Development of a feet and leg scoring method and selection tool for improved soundness in Red Angus cattle

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B.S., Kansas State University, 2015

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

College of Agriculture

KANSAS STATE UNIVERSITY

Manhattan, Kansas

2017

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Abstract

Feet and leg soundness is an important trait for beef producers as it has an impact on cow longevity and animal well-being. The objective of this study was to investigate genetic parameter estimates for feet and leg traits, understand the relationship between feet and leg traits and Stayability EPD, and develop a scoring method for feet and leg traits in Red Angus cattle. Cattle were scored on 14 subjective traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Heel Depth (FHD), Front Hoof Claw Shape (FC), Rear Hoof Angle (RA), Rear Heel Depth (RHD), Rear Hoof Claw Shape (RC), Foot Size (FS), Hoof Orientation (HO), Knee Orientation (KO), Front Side View (FSV), Rear Leg Side View (RS), Rear Leg Hind View (RH), Composite Score (CS). Red Angus cattle (n=1885) were scored for all 14 traits by trained evaluators. All traits except CS were scored with the assumed optimum level being in the middle with undesirable scores being located on the extremes. Scores were observed on a scale of 1-100 and analyzed, then scores were simplified to 1-9 where scores were collapsed by 10's into bins, starting at 10 since there were no observations below that point and the rubric used did not have an associated phenotype below that point. A three-generation pedigree file was obtained from the Red Angus Association of America (RAAA) that contained 13,306 animals, as well as a performance file on all animals observed in the study. Data were modeled using multiple linear bivariate animal models with additive and residual random effects, and age and contemporary group (herd-year) as fixed effects. Genetic parameters were estimated with ASREML4.0. Heritability estimates on the 1-9 scale for BCS, FA, FHD, FC, RA, RHD, RC, FS, HO, KO, FSV, RS, RH, and CS were 0.13, 0.18, 0.12, 0.08, 0.17, 0.24, 0.15, 0.29, 0.15, 0.15, 0.11, 0.29, 0.11, and 0.09 respectively. In general, feet and leg traits were lowly to moderately heritable, and are similar when compared to estimates for the same traits scored on a 1-100 scale. This informs a less granular and more simplified scale

of measurement can be an appropriate method of feet and leg trait classification. Front hoof angle, FHD, RA, and RHD were all highly genetically correlated (r = 0.83 - 0.97), suggesting that angle and heel depth are controlled by many of the same genes. Front claw shape and RC were highly genetically correlated (r = 0.80) with each other but were not as significantly correlated with FA, FHD, RA, RHD (r = -0.43 to 0.38). This suggests that hoof angle/depth should be measured separately from claw shape. Rear leg side view, and RH had a strong correlation (r = 0.69). Strong correlations between FSV, HO, and KO also existed, yet there was noticeable variation among point estimates and standard error. Six traits on the 1-9 scale were selected to generate estimated breeding values (EBV's) based on their heritability and correlation with other traits; BCS RHD, RC, FS, RSV, RH. A linear model was used to determine breeding values for BCS, RHD, RC, FS, FSV and RH. Those breeding values were regressed on Stayability EPD. When fixed effects of herd, age and year born were accounted for, RC ($P < 0.0001$), RSV ($P = 0.0517$), and FS ($P = 0.086$) had relationships as predictor variables for Stayability EPD. The use of feet and leg traits as predictor variables for improved Stayability EPD can be achieved with a simplified scoring system (1-9 vs. 1-100) in Red Angus cattle. By narrowing the number of traits needed to measure with a more simplified scoring method should allow for more rapid adoption among current beef cattle producers. A greater number of observations could be useful to validate these results and provide more accurate point estimates for feet and leg trait heritabilities and correlations.

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Acknowledgements

First, a huge thank you goes out to all the ranches and families that hosted our team throughout the course of the project. Your hospitality and helpfulness made the days we spent scoring cattle in the heat, wind, rain and that one time surrounded by tornado sirens so rewarding and it was a pleasure to have the opportunity to evaluate your cattle and learn from your operations.

Thank you to the Red Angus Association of America, the American Simmental Association and the Global Food Systems initiative for funding this research. I truly believe this will have a lasting impact on the beef industry moving forward.

Another huge thank you to Brady Jensen, who never let the long hours and sunburn slow us down. It was a great experience getting to travel across the country evaluating cattle with you and this time it wasn’t in an uncomfortable 15 passenger van. For learning no matter how far you need to travel, a jumbo margarita is always the answer to a long day scoring in the Texas heat.

Thank you to Dr. Bob Weaber, and Dr. Jenny Bormann for teaching me so much and including me in this project. To Dr. Megan Rolf for never turning down a small chat or question. A special thank you to Dr. Terry Houser who has been one of the most motivational forces in my life and for always seeing the potential in me.

Thank you to my family for your unwavering support and for providing me with so many opportunities in life. I would not be the person I am today without your help and guidance and would not be as passionate about the cattle industry without first seeing your passion and love for raising cattle and tirelessly trying to improve them. To all the friends and colleagues who have helped me get this far. And to Kate, my best friend, for constantly motivating me, and being the person who supports me through thick and thin regardless.

Chapter 1 – Literature Review

Introduction

With decreasing land availability, increased input costs, and tighter margins, beef cattle producers are more motivated to select for traits that improve profitability. Soundness has long been held as an influencer in cow longevity and lifetime herd profitability. Seedstock cattle producers are concerned with the feet and leg structure of the cattle they raise as it relates to longevity. Seedstock genetics have a lasting impact on the production cycle of beef and with the propagation of poor feet and leg structure, other producers are at risk to develop cattle with reduced mobility and longevity. Additionally, animal health and welfare is impacted by poor feet and leg structure.

Development of a standardized genetic evaluation for soundness traits would be valuable to beef cattle producers. Unlike type traits of feet and leg structure in dairy cattle however, genetic parameters for feet and leg structure in beef cattle have not been well established and a standardized scoring method has been untested in the national cowherd.

Scoring Methods for Structural Traits

The U.S. dairy genetic evaluation system utilizes a system of linear type traits which are expressed as Standard Transmitting Abilities (STA's). A pioneer in the classification of conformation (type) traits was the Holstein Association which began recording type traits in the US in 1929. In 1976, descriptive categories were recorded for 11 traits and with the advent of the Sire Evaluation for Type (SET) program in 1976, conformation information is allowed to be scored on unregistered cows. Per recommendations of the National Association of Animal Breeders

(NAAB) in 1983, linear classification was introduced to score traits on a continuous scale, with the primary goal being to identify and to emphasize traits associated with longevity.

Thompson et al, (1983) worked in collaboration with the NAAB and the Holstein-Friesian Association of America (HFAA) to collect data for a linear type trait appraisal project. Descriptions of the traits used by Thompson et al. (1983) can be found in Figure 1.1. At the time, advantages for scoring on a linear scale versus descriptive coding included 1) ability to score traits individually rather than in combination, 2) scores cover the biological range, 3) a wide range of numerical scores can be used, 4) a degree rather than desirability is recorded, and 5) the scoring allows analysis with continuous scale and mixed-model evaluation. They concluded that the trait descriptions must be used when interpreting correlations because scoring is from extreme to extreme (Thompson et al. 1983).

Short et al. (1991) described the addition of Rear Legs Rear View to the list of subjectively scored type traits for Holstein cattle. Criteria to evaluate the merit of new experimental feet and leg type traits must; 1) be defined so that the mean is close to the middle of the scale to best measure the range of differing phenotypes (i.e. 25 points on a scale of 1 to 50), 2) have a standard deviation with enough points to best use the full range of the scale, 3) heritability of the particular trait should be high enough to obtain a useful range of breeding values, 4) each new trait should provide different or better information than currently recorded, 5) the final group of traits recorded should be low to moderately correlated with one another, and 6) all traits should have economic importance in order to justify the costs of collecting the information (Short et al., 1991). This methodology should be considered when developing a genetic evaluation for feet and leg structure in beef cattle.

Scoring Methods in the Dairy Industry

The Holstein Association USA, Inc. (2016) currently measures 17 primary traits on a linear scale with rear leg side view and foot angle being set to an intermediate optimum. A description of current Holstein linear type traits relating to soundness can be found in Figure 1.3. Three traits are related to feet and leg structure; Rear Legs Side View (RS), Rear Legs Rear View (RV), and Foot Angle (FA). There are 3 additional research traits scored including 1 related to feet and leg structure, locomotion (LO). Animals will receive a final score ranging from 1 to 100 based on 5 major breakdown areas; Front End and Body Capacity, Dairy Strength, Rump, Feet and Legs, and Udder, weighted in the final overall score of 15%, 20%, 5%, 20%, and 40% respectively. All animals are scored by a trained classifier (Holstein, 2016a; Holstein, 2016b). Linear type traits are standardized into STA's to allow for easier interpretation when comparing multiple traits.

Holstein Association USA, Inc (2017) currently combines linear trait information of related traits into one numerical value to be used as a composite index. The Feet and Leg Composite (FLC) was designed to develop animals with superior mobility which translates to a longer productive life and lifetime production of milk. The index incorporates the major Feet and Leg Score as well as an additional three linear traits; FA, RV and Stature (ST). Stature is included with a negative weight to allow breeders to improve feet and legs without the risk of making cows taller. The current FLC formula is as follows:

$$FLC = +0.02 + [(.09 \times FA) + (.21 \times RV) + (.70 \times FLS) - (.20 \times ST)] \times 1.09$$

The values +0.02 and 1.09 standardize the composite index to the base population (Holstein, 2017).

The Ayrshire, Brown Swiss, Guernsey and Jersey breed organizations offer similar genetic evaluations which utilize many of the same traits and methodology.

Scoring Methods in the Beef Industry

Compared to the dairy industry, the beef sector has relatively few genetic selection tools aimed at feet and leg structure. The most prominent attempt is by the Australian Angus Association (AuAA) which started collecting feet and leg conformation traits on Angus cattle in the early 2000's. The BeefClass Structural assessment was developed in collaboration with the Beef Improvement Association of Australia (BIA) and the technical committee of the AuAA in 1996. A list of economically important traits (including feet and leg traits) was agreed upon by both entities, as well as 17 Australian Angus producers. It was agreed that scores would be collected by trained classifiers. A list of descriptions regarding the six traits relating to beef soundness in the BeefClass scoring system can be found in Figure 1.4.

Jeyaruban et al. (2012) used data provided by the Australian Angus Association, recorded in Angus seedstock herds using the BeefClass structural assessment to measure six different traits on an intermediate optimum scale. The traits included front feet angle (FA), rear feet angle (RA), front feet claw set (FC), rear feet claw set (RC), rear leg hind view (RH), and rear leg side view (RS). Traits were scored on a 1-9 scale with scores 5 and 6 being considered ideal and scores on the more extreme ends of the scale being considered undesirable. Depictions of traits used by Jeyaruban et al. (2012) can be found in Figure 1.5. Data were analyzed on animals younger than 750 days of age and a majority of the animals had all 6 traits recorded. Further, the study aimed to understand the benefits of using a threshold animal model (TAM) over a traditional linear animal model (AM). To do this, scores were collapsed into three groups; GROUP_1 (scores 1 – 4; Undesirable), GROUP_2 (scores 5 – 6; Desirable), GROUP_3 (scores 7 – 9; Undesirable). They found that AM using all scores may not yield appropriate estimates of genetic parameters or breeding values through standard restricted maximum likelihood (REML) or through best linear unbiased prediction (BLUP), due to lack of normality in the distribution of observations. A TAM using the grouping system yielded higher heritability estimates than estimates derived from an AM (Jeyaruban et al. 2012).

Currently, the American Angus Association (AAA) is collecting observations on two traits in seedstock Angus cattle: foot angle (FA), and Claw Set (Claw), with animals being scored on a 1 – 9 intermediate optimum scale. Depictions of the two traits recommended for scoring by the AAA can be found in Figures 1.6 and 1.7. Guidelines recommend prior to hoof trimming, scoring the poorest hoof. Additionally, scores should be observed on bulls between the ages of 320 to 440 days, and females between the ages of 320 to 460 days. For older animals with observations outside the recommended age range, scores will be adjusted (AAA Foot Score Guidelines, 2017). The American Angus Association is also collaborating with participating universities to allow trained livestock evaluators and members of judging teams to assist in the collection of foot score data.

Impact of Feet and Leg Traits on Longevity

Relationships have been documented that relate linear type traits to stayability or longevity in cattle, most notably locomotive and udder traits in dairy cattle (Boldman et al. 1990, Foster et al., 1989, and Rogers et al., 1989). There are multiple terms used to define longevity in cattle, but all reflect a combination of the characteristics that are directly associated with a cow's ability to successfully stay in the herd (Tsuruta et al. 2005). However, there are some underlying challenges associated with genetic selection for longevity, most notably the inability to collect a complete record until the end of each cow's productive life, which is of lower value for evaluating a sire's genetic potential for transmitting improved longevity. The best solution is to determine indicator traits for longevity to be used in a genetic evaluation to predict a sire's genetic merit.

It is understood that feet and leg structure play a critical role in a cow's ability to successfully stay in a herd (Greer et al. 1980; Rogers et al. 1989; Boldman et al. 1990; Short et al. 1992; VanRaden et al. 1992; Dekkers et al. 1993). Within the dairy industry, Productive Life (PL) is an economic indicator utilized by multiple breed organizations. Productive life is defined as the total number of Days in Milk (DIM) with a limit of 305 DIM per lactation at 84 months of age (VanRaden and Klaaskate, 1993). Productive life is obtained by combining direct PTA for PL along with an indirect prediction of PTA for PL from correlated traits. Tsuruta et al (2005), reported PL genetic correlations with RS, FA, RH and BCS of -0.10, 0.12, 0.14, and 0.05 respectively. They concluded that straighter legs, steeper foot angle and higher overall conformation scores were consistently related to increased longevity. Productive life however, is subject to bias at the producer level in the way they gather phenotypes, and the traits that influence PL can experience variable emphasis from selection throughout time. Similar to PL, Herd Life (HL) is a value defined as the total number of days from the first calving date to the last (culling) date. In registered Holstein cows, Short and Lawlor (1992) reported HL genetic correlations with RS, FA of -0.08 and 0.26 respectively. Those values were similar to values obtained by Tsuruta et al, (2005). Burke and Funk (1993), found that linear type traits accounted for 14% of explained variation for HL after effects for herds and production were considered, however, udder traits explained more variation for HL than other linear type traits.

There are currently a few indicators for determining longevity in beef cattle, however the most influential and prominent tool used by beef cattle producers today is Stayability EPD (STAY). It is defined as a value associated with a cow's ability to remain in the herd until she is six years old, given she calved as a two year old. STAY is heavily influenced by fertility and the ability to wean a calf, however STAY to relatively old ages may also be an indicator of improved soundness, as physical impairments can result in culling (Greer et al. 1980). Rogers et al. (2004) found that dystocia and maternal breeding values for pre-weaning gain significantly increase the risk of a female being culled, yet traits such as age at first calving and calf birth weight are not useful predictors for subsequent longevity. They surmised that genetic improvement of longevity is hindered by relatively low heritability and a lack of useful indicator traits expressed early in life. Few studies have related specific feet and leg structure traits to STAY in beef cattle.

Environmental Impact on Feet and Leg Traits

There is significant value in understanding how feet and leg structure is affected by an animal's surrounding environment. Diets, age, floor surface, and moisture level of the ground have been speculated to have an impact on foot conformation and health disorders.

Hahn et al. (1984) concluded that with advancing age, hoof angles decreased, especially rear hooves, hoof length increased, and hooves from older Holstein cows supported increased weight on a larger surface area. Boettcher et al. (1996) concluded that lameness was more common during the earliest stages of lactation where cows are fed higher energy diets with relatively low ratios of roughage to concentrate. They also concluded that older cows may have poorer feet as they have been exposed to greater cumulative lifetime wear and stress than younger herd mates. Burke and Funk. (1993) looked at the relationship between locomotive traits and HL for different housing types. Cows with intermediate curvature to their rear legs and a steeper foot angle had longer HL in all housing types studied, but the absolute difference between optimum and extreme was greater for those in confinement than cows in loose housing (Burke and Funk, 1993).

Fatehi et al. (2005) evaluated genotype by environment interaction (GXE) for feet and leg traits of Holstein cattle scored in different environments. Management systems included; free stall vs. tie stall, slatted flooring vs. solid flooring, and intact hooves (pre-trimming) vs. trimmed hooves. They concluded that animals experienced poorer feet and leg phenotypes when exposed to tie stalls, slatted floors and no hoof trimming. They found that trimming had little to no effect on genetic parameters. Genetic correlations of feet and leg traits across management systems were ≥0.85, except rear legs rear view, which was 0.79. The authors concluded that effects of a GXE were of little importance and modification of genetic evaluation procedures on the basis of housing, flooring, and hoof conditions is unnecessary (Fatehi et al. 2003).

Feet and Leg Traits

Traits associated with soundness are difficult to measure in beef production. When compared to dairy cows, hoof health is much more difficult to monitor in beef cattle. Mature cows are usually only caught a few times a year, and the lack of a standardized scoring method has inhibited mass collection of feet and leg phenotypes. Genetic parameters for feet and leg traits have been widely estimated in dairy cattle and estimates for certain populations of beef cattle can be found in recent literature. A summarized list of feet and leg trait heritabilities found in dairy and beef cattle can be found in Table 1.1.

