacement can be calculated with the kinematic data. A single frame from a 2-D video can be selected to assess body weight, size, and body condition using pixel count or thermal imagery (Halachmi et al., 2008; Nicolas et al., 2018). These estimates can be taken from the medial plane or superior transverse plane.

3-Dimensional Videos

Depth cameras with stereoscopic sensors are used to create 3-dimensional (3-D) videos measuring distances in pixels. Infrared dots are projected onto the surface and recorded by the infrared camera to provide spatial locations of objects in view (Kawasue et al., 2013). Some cameras also add inertial measurement units (IMU) to better track movement through gyroscope-based sensors that calculate on three axes, pitch, yaw, and roll (Intel Corporation). The depth cameras are commonly placed perpendicular to the superior transverse plane. However, the 3-D coordinates for the back contour line can be taken from above the animal for recording and transferred to the median plane for analysis of the vertical movement of the hip, spine, and head (Jabbar et al., 2016; Van Hertem et al., 2018). The videos can also record data from the superior transverse plane to estimate body weight or volume in cattle and swine (Suwannakhun and

Daungmala, 2018; Le Cozler et al., 2019). Cattle gait analysis uses depth cameras from the median plane to evaluate step overlap, hoof release angle, and body dimensions (Pluk et al., 2010; Pluk et al., 2012; Gomes et al., 2016).

Segmentation of Animals

Defining an animal from the surrounding area allows processing programs to function more accurately. This partitioning of the animal is called segmentation. Segmentation can be categorized as classical image analysis or machine learning techniques (Jena et al., 2018). Classical analysis typically uses gray-scale or binary convert images to define objects based on changes in depth or color (Zaitoun and Aqel, 2015). Machine learning requires training, but as the program gains experience the performance and accuracy of tracking an object increases (Jena et al., 2018). To make this easier, some research implements a solid, neutral background for video recording (Nicolas et al., 2018). Most video processing programs are custom or privately owned so the exact variation between programs is unknown. A Gaussian low-pass filter can be used to blur discontinuities in the video making the video appear more fluent (Jabbar et al., 2016). Once the background is removed, the video is converted to binary for determining spatial locations of a selected point (Nicolas et al., 2018). Manual or automatic selection of focal points such as the tail head, joints, or the poll depends on the program being used. The focal points are tracked on 3 axes to determine the pixel coordinates on each frame (Carvalho et al., 2007; Jabbar et al., 2016).

Available Programs and Software

Videos and images can be captured using various types of cameras as long as they can record spatial location either in 2-D or 3-D. Software and programs that process videos or images and then calculate variables are typically custom-designed, privately owned, or not listed in the methods of the study. Some researchers have used MATLAB software (The MathWorks Inc., Natick, MA, US), Adobe software (Adobe Corporation®, San Jose, CA, US), TrackEye® (Innovativ Vision AB, Linköping, SE) for processing and editing videos and images (Drevemo et al., 1993; Carvalho et al., 2007; Vaizzi et al., 2014). Generally, available software, programs, or even knowledge of how the research was conducted are not reported for data analysis. Adapting software from other industries has been done with the Human Movement Analysis Software (Hu-m-an™, HMA Technology Inc., Ontario, CA) to provide kinematic data for dairy cattle with trimmed or un-trimmed hooves (Carvalho et al., 2007). A few of the major concerns with the limited technology available are that most cameras are light sensitive and animal segmentation can be challenging. Excess or poor lighting can alter how the sensors of the camera perceive the spatial view (Kongsro, 2014; Viazzi et al., 2014). This can lead to incorrect segmentation of the animal from the video when using cameras that do not record stereo depth (Intel Corporation, 2019). The software can not determine the exact animal because it blends into the background or the shadow is accounted as part of the animal (Viazzi et al., 2014).

Alternative Technology

Accelerometers are another kinematic method that can be used to track animal movement. When attached to a limb, 3-D accelerometers can record static and dynamic behavior to determine changes in gait (Veltink et al., 1996; Robert et al., 2009). The accelerometer measures gravitational force to determine if an animal is walking, standing, or laying down (Theurer et al., 2013). The alteration in animal activity can indicate lameness which was previously stated to cause reluctance to move and prolonged laying time. Changes in gait speed, cycle duration, stance, and swing phase can give a more in-depth description of locomotion differences (Chapinal et al., 2011; Alsasod et al., 2017). The reliability of accelerometers is based on sensitivity and specificity on the variable focused on. For example, stride duration has a sensitivity of 75.6% and specificity of 75.0% while walking speed has a sensitivity of 92.7% and specificity of 83.3% (Beer et al., 2016). Not every trait is needed to identify lame cattle because a simple model using walking speed and standing bouts can be used with a sensitivity of 90.2% and specificity of 91.7%. A kinetic model of locomotion and lameness can be determined with a pressure plate. Ground reaction forces are measured by load cells underneath a platform as the animal stands or walks across the surface (Tekscan, Inc.). The pressure sensors can be set up in an alleyway that cattle are familiar with traveling (Bergsten et al., 2015). The pressure plate can calculate contact pressure, contact area, and stance phase duration using HUGEMAT Research 5.83 software (Tekscan, Inc., South Boston, MA, US) to better understand locomotion changes (Coetzee et al., 2017). Additionally, claw conformation can be reported using the color-coded output (Bergsten et al., 2015). The MatScan (Tekscan, Inc., South Boston, MA, US) pressure plate or similar products are widely available but are not commonly used because of the cost and space needed for evaluation (Pastell et al., 2010; Taneja et al., 2020). Pressure plates can be synchronized with 2-D or 3-D videos to enhance the understanding of gait change.

Other Species

Digital technology is not commonly used in beef production but has a strong presence in dairy, equine, and swine production. It is currently not practical in beef production to use digital technology based on analytical and animal management limitations. Dairy cattle travel to the parlor daily to be milked therefore cameras are set up to capture the animal to and from milking (Flower and Weary, 2008; Viazzi et al., 2014). A high-speed camera was used to record dairy cattle movement after being housed on pasture, in a tie-stall, or in cubicles for two and a half years (Herlin and Drevemo, 1997). This study highlighted the need for cows to be removed from indoor housing to maintain joint flexibility. Horses are easy to handle allowing the video process to be done efficiently (Merkens et al., 1985; Leach et al., 1987). Horses are commonly valued by their structural conformation and soundness, so researchers have used accelerometers, pressure plates, and video analysis to better understand horse gait and lameness (Merkens et al., 1985; Barrey, 1999; Leleu et al., 2002). Swine production can use digital technology in a scale or alleyway which is not practical for large-scale operations because animals are not often removed from pens (Mohling et al., 2014; Condotta et al., 2018). Digital technology can be applied to individual housing crates or pen settings to better fit production methods but this approach has been limited (Shi et al., 2019; Yu et al., 2021). Placing video cameras on crates or over a pen allows animals to be tracked to better understand locomotion to identify lameness and estimate body weight (Kashiha et al., 2014; Shi et al., 2019). Digital technology is also being used in humans and dogs to study gait and conformation to improve the prediction of locomotion problems (Oosterlinck et al., 2011; Mariani et al., 2013; Lugade et al., 2014).

RESEARCH NEEDS

The overall lack of volume, consistency, reliability, and general knowledge in the area of locomotion and lameness risk factors for beef feedlot cattle are the major deficiencies in literature. A scoping review to determine the relationship between housing and animal welfare used relative search parameters in five databases to identify 1,147 citations in the field of interest (Park et al., 2020). Multiple screening methods were used to refine the selections to the most appropriate material which resulted in only 37 publications. Within those studies, four major areas were categorized with 13 to 23 subsection numbers. Similarly, a meta-analysis of 18 studies that evaluated the effect of flooring type of performance, lying time, and dirt scores of finishing cattle concluded that each study has different parameters reported making it challenging to draw conclusions across studies (Keane et al., 2018). An additional challenge to making relevant comparisons is that most of the research conducted on the cause and effect of gait alterations is not performed in a US feedlot system. The process of analyzing the digital images often uses patented or private algorithms which limits the repeatability and interpretation across studies. More open-source research is needed to progress the field and facilitate the reproducibility of results. The reliability of automated locomotion scoring systems can have a specificity of 72.8 to 96.4% and sensitivity 39.1% to 90.0% (Schlageter-Tello et al., 2014). Even if the particular study being evaluated has acceptable specificity and sensitivity, the values still need to be validated based on visual assessment limiting the value (Sadig et al., 2017). Some areas of research on gait alterations still need to be investigated. The effect of individual animal conformation and selection methods on locomotion is lacking in feedlot research but should continue despite the technical and logistical challenges. The body of research on adding rubber matting to bare concrete slatted floors has not clearly defined the effects on locomotion and growth performance in cattle. Regardless, rubber matting is a consumable product with a variable lifespan that can differ from wear, rubber source, chemical components, and light exposure. No research has evaluated all of these variables on how they can alter the long-term use of matting and potentially cattle locomotion.

CONCLUSION

Indoor cattle feeding facilities are being built more often and cattle welfare continues to be a focal point for research, so gaining an understanding of how facilities affect cattle welfare, specifically locomotion and lameness, needs to be further investigated. Overall, more large-scale studies need to evaluate these interactions, but doing so in a consistent manner that is reported in detail. The potential that cattle can perform better and receive better welfare management can be impacted by facility design and animal selection but definitive reports can not be drawn with current studies. The advancements in digital technology offer scalable quantitative structural conformation phenotyping to add further understanding to manual analysis. The implications of facility design and animal conformation as it relates to locomotion need to be understood for practical cattle management.

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CHAPTER 2

EFFECTS OF RUBBER MATTING ON FEEDLOT CATTLE GROWTH PERFORMANCE, LOCOMOTION, AND CARCASS CHARACTERISTICS IN SLATTED FACILITIES

ABSTRACT

The objective was to determine effects of old and new rubber matting in a slatted, indoor cattle feeding facility on cattle growth performance, locomotion, and carcass characteristics. In experiment 1, fall-born Angus × Simmental steers (N = 207; BW = 222 ± 38 kg) were blocked by weight and assigned to 32 pens. Pens were randomly assigned to 1 of 4 treatments: no matting/concrete (CONC1, 12-year-old Animat Pebble matting (OLD1), new Animat Maxgrip matting (MG), and new Animat Pebble matting (PEB1). Steers were fed a common diet for 209 d with a minimum stocking density of 3.40 m^2 per animal. Final body weight **(BW**) and average daily gain (**ADG**) were affected ($P = 0.02$ and $P < 0.01$, respectively) by treatment with steers on PEB1 finishing heaviest with the greatest growth, MG and CONC1 intermediate, and OLD1 finishing at the lightest final BW with the least growth. Flooring treatment did not affect overall dry matter intake (**DMI**; $P = 0.16$) or gain to feed ratio (**G:F**; $P = 0.94$). Flooring treatment did not affect ($P \geq 0.19$) any carcass traits. Locomotion scores (**LS**) were affected ($P < 0.01$) by flooring treatment with CONC1 having the worst mobility while OLD1, MG, and PEB1 were similar ($P \geq 0.24$). Locomotion score had a day effect ($P < 0.01$) where cattle gait and mobility worsened as days on feed increased. In experiment 2, fall-born Angus × Simmental steers (N = 189; BW = 352 ± 43 kg) were blocked by weight and assigned to 21 pens. Pens were randomly assigned to 1 of 3 treatments: no matting/concrete (CONC2), 15-year-old Animat Pebble matting

(OLD2), and new Animat Pebble matting (PEB2). Steers were fed a common diet for 112 d with a stocking density of 2.65 m^2 per steer. After 112 days on feed, flooring treatment did not affect ($P \geq 0.30$) BW, ADG, or DMI nor did treatment affect ($P \geq 0.17$) carcass traits. However, steers housed on OLD2 or PEB2 had improved locomotion scores ($P = 0.02$) compared with steers housed on CONC2. Locomotion score had a day effect ($P < 0.01$) as cattle gait and mobility worsened with greater number of days on feed, regardless of treatment. Overall, results suggest new rubber matting increased ADG and HCW during a 209 d trial when cattle were stocked at 3.4 m^2 and that rubber matting regardless of age improved cattle locomotion scores in slatted indoor feeding facilities.

INTRODUCTION

Many feedlot operations in the Midwest have constructed slatted indoor cattle feeding facilities to improve pen conditions in the winter months and decrease land requirements (Grooms et al., 2015; Dewell et al., 2018). Most slatted indoor facilities have a one-time capacity of 250 to 2,500 cattle. From 2012 to 2017, an increasing proportion of the US feedlot inventory was represented in Midwestern states. Specifically, feedlots with 500 to 2,500 cattle have experienced the greatest growth from 2012 to 2017 in inventory as cattle numbers increased 27% and 55% in Iowa and Minnesota, respectively (USDA, 2017). The increase in inventory equates to the addition of roughly 167,000 cattle in Iowa and 82,000 cattle in Minnesota.

Cattle finished in indoor cattle feeding facilities have improved carcass value and ADG compared with cattle finished in outdoor concrete lots with adjacent overhead shelter (Goodrich et al., 1973). Although indoor facilities can improve pen conditions and cattle growth performance, a potential for increased lameness and profit loss on those affected animals may be a concern. Lameness, not caused by injury, was observed in 14% of cattle finished in indoor feedlot facilities with concrete floors (Davis-Unger et al., 2019). In a large 10-year dataset, lame cattle averaged a $555 net loss compared with other injuries in feedlot operations (Davis-Unger et al., 2017).

