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

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Abstract

The objective 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. Angus × Simmental steers (N = 189; BW = 352 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, 15-year-old Animat Pebble matting, and new Animat Pebble matting. 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 throughout the finishing phase. 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 was 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.

Keywords: 3-D imaging, step length, slatted facilities

Introduction

Limited available land and poor winter pen conditions in the Midwest have led to more cattle being housed in slatted feeding facilities (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). Despite the advantages, cattle in slatted facilities have a greater prevalence of lameness (Schültz et al., 2014). Although facility design and management factors such as rubber matting and pen stocking density affect lameness (Cozzi et al., 2013), structural conformation likely contributes to improved mobility and welfare for cattle in indoor slatted facilities. 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. Specifically, 3-D image processing can evaluate animal conformation, lameness, and locomotion (Pluk et al., 2010). Digital evaluation of individual cattle has not been applied to feedlot cattle. Hind leg angle and SL can be measured to describe differences in dairy cow locomotion (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

Experimental design

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 a common finishing diet during the 152 d experiment (Dawson et al., 2022). 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 scored a 0 were considered normal or had no change in their gait. Cattle that 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. Each steer was recorded individually walking through the video recording area on a compacted lime surface. The camera was mounted on a tripod stand centered 6.1 m from the wooden background and 1.05 m from ground level. Across the two video recording sessions, an acceptable video for 94% of steers was recorded.

Videos were manually run through a custom pre-processing program designed in MATLAB (MATLAB version 2021b; The MathWorks, Inc., Natick, MA). The video was played to allow the viewer to indicate the frames best suited for video processing. 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. Forward movement (Mf) was calculated by the differences between the current frame of interest (Fc) and the previous frame (Fp). Backward movement (Mb) was calculated by the differences between the Fp and Fc, while Total movement (Mt) is the sum of Mf and Mb. The total movement was converted to a binary image. 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. 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. 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. 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. This SL was used as the average and maximum length for that animal. 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. 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 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 and discussion

Analyses indicated that model terms were able to account for up to 98% of the observed variance in average LS, overall ADG, and final BW. Over half of the variance (64%) of average LS during the finishing phase was attributed to SL (Figure 1A). This is to be expected as SL is an important component in most locomotion scoring models (Edward-Callaway et al., 2017). A large portion of variance of average LS was attributed to SL×BL×TRT at 28%. For overall ADG, 38% of variance was attributed to SL×BL. Other variables of SL×BL×TRT and TRT represented 35% and 25%, respectively, of the variance for overall ADG (Figure 1B). Animal SL was the greatest attributor of variance in final BW at 38% (Figure 1C). 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%. Hind leg angle did not account for variance in any of the evaluated models.

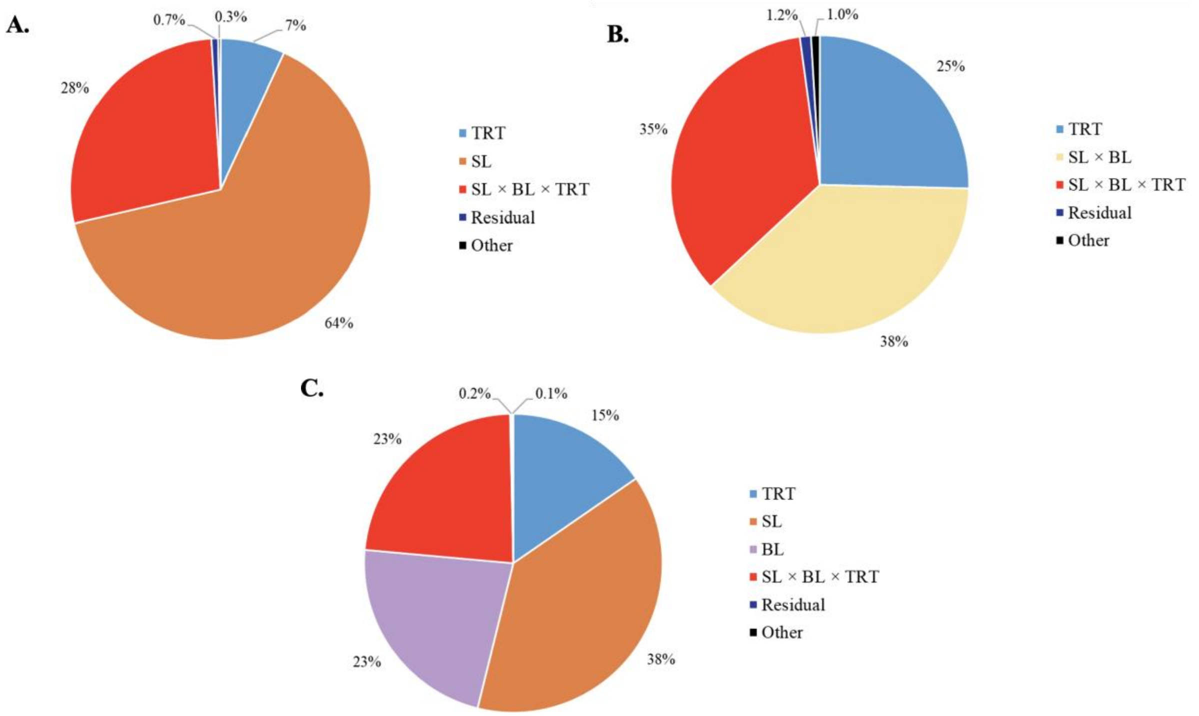

Figure 1: Percent of variance in average locomotion score (A), average daily gain (B), and final body weight (C) attributed to treatment (TRT), sire, initial body weight (BW), hind leg angle, step length (SL), body length (BL), sire, residual, and interactions. Any term not defined in the legend was included in Other.

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, 2021). Traits of interest in these scoring systems include foot angle, claw set, and hind leg angle. While scoring systems can introduce evaluator bias into the data, digital analysis systems can improve accuracy and remove bias.

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 of stride length (Telezhenko et al., 2005). The addition of rubber matting to slatted concrete has been reported to increase SL by up to 8% compared with cattle housed on concrete slatted floors (Telezhenko et al., 2005). Animal BL is not often reported but has been used as a correction factor for stride length (Pluk et al., 2010). 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 relation to the surface.

Lameness is important to dairy production because it can decrease feed intake and milk production 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.

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 before any indications of lameness. In contrast, most gait analysis studies have focused on lameness identification instead of a structural assessment before the onset of lameness. Within a feedlot setting, the ability to predict cattle with poor mobility and subsequent poor performance could allow for preventative management for at-risk animals. In addition, the identification of structural conformational differences could be used as selection criteria to improve overall animal welfare.

Conclusions

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.

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