Front Hoof Angle (FA)

Front hoof angle is measured as the degree of angularity from the toe and the base of the hoof. Hahn et al. (1984) collected objective measurements of FA using a commercial protractor. They calculated front medial claw and front lateral claw angle heritabilities of 0.38 and 0.40 respectively. Since measurements differed between hooves, both feet were measured, then averaged. Jeyaruban et al. (2012) recorded subjective front hoof measurements. They reported heritability estimates using an AM and TAM with data collected on a 1-9 scale and an AM and TAM with grouped data (1-3); of 0.32, 0.50, 0.17, and 0.41 respectively.

Front Heel Depth (FHD)

Front heel depth is measured as the distance between the floor surface to the base of the coronary band on the rear of the front lateral claw. Hahn et al. (1984) found a difference in heritability estimates for heel depth, where those observed on the front half of the animal tended to have higher heritabilities than those found on the rear half. They recorded objective measurements on 257 Holstein heifers and 1051 Holstein cows using a traditional ruler on a clean hoof (after it had been washed) and reported front hoof heel depth heritability at 0.58.

Front Hoof Claw Shape (FC)

Claw shape and uniformity is described as the relative size of toe and shape of the lateral and medial claw of the front feet and distance between claws served to indicate the degree of divergence from one claw to the other. Scores were averaged if inconsistency between feet was present. Fatehi et al. (2003), reported heritabilities for claw uniformity in Holstein cows housed in tie-stall and free-stall barns of 0.03 and 0.04 respectively. However, as the scoring method was on a continuous scale rather than an intermediate optimum scale as most others found, comparing heritabilities from Fatehi et al. (2003) to other estimates from literature should be done with caution. Jeyaruban et al. (2012) reported much higher heritabilities for front hoof claw shape using a subjective, intermediate optimum scoring method. Using an AM and TAM with categorical data and an AM and TAM with grouped data, they reported heritabilities of 0.33, 0.46, 0.22, and 0.36 respectively.

Rear Hoof Angle (RA)

Rear hoof angle is measured as the degree of angularity from the toe and the base of the rear hoof. Hahn et al. (1984) obtained rear hoof measurements using a commercial protractor on the medial and lateral claws of the rear hoof and reported heritabilities of 0.55, and 0.85

respectively. Jeyaruban et al. (2012) reported heritabilities of 0.18, 0.26, 0.29, and 0.35 using an AM and TAM with categorical data and an AM and TAM with grouped data for rear hoof angle.

For many studies foot angle measurements were observed on the rear hoof. Short et al. (1991) observed subjective hoof angle measurements on a scale of 1 to 50 and reported heritability estimates of 0.11. Short and Lawlor (1992) compared genetic parameter estimates between registered and unregistered Holstein cows for linear type traits and reported heritabilities for RA of 0.14, 0.07, and 0.09 respectively. Fatehi et al. (2003) evaluated feet and leg phenotypes in different housing scenarios and reported heritability estimates for RA of 0.12 and 0.11 for Holstein cows in tie-stall and free-stall environments respectively. Tsuruta et al. (2005) observed phenotypes for type traits in cows at 305 days in milk (DIM) and reported a heritability of 0.12 for RA. Van der Waaij. (2005) related feet and leg traits to claw health issues in Dutch crossbred dairy cattle and reported a heritability estimate of 0.18 for RA.

Rear Heel Depth (RHD)

Rear heel depth was measured as the distance from the surface to the base of the coronary band on the rear of the lateral claw. Hahn et al. (1984) reported a lower heritability estimate for RHD than obtained for FHD (0.19 vs. 0.58). Thompson et al (1983) and Fatehi et al. (2003) reported heritability estimates for RHD of 0.15, and 0.06-0.07 respectively.

Rear Hoof Claw Shape (RC)

Claw shape and uniformity is described as the relative size and shape of the lateral and medial claw of the rear feet and distance between claws served to indicate the degree of divergence from one claw to the other. Scores were averaged if inconsistency between feet was present. Jeyaruban et al. (2012) reported heritability estimates of 0.16, 0.40, 0.29, and 0.44 using an AM and TAM with non-modified data and an AM and TAM with grouped data for RC.

Foot Size (FS)

Foot size is a subjective measurement of the size of the foot in relation to the pastern circumference immediately above the hoof. Bone quality is a similar measurement observed by Fatehi et al. (2003) and reported heritability estimates of 0.29, and 0.24 for Canadian Holstein cows in tie-stall and free-stall barns.

Front Side View (FSV)

Front side view is described as the relationship of the front leg set to the angle of the shoulder, set to a vertical line through the hoof immediately perpendicular to the surface. Front side view is a subjective trait most commonly found in livestock judging manuals. No genetic parameter estimates exist for this trait.

Hoof Orientation (HO)

Hoof orientation describes the outward or inward orientation of the front hooves as they are placed on a flat surface. It is a subjective trait found in livestock judging manuals. This trait is commonly associated with improved conformation of an animal, however little is known of its genetic impact on feet and leg structure.

Knee Orientation (KO)

Knee orientation describes the outward or inward orientation of the knees of the front leg set as they are in relation to a vertical line drawn from the hoof to the immediate base of the elbow. This trait is most often found in judging manuals, and little can be found about its genetic impact on soundness.

Rear Leg Side View (RS)

Rear leg side view is described as the curvature of the rear leg set and levelness of hip. It is one of the most commonly studied traits relating to feet and leg structure, and has one of the largest genetic impacts on soundness in cattle. Heritabilities range from 0.09 to 0.22 (Short and Lawlor. 1992; Van der Waaij et al. 2005; Jeyaruban et al. 2012).

Rear Leg Hind View (RH)

Rear leg hind view describes the outward or inward orientation of the rear legs from a rear view. Hocks angled inward is described as cow hocked versus hocks angled outward from each other described as bow-legged. Rear leg hind view is viewed as one of the most important feet and leg type traits in in the international dairy cattle industry. Heritability estimates for RH range from 0.06 to 0.12 in dairy cattle (Wiggans et al. 2006; Tsuruta et al. 2005) and 0.12 to 0.32 in beef cattle (Jeyaruban et al. 2012).

Composite Score (CS)

Composite score is a subjective measurement, culminating all the aforementioned traits into a single value. The only similar trait found in the literature is the Holstein Feet and Legs (FL) trait. Currently, FL is a cumulative measurement of three linear type traits; Foot Angle, Rear Legs Side View, and Rear Legs Rear View. Fatehi et al. (2003) also included claw uniformity, depth of heel, and a measure of bone quality into FL. They reported heritabilities ranging from 0.13 to 0.17, dependent on housing type. Van der Waaij et al. (2005), reported heritability estimates of 0.24 and a genetic correlation of 0.98 between FL and locomotion.

Body Condition Score (BCS)

Body condition score is a score on a scale of 1 to 9, reflecting the amount of fat reserves in a cow's body, where 1 is very thin and 9 is extremely fat (BIF Guidelines, 2016).

Genetic Correlations

Genetic correlations are an important of genetic evaluation for structure traits. To develop the best evaluation, traits should have a low to moderately low genetic correlation with each other to avoid multicollinearity. Further, it's important to understand how selection of one trait will impact another. Jeyaruban et al. (2012) reported genetic correlations for feet and leg traits in beef cattle using a LAM and TAM. Front foot angle was moderately correlated with RSV (r = 0.19 – 0.48) and RC (r = 0.27 – 0.63), lowly correlated with RH (r = 0.02 - 0.31) and highly correlated with RA (r = 0.050 – 0.87) and FC (r = 0.41 – 0.83). Rear foot angle was genetically correlated with RSV (r = 0.23 – 0.86), RH (r = 0.21 – 0.39), and RC (r = 0.30 – 0.82). Rear leg side view was moderately genetically correlated with RH (r = 0.27 – 0.67) and had high variation of correlation with RC (r = 0.17 – 0.62). Rear leg hind view was genetically correlated with FC (r = -0.14 – 0.16) and RC (r = 0.07 – 0.21). Front claw shape was highly correlated with rear claw shape (r = 0.27 – 0.81). Similar correlations for feet and leg traits have been documented in dairy literature (Thompson et al. 1983; Short et al. 1991; Van der Waaij et al. 2005)

Conclusions

Feet and leg structure traits have measurable genetic variation which can be observed at relatively young ages. Genetic parameter estimates for a multitude of feet and leg type traits are prevalent in dairy literature, and progress has been made to develop an evaluation in the beef cattle industry. Heritability estimates indicate improved feet and leg structure traits can be realized through selection pressure in beef cattle.

Using feet and leg traits as predictor variables for stayability and longevity in cattle may improve selection practices to maximize herd profitability. Further investigation is needed to understand which traits have the strongest impact on improved soundness in beef cattle and how to incorporate these new traits into a beef cattle genetic evaluation.

Figure 1.1 Description of Linear Type Traits in cooperation with the National Association of Animal Breeders and Holstein-Friesian Association Linear Type Appraisal Project (Thompson et al., 1983)

Stature
- 99 Very tall at the withers
- 50 very short

Strength of Body
- 99 Extreme width, strength, and substance of bone
- 50 Extremely narrow and frail

Dairy Character
- 99 Extremely sharp, angular, and clean-boned
- 50 Extremely thick and coarse

Rump (side view)
- 99 Extreme slope from hooks to pins
- 50 Pins clearly higher than hooks

Rump Width
- 99 Extremely wide through pelvic area
- 50 Extremely narrow and frail

Rear Legs (side view)
- 99 Extremely sickle-hocked
- 50 Extremely posty

Rear Legs (rear view)
- 99 Straight with no toe out
- 50 Extremely close at hocks, severe toe out

Heel Depth
- 99 Extremely deep heel
- 50 Extremely shallow

Fore Udder Attachment
- 99 Tight, extremely snug attachment
- 50 Extremely broken

Rear Udder Height
- 99 Extremely high attachment
- 50 Extremely low attachment

Rear Udder Width
- 99 Extremely wide
- 50 Extremely narrow

Udder Depth (relative to hocks)
- 99 Extremely shallow, udder floor well above hocks
- 50 Extremely deep, udder floor below hocks

Suspensory Ligament (cleft)
- 99 Extreme cleft
- 50 Extreme negative cleft

Teat Placement (rear view)
- 99 Base of teats nearly touching
- 50 Extremely wide placement and/or extreme strutting

Figure 1.2 Description of type traits using a maximum score optimum (Fatehi et al., 2003)

Trait	Criterion	Low score	High score
Claw uniformity	Relative sizes of the outer and inner claws of the rear feet	One claw clearly larger than the other	Both claws of a uniform size
Depth of heel	Distance between floor and the hairline on the backside of the foot	No or little clearance above floor	At least 4 cm of clearance needed to obtain maximum score
Rear legs, rear view	Deviance of rear legs from imaginary perpendicular lines connecting pin bones and floor	Hocks are inside of perpendicular lines and toes are outside of lines	Rear legs perpendicular with floor
Foot angle	Angle of hairline above hoof when viewed from side	High angle of the hairline. (Low angle of toe to floor)	Low angle of the hairline (High angle of toe to floor)
Bone quality	Degree of flatness of bone in thigh and flank regions	Coarse and round boned	Extremely flat and refined with tendons well defined
Rear legs, side view	Angle of hock	High angle, straight leg	Low angle, curved leg
Feet and legs	Combination of all traits and mobility (when observable)	Low scores for all individual traits	High scores for all traits with no visible defects

Figure 1.3 Holstein Linear Type Appraisal Scoring System Feet and Leg Traits (Holstein Association USA Inc., 2016)

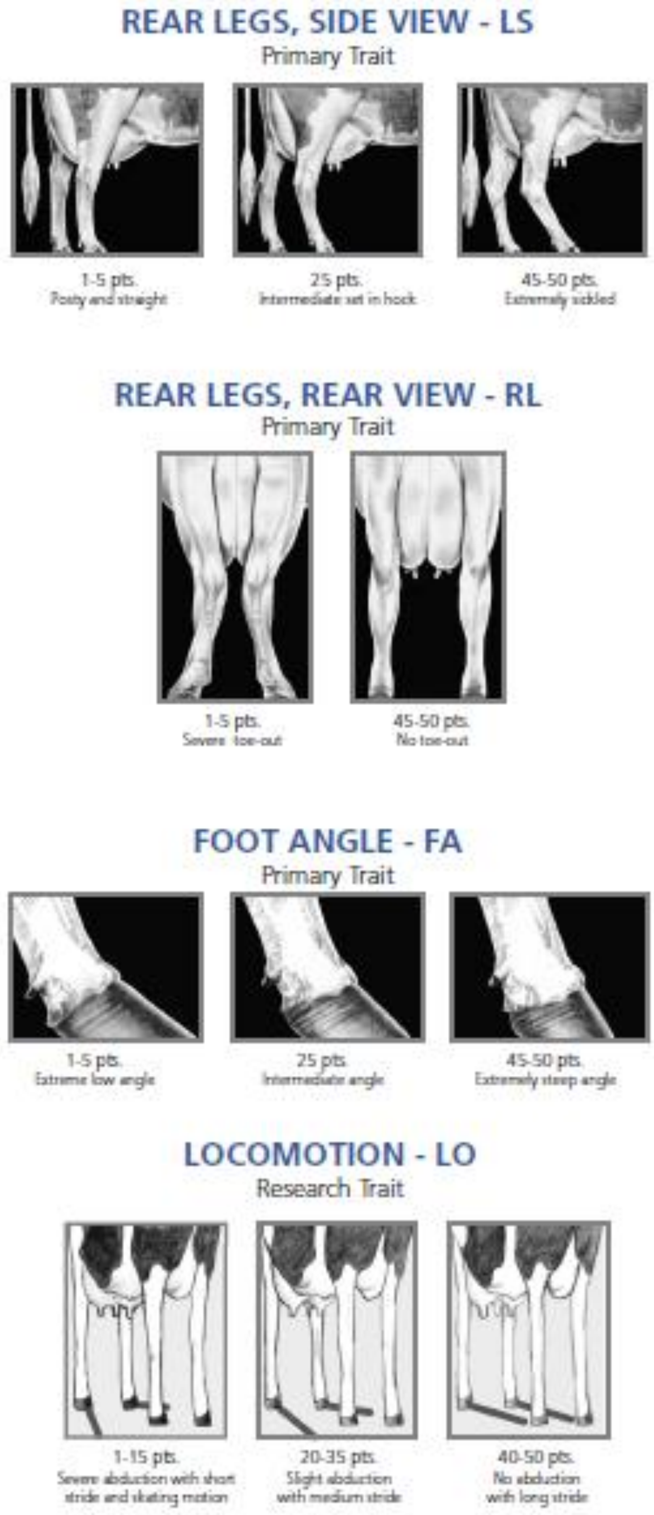

Figure 1.4 Description of Beef Structural Traits and Scoring Range - BeefClass Assessment (Duff, Structural Scoring, Tropical Beef Tech. Services)

Trait	Scoring Range	Description
Front Feet Claw Set	1 - 9	1 - open divergent; 5 - good; 9 - extreme scissor claw
Rear Feet Claw Set	1 - 9	1 - open divergent; 5 - good; 9 - extreme scissor claw
Front Feet Angle	1 - 9	1 - steep (stubbed toe); 5 - good; 9 - shallow heel
Rear Feet Angle	1 - 9	1 - steep (stubbed toe); 5 - good; 9 - shallow heel
Rear Legs Side View	1 - 9	1 - straight (post legged); 5 - good; 9 - sickle hocked
Rear Legs Rear View	1 - 9	1 - bow legged; 5 - good; 9 - cow hocked

Figure 1.5 Foot Scoring Method used by the Australian Angus Association (Jeyaruban et al., 2011)