Although concrete slatted floors potentially cause lameness, the addition of rubber matting may mitigate lameness and joint swelling (Graunke et al., 2011). Rubber matting also improved gait score for dairy cattle compared with concrete floors (Flower et al., 2007). While the use of rubber matting in indoor feedlot facilities is a common practice, most rubber matting research has not been conducted in US feedlot systems - where growth promotants are heavily used. Additionally, rubber matting is a consumable product with a variable lifespan; but, its effect on cattle growth performance and locomotion after long-term use has not been evaluated to determine the length of positive impact. Therefore, the objective was to determine effects of old and new rubber matting in a slatted, indoor cattle feeding facility on cattle growth performance, locomotion, and carcass characteristics.

MATERIALS AND METHODS

Experiment 1

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #16035) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2020).

Experimental Design and Animals

To evaluate the effects of rubber matting on cattle growth performance, locomotion, and carcass characteristics in slatted facilities, 207 Angus × Simmental steers (BW = 222 ± 38 kg) were utilized for this study at the Beef Cattle and Sheep Laboratory in Urbana, IL in a randomized complete block design. Steers were blocked by initial BW into a heavy or light block and then stratified by sire and BW. Then cattle were allotted to 32 pens with 6 or 7 steers per pen. Pens were randomly assigned to 4 treatments: no matting/concrete (**CONC1**), 12-year-old Animat Pebble matting (**OLD1**; Animat, Sherbrooke, QC, CA), new Animat Maxgrip matting (**MG**), and new Animat Pebble matting (**PEB1**). Pens were 4.88 × 4.88 m in dimension with slatted concrete floors and an individual waterer. The minimum stocking density was 3.40 m^2 per steer. Prior to trial initiation, cattle were housed on concrete slats covered with rubber matting for 141 d and fed as a contemporary group. Cattle were fed a common growing and finishing diet through the duration of the experiment (**Table 2.1**) in a feed intake monitoring system (GrowSafe Systems, Alberta, CA) with one feed bunk per pen. Steers were weighed on consecutive days at the initiation and conclusion of the experiment with intermediate weights taken every 42 days. Locomotion scores were conducted at each weigh date using the 0-3 point scale Step-Up Locomotion Scoring System (Zinpro, Eden Prairie, MN) by two trained evaluators which focuses on head movement, stride length, and detectible restricted limb use. Locomotion scores from each evaluator were averaged for analysis. Steers were implanted on d 0 with Component TE-IS (16 mg estradiol and 80 mg trenbolone acetate; Elanco Animal Health, Greenfield, IN) and d 84 with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol USP, and 29 mg tylosin tartrate; Elanco Animal Health, Greenfield, IN). Steers were fed 300 mg per steer per day of Optaflexx 45 (Elanco Animal Health, Greenfield, IN) for the last 28 d before slaughter. On d 209, steers were transported approximately 310 km to Tyson Foods Inc.; Joslin, IL for humane slaughter. Following slaughter, hot carcass weight (**HCW**) was measured and carcass characteristics including 12th rib fat thickness, LM area, yield grade, and marbling score were taken after a 24-h carcass chill with Video Image Analysis as part of the USDA camera system at Tyson Foods Inc. Yield grade was calculated according to USDA (1997).

Sample collection and analysis

Individual feed ingredient samples were collected every 42 days and composited at study completion. Ingredient samples were stored at -20°C until processed. A wet composite was used from individual feed ingredients and were freeze-dried at -80°C. Sample dry matter (**DM**) was determined for each feed ingredient weekly by drying samples in a 105°C forced air for 24h. All samples were ground in a Wiley mill (Arthur, H. Thomas, Philadelphia, PA) with 1 mm screening for composition analysis. Feed samples were analyzed for nitrogen (X6.25 to calculate crude protein, TruMac; LECO Corporation, St. Joseph, MI), ether extract (Ankom Technology method 2; Ankom XT10 Fat extractor, Ankom Technology, Wayne, NY), neutral detergent fiber (Ankom NDF Method 5; Ankom200 Fiber Analyzer, Ankom Technology, Wayne, NY), acid detergent fiber (Ankom ADF Method 6; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), and organic matter (600°C for 12 h; Thermolyte muffle oven Model F30420C, Thermo Scientific, Waltham, MA).

Statistical Analysis

The MIXED procedure of SAS (SAS version 9.4; SAS Inst. Inc., Cary, NC) was utilized to analyze growth performance and carcass characteristic variables. Pen was the experimental unit. Fixed effects included treatment and block in the model statements with initial BW as a covariate for growth performance variables. Individual animal data was included in the model with a random effect of pen nested within treatment (St-Pierre, 2007). Expected progeny difference (EPD; mid-parent average) estimates were used as a covariate to account for inherent genetic differences by selecting the most appropriate EPD for the corresponding response variable (Shike, 2018). If no EPD was appropriate, sire was included as a fixed effect. The GLIMMIX procedure of SAS (SAS version 9.4; SAS Inst. Inc., Cary, NC) was utilized to analyze LS and examined for effects of treatment, time, and treatment × time. A negative binomial distribution with a log transformation was used as best fit based on a chi-square fit statistic. The model included fixed effects of treatment, time, block, sire, and treatment by time interaction. Locomotion scores from d 0 and initial BW were used as covariates. A random effect of pen nested within treatment was included in the model. Least squares means were separated using PDIFF option. Treatment effects were considered significant at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

Experiment 2

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #19020) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2020).

Experimental Design and Animals

To evaluate the effects of rubber matting on cattle growth performance, locomotion, and carcass characteristics in slatted facilities, 189 Angus × Simmental steers (BW = 352 ± 43 kg) were utilized for this study at the Beef Cattle and Sheep Laboratory in Urbana, IL in a randomized complete block design. Steers were blocked by initial BW into a heavy or light block and then stratified by sire and BW. Then cattle were allotted to 21 pens with 9 steers per pen. Pens were randomly assigned to 3 treatments: no matting/concrete (**CONC2**), 15-year-old Animat Pebble matting (**OLD2**, Animat, Sherbrooke, QC, CA), and new Animat Pebble matting (**PEB2**). Pens were 4.88 × 4.88 m in dimension with slatted concrete floors and individual waterer. Average stocking density was 2.65 m^2 per steer with 34 cm of bunk space per steer. Prior to trial initiation, cattle were housed on concrete slats covered with rubber matting for 128 d and fed as a contemporary group. Cattle were fed a common growing and finishing diet through the duration of the experiment (**Table 2.1**). Steers were weighed on consecutive days at initiation and conclusion of the experiment (d 152) with intermediate weights taken every 28 days. Locomotion scores were conducted at each weigh date similar to Exp. 1. Daily observations were recorded by trained staff for occurrence of open sores (hip, stifle, and hock), no switch or broken tails, realizer cattle, and mortality. Steers were implanted on d -23 with Component TE-IS (16 mg estradiol and 80 mg trenbolone acetate; Elanco Animal Health, Greenfield, IN) and d 56 with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol USP, and 29 mg tylosin tartrate; Elanco Animal Health, Greenfield, IN). Steers were fed 300 mg per steer per day of Optaflexx 45 (Elanco Animal Health, Greenfield, IN) for the last 30 d before slaughter. On d 152, steers were transported approximately 310 km to Tyson Foods Inc.; Joslin, IL for humane slaughter. Following slaughter, hot carcass weight was measured and carcass characteristics including 12th rib fat thickness, LM area, yield grade, and marbling score were taken after a 24-h carcass chill with Video Image Analysis as part of the USDA camera system at Tyson Foods Inc. Yield grade was calculated according to USDA (1997).

Sample collection and analysis

Feed refusals were collected every 7 days to determine pen feed intake. Feed refusal samples were dried at 105°C for 24h in a forced air oven to determine DM content. Individual feed ingredient samples were collected every 14 days and composited at study completion. Ingredient samples were stored at -20°C until processed. A wet composite was used from individual feed ingredients and were freeze-dried at -80°C. Sample DM was determined for each feed ingredient weekly by drying samples in a 105°C forced air for 24h. Samples were ground and analyzed similar to procedures in Exp. 1.

Statistical Analysis

The MIXED procedure of SAS (SAS version 9.4; SAS Inst. Inc., Cary, NC) was utilized to analyze all growth performance and carcass characteristic variables. Pen was used as the experimental unit. Fixed effects included treatment, time, block and the treatment by time interaction in the model statements with initial BW as a covariate for growth performance variables. Individual animal data was included in the model with a random effect of pen nested within treatment (St-Pierre, 2007). Mid-parent average EPD estimates were used as a covariate to account for inherent genetic differences by selecting the most appropriate EPD for the corresponding response variable (Shike, 2018). If no EPD was appropriate, sire was included as a fixed effect. The MIXED procedure of SAS (SAS version 9.4; SAS Inst. Inc., Cary, NC) was utilized to analyze LS. The residuals were evaluated and concluded that the best fit was untransformed values. Fixed effects included treatment, block, and sire. Locomotion scores from d 0 and initial BW were used as covariates. A repeated measure analysis using ante(1) for a covariate structure was added to the model. The covariate structure was selected based on the AIC statistic. A random effect of pen nested within treatment was included in the model. Least squares means were separated using PDIFF option.

A post-hoc analysis was conducted to determine the effect of final locomotion score on overall ADG, final BW, and HCW irrespective of flooring treatment. These results are applicable to feedlot producers since most operations are currently using rubber matting in their slatted facilities. The maximum locomotion score prior to slaughter was used to classify steers for analysis into 3 groups. The MIXED procedure of SAS 9.4 was used for the post-hoc analysis.

Fixed effects in the model included final maximum locomotion, flooring treatment, the interaction of final maximum locomotion score and flooring treatment, appropriate EPD, initial body weight, and block. A random effect of pen nested within treatment was also included. One animal that received a 0 for the final locomotion score was removed from the analysis. Effects were considered significant at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

RESULTS

Experiment 1

Flooring treatment did not affect ($P = 0.38$) BW on d 84 (**Table 2.2)**. At d 209, final BW was affected ($P < 0.01$) by treatment. Cattle on MG and PEB1 had up to a 4.3% heavier final BW compared with cattle on OLD1 but cattle on CONC1 were intermediate and not different in final BW from OLD1 or MG. Steers finished on PEB1 had the greatest ADG ($P<0.01$) and were not different than steers on MG; steers fed on OLD1 gained the least overall and were not different than steers on CONC1. No treatment effect ($P > 0.19$) was observed for steer DMI or G:F. Flooring type affected ($P = 0.04$) HCW (**Table 2.3**); steers housed on PEB1 had the greatest HCW while steers on OLD1 has the least, steers on MG and CONC1 were intermediate but not different ($P = 0.35$) from steers finished on other treatments. No 12th rib fat differences ($P = 0.39$) were observed. No differences ($P > 0.22$) were detected across treatments for longissimus muscle (**LM**) area, yield grade, or marbling score.

While there was no ($P = 0.88$) treatment × time interaction for locomotion score (**Figure 2.1**), flooring type affected ($P = 0.02$) locomotion scores. Steers on CONC1 had the worst ($P < 0.01$) locomotion score which corresponded with cattle exhibiting more lameness or change in gait compared with steers housed on OLD1, MG, and PEB1 which were similar ($P \geq 0.24$). Locomotion scores were affected ($P < 0.01$) by time and increased as expected during the experiment. Cattle had the least desirable (P < 0.01) LS and most affected gait at d 209 compared with the 4 preceding time points. On d 168, LS were less desirable (P ≤ 0.01) than d 126 and d 84. Comparatively, d 126 and d 84 were similar (P = 0.15) in LS but less desirable (P ≤ 0.03) than d 42. Final maximum locomotion scores (**Table 2.4**) were summarized prior to slaughter. There was no difference (*P* ≥ 0.17) in final BW, ADG, or HCW based on final maximum locomotion score.

Experiment 2

There was no difference (*P* ≥ 0.26) in steer BW on d 56 and d 152 or ADG (*P* = 0.80) across treatments (**Table 2.5**). No differences (*P* ≥ 0.61) in DMI and G:F were observed across all flooring types. There were no differences across treatments (*P* > 0.17) in HCW, LM area, 12th rib fat thickness, USDA yield grade, or marbling score.

There were no flooring treatment × time effects (*P* = 0.02) on steer locomotion scores (**Figure 2.1**). Steers fed on CONC2 had a less desirable (*P* ≤ 0.02) locomotion score and steers on OLD2 and PEB2 did not differ (*P* = 0.93). Locomotion scores increased (*P* < 0.01) over time. On d 28, cattle had the least affected locomotion scores (*P* < 0.01) and exhibited no or minimal signs of gait change compared with the 4 subsequent time points. Locomotion scores on d 56 tended (*P* = 0.06) to be similar to d 84 but were more desirable (*P* < 0.01) compared with d 112 and d 152. Cattle locomotion scores on d 84 were more desirable (*P* < 0.01) compared with d 112 and d 152. Cattle locomotion scores on d112 were more desirable (*P* < 0.01) than d 152. Final maximum locomotion scores were summarized prior to slaughter. Cattle with a final maximum locomotion score of 1 or 2 had a greater (*P* < 0.01) final BW, ADG, and HCW than cattle scored 3 (**Table 2.6**).