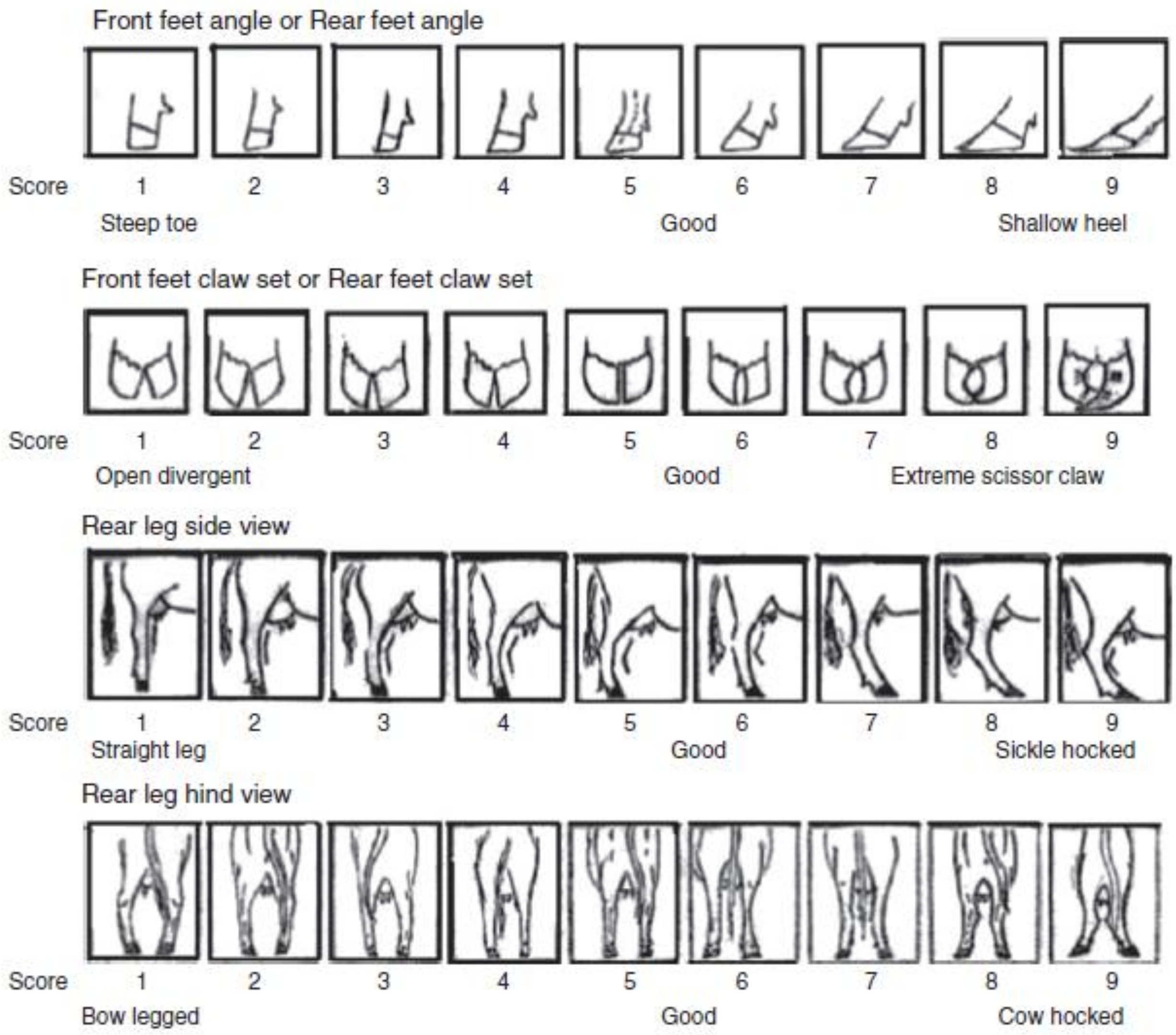

Figure 1.6 Description of Traits used by the American Angus Association (American Angus Association, 2017)

Foot Score Guidelines		
Foot Angle		**Claw Set**
Extremely straight pasturns. Very short toe. Unsound	**- 1 -**	Extremely weak, open, divergent claw set. Unsound
Straight front and rear pasterns. Marginally unsound	**- 2 -**	Open divergent claw set. Marginally unsound
Moderately straight front and rear pasterns	**- 3 -**	Moderately open/divergent claw set
Slightly straight front and rear pasterns	**- 4 -**	Slightly open/divergent claw set
Ideal. Approx. 45-degree angle at pastern joint. Appropriate length of toe and depth of heel	**- 5 -**	Ideal. Symmetric claws, with appropriate space between claws
Slightly shallow heel and long toe	**- 6 -**	Slight tendency for claws to curl. One claw may be slightly larger than the other
Moderately shallow heel and long toe. Somewhat weak pasterns	**- 7 -**	Tendency for claws to curl, with one claw larger than the other
Shallow heel and long toe. Marginally unsound	**- 8 -**	Moderate scissor claw and/or screw claw. Curling of one or both claws. Near crossing of claws. Marginally unsound
Extremely shallow heel and long toe. Extremely weak pasterns. Unsound	**- 9 -**	Extreme scissor claw and/or screw claw. Curling of one or both claws. Crossing of claws. Unsound

Figure 1.7 Foot Scoring Method used by the American Angus Association (American Angus Association, 2017)

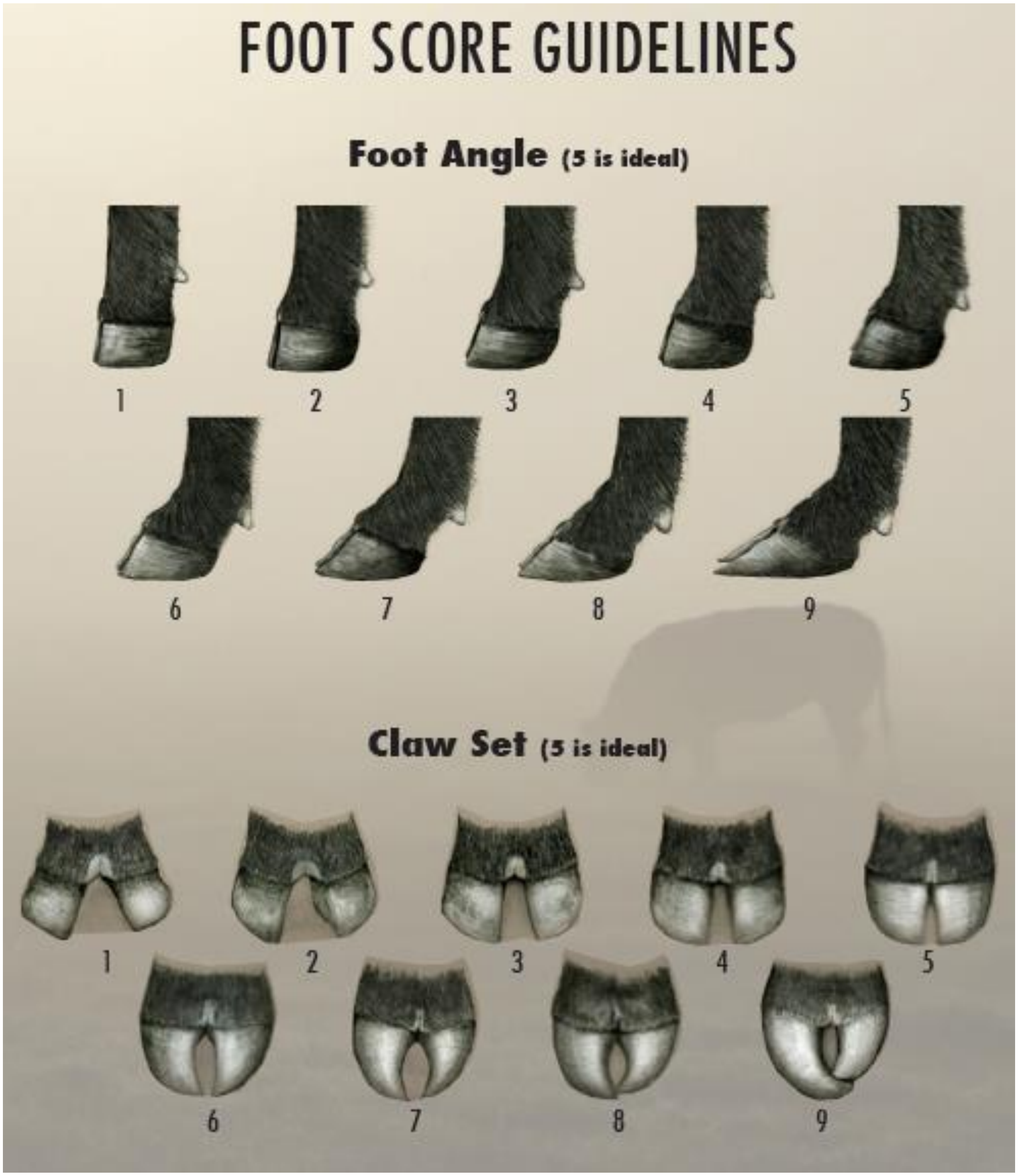

Table 1.1 Heritability Estimates for Feet and Leg Structural Traits

Trait	Breed	Model [a]	Reference	Heritability
Front Foot Angle	Holstein	LAM	Hahn et al. 1984	0.39
	Angus	LAM	Jeyaruban et al. 2012	0.17-0.32
	Angus	TAM	Jeyaruban et al. 2012	0.41 – 0.50
Rear Foot Angle	Holstein	LSM	Hahn et al. 1984	0.70
	Angus	LAM	Jeyaruban et al. 2012	0.18-0.29
	Angus	TAM	Jeyaruban et al. 2012	0.26-0.35
Foot Angle	Holstein	LSM	Short et al. 1991	0.11
	Holstein	LSM	Short and Lawlor. 1992	0.07 – 0.14
	Holstein	LAM	Fatehi et al. 2003	0.11 – 0.12
	Holstein	LSM	Tsuruta et al. 2005	0.12
	Crossbred Holstein	LSM	Van Der Waaij et al. 2005	0.18
	Brown Swiss	LAM	Wiggans et al. 2006	0.13
	Guernsey	LAM	Wiggans et al. 2006	0.10
	Brown Swiss	LAM	Wright et al. 2013	0.09
Front Heel Depth	Holstein	LSM	Hahn et al. 1984	0.58
Rear Heel Depth	Holstein	LSM	Hahn et al. 1984	0.19
Heel Depth	Holstein	LSM	Thompson et al. 1983	0.15
	Holstein	LAM	Fatehi et al. 2003	0.06 – 0.07
Claw Uniformity	Holstein	LAM	Fatehi et al. 2003	0.04
Front Claw Shape	Angus	LAM	Jeyaruban et al. 2012	0.22 – 0.33
	Angus	TAM	Jeyaruban et al. 2012	0.36 – 0.46
Rear Claw Shape	Angus	LAM	Jeyaruban et al. 2012	0.16 – 0.29
	Angus	TAM	Jeyaruban et al. 2012	0.40 – 0.44
Bone Quality	Holstein	LAM	Fatehi et al. 2003	0.24-0.29
Rear Legs Side View	Holstein	LSM	Thompson et al. 1983	0.15
	Holstein	LSM	Short et al. 1991	0.17
	Holstein	LSM	Short and Lawlor. 1992	0.09 – 0.15
	Holstein	LAM	Fatehi et al. 2003	0.17 -0.19
	Crossbred Holstein	LSM	Van Der Waaij et al. 2005	0.22
	Holstein	LSM	Tsuruta et al. 2005	0.19
	Brown Swiss	LAM	Wiggans et al. 2006	0.18
	Guernsey	LAM	Wiggans et al. 2006	0.16
	Angus	LAM	Jeyaruban et al. 2012	0.10 – 0.21
	Angus	TAM	Jeyaruban et al. 2012	0.16 -0.22
	Brown Swiss	LAM	Wright et al. 2013	0.14
Rear Legs Rear View	Holstein	LSM	Thompson et al. 1983	0.12
	Holstein	LSM	Short et al. 1991	0.09
	Holstein	LAM	Fatehi et al. 2003	0.07 – 0.09
	Crossbred Holstein	LSM	Van Der Waaij et al. 2005	0.11
	Holstein	LSM	Tsuruta et al. 2005	0.12
	Brown Swiss	LAM	Wiggans et al. 2006	0.10
	Guernsey	LAM	Wiggans et al. 2006	0.08
	Angus	LAM	Jeyaruban et al. 2012	0.16 – 0.17
	Angus	TAM	Jeyaruban et al. 2012	0.12 – 0.32
	Brown Swiss	LAM	Wright et al. 2013	0.06
Feet and Legs	Holstein	LAM	Fatehi et al. 2003	0.13 – 0.17
	Crossbred Holstein	LSM	Van Der Waaij et al. 2005	0.24

[a] Model Terms: Linear Animal Model (LAM), Linear Sire Model (LSM), Threshold Animal Model (TAM)

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Chapter 2 – Genetic Parameter Estimates for Feet and Leg Traits Observed on a 1-9 Scale in Red Angus Cattle

Introduction

Genetic evaluations for beef cattle have greatly maximized production and output from animals realized through improved selection of productive traits such as birth weight, yearling weight, milk and carcass weight. Lacking however has been an emphasis of selection towards economically relevant traits more difficult to measure such as feet and leg structure. Feet and leg structure contributes to the overall soundness of an animal, and with poor feet and leg structure, animals may face the risk of being culled. Recent industry constraints including the volatility of markets, animal welfare concerns and rising input costs have pressured the need for a feet and leg selection tool in the beef industry.

Keeping cattle in the herd longer maximizes the efficiency of an operation, thus allowing for increased economic gain. Selecting for soundness may improve longevity of an animal thereby reducing culling and costs associated with developing replacements. In order for a ranch to remain economically viable, cattle producers must keep replacement heifers in the herd until they have produced enough calves to cover the cost of developing that female (Doyle et al., 2000).

The dairy industry found early that the structural integrity of cows played a key role in the profitability of the cowherd. Forabosco et al. (2009) found that "straight-leggedness" significantly decreases the mobility and comfort of an animal while contributing to a 59% greater probability of being replaced compared with cows with a moderate angle to the hock. Dekkers et al. (1994) found that the relationship of linear type traits and Functional Herd Life (FHL) tended to be strongest with traits such as feet and legs. Enting et al. (1997) concluded that clinical lameness is one of the most costly diseases in dairy cattle and led to decreased expression of estrus, increased open days, longer calving intervals, and increased culling. A global feet and leg evaluation has been implemented for Holstein cattle, and in a recent survey has been deemed one of the top five most important traits of selection used by producers (HAA).

The beef industry has fewer selection tools for feet and leg structure. Recently, the Australian Angus Association has implemented a feet and leg evaluation, which offers Angus cattle producers the ability to make selection decisions for improved soundness. Jeyaruban et al. (2012) was one of the first to explore the development of a genetic evaluation system for feet and leg traits in beef cattle. Within the United States beef industry multiple breed organizations are conducting exploratory research necessary to implement a feet and leg evaluation system into beef production. With different scoring methods and scaling techniques found in the literature, it is unclear what the appropriate scale of measurement is for feet and leg traits. The objective of this study was to estimate the genetic parameters and understand correlations for feet and leg traits in a diverse population of Red Angus cattle. A comparison of estimates between two measures of scale will serve to determine how to best observe feet and leg trait phenotypes.

Materials and Methods

Data were obtained on 1885 Red Angus cattle from August 2015 through April 2017 for the subjective measures of Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS). A description of traits can be found in Table 2.1. Scores were obtained by trained livestock evaluators as subjective measurements and each animal was scored separately by at least two trained observers. Multiple scores obtained on the same animal were averaged to reduce scorer bias. Measurements were collected with a Samsung Galaxy Tab4™ using the offline data collection app and survey developed by Qualtrics™. Phenotypes were scored for FA, FHD, FC, RA, RHD, RC, FSV, HO, KO, RS, and RH on a scale of 1 to 100 where 50 was assumed optimal, BCS on a scale of 1 to 9 (BIF Guidelines), and CS on a scale of 1 to 50 where 1 was assumed unsound, and 50 was assumed ideal. A visual rubric was placed immediately above the scale to properly identify specific phenotypes. See Figures 2.1 to 2.11 for a description of the scoring system. To further analyze granularity of scale, the 1 – 100 scale was simplified to a 1 – 9 scale for traits; FA, FHD, FC, RA, RHD, RC, FSV, HO, KO, RS, and RH, and CS was simplified to 1 - 4. Scores were binned by 10's (i.e. scores 50 - 59 binned into a 5) and observations from 0 to 9 were discarded as no phenotypes were collected in that range and the visual rubric did have a specific phenotype for scores beneath 10.

Red Angus Association of America (RAAA) provided a three-generation pedigree for all animals scored. The file included 13,306 animals (3157 sires, 1282 sire of sires, 2249 dam of sires, 8754 dams, 2467 sire of dams, and 5913 dam of dams). Contemporary groups (n=48) were defined by herd by year and sex. Records were removed if there was no corresponding registration number and if scored by less than 2 evaluators. The final dataset consisted of 1720 Red Angus animals.

A bivariate animal model was used on the 1-9 scale data to calculate genetic parameter estimates between pairs of traits where additive genetic and residual effects were considered random and fixed effects included contemporary group and age in months as a covariate. The bivariate model was:

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} X_1 & \beta_1 \\ X_2 & \beta_2 \end{bmatrix} + \begin{bmatrix} Z_1 & u_1 \\ Z_2 & u_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$$

Where $\boldsymbol{Y_i}$ was a vector of observations for trait 1 and trait 2 including all traits scored, $\boldsymbol{X_i}$ was an incidence matrix relating observations to the levels of fixed effects, $\boldsymbol{\beta_i}$ was a vector of fixed effects for contemporary group and age in months, $\boldsymbol{Z_i}$ was an incidence matrix relating observations to additive genetic effects and permanent environmental effects, $\boldsymbol{u_i}$ was a vector of random additive genetic effects, and $\boldsymbol{e_i}$ was a vector of random residuals. Feet and leg traits were evaluated in 91 paired bivariate analyses as a multiple trait animal model was too large for the dataset. Heritability was calculated from the average of the 13 additive genetic variances and 13 phenotypic variances resulting from each individual bivariate analysis. The structure for residual (co)variances was:

$$\begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} I\sigma_{e1}^2 & I\sigma_{e1,e2} \\ I\sigma_{e2,e1}^2 & I\sigma_{e2}^2 \end{bmatrix}$$

where **I** represented an identity matrix with dimensions equal to the number of records for each specific trait. Error covariance between trait 1 and trait 2 were calculated as every animal was scored for every trait. The structure for genetic (co)variances was:

$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} A\sigma_{u1}^2 & A\sigma_{u1,u2} \\ A\sigma_{u2,u1} & A\sigma_{u2}^2 \end{bmatrix}$$

where **A** represents a relationship matrix generated from pedigree relationships. Variances were estimated using ASREML (V4.0, VSN International, LTD., Hemel Hempstead, UK).

Results and Discussion

Descriptive statistics are provided in Table 2.2. The data contained 1,217 females and 503 males. The distributions of age can be found in Figure 2.12. All males scored were all under two years of age as most production systems would not possess large contemporary groups of mature bulls. Most females scored were heifers and young cows, with the number of scores decreasing for animals with increasing age.

Average residual and additive variances for traits measured on the 1 to 9 scale are presented in Tables 2.3 and 2.4. Estimates are similar to Jensen (2017) which analyzed the same dataset using the original scale (1-100). A comparison between the simplified scale and the original scale (Jensen 2017) for residual variance and additive variance estimates can be found in Tables 2.5, and 2.6 respectively.

Heritability Estimates

An average and range of heritability estimates for data on the 1-9 scale can be found in Table 2.7. Heritability estimates were similar to literature estimates and were also similar to the values obtained by Jensen (2017) using the original 1-100 scale. A comparison between the simplified scale and the original scale for heritability estimates can be found in Table 2.7. Heritabilities from the simplified scale were consistently lower than the original scale to a small degree. During the simplification the variation among scores for a trait decreased resulting in marginally lower heritability estimates from the 1-9 scale.

Foot angle and FHD were moderately heritable at 0.18 and 0.11. Hahn et al (1984), obtained higher estimates for Front Angle (0.38-0.40) and Front Heel Depth (0.58) on Holstein cows. Jeyaruban et al. (2012) also obtained higher estimates for FA (0.17-0.32) using a similar model on Australian Angus cows.

The heritability of FC (0.08) was lower than most values previously found in literature. Although there was measurable phenotypic variance for FC, there was little additive variance for the trait. With increased weight on the front half of the animal versus the rear half, there is potentially an interaction with weight and FC causing the weight distribution per claw to shift as weight increases. Estimates obtained by Jeyaruban et al. (2012) were significantly higher for FC using an Animal Model (0.22-0.33), and using a Threshold Model (0.36-0.46).

Heritabilities for RA and RHD were estimated to be 0.17, and 0.24 respectively. The estimate for RA was higher than values found in dairy cattle literature (Short et al. 1991; Short and Lawlor. 1992; Tsuruta et al. 2005; Wiggans et al. 2006; Wright et al. 2013) and was most similar to Dutch crossbred dairy cattle (Van der Waaij et al. 2005). In beef cattle, Jeyaruban et al. (2012) reported higher estimates for RA using a TAM (0.26-0.35) than an AM (0.18-0.29). The estimate for RHD was higher than that found in literature (0.19; Hahn et al. 1984) Hahn et al. (1984) found heritability of RHD to be lower than the value they obtained for FHD (0.19 vs. 0.58). The present study found conflicting estimates, where the RHD heritability was estimated higher than FHD (0.24 vs. 0.12).

The heritability estimate for RC is 0.15, which is similar to values reported by Jeyaruban et al. (2012) using similar modelling (0.16-0.29). The estimate for RC in this study was higher than the value obtained for FC (0.08). The difference in heritability estimates for claw structure on either end of the animal is likely impacted by the increased weight on the front half of the animal, thus increasing the residual variance for FC.

Foot Size is a novel trait not previously found in the literature, however a similar trait, Bone Quality, was observed by Fatehi et al. (2003). They reported heritability estimates for Bone Quality of 0.29 and 0.24 for Canadian Holsteins in different housing types. Using a 1-9 scale, the present study found the FS heritability estimate to be 0.29.

Heritabilities for FSV, HO, and KO had heritabilities of 0.15, 0.15, and 0.11 respectively. These heritabilities suggest that moderate genetic gain can be made with some selection pressure.

However, with no prior research these traits should be investigated further with a larger number of animals than the present study to determine how these traits impact longevity.

The heritability for RSV was 0.29 which was higher than previously reported values in the literature. Jeyaruban et al. (2012) reported heritability estimates for RSV of 0.10-0.21 using an Animal Model, and 0.16-0.22 using a Threshold Model. Estimates found in dairy literature were moderately low (Thompson et al. 1983; Short et al. 1991; Short and Lawlor.1992; Van der Waaij. 2005; Tsuruta et al. 2005; Wiggans et al. 2006; Wright et al. 2013). Similar to Jensen (2017), heritability for RSV in this study was one of the highest of the 14 traits measured.

Rear Leg Hind View had a heritability of 0.11 which is similar to estimates found in dairy and beef cattle literature. Heritability estimates for RH of dairy cattle range from 0.06 to 0.12 (Wiggans et al. 2006; Tsuruta et al. 2005). Jeyaruban et al. (2012), reported heritability estimates for RH in Angus cattle of 0.12 to 0.32 using different models.

The heritability estimate for CS was 0.09. A similar trait in dairy cattle which measures the overall feet and legs of an animal has higher heritability estimates. Van der Waaij et al. (2005) reported a heritability estimate for overall Feet and Leg (FL), of 0.24. Other estimates for FL ranged from 0.13-0.17 (Fatehi et al. 2003). This difference of estimates from FL literature estimates and CS could be linked to the interpretation of the scale and with the increased number of traits included in the evaluation, evaluator preference towards specific phenotypes likely played a role in the difference.

There was a slight decrease in heritability point estimates when collapsing the scores into a less granular scale (1-9 vs. 1-100), yet the decrease is not entirely unexpected. The more granular scale offered benefit to identify variation of feet and leg trait characteristics, yet it also introduced a higher degree of error. Likely, the ability of a trained observer to accurately select a specific point on a 1-100 scale for a feet and leg phenotype is more difficult than on a 1-9 scale. The comparison of heritability estimates between both measures of scale serve to differentiate how much information is lost when condensing the scale. These results indicate that granularity of scale had little effect on the nature of the differences when simplifying the original scale (1-100) to the modified scale (1-9).

Genetic and Phenotypic Correlations between Feet and Leg Traits

Genetic and phenotypic correlations for the 14 feet and leg traits on the 1-9 scale can be found in Table 2.9. A comparison of correlations between the present study and estimates obtained by Jensen (2017) can be found in Tables 2.10 to 2.23. Standard errors for the genetic correlations on the 1-9 scale were consistently slightly higher than the standard errors on the 1-100 scale.

Body condition score had little phenotypic correlation with any of the traits, but had a strong negative genetic correlation with HO (r = -0.58) and KO (r = -0.75) and a strong positive genetic correlation with FSV (r = 0.49). This suggests that as selection for animals with more inward hoof orientation and outward knee orientation occurs, there should be a correlated response from an increase in an animals BCS. Body condition score also had a moderately strong genetic correlation with FS (r = 0.40). The relationship with FS suggests that FS increases to more appropriately accommodate the increased weight as a result of an increase in BCS. There was a moderately strong genetic correlation between BCS and FC (r = 0.42) and RC (r = 0.34). There was little change in the point estimates obtained from both measurements of scale. The comparison of scale for the genetic correlation of FHD with BCS was slightly lower on the 1-9 scale (r = 0.06 versus 0.20).

Front hoof angle, FHD, RA, and RHD were all highly genetically correlated (r = 0.83 - 0.97). Front hoof angle and FHD additionally had a strong phenotypic correlation (r = 0.67), with a similar relationship taking place with RA and RHD (r = 0.71). Jeyaruban et al. (2012) found a similarly strong relationship between FA and RA (r = 0.87). The strong genetic correlation between FA, FHD, RA, and RHD indicates similar genes are influencing these traits. The comparison between both measures of scale for the genetic correlation between FA and KO was notably higher (r = -0.40 versus -0.05) and slightly higher for RA and FC (r = 0.38 versus 0.13).

Front claw shape and RC were highly genetically correlated with each other (r = 0.80) but had a lower phenotypic correlation (r = 0.34). Jeyaruban et al. (2012) found a similar genetic relationship between FC and RC (r = 0.69). This suggests that only one of these traits should be considered for further scoring methods. The genetic correlation point estimates for both measures of scale were similar, however the standard error for RC and CS on the 1-9 scale was notably higher than the standard error on the 1-100 scale (SE = 0.40 versus 0.26).

The genetic relationship between FC and FA, FHD, RA, RHD (r = -0.43 to 0.38) was not significant due to the high SE, nor was the genetic relationship between RC and FA, FHD, RA, RHD (r = -0.21 to 0.08 due to high SE). This suggests that the genes controlling hoof angle and heel depth are not the same genes controlling claw shape. However, Jeyaruban et al. (2012) did find a slightly more significant genetic relationship between FA and RA with FC and RC (r = 0.40 - 0.79).

Foot size is lowly correlated with all feet and leg traits with the exception of CS and BCS. The genetic correlation between FS and BCS is r = 0.40 and the correlation between FS and CS is r = 0.40. The moderate correlation with BCS suggests that as an animal has the ability for increased weight and body condition, they are likely supported on a more substantial size of hoof which shows up more positively in the composite score. All estimates between both measurements of scale were consistent for FS.

Front side view is strongly negatively correlated with HO (r = -0.71) and KO (r = -0.57) and strongly correlated with CS (r = 0.69). The strong negative genetic correlations with HO and KO suggest the structural genes controlling a straight shoulder also result in more outward appearing knees and inward hoof orientation, while a more angular shoulder tends to result in knees that are more inward in their appearance with outward facing hooves. The genetic relationship of FSV, HO, and KO suggests that selection pressure in one area will result in change in the others. There is little research indicating what the optimum level is for these three traits, nor the implications of selection pressure on any one of these traits. There was some slight variation in genetic correlation point estimates between the two measures of scale for FSV, notably between FHD and CS.

Hoof orientation had a strong positive genetic correlation with KO (r = 0.95). As an animal becomes more outward in the appearance at the knee, the hoof turns inward, and as an animal becomes more inward at the knee, their hooves turn outward. There was a notable difference between the two measurements of scale for the genetic correlation between HO and RHD (r = -0.49 versus -0.24). The comparison of correlations for both measures of scale for KO suggested similar variation in point estimates for the genetic correlations of KO with FA and CS.

Rear leg side view had moderate positive genetic relationships with FA (r = 0.57), FHD (r = 0.51), RA (r = 0.55), and RHD (r = 0.49). This suggest that animals with more set and angularity to their hock and leg had shallower hooves, and inversely animals with a straighter hock and leg would indicate a deeper and steeper hoof. There was a negative genetic correlation between RSV and RC (r = -0.45), HO (r = -0.64), and KO (r = -0.40). Jeyaruban et al. (2012) reported similar genetic correlations between FA and RA with RSV (r = 0.32 and 0.68), but reported a contrasting genetic correlation with RSV and RC (r = 0.34 vs. -0.45). The genetic relationship of RV with HO and KO suggests that animals with more set to their hock and leg would have more inward facing hooves and bowed-out knees. The comparison between scales showed little variation between RSV and the other feet and leg traits.

Rear leg hind view had a strong positive correlation with RHD (r = 0.69). This suggests that animals exhibiting cow-hocked hind legs tended to appear shallower heeled. There were also positive genetic relationships with FHD (r = 0.55), and RA (r = 0.41), however those traits have already been identified to be highly similar. Jeyaruban et al. (2012) reported similar genetic correlations between FA and RA with RH (r = 0.22 to 0.33). They also reported a higher genetic relationship than the present study between RH and RSV (r = 0.47). There was little variation between measures of scale and correlation point estimates for RH and other traits.

Composite score had low heritability (0.09), yet exhibited strong genetic correlations with a multitude of traits; FA (r = -0.50), FHD (r = -0.42), RA (r = -0.54), RHD (r = -0.56), FS (r = 0.40), FSV (r = 0.69), KO (r = 0.46), RSV (r = -0.42), and RH (r = -0.52). This suggests selecting for CS could result in change in feet and leg traits simultaneously, but at the added cost of increased time to realize genetic progress. There was notable variation between genetic correlation point estimates and standard error between the two measures of scale for CS and traits; FA, RC, FSV, HO, KO and RH. Likely in the simplification of scale for CS some small amount of information was lost.

Conclusion

Granularity of scale was evaluated in the present study with only minor changes to heritability estimates and correlations were found. A less granular scale may be easier to interpret and phenotypically score while still retaining the same level of information. In the present study, visual aids for phenotypes were placed immediately above the scoring method for quick reference which aided in appropriately scoring a specific phenotype. The visual rubric allows for scoring phenotypes with an equal width of scale. A visual rubric should be used when evaluating feet and leg traits in beef cattle.

The parameter estimates are similar to those found in the dairy industry which has successfully integrated feet and leg trait selection into their genetic evaluations. However, the difference lies in the way traits are measured. The dairy industry has trained classifiers travel to dairy operations to score animals for type traits that are later integrated into breed evaluations. The beef industry requests producer submitted data, which may have some issues with consistency and scorer bias. Thus, it may be unreasonable to require beef cattle producers to categorize 14 feet and leg type traits for all animals in a production system. By developing a simpler and less intensive scoring method that accurately predicts improved soundness in Red Angus cattle, it should be manageable for beef producers to collect the data that would allow for a genetic evaluation for feet and leg traits.