Daily observations reported 5% of cattle developed open wounds, 7% of cattle with no switch or a broken tail, 3% of group became realizer cattle, and 3% mortality rate from euthanasia and death. Consult the supplement (**Table 2.7**) for additional information.

DISCUSSION

Beef cattle research on flooring types is specific to the individual facility and unique characteristics of an operation. This research sought to quantify the effects of rubber matting in a Midwestern slatted, indoor feedlot that fed cattle to typical slaughter weights while utilizing growth promotants. Importantly, the age of the rubber matting in use is often not reported but is essential because rubber flooring deteriorates over time. The deterioration of rubber is highly variable because of wear, rubber source, chemical components, and light exposure (Lafrance, 2013). The authors are not aware of existing research comparing old, heavily used matting with new matting or bare concrete.

Given the many influencing factors affecting cattle flooring types, there is not a defined benefit for rubber matting in slatted finishing facilities. As a result, inconsistent and limited conclusions can be drawn across studies as reported in a meta-analysis of 18 studies comparing at least two flooring types for finishing beef cattle (Keane et al., 2018). Additionally, much of the research on flooring type has been conducted in European production systems. European feedlot cattle are typically intact males from Continental breeds that are fed fewer days without growth promotors such as beta-agonists or implants and marketed at a lighter weight.

In Exp. 1, cattle on all matting treatments received more desirable locomotion scores compared with CONC1 which could have improved animal welfare (Rushen et al, 2006). However, locomotion score did not follow growth performance responses. More restricted gait and locomotion typically translates to poorer growth (Dewell et al., 2018). In Exp. 1, steers on

PEB1 finished with up to 3.3% greater final BW and 5.0% greater overall ADG compared with steers finished on OLD1 and CONC1. This is consistent with other reports stating that cattle on rubber matting have greater final BW (2.8 to 6.1% improvement) and ADG (3.9 to 13.1% improvement) compared with cattle housed on concrete slats (Cozzi et al., 2013; Brscic et al., 2015b; Lowe et al., 2019). Consistent with Exp. 2, others report no difference in final BW and ADG for cattle housed on concrete or rubber matted flooring (Lowe et al., 2001; Elmore et al., 2015; Dewell et al., 2018; Murphy et al., 2018). In Exp. 2, no growth performance or carcass characteristic differences were observed across treatments. Supported by prior research, the current experiments report that carcass quality traits of fat depth and intramuscular fat deposition were not affected by treatment (Keane et al., 2017; Earley et al., 2017; Lowe et al., 2019).

Small pens can have a negative impact on productivity and feed conversion (Park et al., 2020). Industry standard stocking density is not adjusted based on overall pen space. A smaller pen size limits the steers' ability to travel and take a normal, full stride when in motion. This is important to consider relative to other research and commercial facilities that have larger pen sizes but greater stocking density. Utilizing a small pen design with an industry standard stocking density likely exacerbated the negative small pen effects on all cattle in Exp. 2 and explain the overall occurrence of lameness. The pens that cattle were housed in have a 20 cm wide ledge in front of the concrete feed bunks and water systems. The concrete ledge and square corners reduced the available space that cattle have to lay down even though the stocking density is 2.7 m^2. Across all treatments, Exp. 2 had a greater proportion (79% versus 16%) than Exp. 1 of cattle moderately or severely lame ($LS \geq 2$) at trial termination. A smaller pen size would limit the steers' ability to travel and take a normal, full stride when in motion (Gygax et al., 2007; Margin et al., 2019). This could lead to more lying time and inactivity which may result in stiffer joints and muscles leading to poorer locomotion scores (Cozzi et al., 2013; Park et al., 2020). As lying time and inactivity increases, the occurrence of fatal injuries and mortality rate increases (Brscic et al., 2015a) like reported in Exp. 2.

Some studies reported the addition of rubber matting to fully slatted concrete flooring improved locomotion score by 47% (Dewell et al., 2018). Although the mats in Exp. 2 were slightly older, the wear and condition of the rubber was similar to Exp. 1. Locomotion scores were less desirable for steers on CONC1 throughout Exp. 1 (35.2 to 52.2% higher scores). Although cattle on all matting treatments received more desirable locomotion scores compared with CONC1 which could have resulted in greater comfort (Rushen et al, 2006), but this did not correlate to growth performance characteristics. In contrast, more restricted gait and locomotion typically translates to poorer growth (Dewell et al., 2018). In Exp. 1, 25% of cattle on slats without rubber matting and 31% of cattle on rubber matting treatments had an unaffected gait. In Exp. 2, there was only one animal that had an unaffected gait. Additionally, differences between flooring type are drastic in the number of moderately and severely lame cattle. Only 11% of cattle on rubber matting treatments in Exp. 1 had LS ≥ 2 while 32% of cattle on slats without rubber matting received similar scores. In Exp. 2, 52% of cattle on rubber matting treatments had LS ≥ 2 while 84% of cattle on slats without rubber matting received similar scores. The addition of rubber matting limited the occurrence of moderately or severely lame cattle even in populations of high lameness prevalence. Considering the poor locomotion scores observed in Exp. 2, the expected benefits of rubber matting as commonly reported in the literature and observed in Exp. 1 were not realized.

The time effect for locomotion score describes the increase in degree of lameness in cattle over time. This could be from structural alterations from an extended period of time on a slats and limited space (Gygax et al., 2007; Margin et al., 2019). Additionally, the magnitude of locomotion score differences between experiments is notable. Experiment 2 cattle averaged over a 1 on locomotion score at 112 days which is roughly half the days on feed as Exp. 1. Experiment 1 on average did not exceed a 1 on locomotion score for the duration of the study. Cattle from both experiments were sourced from the same location and housed in identical facilities. Steers in Exp. 1 were on a slatted floor for 350 d in total while steers in Exp. 2 were only on a slatted floor for 280 d. Even with cattle in Exp. 2 being on slatted floors for a shorter duration of time, their LS were substantially higher than Exp. 1 through the study. The similarities in contemporary group growth performance and poor locomotion are attributed to the more compact stocking density.

In conclusion, new rubber matting increased ADG and HCW during a 209 d trial when cattle were stocked at 3.4 m^2 and rubber matting regardless of age improved cattle locomotion scores in slatted indoor feeding facilities. In addition, the current study highlights that cattle housed on old rubber matting perform similar to cattle on concrete slats for growth performance but neither perform as well as cattle on new matting. Further research is needed to determine the effective longevity of rubber matting on growth performance, carcass characteristics, and locomotion.

TABLES

Table 2.1. Diet composition and chemical analysis

Item	Growing Exp. 1 (d 0-84)	Finishing Exp. 1 (d 85-209)	Growing Exp. 2 (d 0-55)	Finishing Exp. 2 (d 56-152)
Ingredient, % DM				
Dry-rolled corn	40	50	-	-
High moisture corn	-	-	35	55
Corn silage	30	20	40	20
MWDGS[1]	20	20	15	15
Supplement				
Ground corn	7.61	7.61	7.61	7.61
Limestone	1.59	1.59	1.59	1.59
Urea	0.60	0.60	0.60	0.60
Trace mineral premix[2]	0.09	0.09	0.09	0.09
Rumensin 90	0.02	0.02	0.02	0.02
Tylosin 40	0.01	0.01	0.01	0.01
Fat	0.08	0.08	0.08	0.08
Chemical Analysis, % DM				
Dry matter	62.2	68.7	55.7	64.2
Organic matter	96.1	96.3	96.2	96.6
Crude protein	13.8	13.9	13.9	14.1
Neutral detergent fiber	25.8	22.6	24.1	17.9
Acid detergent fiber	11.6	9.3	14.6	12.0
Ether extract	4.2	4.4	5.7	6.2

[1] Modified wet distillers grains with solubles

[2] 8.4% Ca, 5% Mg, 7.5% K, 6.7% Cl, 10% S, 0.5% Cu, 2% Fe, 3% Mn, 3% Zn, 278 mg/kg Co, 250 mg/kg I, 150 mg/kg Se, 2,205 KIU/kg Vit A, 662.5 KIU/kg Vit D, 22,047.5 IU/kg Vit E

Table 2.2. Effect of rubber matting on body weight (BW), average daily gain (ADG), dry matter intake (DMI), and gain:feed ratio (G:F) in Exp. 1

	Treatment[1,2]					*P*-value[3]
Item	CONC1	OLD1	MG	PEB1	SEM	Trt
BW, kg						
d 0	221	220	219	221	3.0	0.96
d 84	380	377	384	382	3.0	0.38
d 209	586^{bc}	583^{c}	597^{ab}	603^{a}	4.5	<0.01
ADG, kg	1.74^{bc}	1.73^{c}	1.80^{ab}	1.82^{a}	0.021	<0.01
DMI, kg	10.2	10.0	10.4	10.5	0.17	0.23
G:F	0.173	0.173	0.175	0.175	0.003	0.84

[1] CONC1 = no matting/concrete; OLD1 = 12-year-old Pebble matting; MG = new Maxgrip matting; PEB1 = new Pebble matting

[2] Means in row with unlike superscripts differ ($P \leq 0.05$)

[3] Trt = treatment effect

Table 2.3. Effect of rubber matting on carcass characteristics in Exp. 1

	Treatment[1,2]					P-value[3]
Item	CONC1	OLD1	MG	PEB1	SEM	Trt
HCW, kg	359^{ab}	356^{b}	363^{ab}	367^{a}	2.8	0.04
LM area, cm^2	83.2	82.2	82.7	83.2	1.16	0.90
12th rib fat thickness, cm	1.51	1.46	1.50	1.55	0.037	0.39
USDA yield grade	3.42	3.39	3.49	3.54	0.075	0.49
Marbling score[4]	492	506	495	489	6.1	0.22

[1] CONC1 = no matting/concrete; OLD1 = 12 year-old Pebble matting; MG = new Maxgrip matting; PEB1 = new Pebble matting

[2] Means in row with unlike superscripts differ ($P \leq 0.05$)

[3] Trt = treatment effect

[4] 300 = Select +; 400 = Choice -; 500 = Choice °; 600 = Choice +; 700 = Prime -

Table 2.4. Effect of final maximum locomotion score on final body weight (BW), average daily gain (ADG), and hot carcass weight (HCW) in Exp. 2

	Final maximum locomotion score[1,2]				
Item	0	1	2	3	*P*-value[3]
Number of observations	0	33	89	60	
Final BW, kg	-	631^{a}	618^{a}	596^{b}	<0.01
ADG, kg/d	-	1.82^{a}	1.75^{a}	1.61^{b}	<0.01
HCW, kg	-	384^{a}	381^{a}	366^{b}	<0.01

[1] Locomotion scores were conducted by two trained evaluators with the final maximum locomotion scores prior to slaughter being used in this post-hoc analysis

[2] Means in row with unlike superscripts differ ($P \leq 0.05$)

[3] Main effect of final maximum locomotion score

Table 2.5. Effect of rubber matting on body weight (BW), average daily gain (ADG), dry matter intake (DMI), and gain:feed ratio (G:F) in Exp. 2

	Treatment[1]				*P*-value[2]
Item	CONC2	OLD2	PEB2	SEM	Trt
BW, kg					
d 0	347	347	348	2.7	0.87
d 56	455	457	458	2.7	0.26
d 152	610	613	615	5.2	0.79
ADG, kg	1.69	1.71	1.72	0.033	0.80
DMI, kg	9.3	9.5	9.5	0.19	0.61
G:F	0.184	0.183	0.182	0.0037	0.92

[1] CONC2 = no matting/concrete; OLD2 = 15-year-old Pebble matting; PEB2 = new Pebble matting

[2] Trt = treatment effect

Table 2.6. Effect of rubber matting on carcass characteristics in Exp 2

	Treatment[1]				*P*-value[2]
Item	CONC2	OLD2	PEB2	SEM	Trt
HCW, kg	375	377	377	3.0	0.93
LM area, cm^2	87.7	87.5	88.3	0.93	0.81
12th rib fat thickness, cm	1.50	1.59	1.45	0.055	0.23
USDA yield grade	3.19	3.31	3.10	0.073	0.17
Marbling score[3]	476	485	459	12.3	0.33

[1] CONC2 = no matting/concrete; OLD2 = 15-year-old Pebble matting; PEB2 = new Pebble matting

[2] Trt = treatment effect

[3] 300 = Select +; 400 = Choice -; 500 = Choice °; 600 = Choice +; 700 = Prime -

Table 2.7. Number of observations for open sores[1], no switch or broken tails, realizer cattle[2], and mortality[3] in Exp. 2

Item	CONC2	OLD2	PEB2
Open Sore	3	3	4
No switch or broken tail	5	3	6
Realizer cattle	4	1	0
Mortality	2	2	2

[1] Open sores occurring on the hip, stifle, and hock

[2] Slaughtered ~30 days prior to the contemporary group due to extremely poor mobility