Figure 2.1 Body Condition Score Scoring Method

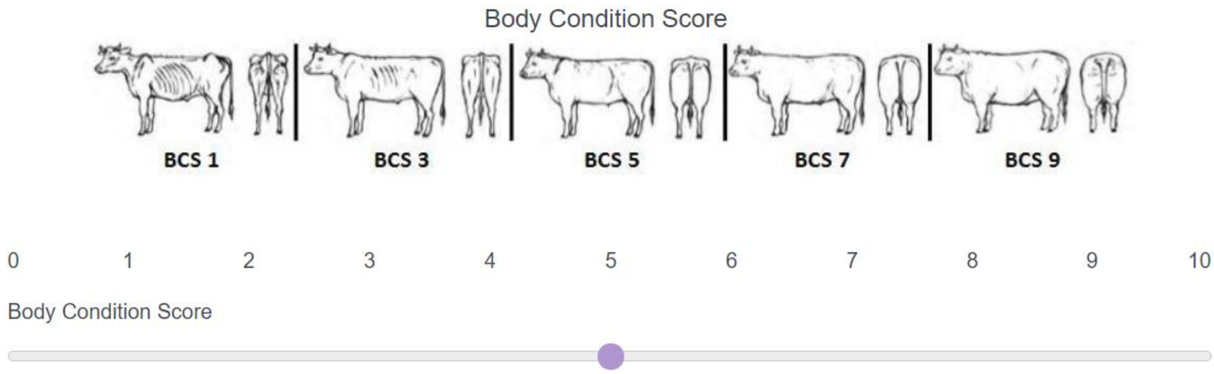

Figure 2.2 Front Hoof Angle and Heel Depth Scoring Method

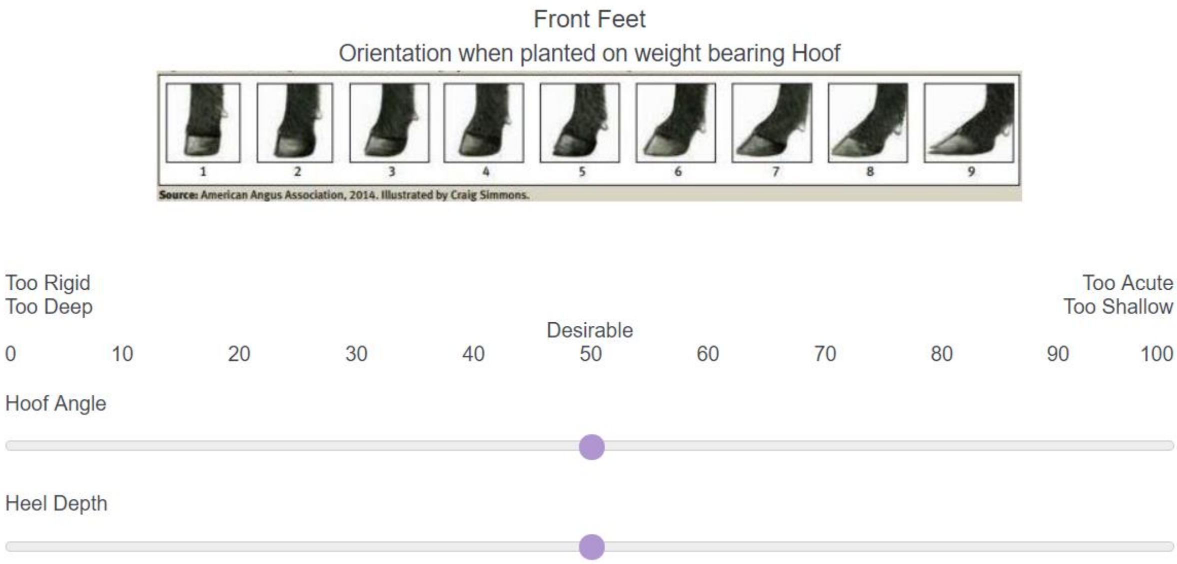

Figure 2.3 Front Claw Shape Scoring Method

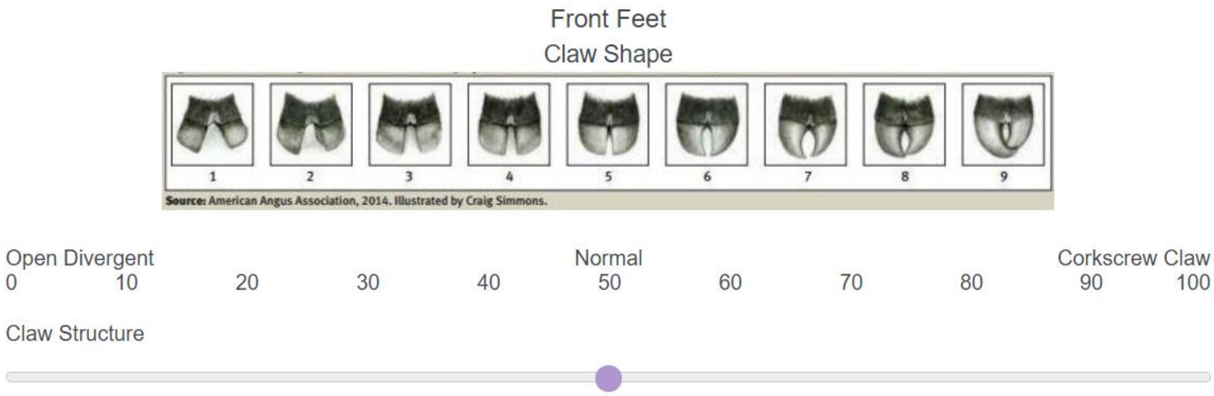

Figure 2.4 Front Hoof Angle and Heel Depth Scoring Method

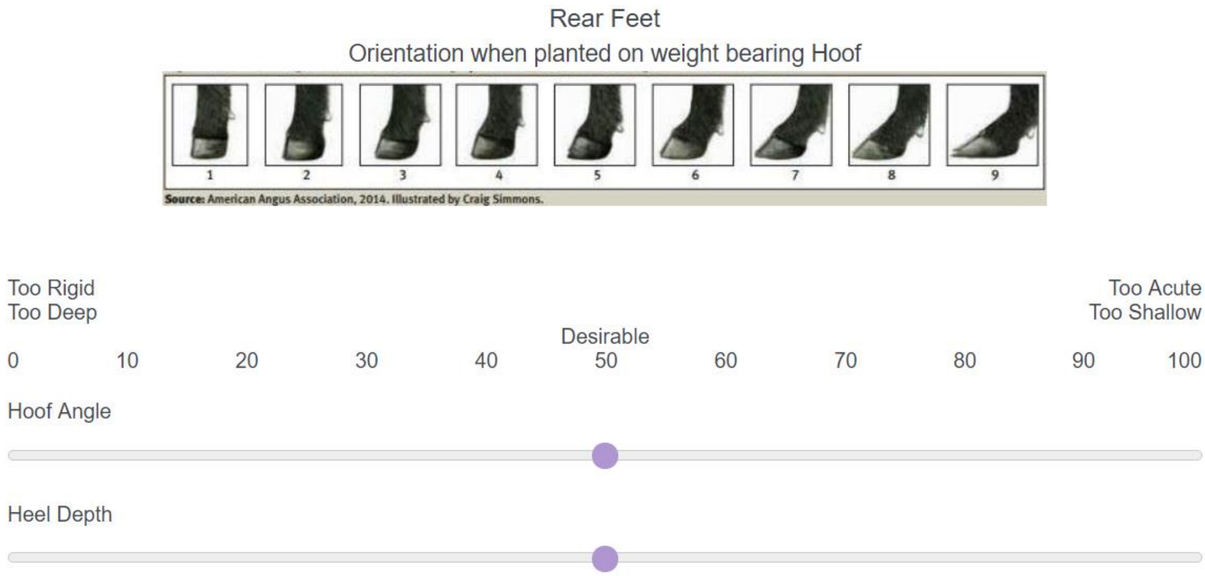

Figure 2.5 Rear Claw Shape Scoring Method

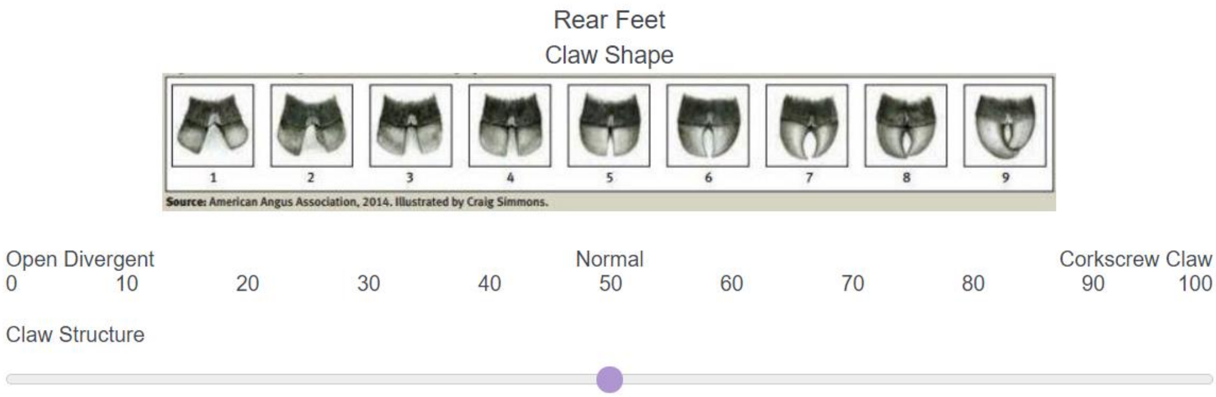

Figure 2.6 Foot Size Scoring Method

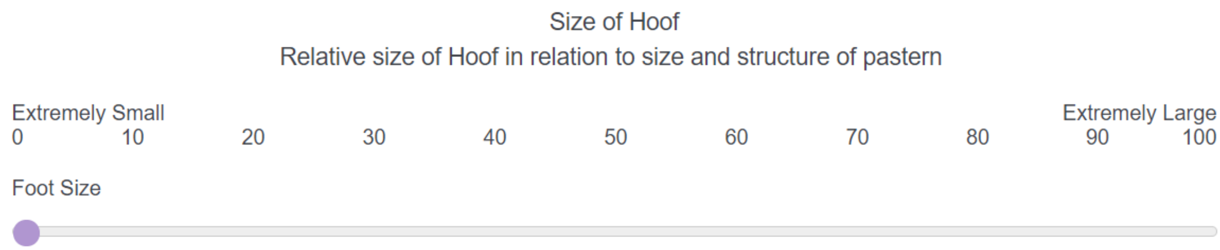

Figure 2.7 Front Side View Scoring Method

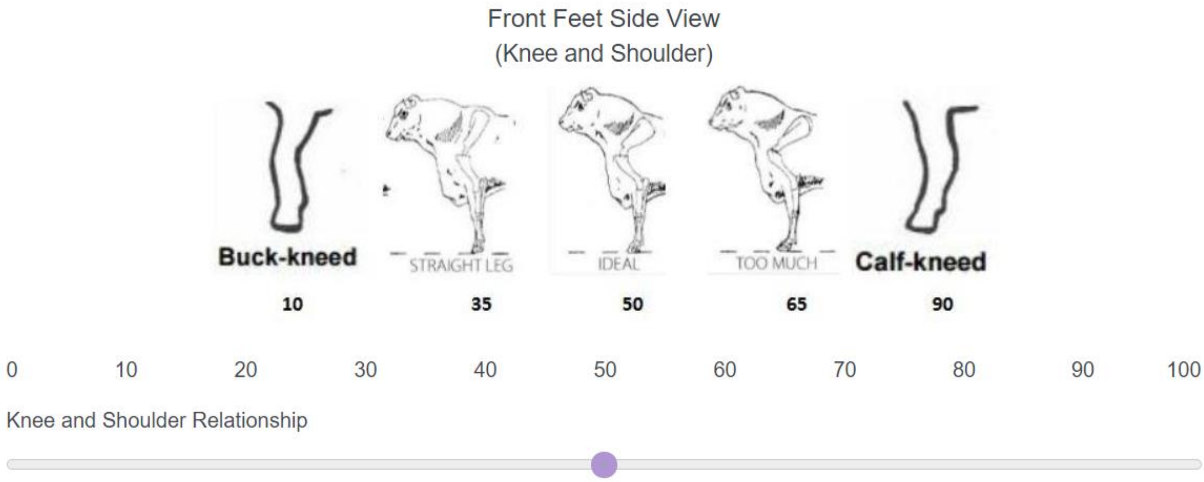

Figure 2.8 Hoof and Knee Orientation Scoring Method

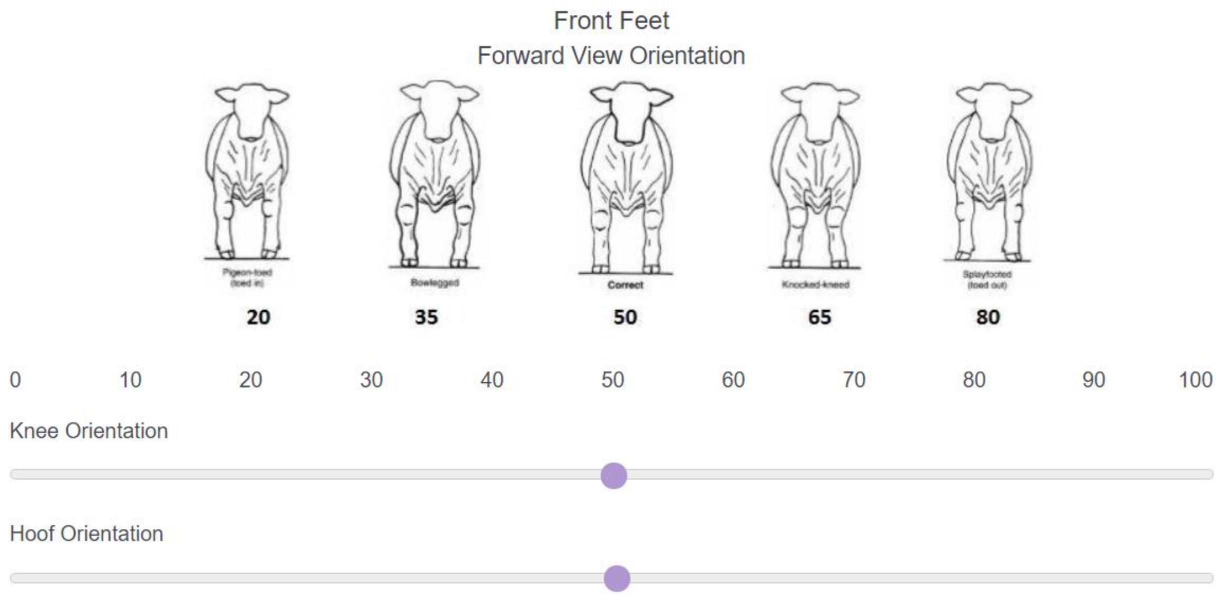

Figure 2.9 Rear Leg Side View Scoring Method

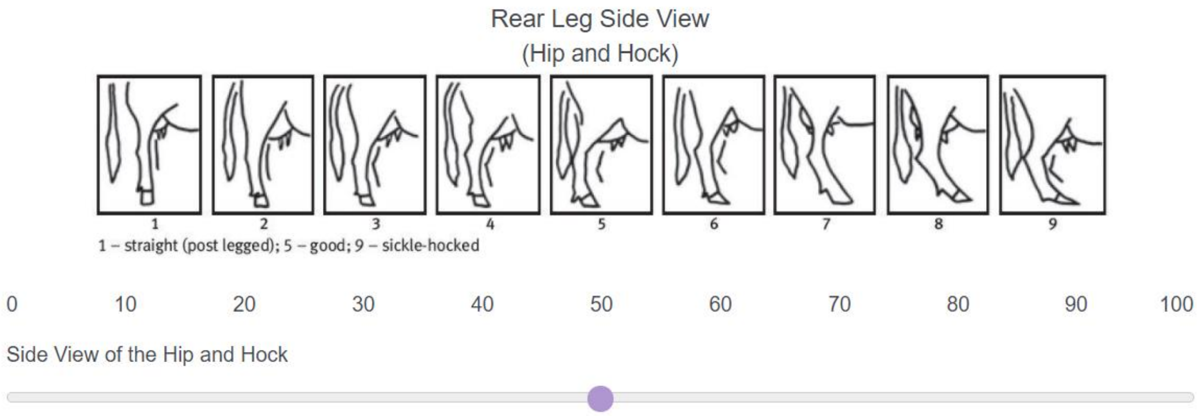

Figure 2.10 Rear Leg Hind View Scoring Method

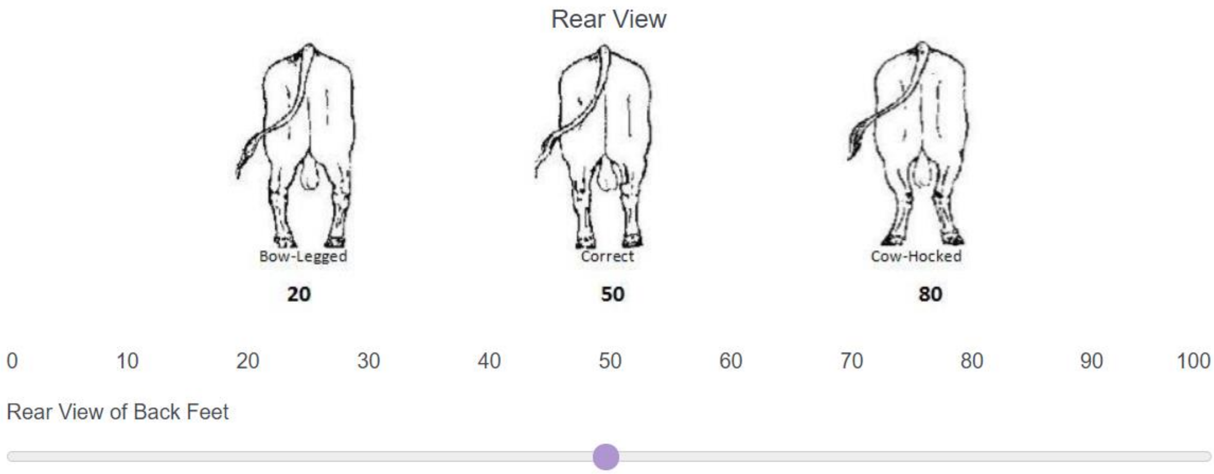

Figure 2.11 Composite Scoring Method

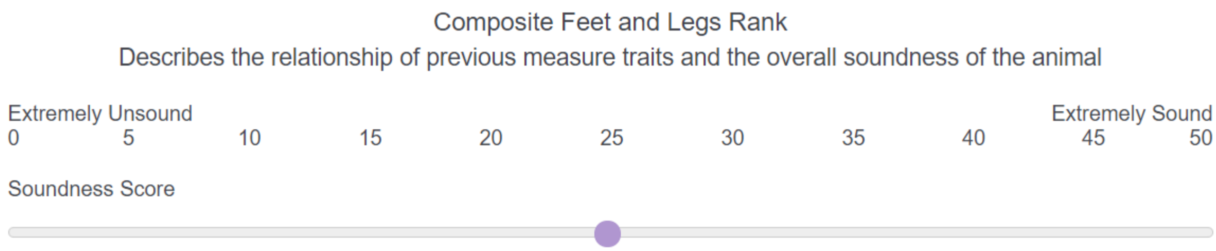

Figure 2.12 Age Distribution of All Animal Scored in Years

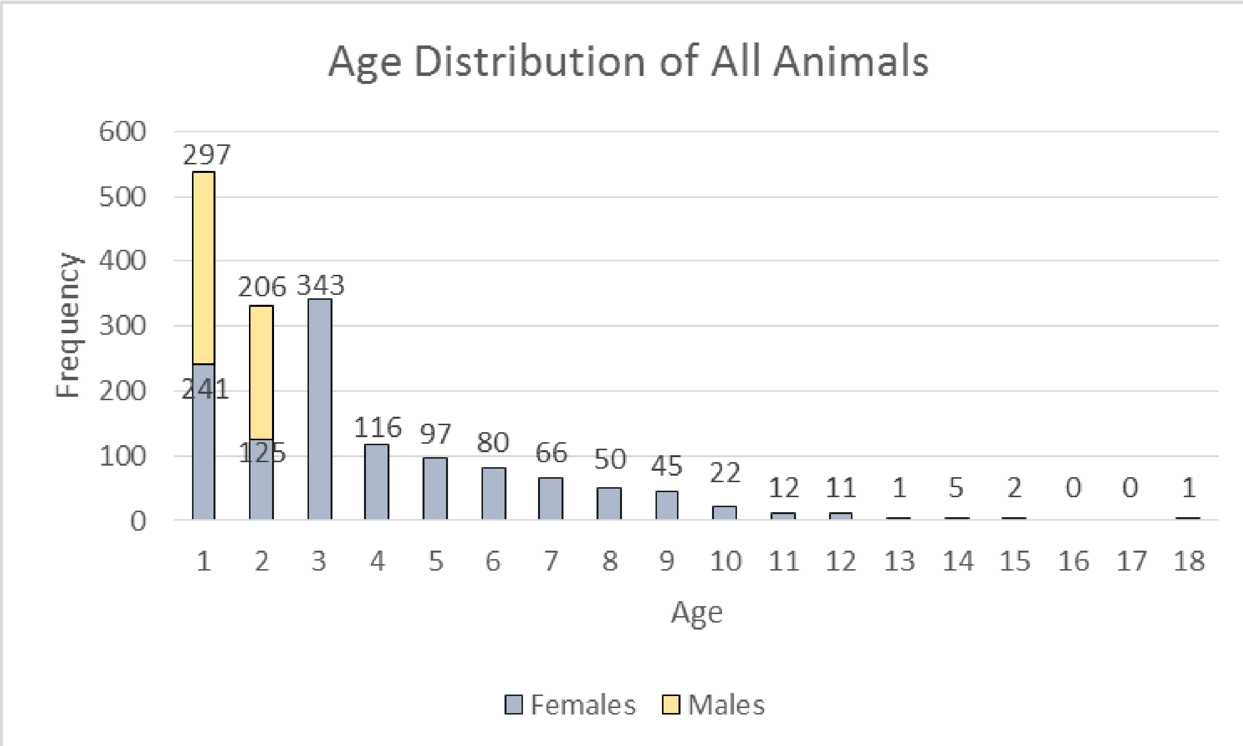

Table 2.1 Description of Feet and Leg Trait Traits

	Description of Feet and Leg trait phenotypes		
Trait	Low Score (1)	Mid Score (5)	High Score (9)
Body Condition Score	Emaciated (extremely thin)	Optimum (moderate fat cover)	Wasty (extremely fat)
Front Hoof Angle	Extremely steep and rigid	Moderate angle to the hoof	Extremely low angle
Front Heel Depth	Too deep and straight	Moderate substance with mobility	Too shallow with little substance
Front Claw Shape	Extremely weak and open divergent	Symmetrical and appropriately spaced	Extreme curling of claws and/or crossing
Rear Hoof Angle	Extremely steep and rigid	Moderate angle to the hoof	Extremely low angle
Rear Heel Depth	Too deep and straight	Moderate substance with mobility	Too shallow with little substance
Rear Claw Shape	Extremely weak and open divergent	Symmetrical and appropriately spaced	Extreme curling of claws and/or crossing
Foot Size	Extremely small foot relative to bone size	Moderate hoof size, similar to bone	Extremely large hoof, obstructive/clunky
Front Side View	Extremely straight shoulder angle, low head carriage	Moderate angle to shoulder, appropriate head carriage	Extremely set back in the angle of the shoulder, difficulty taking a step
Front Hoof Orientation	Extreme pigeon-toe inward	Symmetrical and forward-facing	Extreme outward facing toes
Knee Orientation	Extremely bowlegged	Symmetrical and sturdy	Extremely knock-kneed
Rear Leg Side View	Extremely straight, and rigid hind leg set	Desirable, with flexibility	Extremely sickle-hocked
Rear Leg Hind View	Extremely bowlegged	Symmetrical and sturdy	Extremely cow-hocked
	1		4
Composite Score	Extremely unsound, should be considered for culling		Extremely sound, desirable mobility and foot trait conformation

Table 2.2 Descriptive Statistics for Feet and Leg Scores (1-9 scale and 1-100 scale Data)

	1-9				1-100 [a]			
Trait	Mean	SD	Min	Max	Mean	SD	Min	Max
Body Condition Score	5.30	0.55	3.00	8.00	5.65	0.52	3.70	8.55
Front Hoof Angle	5.23	0.47	3.00	8.00	56.59	4.57	38.00	82.50
Front Heel Depth	5.31	0.46	3.00	7.00	57.21	4.56	37.00	75.00
Front Claw Shape	5.38	0.61	3.50	9.00	57.47	6.43	38.00	93.50
Rear Hoof Angle	5.41	0.55	3.00	7.67	58.40	5.57	37.50	80.00
Rear Hoof Depth	5.56	0.57	3.00	7.67	59.69	5.73	34.50	83.00
Rear Claw Shape	4.98	0.56	2.50	9.00	52.76	5.76	29.50	95.33
Size of Hoof	4.54	0.56	2.00	7.00	49.63	5.35	25.50	74.00
Front Side View	4.19	0.43	2.50	6.00	46.04	3.66	29.00	61.00
Knee Orientation	5.02	0.29	2.67	6.50	53.71	2.97	32.00	70.00
Front Hoof Orientation	5.15	0.49	2.00	7.00	55.78	4.96	23.50	74.50
Rear Leg Side View	5.09	0.55	2.50	7.50	55.17	5.43	30.00	82.00
Rear Leg Rear View	5.26	0.38	3.50	7.50	56.62	3.81	37.00	77.50
Composite Score	2.68	0.43	1.00	4.00	31.37	4.04	15.00	44.00

[a]Jensen (2017)

Table 2.3 Average Residual Variance (σ_e^2), Average Standard Error (SE), Range of Residual Variances (σ_e^2 $Range$), and Range of Standard Error (SE Range) for 1-9 Scale

Trait	σ_e^2	SE	σ_e^2 $Range$	SE Range
Body Condition Score	0.145	0.008	0.144-0.147	0.008-0.008
Front Hoof Angle	0.132	0.009	0.130-0.135	0.008-0.009
Front Heel Depth	0.152	0.008	0.148-0.153	0.008-0.008
Front Claw Shape	0.239	0.012	0.238-0.240	0.012-0.012
Rear Hoof Angle	0.159	0.010	0.145-0.161	0.010-0.11
Rear Heel Depth	0.174	0.013	0.169-0.178	0.013-0.013
Rear Claw Shape	0.226	0.013	0.224-0.228	0.013-0.013
Foot Size	0.169	0.013	0.166-0.170	0.013-0.013
Front Side View	0.146	0.009	0.145-0.147	0.008-0.009
Hoof Orientation	0.185	0.011	0.180-0.189	0.011-0.011
Knee Orientation	0.071	0.004	0.070-0.071	0.004-0.004
Rear Leg Side View	0.190	0.015	0.185-0.192	0.015-0.015
Rear Leg Rear View	0.114	0.006	0.113-0.114	0.006-0.006
Composite Score	0.119	0.006	0.118-0.120	0.006-0.006

Table 2.4 Average Additive Variance (σ_a^2), Average Standard Error (SE), Range of Additive Variances (σ_a^2 $Range$), and Range of Standard Error (SE Range) for 1-9 Scale

Trait	σ_a^2	SE	σ_a^2 *Range*	SE Range
Body Condition Score	0.022	0.008	0.020-0.023	0.008-0.009
Front Hoof Angle	0.029	0.009	0.027-0.032	0.009-0.010
Front Heel Depth	0.021	0.008	0.019-0.026	0.008-0.008
Front Claw Shape	0.021	0.011	0.020-0.023	0.010-0.011
Rear Hoof Angle	0.032	0.011	0.030-0.035	0.010-0.011
Rear Heel Depth	0.055	0.016	0.050-0.061	0.015-0.016
Rear Claw Shape	0.038	0.013	0.032-0.042	0.011-0.014
Foot Size	0.069	0.016	0.061-0.071	0.016-0.016
Front Side View	0.026	0.009	0.025-0.027	0.008-0.009
Hoof Orientation	0.032	0.011	0.027-0.039	0.011-0.012
Knee Orientation	0.009	0.004	0.008-0.010	0.004-0.004
Rear Leg Side View	0.076	0.018	0.073-0.082	0.018-0.019
Rear Leg Rear View	0.014	0.006	0.013-0.014	0.006-0.006
Composite Score	0.011	0.006	0.010-0.013	0.006-0.006

Table 2.5 Comparison of Average Residual Variance Estimates for Modified Scale (1-9) versus Non-Modified Scale (1-100)

	1-9 Scale		1-100 Scale [a]	
Trait	σ_e^2	SE	σ_e^2	SE
Front Hoof Angle	0.132	0.009	11.36	0.77
Front Heel Depth	0.152	0.008	12.84	0.80
Front Claw Shape	0.239	0.012	23.84	1.20
Rear Hoof Angle	0.159	0.010	13.29	0.87
Rear Heel Depth	0.174	0.013	15.49	1.18
Rear Claw Shape	0.226	0.013	21.25	1.29
Foot Size	0.169	0.013	12.94	1.14
Front Side View	0.146	0.009	6.91	0.59
Hoof Orientation	0.185	0.011	6.91	0.44
Knee Orientation	0.071	0.004	18.25	1.16
Rear Leg Side View	0.190	0.015	17.80	1.47
Rear Leg Rear View	0.114	0.006	10.35	0.60
Composite Score	0.119	0.006	9.26	0.53

[a]Jensen (2017)

Table 2.6 Comparison of Average Additive Variance Estimates for Modified Scale (1-9) versus Non-Modified Scale (1-100)

	1-9 Scale		1-100 Scale [a]	
Trait	σ_a^2	SE	σ_a^2	SE
Front Hoof Angle	0.029	0.009	2.77	0.86
Front Heel Depth	0.021	0.008	2.65	0.85
Front Claw Shape	0.021	0.011	2.26	1.06
Rear Hoof Angle	0.032	0.011	3.02	0.95
Rear Heel Depth	0.055	0.016	5.20	1.39
Rear Claw Shape	0.038	0.013	4.21	1.35
Foot Size	0.069	0.016	7.24	1.46
Front Side View	0.026	0.009	1.88	0.60
Hoof Orientation	0.032	0.011	1.43	0.48
Knee Orientation	0.009	0.004	3.68	1.24
Rear Leg Side View	0.076	0.018	7.71	2.01
Rear Leg Rear View	0.014	0.006	1.74	0.61
Composite Score	0.011	0.006	1.27	0.52

[a]Jensen (2017)

Table 2.7 Average Heritability (h^2), Average Standard Error (SE), Range of Heritability Estimates (h^2 $Range$), and Range of Standard Error (SE Range) for 1-9 Scale

Trait	h^2	SE	h^2 *Range*	SE Range
Body Condition Score	0.13	0.05	0.12-0.14	0.05-0.05
Front Hoof Angle	0.18	0.06	0.16-0.20	0.05-0.06
Front Heel Depth	0.12	0.04	0.11-0.15	0.04-0.05
Front Claw Shape	0.08	0.04	0.08-0.09	0.04-0.04
Rear Hoof Angle	0.17	0.05	0.16-0.18	0.05-0.05
Rear Heel Depth	0.24	0.06	0.22-0.27	0.06-0.06
Rear Claw Shape	0.15	0.05	0.14-0.16	0.05-0.05
Foot Size	0.29	0.06	0.29-0.30	0.06-0.06
Front Side View	0.15	0.05	0.14-0.16	0.05-0.05
Hoof Orientation	0.15	0.05	0.13-0.18	0.05-0.05
Knee Orientation	0.11	0.05	0.10-0.12	0.05-0.05
Rear Leg Side View	0.29	0.06	0.28-0.31	0.06-0.06
Rear Leg Rear View	0.11	0.04	0.10-0.11	0.04-0.04
Composite Score	0.09	0.04	0.08-0.10	0.04-0.04

Table 2.8 Comparison of Average Heritability Estimates for Modified Scale (1-9) versus Non-Modified Scale (1-100)

	1-9 Scale		1-100 Scale [a]	
Trait	h^2	SE	h^2	SE
Front Hoof Angle	0.18	0.06	0.20	0.06
Front Heel Depth	0.12	0.04	0.17	0.05
Front Claw Shape	0.08	0.04	0.09	0.04
Rear Hoof Angle	0.17	0.05	0.19	0.06
Rear Heel Depth	0.24	0.06	0.25	0.06
Rear Claw Shape	0.15	0.05	0.17	0.05
Foot Size	0.29	0.06	0.36	0.06
Front Side View	0.15	0.05	0.16	0.05
Hoof Orientation	0.15	0.05	0.17	0.05
Knee Orientation	0.11	0.05	0.17	0.05
Rear Leg Side View	0.29	0.06	0.30	0.06
Rear Leg Rear View	0.11	0.04	0.14	0.05
Composite Score	0.09	0.04	0.12	0.05

[a]Jensen (2017)

Table 2.9 Genetic Correlations and SE (above diagonal) and Phenotypic Correlations and SE (below diagonal)

Trait	BCS	FA	FHD	FC	RA	RHD	RC	FS	FSV	HO	KO	RSV	RH	CS
BCS		0.2847	0.0568	0.4173	-0.0342	0.074	0.3419	0.4022	0.487	-0.5814	-0.7536	-0.1994	-0.3827	0.0872
		0.2529	0.2775	0.2837	0.2566	0.2355	0.2447	0.1888	0.2237	0.2546	0.2354	0.2165	0.2555	0.3118
FA	-0.0391		0.9696	-0.2502	0.8705	0.8288	-0.0654	0.1003	0.3179	-0.3936	-0.3978	0.5725	0.2112	-0.5005
	0.0257		0.0636	0.2819	0.1004	0.1094	0.2424	0.1952	0.2192	0.2334	0.2635	0.1612	0.2628	0.2625
FHD	-0.0284	0.6729		-0.4297	0.7378	0.8229	-0.2109	-0.1557	0.2802	-0.1905	0.0296	0.506	0.5539	-0.4188
	0.0253	0.0138		0.2976	0.145	0.1059	0.2666	0.2174	0.2355	0.2648	0.2978	0.1849	0.2717	0.305
FC	0.0184	0.0865	0.0802		0.381	0.1386	0.802	0.1301	0.0853	0.1272	0.1468	-0.0167	-0.0025	-0.1865
	0.0252	0.0253	0.025		0.2845	0.2715	0.1815	0.2553	0.2937	0.3013	0.3331	0.2599	0.3208	0.3454
RA	-0.0121	0.4225	0.3841	0.121		0.8332	-0.0916	-0.0497	0.1993	-0.3383	0.0564	0.5493	0.4153	-0.5383
	0.0256	0.0212	0.0217	0.0249		0.0814	0.2472	0.1999	0.2329	0.2246	0.2809	0.1746	0.2535	0.2537
RHD	-0.0058	0.3967	0.4549	0.123	0.7126		0.0817	-0.2901	0.2284	-0.4917	-0.079	0.4915	0.6931	-0.5587
	0.0261	0.022	0.0204	0.0253	0.0128		0.228	0.1636	0.2129	0.1965	0.2564	0.166	0.2029	0.2256
RC	0.0319	0.0408	0.0438	0.3429	0.1345	0.1558		-0.0893	0.1401	0.3989	0.4512	-0.4546	-0.0551	-0.1086
	0.0255	0.0257	0.0253	0.0221	0.0253	0.0255		0.2082	0.2451	0.2177	0.2352	0.1856	0.2708	0.2993
FS	0.2209	0.0116	-0.0485	0.0547	0.0334	-0.026	0.0208		0.1702	0.055	0.149	-0.0017	-0.2036	0.3953
	0.0248	0.0266	0.0259	0.0256	0.0264	0.0273	0.0262		0.1994	0.206	0.2304	0.1695	0.2169	0.2299
FSV	0.1297	0.063	0.0397	-0.039	0.0295	0.049	-0.0025	0.1687		-0.709	-0.5686	0.1077	-0.1156	0.6901
	0.025	0.0257	0.0254	0.0251	0.0257	0.0262	0.0255	0.0255		0.2084	0.2481	0.2068	0.2604	0.2353
HO	-0.1399	-0.0239	-0.0081	0.0983	0.0087	-0.0135	0.0406	-0.0987	-0.2147		0.9503	-0.6437	0.0138	0.1367
	0.0248	0.0257	0.0253	0.0249	0.0259	0.0264	0.0257	0.0262	0.0242		0.0819	0.1613	0.2692	0.295
KO	-0.1144	0.0244	0.0179	0.0524	0.0318	0.0331	0.0172	-0.0769	-0.0963	0.6386		-0.4039	0.2731	0.4572
	0.025	0.0256	0.0252	0.025	0.0255	0.026	0.0256	0.026	0.0251	0.0149		0.2184	0.3002	0.2861
RSV	-0.1001	0.1476	0.1587	-0.0141	0.2092	0.2098	-0.026	0.0127	0.1032	0.0379	0.0581		0.2853	-0.424
	0.0259	0.026	0.0254	0.0258	0.0251	0.0257	0.0265	0.0272	0.026	0.0269	0.0261		0.2198	0.2404
RH	-0.1116	0.062	0.0885	0.0205	0.1387	0.175	0.019	-0.0475	-0.0919	0.1673	0.0978	0.2489		-0.5196
	0.025	0.0254	0.0249	0.025	0.0249	0.0249	0.0253	0.0259	0.0251	0.0247	0.0249	0.0244		0.2651
CS	0.1304	-0.1257	-0.1673	-0.2552	-0.1714	-0.2063	-0.2033	0.1866	0.3103	-0.0518	-0.0062	-0.0477	-0.248	
	0.0248	0.025	0.0243	0.0233	0.0246	0.0246	0.0242	0.0249	0.0227	0.0253	0.0253	0.0258	0.0235	