[3] Unexplained death or euthanized due to joint/bone fractures

FIGURE

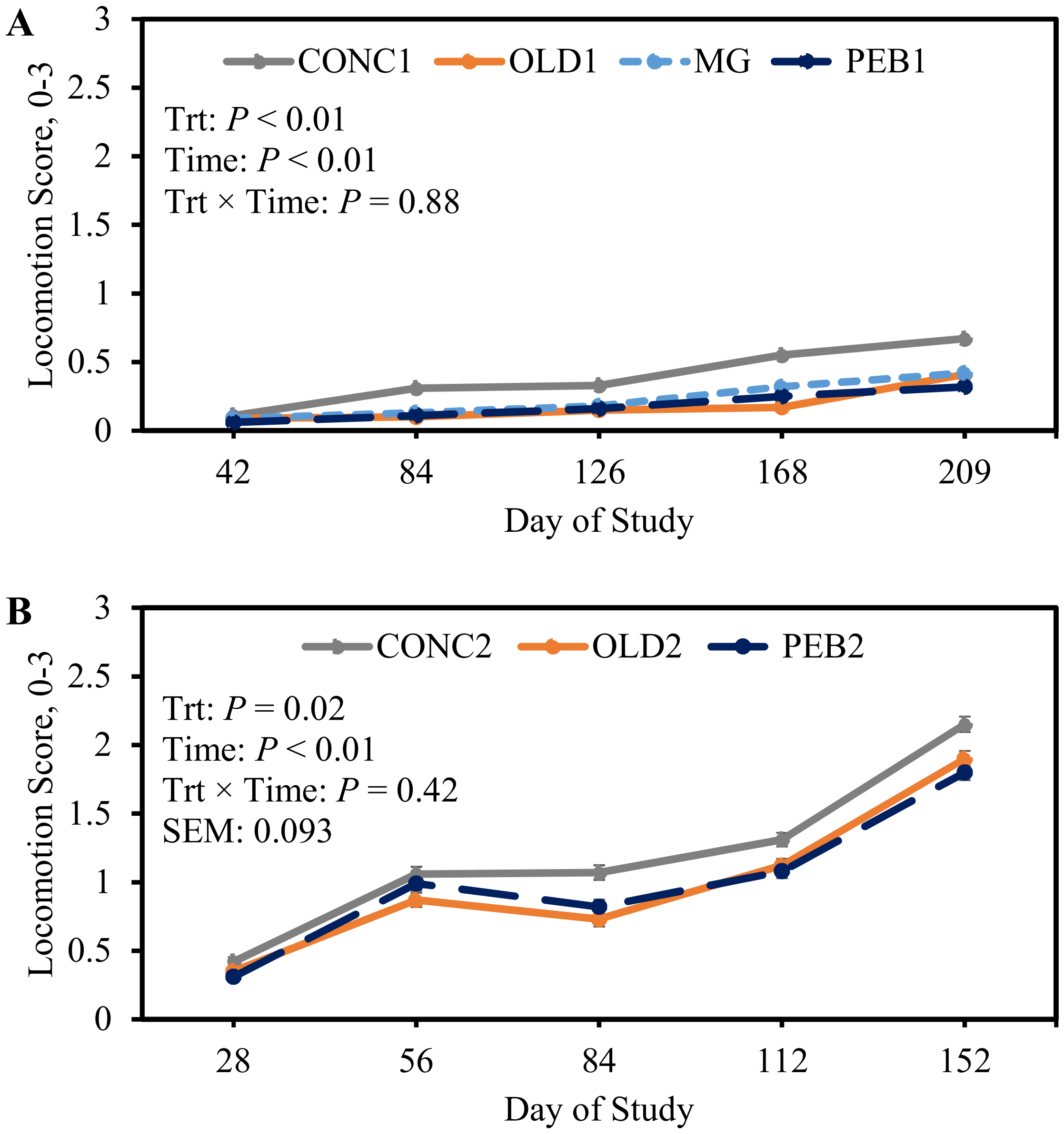

Figure 2.1. Effect of rubber matting treatment on locomotion score in Exp. 1 (A) and Exp. 2 (B). Treatments for Exp. 1 included no matting/concrete (CONC1), 12-year-old Animat Pebble matting (OLD1), new Animat Maxgrip matting (MG), and new Animat Pebble matting (PEB1). Treatments for Exp. 2 included no matting/concrete (CONC2), 15-year-old Animat Pebble matting (OLD2), and new Animat Pebble matting (PEB2). For Exp. 1, flooring type affected ($P < 0.01$) locomotion scores. Locomotion scores were affected ($P < 0.01$) by time and increased during the experiment. There was no ($P = 0.88$) treatment × time interaction for locomotion score. For exp. 1, flooring type affected ($P = 0.02$) locomotion scores. Locomotion scores were affected ($P < 0.01$) by time and increased during the experiment. There was no ($P = 0.42$) treatment × time interaction for locomotion score.

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CHAPTER 3

HIND LEG ANGLE AND STEP LENGTH MEASURED BY 3-D IMAGING ACCOUNT FOR VARIANCE OF LOCOMOTION SCORE AND GROWTH PERFORMANCE OF CATTLE IN SLATTED FEEDING FACILITIES

ABSTRACT

The objective for Chapter 3 was to determine the variance of locomotion score (**LS**) and growth performance attributable to flooring treatment, hind leg angle and step length (**SL**) measured by 3-D image analysis for cattle in slatted feeding facilities. Inherent individual differences in structural conformation may be related to cattle mobility and growth performance in indoor slatted facilities. Angus × Simmental steers (N = 189; BW = 352 ± 43 kg) were blocked by initial BW and assigned to 21 pens. Pens were randomly assigned to 1 of 3 treatments (**TRT**): concrete slats with no matting (**CONC**), 15-year-old Animat Pebble matting (**OLD**), and new Animat Pebble matting (**PEB**). Steers were fed for 152 days. Individual steers videos were recorded on d 0 using an Intel RealSense depth camera and processed using MATLAB to estimate hind leg angle, SL, and body length (**BL**). Locomotion scores were assigned using a 0 to 3 scale (Zinpro Step-Up® Locomotion Scoring System) throughout the finishing phase. The CORR procedure of SAS 9.4 was utilized to measure correlation of structural conformation traits to average LS, overall ADG, and final BW. Average LS had the greatest correlated (r = -0.23) to SL/BL during the finishing phase. The greatest correlation (r = -0.49) to overall ADG was average LS. Final BW had the strongest correlation (r = 0.51) to BL. The MIVQUE0 option of the MIXED procedure of SAS 9.4 was utilized to estimate the proportion of variance in average LS, overall ADG, and final BW. Variance of average LS was attributed to SL and SL × BL ×

TRT at 64% and 28%, respectively. For overall ADG, variance was attributable to SL × BL, SL × BL × TRT, and TRT at 38%, 35%, and 25%, respectively. Variables of SL, BL, SL × BL × TRT, and TRT accounted for 38%, 23%, 23%, and 15% of the variance in final BW, respectively. Overall, variance of average LS, overall ADG, and final BW were primarily attributed to SL, BL, TRT, and their interactions. Individual animal differences in structural conformation are related to cattle mobility and growth performance in slatted indoor facilities.

INTRODUCTION

Limited available land and poor winter pen conditions in the Midwest have led to more cattle being housed in slatted feeding facilities (Grooms et al., 2015; Dewell et al., 2018). Slatted feeding facilities reduce the influence of environmental conditions (e.g. precipitation, snow, and heat stress) on cattle growth and welfare (Albright and Alliston, 1971; Carroll, 2020; Neville, 2020). Despite the advantages, cattle in slatted facilities have a greater prevalence of lameness (Schültz et al., 2014; Dewell et al., 2018). Although facility design and management factors such as rubber matting and pen stocking density affect lameness (Cozzi et al., 2013, Magrin et al., 2019), structural conformation likely contributes to improved mobility and welfare for cattle in indoor slatted facilities.

Breeding cattle selection prioritizes structural conformation because it impacts locomotion and longevity within the herd (Onyiro and Brotherstone, 2008). Dairy cattle with a shallower foot angle and hind leg set are more likely to develop lameness and altered locomotion (Van Dorp et al., 1998). While structural conformation is not typically considered for feedlot cattle, lameness decreased ADG by 5.6% in steers housed in open lots (Kruse et al., 2013). Based on greater lameness presence in indoor slatted facilities, a further reduction in gain and net return would be expected compared with open pen feedlots.

Precision livestock management tools can be leveraged to improve livestock production (Wathes, 2009). Specifically, 3-D image processing can evaluate animal conformation, lameness, and locomotion (Pluk et al., 2010; Pluk et al., 2012). While digital evaluation of individual cattle is most commonly done in dairy production, these techniques have not been applied to feedlot cattle. Hind leg angle and SL can be measured to describe differences in dairy cow locomotion (Van Dorp et al., 2004; Van Nuffel et al., 2013). The hypothesis was that locomotion score and growth performance are affected by inherent individual differences in structural conformation for cattle in indoor slatted facilities. Therefore, the objective was to determine the variance of locomotion score and growth performance attributable to flooring treatment, step length and hind leg angle measured by 3-D image analysis for cattle in slatted feeding facilities.

MATERIALS AND METHODS

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #19020) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2020).

Experimental Design and Animals

To determine the variance of LS and growth performance attributable to flooring treatment, hind leg angle and SL measured by 3-D image analysis for cattle in slatted feeding facilities, 189 Angus × Simmental steers (BW = 352 ± 43 kg) were utilized for this study at the Beef Cattle and Sheep Laboratory in Urbana, IL in a randomized complete block design. Steers were blocked by initial BW into a heavy and light block and then stratified by sire and BW to 21 pens with 9 steers per pen. Pens were randomly assigned to 3 treatments: no matting/concrete (**CONC**), 15-year-old Animat Pebble matting (**OLD**, Animat, Sherbrooke, QC, CA), and new

Animat Pebble matting (**PEB**). Pens were 4.88 × 4.88 m in dimension with slatted concrete floors and individual waterer. Average stocking density was 2.65 m^2 per steer with 34 cm of bunk space per steer. Cattle were fed two diets during the 152 d experiment. The growing diet contained high-moisture corn, corn silage, modified wet distiller's grains with solubles, and a ground corn-based supplement included at 35%, 40%, 15%, and 10% of diet dry matter, respectively. The finishing diet contained high-moisture corn, corn silage, modified wet distiller's grains with solubles, and a ground corn-based supplement included at 55%, 20%, 15%, and 10% of diet dry matter, respectively. Steers were implanted on d -23 with Component TE-IS (16 mg estradiol and 80 mg trenbolone acetate; Elanco Animal Health, Greenfield, IN) and d 56 with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol USP, and 29 mg tylosin tartrate; Elanco Animal Health, Greenfield, IN). Steers were fed 300 mg per steer per day of Optaflexx 45 (Elanco Animal Health, Greenfield, IN) for the last 30 d before slaughter. Locomotion scores were conducted on five different days throughout the finishing phase using the Step-Up Locomotion Scoring System (Zinpro, Eden Prairie, MN) by two trained evaluators. Scores ranged from 0-3 where cattle that were scored a 0 were considered normal or had no change in their gait. Cattle that were scored a 3 were considered severely lame where they apply little to no weight on a limb and are reluctant to move. Locomotion scores from each evaluator and every time point were averaged for analysis.

Video recording and analysis

Individual animal videos were recorded for gait analysis on d 0 and 1. Videos were recorded using a stereo depth camera (RealSense™ model D435i; Intel Corporation, Santa Clara, CA) at 30 frames per second (fps) for color (RGB) videos and at 90 fps for depth videos. The resolution for RGB videos was 1920 × 1080 pixels while depth videos were recorded with a resolution of 1280 × 720 pixels. Prior to video recordings, cattle were walked approximately 145 m to reduce restlessness.

Each steer was recorded individually walking through the video recording area. The video recording setup was constructed adjacent to the cattle feeding facility (**Figure 3.1**). Steers traveled 10.7 m on a compacted lime surface. Green painted wood paneling was used for 6.1 m of the background to improve identification of the animal from the background. To minimize variation in cattle distance from the camera, five strands of poly-wire ran parallel with the wood panel, forming a 1.8 m wide pathway to guide steers. The poly-wire served as a visual barrier and was not electrified. A secondary containment area was constructed using metal gates with the camera placed outside this area. The camera was mounted on a tripod stand centered 6.1 m from the wooden background and 1.05 m from ground level.

Steers were brought individually to the video recording area. Two trained individuals were used to control the steer's speed, with one individual walking in front and one behind the animal. Videos of cattle that took at least two relaxed, normal strides perpendicular to the camera were considered acceptable. A normal stride was defined as full extension of a limb within the plane of the animal's center mass at a walking speed. If the first recording did not produce an acceptable video, additional attempts were made. Attempts were considered unsuccessful if the steer did not continuously walk through the recording area perpendicular to the camera or the animal traveled faster than a walking pace. For steers with no acceptable video obtained from d 0, the video recording was repeated on d 1 using the same procedure. Given the variation animal temperament and docility, an acceptable video was not obtained on every steer. Across the two video recording sessions, an acceptable video for 94% of steers was recorded.

The videos were stored on an external hard drive as ".bag" files for further processing. Videos were manually run through a custom pre-processing program designed in MATLAB (MATLAB version 2021b; The MathWorks, Inc., Natick, MA). Each animal video was uploaded into the program. The video was played to allow the viewer to indicate the frames best suited for video processing. After that, the video would play a second time for the selection of frames. An individual selected the best starting and ending frames where the animal is entirely within the camera's field of view and at peak extension of a hind limb.