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

Table 2.10 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for BCS

	Phenotypic Correlations				Genetic Correlations			
BCS	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
FA	-0.04	0.03	-0.03	0.026	0.28	0.25	0.27	0.25
FHD	-0.03	0.03	-0.02	0.025	0.06	0.28	0.20	0.26
FC	0.02	0.03	0.05	0.025	0.42	0.28	0.51	0.28
RA	-0.01	0.03	-0.01	0.026	-0.03	0.26	0.08	0.26
RHD	-0.01	0.03	-0.01	0.026	0.07	0.24	-0.04	0.24
RC	0.03	0.03	0.03	0.025	0.34	0.24	0.19	0.25
FS	0.22	0.02	0.23	0.025	0.40	0.19	0.40	0.19
FSV	0.13	0.03	0.13	0.025	0.49	0.22	0.38	0.25
HO	-0.14	0.02	-0.14	0.025	-0.58	0.25	-0.70	0.24
KO	-0.11	0.03	-0.11	0.025	-0.75	0.24	-0.68	0.26
RSV	-0.10	0.03	-0.12	0.026	-0.20	0.22	-0.27	0.22
RH	-0.11	0.03	-0.12	0.025	-0.38	0.26	-0.26	0.26
CS	0.13	0.02	0.15	0.025	0.09	0.31	0.07	0.29

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.11 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for FA

	Phenotypic Correlations				Genetic Correlations			
FA	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.04	0.03	-0.03	0.026	0.28	0.25	0.27	0.25
FHD	0.67	0.01	0.82	0.01	0.97	0.06	0.89	0.06
FC	0.09	0.03	0.10	0.03	-0.25	0.28	-0.21	0.27
RA	0.42	0.02	0.51	0.02	0.87	0.10	0.88	0.08
RHD	0.40	0.02	0.46	0.02	0.83	0.11	0.85	0.09
RC	0.04	0.03	0.03	0.03	-0.07	0.24	-0.17	0.22
FS	0.01	0.03	-0.003	0.03	0.10	0.20	0.11	0.18
FSV	0.06	0.03	0.07	0.03	0.32	0.22	0.46	0.19
HO	-0.02	0.03	0.02	0.03	-0.39	0.23	-0.25	0.23
KO	0.02	0.03	0.03	0.03	-0.40	0.26	-0.05	0.23
RSV	0.15	0.03	0.16	0.06	0.57	0.16	0.63	0.15
RH	0.06	0.03	0.10	0.03	0.21	0.26	0.36	0.23
CS	-0.13	0.03	-0.15	0.03	-0.50	0.26	-0.33	0.24

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.12 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for FHD

	Phenotypic Correlations				Genetic Correlations			
FHD	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.03	0.03	-0.02	0.025	0.06	0.28	0.20	0.26
FA	0.67	0.01	0.82	0.01	0.97	0.06	0.89	0.06
FC	0.08	0.03	0.10	0.03	-0.43	0.30	-0.31	0.27
RA	0.38	0.02	0.47	0.02	0.74	0.15	0.85	0.10
RHD	0.45	0.02	0.52	0.02	0.82	0.11	0.94	0.06
RC	0.04	0.03	0.05	0.03	-0.21	0.27	-0.12	0.24
FS	-0.05	0.03	-0.05	0.03	-0.16	0.22	-0.06	0.19
FSV	0.04	0.03	0.05	0.03	0.28	0.24	0.45	0.19
HO	-0.01	0.03	0.03	0.03	-0.19	0.26	-0.20	0.23
KO	0.02	0.03	0.03	0.03	0.03	0.30	0.05	0.24
RSV	0.16	0.03	0.15	0.03	0.51	0.18	0.51	0.17
RH	0.09	0.02	0.13	0.03	0.55	0.27	0.51	0.22
CS	-0.17	0.02	-0.20	0.03	-0.42	0.31	-0.36	0.24

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.13 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for FC

	Phenotypic Correlations				Genetic Correlations			
FC	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	0.02	0.03	0.05	0.025	0.42	0.28	0.51	0.28
FA	0.09	0.03	0.10	0.03	-0.25	0.28	-0.21	0.27
FHD	0.08	0.03	0.10	0.03	-0.43	0.30	-0.31	0.27
RA	0.12	0.02	0.14	0.03	0.38	0.28	0.13	0.28
RHD	0.12	0.03	0.12	0.03	0.14	0.27	-0.05	0.26
RC	0.34	0.02	0.38	0.02	0.80	0.18	0.75	0.17
FS	0.05	0.03	0.04	0.03	0.13	0.26	0.20	0.24
FSV	-0.04	0.03	-0.05	0.03	0.09	0.29	0.08	0.28
HO	0.10	0.02	0.12	0.03	0.13	0.30	0.12	0.28
KO	0.05	0.03	0.11	0.03	0.15	0.33	0.15	0.28
RSV	-0.01	0.03	0.002	0.03	-0.02	0.26	-0.01	0.25
RH	0.02	0.03	0.07	0.03	0.00	0.32	0.17	0.29
CS	-0.26	0.02	-0.30	0.02	-0.19	0.35	-0.13	0.31

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.14 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for RA

	Phenotypic Correlations				Genetic Correlations			
RA	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.01	0.03	-0.01	0.026	-0.03	0.26	0.08	0.26
FA	0.42	0.02	0.51	0.02	0.87	0.10	0.88	0.08
FHD	0.38	0.02	0.47	0.02	0.74	0.15	0.85	0.10
FC	0.12	0.02	0.14	0.03	0.38	0.28	0.13	0.28
RHD	0.71	0.01	0.83	0.01	0.83	0.08	0.86	0.06
RC	0.13	0.03	0.18	0.03	-0.09	0.25	-0.09	0.23
FS	0.03	0.03	0.01	0.03	-0.05	0.20	0.004	0.18
FSV	0.03	0.03	0.08	0.03	0.20	0.23	0.29	0.21
HO	0.01	0.03	0.02	0.03	-0.34	0.22	-0.24	0.22
KO	0.03	0.03	0.04	0.03	0.06	0.28	-0.04	0.23
RSV	0.21	0.03	0.24	0.03	0.55	0.17	0.72	0.15
RH	0.14	0.02	0.19	0.03	0.42	0.25	0.51	0.21
CS	-0.17	0.02	-0.21	0.03	-0.54	0.25	-0.44	0.22

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.15 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for RHD

	Phenotypic Correlations				Genetic Correlations			
RHD	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.01	0.03	-0.01	0.026	0.07	0.24	-0.04	0.24
FA	0.40	0.02	0.46	0.02	0.83	0.11	0.85	0.09
FHD	0.45	0.02	0.52	0.02	0.82	0.11	0.94	0.06
FC	0.12	0.03	0.12	0.03	0.14	0.27	-0.05	0.26
RA	0.71	0.01	0.83	0.01	0.83	0.08	0.86	0.06
RC	0.16	0.03	0.18	0.03	0.08	0.23	0.11	0.21
FS	-0.03	0.03	-0.03	0.03	-0.29	0.16	-0.23	0.16
FSV	0.05	0.03	0.08	0.03	0.23	0.21	0.19	0.21
HO	-0.01	0.03	0.01	0.03	-0.49	0.20	-0.24	0.21
KO	0.03	0.03	0.05	0.03	-0.08	0.26	0.01	0.21
RSV	0.21	0.03	0.23	0.03	0.49	0.17	0.56	0.15
RH	0.18	0.02	0.21	0.03	0.69	0.20	0.63	0.19
CS	-0.21	0.02	-0.23	0.03	-0.56	0.23	-0.57	0.18

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.16 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for RC

	Phenotypic Correlations				Genetic Correlations			
RC	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	0.03	0.03	0.03	0.025	0.34	0.24	0.19	0.25
FA	0.04	0.03	0.03	0.03	-0.07	0.24	-0.17	0.22
FHD	0.04	0.03	0.05	0.03	-0.21	0.27	-0.12	0.24
FC	0.34	0.02	0.38	0.02	0.80	0.18	0.75	0.17
RA	0.13	0.03	0.18	0.03	-0.09	0.25	-0.09	0.23
RHD	0.16	0.03	0.18	0.03	0.08	0.23	0.11	0.21
FS	0.02	0.03	0.02	0.03	-0.09	0.21	-0.11	0.19
FSV	0.00	0.03	-0.02	0.03	0.14	0.25	0.03	0.23
HO	0.04	0.03	0.03	0.03	0.40	0.22	0.38	0.21
KO	0.02	0.03	0.05	0.03	0.45	0.24	0.41	0.21
RSV	-0.03	0.03	-0.03	0.03	-0.45	0.19	-0.36	0.18
RH	0.02	0.03	0.05	0.03	0.27	-0.20	0.14	0.24
CS	-0.20	0.02	-0.28	0.03	0.30	0.40	-0.06	0.26

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.17 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for FS

	Phenotypic Correlations				Genetic Correlations			
FS	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	0.22	0.02	0.23	0.025	0.40	0.19	0.40	0.19
FA	0.01	0.03	-0.003	0.03	0.10	0.20	0.11	0.18
FHD	-0.05	0.03	-0.05	0.03	-0.16	0.22	-0.06	0.19
FC	0.05	0.03	0.04	0.03	0.13	0.26	0.20	0.24
RA	0.03	0.03	0.01	0.03	-0.05	0.20	0.004	0.18
RHD	-0.03	0.03	-0.03	0.03	-0.29	0.16	-0.23	0.16
RC	0.02	0.03	0.02	0.03	-0.09	0.21	-0.11	0.19
FSV	0.17	0.03	0.02	0.03	0.17	0.20	0.11	0.18
HO	-0.10	0.03	-0.13	0.03	0.06	0.21	0.17	0.18
KO	-0.08	0.03	-0.11	0.03	0.15	0.23	0.06	0.19
RSV	0.01	0.03	-0.01	0.03	0.00	0.17	0.03	0.16
RH	-0.05	0.03	-0.10	0.03	-0.20	0.22	-0.17	0.19
CS	0.19	0.02	0.25	0.03	0.40	0.23	0.32	0.19

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.18 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for FSV

	Phenotypic Correlations				Genetic Correlations			
FSV	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	0.13	0.03	0.13	0.025	0.49	0.22	0.38	0.25
FA	0.06	0.03	0.07	0.03	0.32	0.22	0.46	0.19
FHD	0.04	0.03	0.05	0.03	0.28	0.24	0.45	0.19
FC	-0.04	0.03	-0.05	0.03	0.09	0.29	0.08	0.28
RA	0.03	0.03	0.08	0.03	0.20	0.23	0.29	0.21
RHD	0.05	0.03	0.08	0.03	0.23	0.21	0.19	0.21
RC	0.00	0.03	-0.02	0.03	0.14	0.25	0.03	0.23
FS	0.17	0.03	0.02	0.03	0.17	0.20	0.11	0.18
HO	-0.21	0.02	-0.24	0.03	-0.71	0.21	-0.75	0.18
KO	-0.10	0.03	-0.13	0.03	-0.57	0.25	-0.59	0.21
RSV	0.10	0.03	0.09	0.03	0.11	0.21	-0.07	0.20
RH	-0.09	0.03	-0.10	0.03	-0.12	0.26	-0.10	0.24
CS	0.31	0.02	0.38	0.02	0.69	0.24	0.87	0.19

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.19 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for HO

	Phenotypic Correlations				Genetic Correlations			
HO	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.14	0.02	-0.14	0.025	-0.58	0.25	-0.70	0.24
FA	-0.02	0.03	0.02	0.03	-0.39	0.23	-0.25	0.23
FHD	-0.01	0.03	0.03	0.03	-0.19	0.26	-0.20	0.23
FC	0.10	0.02	0.12	0.03	0.13	0.30	0.12	0.28
RA	0.01	0.03	0.02	0.03	-0.34	0.22	-0.24	0.22
RHD	-0.01	0.03	0.01	0.03	-0.49	0.20	-0.24	0.21
RC	0.04	0.03	0.03	0.03	0.40	0.22	0.38	0.21
FS	-0.10	0.03	-0.13	0.03	0.06	0.21	0.17	0.18
FSV	-0.21	0.02	-0.24	0.03	-0.71	0.21	-0.75	0.18
KO	0.64	0.01	0.73	0.01	0.95	0.08	0.95	0.07
RSV	0.04	0.03	0.08	0.03	-0.64	0.16	-0.46	0.18
RH	0.17	0.02	0.23	0.03	0.01	0.27	0.16	0.24
CS	-0.05	0.03	-0.09	0.03	0.14	0.30	-0.25	0.27

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.20 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for KO

	Phenotypic Correlations				Genetic Correlations			
KO	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.11	0.03	-0.11	0.025	-0.75	0.24	-0.68	0.26
FA	0.02	0.03	0.03	0.03	-0.40	0.26	-0.05	0.23
FHD	0.02	0.03	0.03	0.03	0.03	0.30	0.05	0.24
FC	0.05	0.03	0.11	0.03	0.15	0.33	0.15	0.28
RA	0.03	0.03	0.04	0.03	0.06	0.28	-0.04	0.23
RHD	0.03	0.03	0.05	0.03	-0.08	0.26	0.01	0.21
RC	0.02	0.03	0.05	0.03	0.45	0.24	0.41	0.21
FS	-0.08	0.03	-0.11	0.03	0.15	0.23	0.06	0.19
FSV	-0.10	0.03	-0.13	0.03	-0.57	0.25	-0.59	0.21
HO	0.64	0.01	0.73	0.01	0.95	0.08	0.95	0.07
RSV	0.06	0.03	0.10	0.03	-0.40	0.22	-0.38	0.19
RH	0.10	0.02	0.21	0.03	0.27	0.30	0.19	0.23
CS	-0.01	0.03	-0.07	0.03	0.46	0.29	0.07	0.26

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.21 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for RSV

	Phenotypic Correlations				Genetic Correlations			
RSV	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.10	0.03	-0.12	0.026	-0.20	0.22	-0.27	0.22
FA	0.15	0.03	0.16	0.06	0.57	0.16	0.63	0.15
FHD	0.16	0.03	0.15	0.03	0.51	0.18	0.51	0.17
FC	-0.01	0.03	0.002	0.03	-0.02	0.26	-0.01	0.25
RA	0.21	0.03	0.24	0.03	0.55	0.17	0.72	0.15
RHD	0.21	0.03	0.23	0.03	0.49	0.17	0.56	0.15
RC	-0.03	0.03	-0.03	0.03	-0.45	0.19	-0.36	0.18
FS	0.01	0.03	-0.01	0.03	0.00	0.17	0.03	0.16
FSV	0.10	0.03	0.09	0.03	0.11	0.21	-0.07	0.20
HO	0.04	0.03	0.08	0.03	-0.64	0.16	-0.46	0.18
KO	0.06	0.03	0.10	0.03	-0.40	0.22	-0.38	0.19
RH	0.25	0.02	0.32	0.02	0.29	0.22	0.31	0.20
CS	-0.05	0.03	-0.06	0.03	-0.42	0.24	-0.40	0.21

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.22 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for RH

	Phenotypic Correlations				Genetic Correlations			
RH	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	-0.11	0.03	-0.12	0.025	-0.38	0.26	-0.26	0.26
FA	0.06	0.03	0.10	0.03	0.21	0.26	0.36	0.23
FHD	0.09	0.02	0.13	0.03	0.55	0.27	0.51	0.22
FC	0.02	0.03	0.07	0.03	0.00	0.32	0.17	0.29
RA	0.14	0.02	0.19	0.03	0.42	0.25	0.51	0.21
RHD	0.18	0.02	0.21	0.03	0.69	0.20	0.63	0.19
RC	0.02	0.03	0.05	0.03	0.27	-0.20	0.14	0.24
FS	-0.05	0.03	-0.10	0.03	-0.20	0.22	-0.17	0.19
FSV	-0.09	0.03	-0.10	0.03	-0.12	0.26	-0.10	0.24
HO	0.17	0.02	0.23	0.03	0.01	0.27	0.16	0.24
KO	0.10	0.02	0.21	0.03	0.27	0.30	0.19	0.23
RSV	0.25	0.02	0.32	0.02	0.29	0.22	0.31	0.20
CS	-0.25	0.02	-0.32	0.02	-0.52	0.27	-0.64	0.18

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

Table 2.23 Comparison of Correlations and SE of Modified Scale (1-9) and Original Scale (1-100) for CS

	Phenotypic Correlations				Genetic Correlations			
CS	1-9	SE	1-100[a]	SE[a]	1-9	SE	1-100[a]	SE[a]
BCS	0.13	0.02	0.15	0.025	0.09	0.31	0.07	0.29
FA	-0.13	0.03	-0.15	0.03	-0.50	0.26	-0.33	0.24
FHD	-0.17	0.02	-0.20	0.03	-0.42	0.31	-0.36	0.24
FC	-0.26	0.02	-0.30	0.02	-0.19	0.35	-0.13	0.31
RA	-0.17	0.02	-0.21	0.03	-0.54	0.25	-0.44	0.22
RHD	-0.21	0.02	-0.23	0.03	-0.56	0.23	-0.57	0.18
RC	-0.20	0.02	-0.28	0.03	0.30	0.40	-0.06	0.26
FS	0.19	0.02	0.25	0.03	0.40	0.23	0.32	0.19
FSV	0.31	0.02	0.38	0.02	0.69	0.24	0.87	0.19
HO	-0.05	0.03	-0.09	0.03	0.14	0.30	-0.25	0.27
KO	-0.01	0.03	-0.07	0.03	0.46	0.29	0.07	0.26
RSV	-0.05	0.03	-0.06	0.03	-0.42	0.24	-0.40	0.21
RH	-0.25	0.02	-0.32	0.02	-0.52	0.27	-0.64	0.18

Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS)

[a]Jensen (2017)

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Chapter 3 – Evaluation of Feet and Leg Traits Impact on Stayability EPD in Red Angus Cattle

Introduction

For beef cattle producers there has been a disparity between traits that have been scientifically studied to have economic impact and traits for which producers are selecting. Feet and leg structure remains one of those traits producers desire to improve, yet have little understanding of its genetic control. Many cattle producers would like a selection tool for feet and leg structure traits. At the core of the discussion remains the question of which feet and leg traits impact longevity.