The RGB and depth videos' frames were aligned in order and saved as separate images within a ".mat" file. All processing was done within MATLAB. The region of interest was established as the green painted wood paneling area. Forward movement (Mf) was calculated by the differences between the current frame of interest (Fc) and the previous frame (Fp).

$Mf = Fc - Fp$

Backward movement (Mb) was calculated by the differences between the Fp and Fc.

$Mb = Fp - Fc$

Total movement (Mt) is the sum of Mf and Mb.

$Mt = Mf + Mb$

The total movement was converted to a binary image where pixels larger than 15 were changed to a 1, and the remaining pixels were set as 0 using a scale of 0 to 255 pixels. A new ROI was determined through the following morphological operations, followed by selecting the second-largest "blob" on the resulting image: (1) set a pixel to 1 if five or more pixels in its 3-by-3 neighborhood are 1; otherwise, set the pixel to 0. (2) with n = Inf, add pixels to the exterior of objects until doing so would result in previously unconnected objects being 8-connected. (3) set 0-valued pixels to 1 if they have two nonzero neighbors that are not connected. (4) dilation with a disk structured element of diameter 30. The bounding box of the resulting "blob" was set as the new ROI.

An intensity threshold of 45 was applied to each channel of the color image within the ROI on a scale of 0 to 255 for background subtraction. The resulting image was binarized with nonzero values set to 1. A binary mask was obtained through a series of morphological operations: (1) dilation with a disk of diameter 2 as the structured element (SE); (2) erosion with a rectangle of 10 × 4 as SE; (3) selection of the largest area in the resulting image; (4) dilation with a disk of diameter 2 as the SE. This was done to smooth the defined animal edge and to recover the missing regions of the animal. The resulting mask was used to segment both depth and RGB frames. After that, frames were evaluated for suitability to be processed if the full animal was present on the image based on an area threshold. If the animal was in the frame the process continued, but if it was not, then the next frame would not be analyzed. A bounding box around the animal region binary mask and its centroid were calculated.

The animal region within the bounding box was divided into four quadrants based on the centroid position of the animal. A convex hull for each quadrant was calculated. Any points at least 10 px apart and that were located on the edge of the animal were selected for consideration. The easternmost point above the upper-right-hand quadrant's centroid was computed as the rump point. The westernmost point above the upper-left-hand quadrant's centroid of the animal was computed as the poll point. The distance between the poll and rump points was used as the animal BL.

The hoof region was selected as 50 px above the established ground row from the bounding box that segmented each leg region. The leg angle was based on the orientation of a fitted ellipse around the leg "blob." Legs were identified based on depth and x-axis location. The

SL value was determined by the distance between both hind legs' centroids. Dimensions obtained in pixels (lpx) were transformed to meters (lm) based on frame resolution (Res), camera field of view (FOV), and average animal distance from the camera in meters (Zm; Condotta et al., 2020).

$$\mathrm{lm} = \frac{2 \times \mathrm{lpx} \times \tan\frac{\mathrm{FOV}}{2} \times \mathrm{Zm}}{\mathrm{Res}}$$

A different MATLAB program calculated left hind leg angle, BL, animal bounding box, and SL from every frame selected in the pre-processing step. The hind leg angle calculation and BL were placed on a copy of every frame and saved for manual validation of the program accuracy. One individual would view each frame in a standard image viewer to select the first two frames where the leg angle was accurately calculated when the foot first touches the ground. Frames from one animal where the analysis produced only one acceptable angle calculation, poor angle calculations, or no angle calculations were evaluated manually. Frames were uploaded into ImageJ (National Institutes of Health, Bethesda, MD, U.S.), and one individual used the angle-drawing tool to calculate the leg angle. These values were recorded and averaged.

One individual selected BL by inspecting each frame in a standard image viewer to record the shortest BL accurately calculated when the animal was in a normal gait position perpendicular to the camera. When the analysis produced inaccurate BL calculations within the validation frames of one animal, the shortest horizontal length of the perimeter box when the animal was in a normal gait position perpendicular to the camera was used as the animal BL. If no validation frames were produced, those individual animal frames were reprocessed in the program with fewer restriction statements to produce more frames for consideration. These frames were processed similarly to previously stated selections and recorded. Animal BL were converted from pixels to meters using a formula developed by Condotta et al. (2020).

The SL values were calculated within the program by taking the difference between both hind limbs. The largest three SL of all frames analyzed were selected, averaged, and the coefficient of variation (**CV**) was calculated for each animal. If the CV was less than 10%, all three SL were used for an average and a maximum SL was selected from those options. If the CV was greater than 10%, the frames were manually checked by one individual to determine the accuracy of the calculations. A SL value was acceptable if the program correctly identified the position of both limbs and selected a stride at full extension. When there were only two acceptable lengths, the average and maximum of those two lengths were used. When there was only one acceptable length, it was used as the average and maximum SL for that animal. For cattle with no acceptable SL calculated, one individual would select an appropriate frame to manually select the distance between hind limbs using the image viewer app from MATLAB. This SL was used as the average and maximum length for that animal. If no validation frames were produced, those individual animal frames were reprocessed in the program with fewer restriction statements to produce more frames for consideration. The resulting SL were processed similar to previously stated selections to be used as the average and maximum SLfor that animal. Manual SL were converted from pixels to meters using a formula developed by Condotta et al. (2020).

The SL value is the horizontal distance from the fetlock joint of one hind limb to the fetlock joint on the other hind limb in one single frame (**Figure 3.2**). The BL value is the horizontal distance from the poll to the rump of an animal. Hind leg angle is the angle in degrees of the left hind leg from the tarsal joint to the fetlock joint at first ground contact during a normal stride with the horizon at 0°.

Statistical Analysis

The Anderson-Darling test was utilized in the UNIVARIATE procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) to test for normal distribution of structural conformation traits. Data sets were considered normally distributed at $P > 0.05$ and not normally distributed at $P \leq 0.05$

The CORR procedure of SAS 9.4 was utilized to determine correlations of individual gait analysis traits from novel 3-D image analysis with growth performance and mobility during the finishing phase. Variables of hind leg angle, SL, BL, average LS, and SL divided by BL (**SL/BL)** were correlated to average locomotion score, overall ADG, and final BW. Correlations were considered significant at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

The MIXED procedure of SAS 9.4 was utilized to determine the proportion of variance contributing to the total variance in average LS, overall ADG, and final BW. The MIVQUE0 method was used in the MIXED procedure to generate covariance parameter estimates. Terms in the model included block, sire, pen nested within TRT, initial BW, and all main effects and possible interactions between TRT, hind leg angle, SL, and BL. Variance that was not attributed to random effects were accounted for in residual error.

RESULTS

Hind leg angle values were normally distributed with a mean of 55.06 deg (**Figure 3.3**). The distribution of the SL values were not normal ($P < 0.01$) with a mean of 0.57 m (**Figure 3.4**). Data were skewed right with 42% of the values were greater than the mean within 1 standard deviation. The distribution of the BL values were normal with a mean of 1.47 m (**Figure 3.5**).

Correlation coefficients were calculated for average LS, overall ADG, and final BW (**Table 3.1**). The variable of SL/BL had the strongest correlation ($r = -0.23$; $P < 0.01$) to average

LS. Hind leg angle was correlated (r = 0.16; $P = 0.03$) to average LS. There was a negative correlation (r = -0.22; $P < 0.01$) of average LS to SL. The strongest correlation (r = -0.49; $P < 0.01$) to overall ADG was average LS. Overall ADG was negatively correlated (r = -0.24; $P < 0.01$) with hind leg angle. Animal BL had the strongest correlation (r = 0.51; $P < 0.01$)) to final BW. Animal SL was correlated (r = 0.22; $P < 0.01$) to final BW. Hind leg angle and average LS tended ($P \leq 0.10$) to be correlated (r = -0.13 and r = -0.12, respectively) to final BW.

Terms in the model were able to account for up to 98% of the variance in average LS, overall ADG, and final BW. Over half of the variance of average LS during the finishing phase was attributed to SL at 64% (**Figure 3.6**). A large portion of variance of average LS was attributed to SL × BL × TRT at 28%. For overall ADG, 38% of variance is attributable to SL × BL (**Figure 3.7**). Other variables of SL × BL × TRT and TRT represent 35% and 25%, respectively, of the variance for overall ADG. Animal SL was the greatest attributor of variance in final BW at 38% (**Figure 3.8**). The BL measurement accounted for 23% of variance in final BW. The interaction of SL × BL × TRT accounted for the same amount of final BW variance at 23%.

DISCUSSION

Structural conformation traits are typically considered intermediate-optimum traits. The interpretation of correlations becomes more challenging when intermediate-optimum traits are involved because they focus on directionality (Giess et al., 2021a). Distributions were provided to better understand the relationships reported.

The importance of structural conformation for cattle in indoor facilities is well-documented by animal longevity and return in dairy operations (Onyiro and Brotherstone, 2008). Interest in genetic selection for more structurally sound beef cattle has increased with multiple breed associations implementing structural conformation scoring systems (Giess, 2021b). Traits of interest in these scoring systems include foot angle, claw set, and hind leg angle. The use of these structural conformation scoring systems will facilitate characterization and selection within the population. The scoring systems are conducted by evaluators which introduces bias into the data. When using digital analysis or quantitative systems, the bias can be removed to improve the accuracy of the data. Regardless of the methodology to characterize structural conformation, more research is needed to identify relationships with meaningful production measures in a variety of production systems.

Measuring SL is not commonly reported in beef cattle research. Typically, stride length is reported in dairy cattle locomotion research (Alsaaod et al., 2017). Based on limited studies, SL is roughly half the distance on stride length (Telezhenko et al., 2005). The range of SL reported for dairy cattle have been from 0.44 to 0.83 m (Telezhenko et al., 2005; Van Nuffel et al., 2013). The addition of rubber matting to slatted concrete has been reported to increase SL by up to 8% when compared with cattle housed on concrete slatted floors (Telezhenko et al., 2005). A study evaluating pain alleviation in lightweight (BW = 118 ± 12 kg) beef calves after castration reported baseline stride length ranging from 1.42 to 1.48 m (Currah et al., 2009). In another experiment where lameness was induced in lightweight (BW = 345 ± 47 kg) beef calves, the average stride length ranged from 0.62 to 0.67 m (Coetzee et al., 2014). Recording stride length is prevalent in dairy cattle research. Stride length decreased from 1.69 to 1.54 m for cattle with LS of 1 compared with cattle is a LS of 3 (Blackie et al., 2013). In a different study focused on space allowance and flooring type, dairy cattle had stride lengths ranging from 1.40 to 1.55 m for cattle housed on rubber matting or slatted concrete floors (Schütz et al., 2015). Animal BL is reported in minimal research but has been noted to be up to 1.85 m in dairy heifers (Heinrichs et al., 1992). The BL values has been used as a correction factor for stride length (Pluk et al., 2010). Individual differences in BL and leg length impact the animal's stride length. Hind leg angle is rarely reported in degree because of the difficulty collecting measurements. Typically, breed associations like the American Simmental Association use visual scoring systems while the animal is standing still. Within this study, hind leg angle was measured at one time point in the animal's gate to understand structural conformation. Hind leg angle is normally reported as the angle from the stifle joint to tarsal joint to fetlock joint (Salau et al., 2017). The video processing method and large number of animals within the study made it challenging to use a similar process. As a result, this study analyzed hind leg angle from the tarsal joint to the fetlock joint in relationship to the surface. Any studies digitally measuring hind leg angle from the tarsal joint to the fetlock joint is unknown to the authors. Hind leg angle and BL are evenly distributed, but the distribution of SL was skewed. This is a result of a 42% of cattle within one standard deviation are greater than the mean. Even though this data is skewed, SL is important because of the correlation to LS and the role it plays in accounting for variance in values of interest.

Differences in ADG as a result of changes in locomotion have been documented in feedlot cattle (Kruse et al., 2013; Dawson et al., 2020). In the present study, LS was negatively correlated to overall ADG as increasing LS (less desirable) corresponded to decreasing overall ADG as expected. Average LS was correlated to hind leg angle, SL, and SL/BL. Based on finding with dairy cattle, hind leg angle and SL can be associated with alterations in LS (Sprecher et al., 1997; Telezhenko and Bergsten, 2005). Hind leg angle has been correlated to locomotion score in dairy cattle similar to the current findings (Van Dorp et al., 2004). Overall ADG was negatively correlated to hind leg angle meaning as the hind leg angle increased, overall ADG decreased. Hind leg angle was correlated to average LS which is highly correlated to overall ADG. When considering the high occurrence rate (46%) of steers in the present study that had an average LS greater than 1, it was more evident that steers with a more acute angle had greater growth performance (Dawson et al., 2020). Final BW had the strongest correlation to BL. Longer cattle weighed more at trial termination which is similar to other research (Francis et al., 2002; Ozkaya and Bozkurt, 2008). With final BW also correlated to SL, it is reasonable to assume that heavier cattle were longer bodied so that contributed to a longer SL.

Variance estimates of average LS, overall ADG, and final BW accounted for >97% of variance with very little residual error. Over half (64%) of the variance of average LS was attributed to SL at d 0. This is to be expected with increases in LS occurring as SL decreases and SL is an important component in most locomotion scoring models (Blackie et al., 2013; Edward-Callaway et al., 2017). The interaction of SL × BL × TRT accounted 38% of the variance of overall ADG.

Evaluating a scatter plot (**Figure 3.9**) of the SL and overall LS indicated that cattle with longer SL usually had lower LS. Two scatter plots (**Figure 3.10**; **Figure 3.11**) of SL and BL with final BW specify that as SL and BL increase cattle usually weighed more. This data suggests structural conformation is an important factor for growth performance. Variance of final BW was attributed at 38% to SL while SL and final BW were correlated. This may be due to the relationship of SL to LS and the affect it has on BW. Additionally, BL accounts for 23% of the variance of final BW which is likely due to larger cattle typically are heavier.

Lameness is important to dairy production because it can depress milk production (Warnick et al., 2001). In dairy cattle, hind leg angle is linearly correlated to locomotion score (Kougioumtzis et al., 2014). Also, dairy cattle with a more vertical hind leg angle are more susceptible to hoof injuries and increasing the prevalence of lameness (Vermunt and Greenough, 1996). In contrast to hind leg angle and SL, dairy cow BL in has not been associated with locomotion but it is positively correlated to milk production (Sieber et al., 1988). In general, increased lameness and locomotion alterations decrease milk production and reproductive performance (Sprecher et al., 1996; Kougioumtzis et al., 2014). Therefore, hind leg angle, SL, and BL are all relevant contributors to animal performance.

Hind leg angle and SL in the current study were correlated to average LS, overall ADG, and final BW. Animal LS had a negative correlation to overall ADG and final BW, so the connection could be made that hind leg angle and SL can affect growth performance eventually influencing net return. The present study used a novel process of evaluating structural conformation to identify factors contributing to lameness and locomotion problems at a finished weight. Uniquely, the present study focused on structural conformation at the onset of the study prior to any indications of lameness. In contrast, most gait analysis studies have focused on lameness identification instead of assessment prior to the onset of lameness. Within a feedlot setting, the ability to predict cattle with poor mobility and subsequent poor performance could allow for prevention through different management practices for at-risk animals. In addition, the identification of structural conformational differences could be used as selection criteria to improve overall animal welfare. Research should be conducted on how animals with different structural conformational traits perform in both indoor and outdoor feedlot facilities.

Flooring treatment and structural conformation traits especially SL accounted for variance of average LS, overall ADG, and final BW. The interaction that exists between flooring type and structural conformation traits is also attributable to variance of average LS, overall ADG, and final BW. It is important for cattle producers to further understand how pen flooring, cattle gait, and lameness are connected to animal growth performance. As more analysis of structural conformation is conducted, better genetic selection and management decisions can be made to improve animal welfare and growth performance in indoor feeding facilities.

TABLE

Table 3.1. Correlation coefficients for average locomotion score (LS), overall average daily gain (ADG), and final body weight (BW)

	Average LS		Overall ADG		Final BW	
Item	r	*P*-value	r	*P*-value	r	*P*-value
Hind Leg Angle	0.16	0.03	-0.24	<0.01	-0.13	0.09
Step Length	-0.22	<0.01	0.10	0.19	0.22	<0.01
Body Length	0.03	0.71	0.12	0.11	0.51	<0.01
Average LS	-	-	-0.49	<0.01	-0.12	0.10
SL/BL[1]	-0.23	<0.01	0.05	0.49	0.02	0.77

[1] SL/BL = step length divided by body length

FIGURES

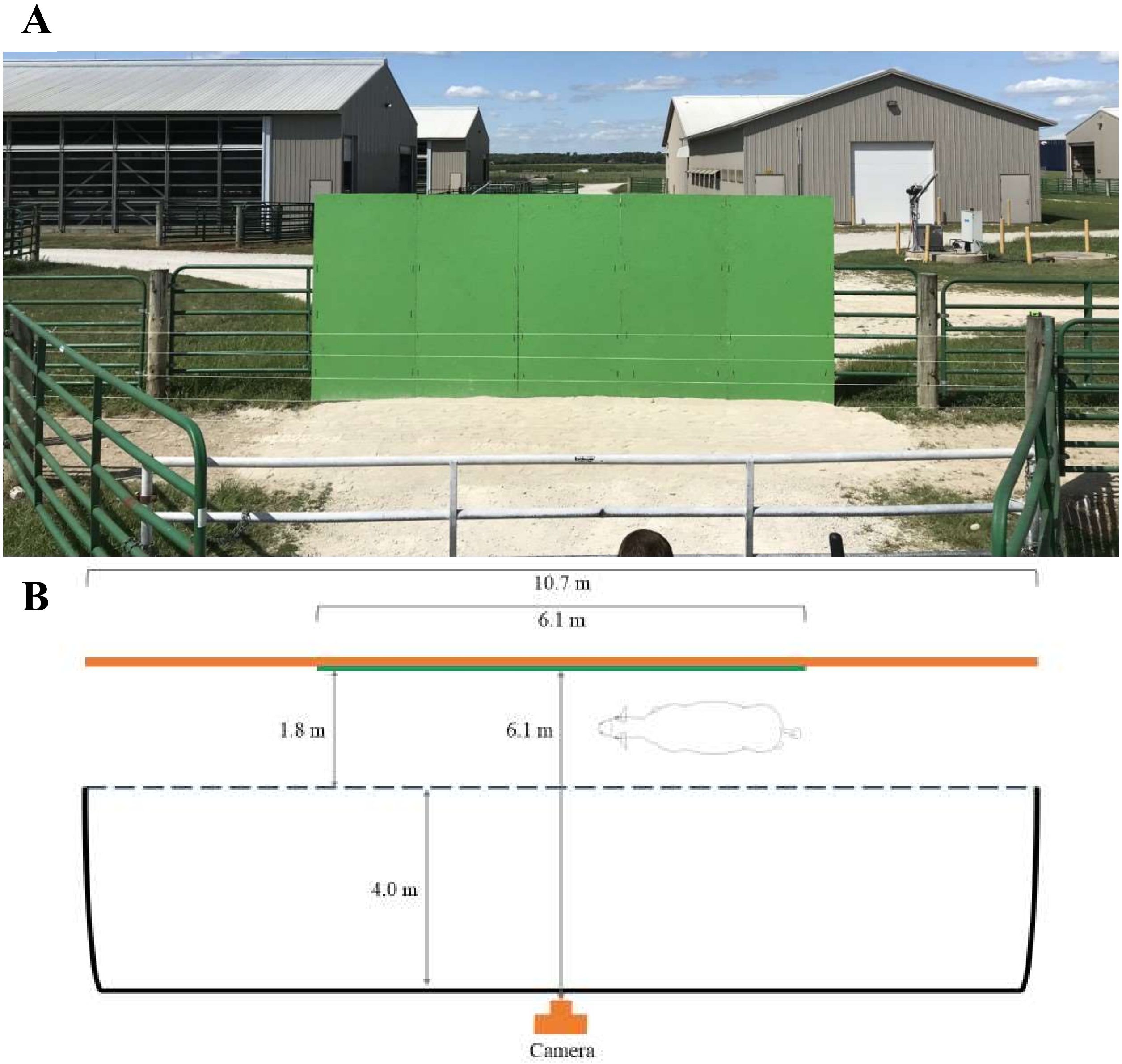

Figure 3.1. (A) Picture of video recording area. (B) Overview of video recording area with dimensions. The orange line corresponds to the permanent metal paneling. The green line corresponds to the green painted wood paneling. The dashed blue line corresponds to the poly-wire. The black curved line corresponds to the secondary containment area.

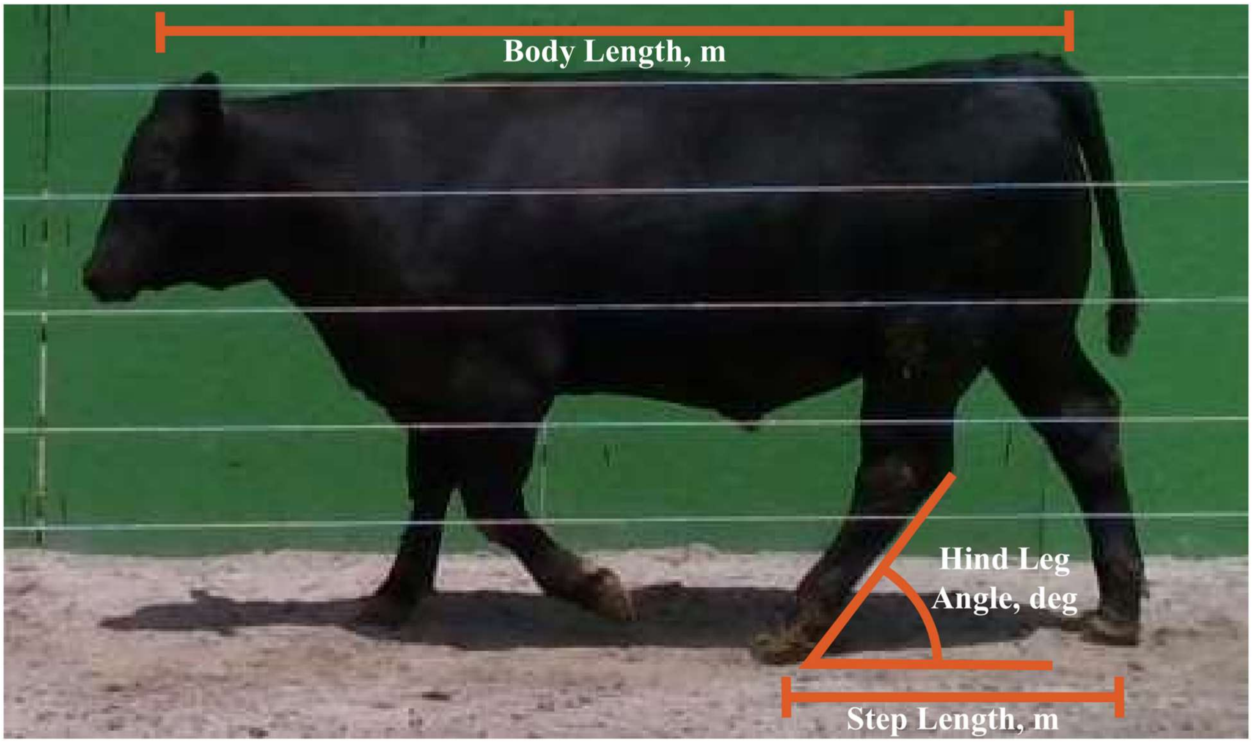

Figure 3.2. Structural conformation traits measurements. Step length is the horizontal distance in meters from the fetlock joint of one hind limb to the fetlock joint on the other hind limb. Body length is the horizontal distance in meters from the poll to the rump of an animal. Hind leg angle is the angle in degrees of the left hind leg from the tarsal joint to the fetlock joint at first ground contact.

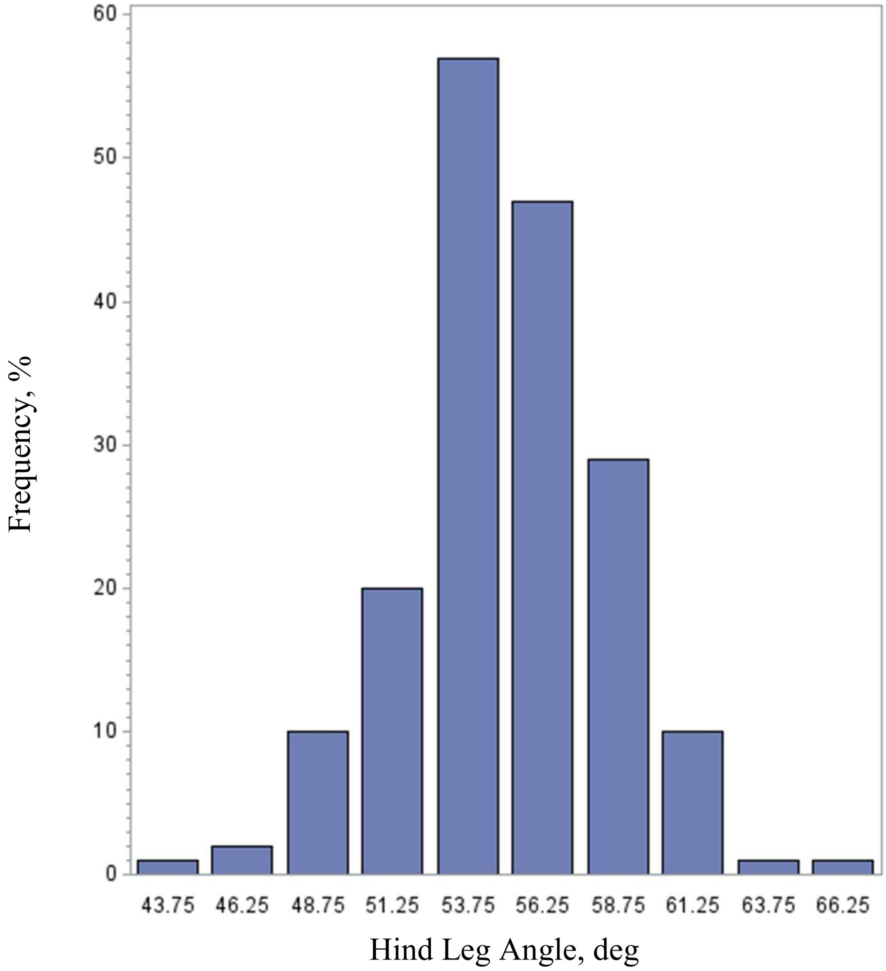

Figure 3.3. Distribution of hind leg angle. Hind leg angle had a mean of 55.06 deg and was normally distributed (*P* = 0.06) based on the Anderson-Darling goodness-of-fit test.

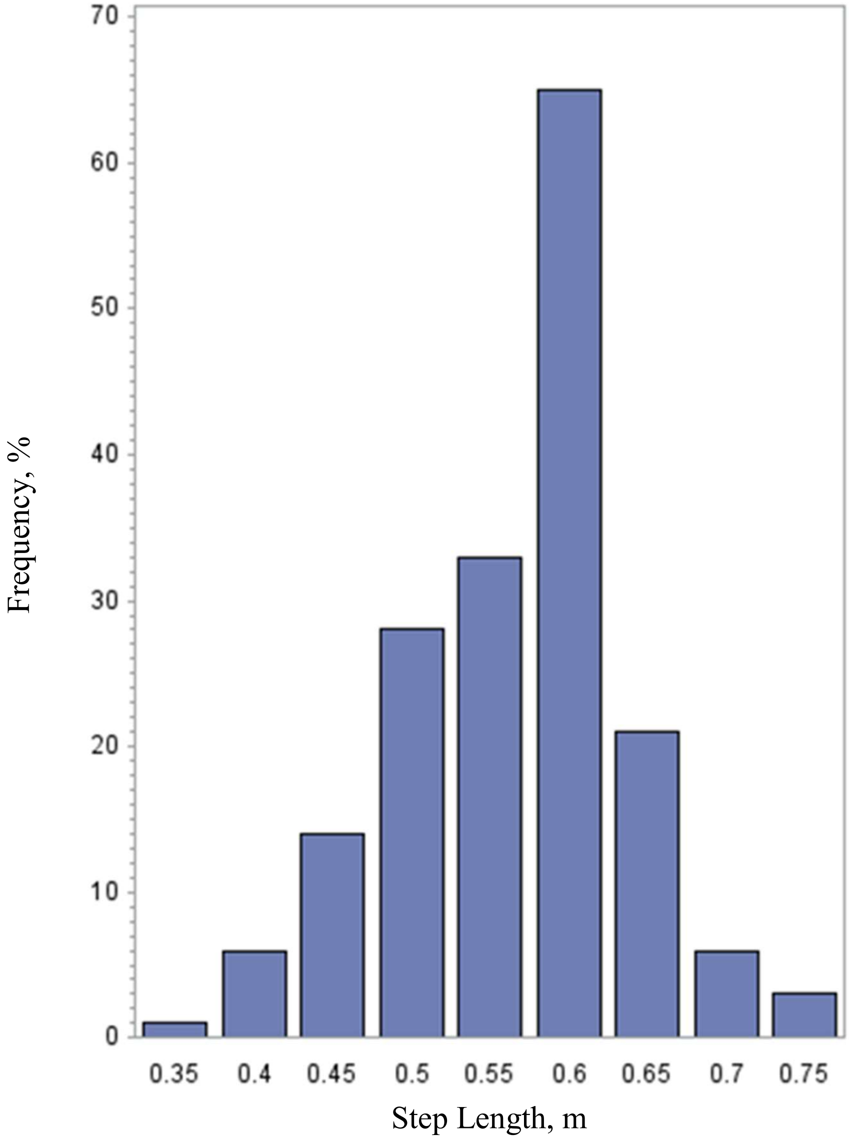

Figure 3.4. Distribution of step length. Step length had a mean of 0.57 m and was not normally distributed (*P* < 0.01) based on the Anderson-Darling goodness-of-fit test.

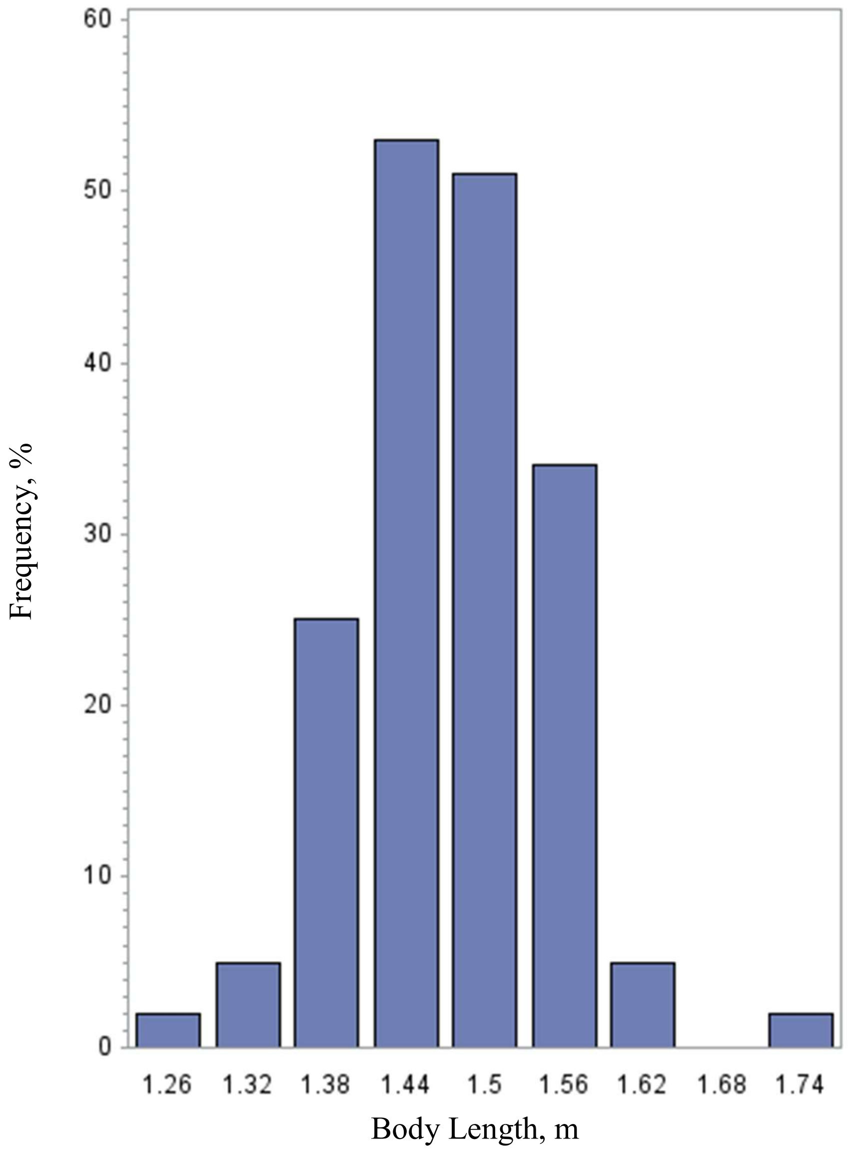

Figure 3.5. Distribution of body length. Body length had a mean of 1.47 m and was normally distributed (*P* > 0.25) based on the Anderson-Darling goodness-of-fit test.

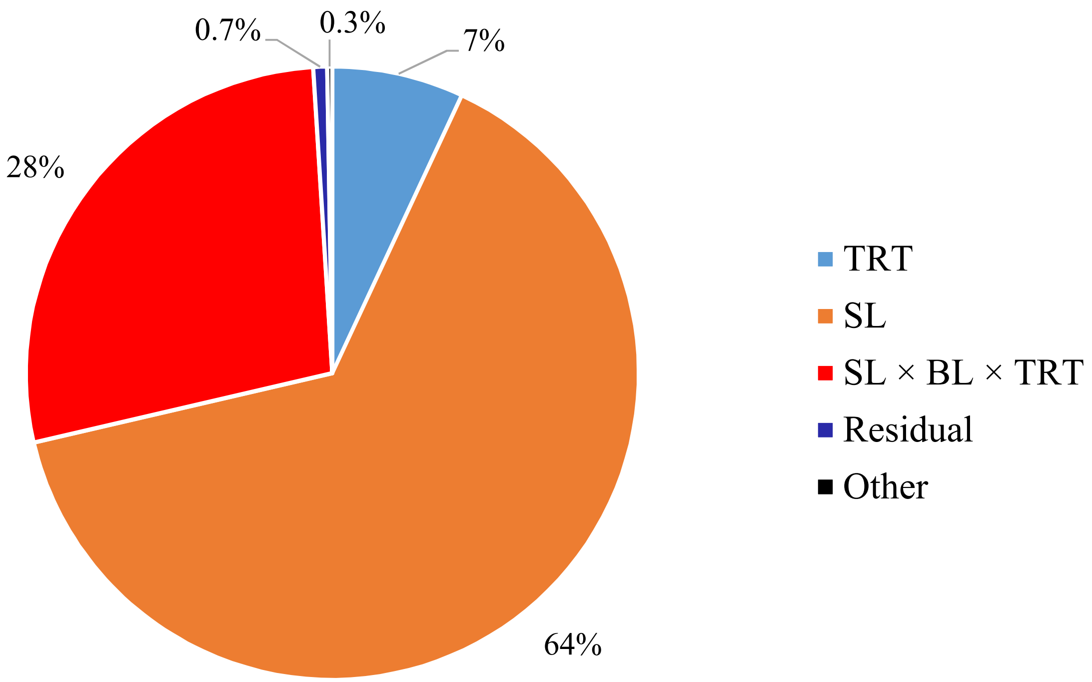

Figure 3.6. Percent of variance in average locomotion score attributed to treatment (TRT), sire, initial body weight (BW), hind leg angle, step length (SL), body length (BL), sire, residual, and interactions.

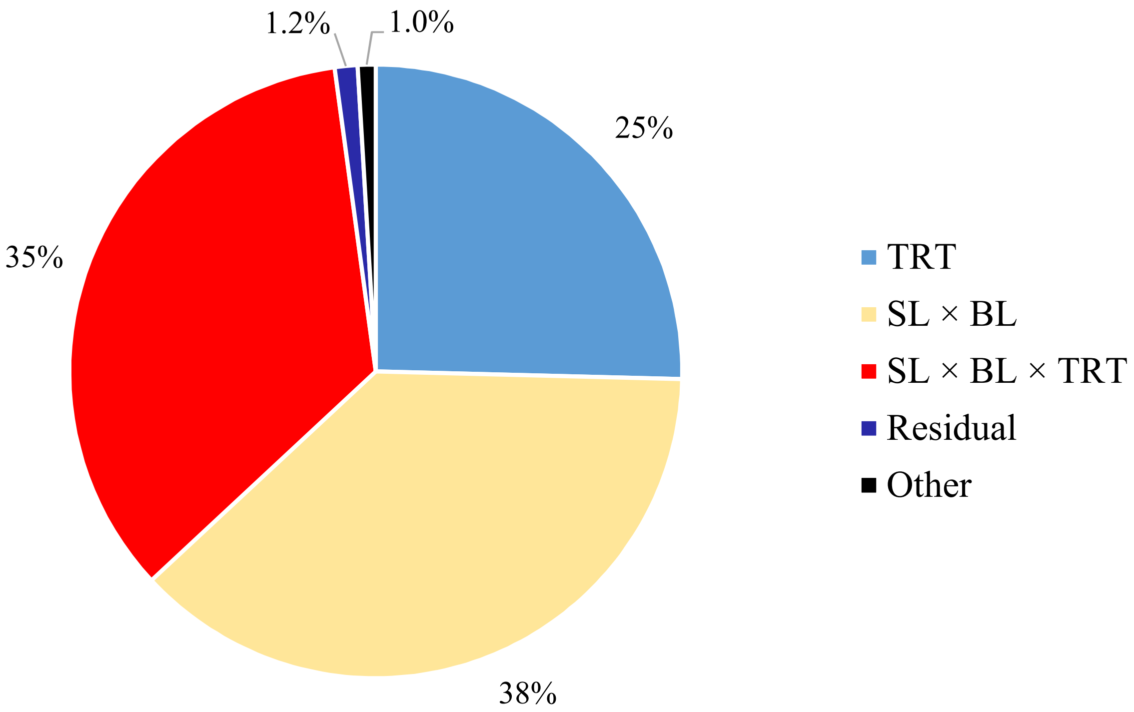

Figure 3.7. Percent of variance in overall average daily gain attributed to treatment (TRT), sire, pen nested within treatment, initial body weight (BW), hind leg angle, step length (SL), body length (BL), residual, and interactions.

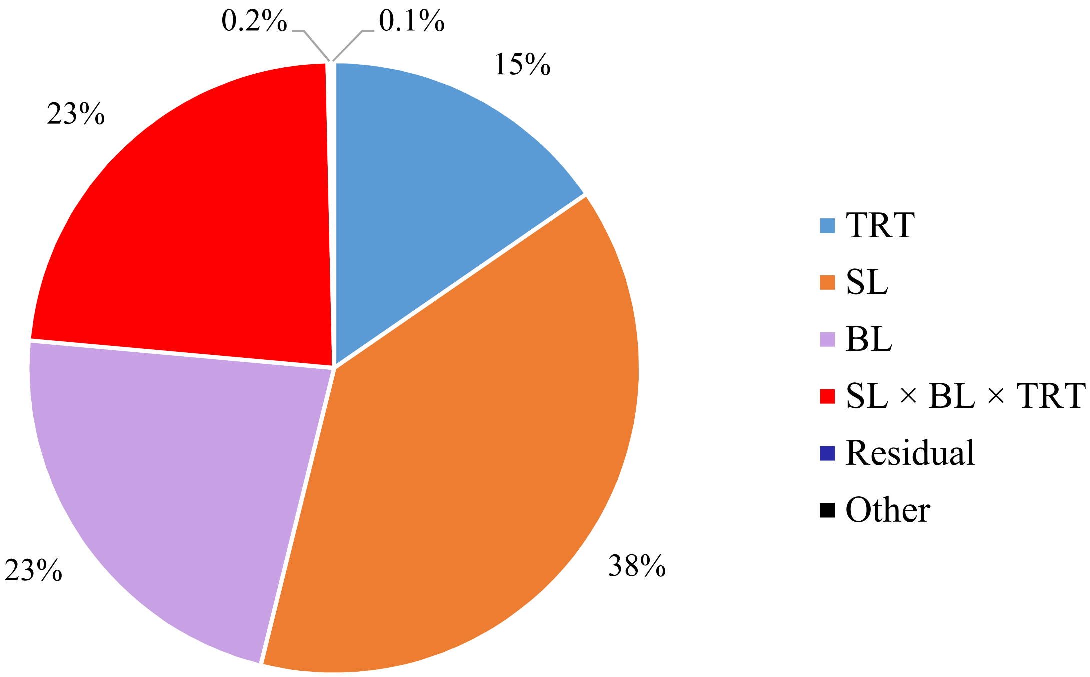

Figure 3.8. Percent of variance in final body weight attributed to treatment (TRT), block, sire, pen nested within treatment, initial body weight (BW), hind leg angle, step length (SL), body length (BL), residual, and interactions.

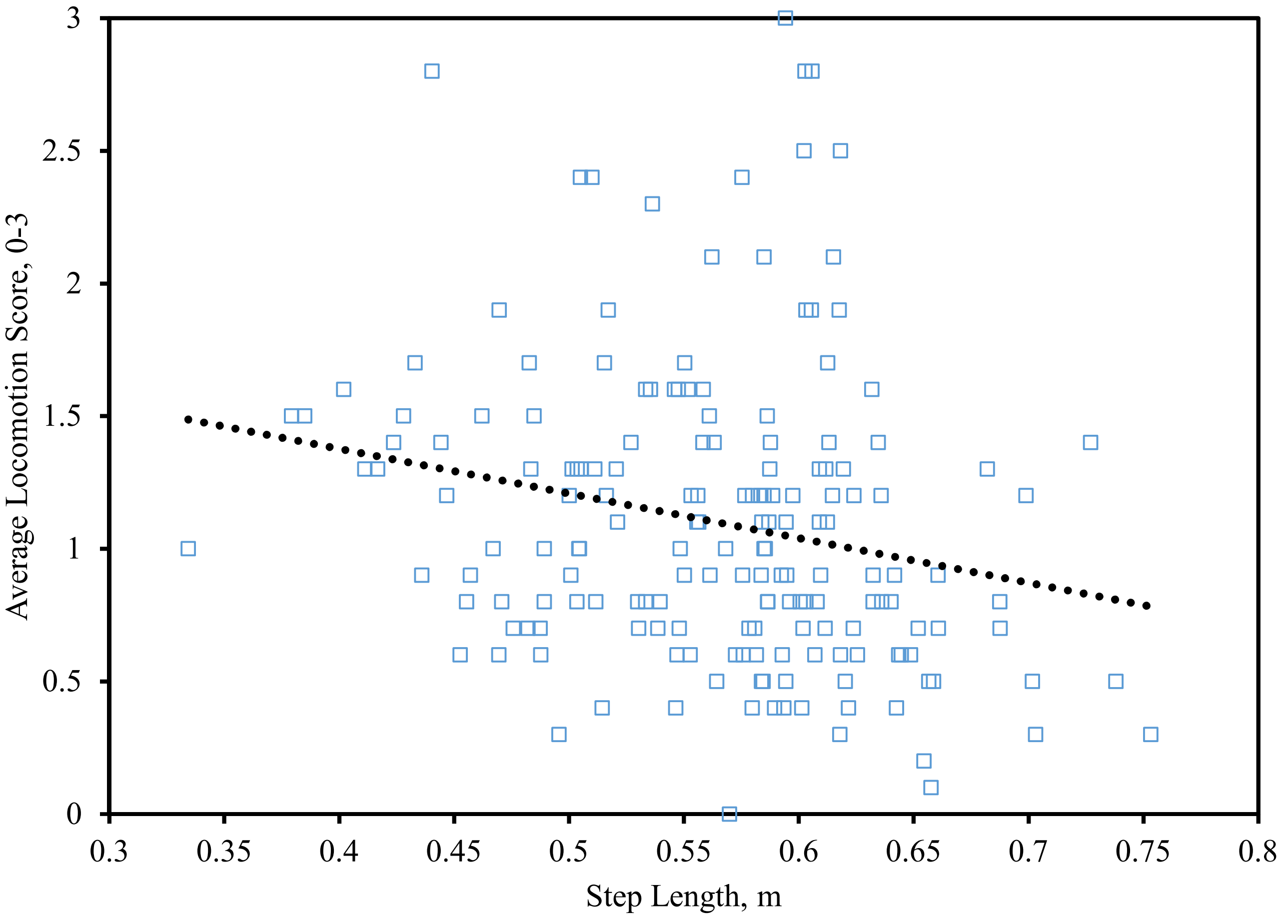

Figure 3.9. Scatter plot of step length with relation to average locomotion score. The blue squares are individual animal data. The dotted black line represents the line of best fit for this data set.

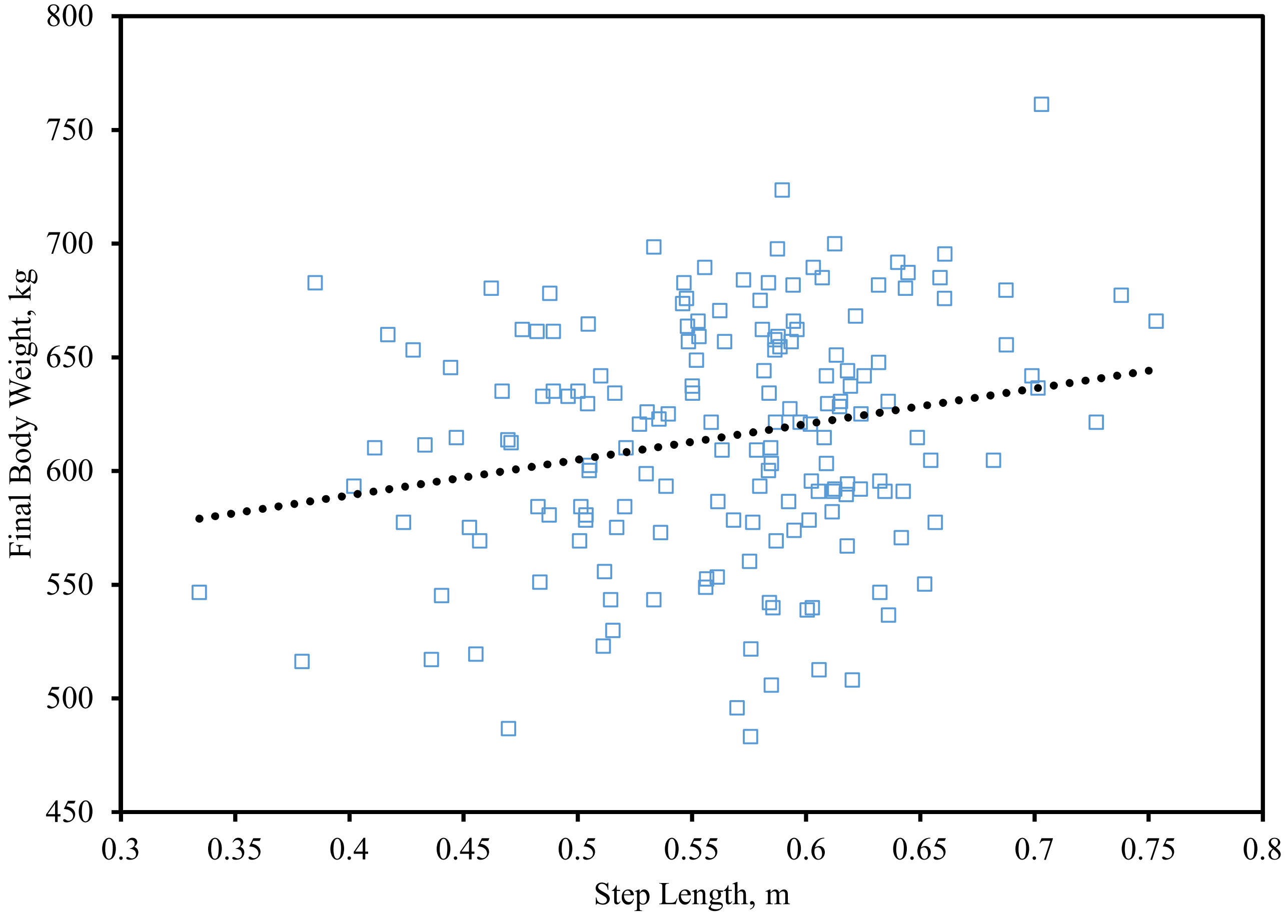

Figure 3.10. Scatter plot of step length with relation to final body weight. The blue squares are individual animal data. The dotted black line represents the line of best fit for this data set.

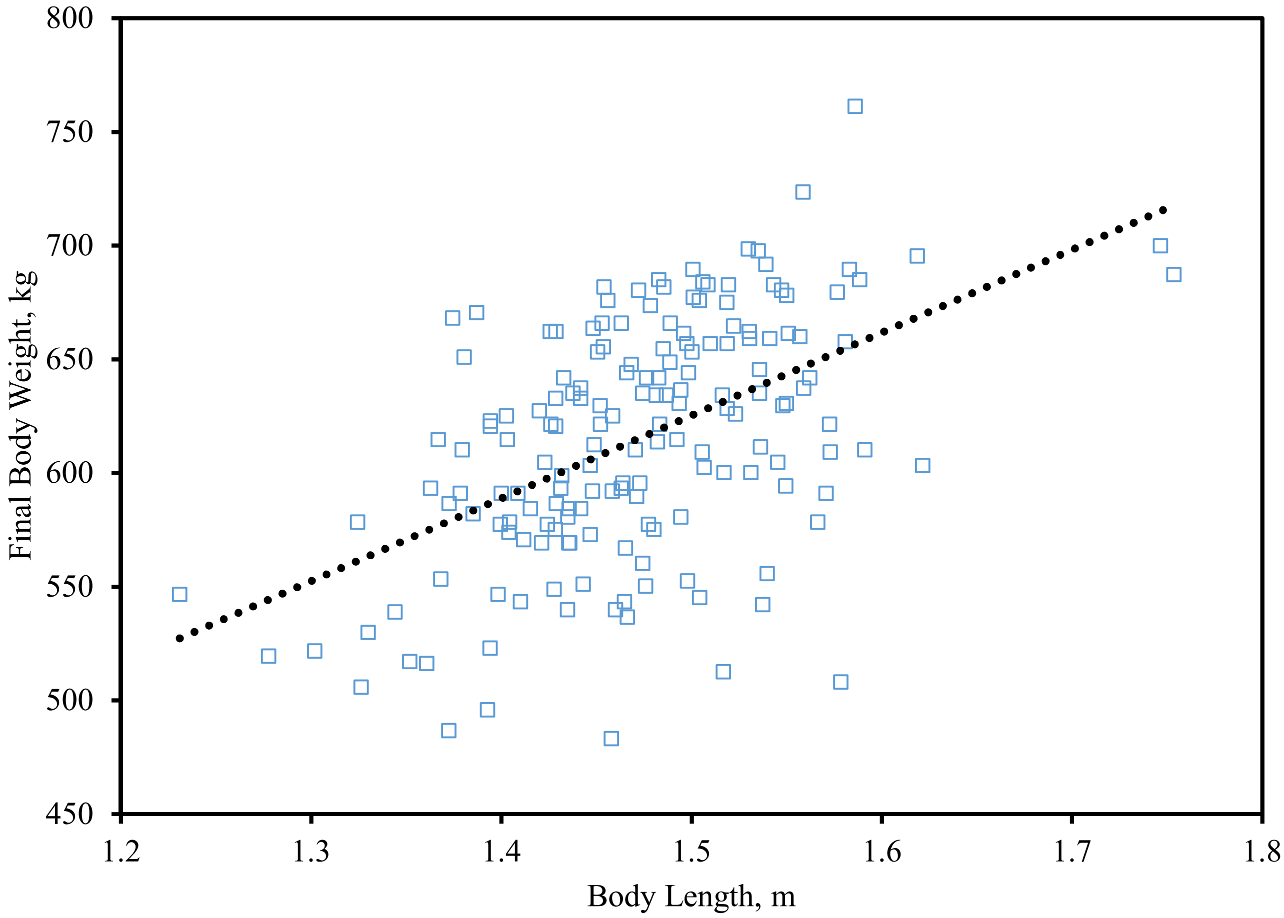

Figure 3.11. Scatter plot of body length with relation to final body weight. The blue squares are individual animal data. The dotted black line represents the line of best fit for this data set.

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