The dairy cattle industry has an established genetic evaluation for feet and leg traits (Short and Lawlor. 1992; Tsuruta 2005) and economic losses due to poor feet and leg type traits have been documented (Enting et al. 1997). In the beef cattle industry, current production practices do not include mass collection of feet and leg phenotypes.

Feet and leg traits are scored as an ordered category with the perceived desirable score in the middle and less desirable scores on the two extremes. For traits with a perceived intermediate optimum, conventional analyses such as linear modelling and Pearson/Spearman correlations with production traits become harder to interpret.

Snell (1964) described a procedure to transform data on an intermediate optimum scale to properly identify desirable and undesirable scores. The transformed scores have the highest value in the middle of the distribution and zeros at the extremes. Jeyaruban et al. (2012) determined that a threshold model using the procedure of Snell (1984) instead of a traditional linear mixed animal model may be a more appropriate method.

Properly interpreting and modelling intermediate optimum traits help determine their true economic impact. In beef cattle, Stayability EPD provides insight as to how long a cow will remain in the herd which is of economic significance. Feet and leg soundness undeniably plays a crucial role in cow longevity (Greer et al. 1980; Rogers et al. 1989; Short et al. 1992; VanRaden and Klasskate 1993; Dekkers et al. 1994). The goal of this study was to determine which feet and leg traits are most highly related to STAY and can serve as indicator traits for Stayability EPD.

Materials and Methods

In the previous chapter, genetic parameters were estimated for all 14 feet and leg traits using scores on the 1-9 scale and compared with estimates on the 1-100 scale from Jensen (2017). To further simplify the feet and leg scoring method and eliminate non-integral traits, a list of criteria defined by Short et al. (1991) helped determine which traits should be further analyzed.

For the present study, traits determined to have merit as a further studied feet and leg trait needed to have a high enough heritability (> 0.10) to obtain a useful range of breeding values. Heritability estimates must be prevalently found in literature and a general understanding of its genetic impact must be established. Traits must have little genetic correlation to each other (not > ±0.60). If a moderate genetic correlation existed between traits, the traits were included separately if they had been previously differentiated in the literature. Body condition score, RHD, RC, FS, RSV, and RH were selected.

It was determined that there were not enough observations to conduct a threshold animal model on this dataset as there were not enough records on the extremes of the scale to have impact in a threshold analysis. Therefore, a multiple trait animal model was used to determine breeding values on the 6 traits previously identified, with random effects of additive genetic, and residual and fixed effects of contemporary group and age in months. Variance components from the previous study were used in the multiple trait model and were fixed. The multiple trait model was used to solve EBV's and variance components were not estimated a second time. The multiple trait model was:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \end{bmatrix} = \begin{bmatrix} X_1 & \beta_1 \\ X_2 & \beta_2 \\ X_3 & \beta_3 \\ X_4 & \beta_4 \\ X_5 & \beta_5 \\ X_6 & \beta_6 \end{bmatrix} + \begin{bmatrix} Z_1 & u_1 \\ Z_2 & u_2 \\ Z_3 & u_3 \\ Z_4 & u_4 \\ Z_5 & u_5 \\ Z_6 & u_6 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \end{bmatrix}$$

Where $\boldsymbol{Y_i}$ was a vector of observations for trait 1 and trait 2 including all traits scored, $\boldsymbol{X_i}$ was an incidence matrix relating observations to the levels of fixed effects, $\boldsymbol{\beta_i}$ was a vector of fixed effects for contemporary group and age in months, $\boldsymbol{Z_i}$ was an incidence matrix relating observations to additive genetic effects and permanent environmental effects, $\boldsymbol{u_i}$ was a vector of random additive genetic effects, and $\boldsymbol{e_i}$ was a vector of random residuals. The structure for residual (co)variances was:

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \end{bmatrix} = \begin{bmatrix} I\sigma^2_{e1} & I\sigma^2_{e1,e2} & I\sigma^2_{e1,e3} & I\sigma^2_{e1,e4} & I\sigma^2_{e1,e5} & I\sigma^2_{e1,e6} \\ I\sigma^2_{e2,e1} & I\sigma^2_{e2} & I\sigma^2_{e2,e3} & I\sigma^2_{e2,e4} & I\sigma^2_{e2,e5} & I\sigma^2_{e2,e6} \\ I\sigma^2_{e3,e1} & I\sigma^2_{e3,e2} & I\sigma^2_{e3} & I\sigma^2_{e3,e4} & I\sigma^2_{e3,e5} & I\sigma^2_{e3,e6} \\ I\sigma^2_{e4,e1} & I\sigma^2_{e4,e2} & I\sigma^2_{e4,e3} & I\sigma^2_{e4} & I\sigma^2_{e4,e5} & I\sigma^2_{e4,e6} \\ I\sigma^2_{e5,e1} & I\sigma^2_{e5,e2} & I\sigma^2_{e5,e3} & I\sigma^2_{e5,e4} & I\sigma^2_{e5} & I\sigma^2_{e5,e6} \\ I\sigma^2_{e6,e1} & I\sigma^2_{e6,e2} & I\sigma^2_{e6,e3} & I\sigma^2_{e6,e4} & I\sigma^2_{e6,e5} & I\sigma^2_{e6} \end{bmatrix}$$

where **I** represented an identity matrix with dimensions equal to the number of records for each specific trait. Error covariances between all traits were calculated because every animal was scored for every trait. The structure for genetic (co)variances was:

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \end{bmatrix} = \begin{bmatrix} A\sigma^2_{u1} & A\sigma_{u1,u2} & A\sigma_{u1,u3} & A\sigma_{u1,u4} & A\sigma_{u1,u5} & A\sigma_{u1,u6} \\ A\sigma_{u2,u1} & A\sigma^2_{u2} & A\sigma_{u2,u3} & A\sigma_{u2,u4} & A\sigma_{u2,u5} & A\sigma_{u2,u6} \\ A\sigma_{u3,u1} & A\sigma_{u3,u2} & A\sigma^2_{u3} & A\sigma_{u3,u4} & A\sigma_{u3,u5} & A\sigma_{u3,u6} \\ A\sigma_{u4,u1} & A\sigma_{u4,u2} & A\sigma_{u4,u3} & A\sigma^2_{u4} & A\sigma_{u4,u5} & A\sigma_{u4,u6} \\ A\sigma_{u5,u1} & A\sigma_{u5,u2} & A\sigma_{u5,u3} & A\sigma_{u5,u4} & A\sigma^2_{u5} & A\sigma_{u5,u6} \\ A\sigma_{u6,u1} & A\sigma_{u6,u2} & A\sigma_{u6,u3} & A\sigma_{u6,u4} & A\sigma_{u6,u5} & A\sigma^2_{u6} \end{bmatrix}$$

where **A** represented a relationship matrix from pedigree relationships. Breeding values were estimated using ASREML (Ver 4.0, VSN International, LTD., Hemel Hempstead, UK).

The assumed desirable breeding values were near zero, and values moving further away from zero were deemed undesirable. The absolute values of the feet and leg trait EBVs were obtained to modify the values to a more linear form. This assumed that the average of the EBVs near zero were assumed optimum and values that were more positive were undesirable. By transforming the breeding values, it allowed for a more appropriate analysis with Stayability EPD. Pearson Correlation Coefficients between transformed EBVs and Stayability EPD were calculated using SAS 9.2(SAS Institute Inc., Cary, NC).

Regression analysis using phenotypic data, EBV's and Stayability EPD was performed using SAS 9.2 (SAS Institute Inc., Cary, NC). A linear model was used to determine which traits were predictors for Stayability EPD using phenotypic data and breeding values. Contemporary group (n=48), age in months and sex were fit as fixed effects. Contemporary group included ranch and year born. Original scores (1-100), modified scores (phenotypes simplified to a 1-9), and trait EBVs (non-transformed and transformed) were regressed on Stayability EPD in separate analyses where R^2 and Type III Sum of Squares were compared.

Results and Discussion

Descriptive statistics for breeding values can be found in Table 3.1. Heritability and standard errors for BCS, RHD, RC, FS, RSV, RH traits from both measurements of scale can be found in Table 3.2. Foot Size, RSV, and RHD had the highest heritability estimates of 0.29, 0.29, and 0.24 respectively. Rear claw shape, RH, and BCS had lower estimates of 0.15, 0.11, and 0.13 respectively. Most traits were lowly genetically correlated with each other with the exception of RHD and RH (r = 0.69). This estimate was higher than previously reported (Jeyaruban et al. 2012; Wiggans et al. 2006).

Phenotypic scores were fit in a linear model with Stayability EPD (STAY) as the dependent variable. Once fixed effects were accounted for, RC and RSV significantly ($P < 0.05$) predicted STAY regardless of the scale (R^2 = 0.426 vs. 0.43). Rear hoof angle had a strong relationship with STAY on the 1-100 scale (P = 0.021). Age had a significant impact on STAY for the 1-9 scale and 1-100 scale (P=0.030 and P=0.016 respectively). Body condition score did not significantly predict STAY. Foot size and RH did not significantly predict STAY using phenotypic values on both measures of scale. Table 3.3 contains phenotypic Type III SS and P values for both scales of measurement.

Some complications arise when fitting a non-linear explanatory variable with a continuous or linear dependent variable. Interpretation becomes difficult, especially when trying to determine the optimum level of a particular trait. Since the measurement of scale was similar to a quadratic curve, the phenotypic data were squared and fit in a linear model with Stayability EPD to determine if a quadratic relationship was present. Once fixed effects were accounted for, RHA, RC, and RSV had a significant relationship as predictor values for STAY (r = 0.015, 0.002, and 0.028 respectively). The comparison between phenotypes fit linearly and those fit in a quadratic form to

STAY showed no notable increase in significance. There is likely significant non-linear relationships with feet and leg phenotypic values and STAY that would require a larger dataset with increased variation to further understand those relationships. Table 3.4 contains the quadratic phenotypic scores Type III SS and P-Values for both measures of scale.

Actual estimated breeding values for the 6 traits were fit as predictor variables in a linear model with STAY. Table 3.5 contains breeding value Type III SS and P values for the 1-9 scale of measurement. Rear claw shape was an accurate predictor of STAY ($P<0.0001$). Foot size and RSV tended to have a relationship with STAY as predictor variables ($P<0.09$). Body condition score and RHD did not have a significant relationship with STAY, indicating breeding values for these traits are not good indicators of improved STAY and likely are impacted more so by management practices. There was also little relationship with phenotypic scores for BCS and RHD as predictors of STAY.

The absolute values of EBV's for the 6 traits analyzed were fit in a linear model with STAY as the dependent variable. Type III SS and P values for the absolute value EBVs can also be found in Table 3.5. Rear leg side view indicated the highest significance as a predictor variable for STAY ($P = 0.0514$). Foot size and RC also hinted at some significance as predictor variables for STAY ($P = 0.147$ and 0.153 respectively). There was a notable decrease in significance between actual EBV and the absolute value EBV for RC ($P < 0.0001$ versus $P = 0.1533$). Likely there is a nonlinear relationship with RC as a predictor variable for STAY. Further analysis with increased numbers of records is needed to determine if the absolute value of a trait properly identifies animals exhibiting an optimum level for a given trait.

The Pearson Correlation Coefficients for STAY, and absolute value EBVs for BCS, RHD, RC, FS, RSV, and RH can be found in Table. 3.7. There were some moderate correlations with traits, however there was not the expected negative correlation indicating traits with an intermediate optimum level. With the ideal value being a zero on the modified breeding values, a negative correlation with STAY as a linear variable would indicate an intermediate optimum level. A broader selection of animals and variation would help further identify if an intermediate optimum scale is appropriate.

Covariates for age in months for the 6 feet and leg traits for both measures of scale (1-9 and 1-100) can be found in Table 3.6. Age appeared to have the greatest effect on BCS, FS, and RSV (-0.247, 0.0231, and 0.0239) on the 1-9 scale. The comparison between both measures of scale showed a significant decrease in the covariate, however with the simplification this was expected. Body condition score tends to decrease with increasing age and foot size tends to increase with increasing age. Similarly, a rear leg set tends to grow more curved with increasing age. Covariates for age and feet and leg traits will help better understand how a specific phenotype changes with increasing age and help understand how to increase an animal's opportunity to stay in a herd longer.

Table 3.8 contains the different regressions of feet and leg traits on STAY and their corresponding R-square values. Phenotypic models included all 14 traits with herd/year and sex fit as fixed effects and age fit as a covariate. Models using EBVs included the 6 traits previously identified with herd/year and sex fit as fixed effects and age fit as a covariate. There was no difference in R-square values between the 4 methods analyzed. This informs fewer traits can impart the necessary information to help predict STAY.

Conclusion

Using feet and leg traits as predictor variables for Stayability EPD may provide increased accuracy for producers looking to improve herd longevity. A simplified, less granular scoring method, and fewer traits to measure offers some incentive for cattle producers to submit records to breed associations for genetic evaluation. Six traits were identified to offer marginal progress through selection and showed some significance as predictor variables for Stayability EPD in Red Angus cattle. Notably FS, RC and RSV impact STAY and have some economic importance for beef cattle producers.

The use of breeding values rather than phenotypic data offers just as much information as predictors for Stayability EPD and should be used moving forward as indicator values. It is still not understood how to best analyze traits assumed to have an intermediate optimum level. Increased animal records on a broader dataset will offer further insights to the understanding of feet and leg traits in Red Angus cattle and the impact they have on cow longevity and herd profitability.

Table 3.1 Descriptive Statistics of Estimated Breeding Values for 6 Feet and Leg Traits (1-9 Scale)

	1-9 Scale			
Trait	Mean	SD	Min	Max
Body Condition Score	-0.02831	0.114881	-1.424	1.24
Rear Heel Depth	0.022366	0.127982	-1.41	1.287
Rear Claw Shape	-0.00286	0.14649	-1.479	2.301
Foot Size	-0.01758	0.127475	-1.577	1.291
Rear Leg Side View	-0.01741	0.140195	-1.263	1.754
Rear Leg Hind View	0.01057	0.096324	-1.045	1.108

Table 3.2 Comparison of Heritability Estimates for Modified Scale (1-9) versus Non-Modified Scale (1-100) [a]

	1-9 Scale		1-100 Scale	
Trait	h^2	SE	h^2	SE
Body Condition Score	0.13	0.05	0.11	0.04
Rear Heel Depth	0.24	0.06	0.25	0.06
Rear Claw Shape	0.15	0.05	0.17	0.05
Foot Size	0.29	0.06	0.36	0.06
Rear Leg Side View	0.29	0.06	0.30	0.06
Rear Leg Rear View	0.11	0.04	0.14	0.05

[a] Jensen (2017)

Table 3.3 Relationship of Measured phenotypes and Stayability EPD Type III Sum of Squares (Pr>F)

	1-9			1-100		
Variables	Type III SS	F-Value	Pr>F	Type III SS	F-Value	Pr>F
Herd/Year (n=48)	3605.03	13.72	<.0001	3631.13	13.92	<.0001
Sex	9.81	1.76	0.1854	9.07	1.63	0.2013
Age	26.31	4.71	0.0302	32.45	5.85	0.0157
Body Condition Score	12.33	2.21	0.1377	11.48	2.07	0.1505
Front Hoof Angle	2.43	0.44	0.5096	3.08	0.55	0.4566
Front Heel Depth	2.07	0.37	0.5430	5.74	1.03	0.3093
Front Claw Shape	13.16	2.35	0.1252	8.55	1.54	0.2147
Rear Hoof Angle	6.92	1.24	0.2659	29.59	5.33	0.0210
Rear Hoof Depth	2.66	0.48	0.4904	18.03	3.25	0.0717
Rear Claw Shape	76.28	13.65	0.0002	69.65	12.55	0.0004
Size of Hoof	4.61	0.82	0.3640	4.91	0.88	0.3470
Front Side View	0.51	0.09	0.7630	0.64	0.12	0.7339
Knee Orientation	5.39	0.97	0.3260	0.02	0.00	0.9580
Front Hoof Orientation	1.34	0.24	0.6249	2.91	0.52	0.4690
Rear Leg Side View	27.71	4.96	0.0261	30.25	5.45	0.0197
Rear Leg Rear View	6.25	1.12	0.2903	6.57	1.18	0.2768
Composite Score	2.42	0.43	0.5110	4.42	0.80	0.3721

Table 3.4 Quadratic Relationship of Measured Phenotypes and Stayability EPD Type III Sum of Squares (Pr>F)

	1-9			1-100		
Variables	Type III SS	F-Value	Pr>F	Type III SS	F-Value	Pr>F
Herd/Year (n=48)	3605.03	13.72	<.0001	3631.13	13.92	<.0001
Sex	9.81	1.76	0.1854	9.07	1.63	0.2013
Age	26.31	4.71	0.0302	32.45	5.85	0.0157
Body Condition Score^2	12.12835	2.17	0.1409	10.77051	1.94	0.1637
Front Hoof Angle^2	3.08455	0.55	0.4577	4.599568	0.83	0.3627
Front Heel Depth^2	2.678812	0.48	0.4889	7.584885	1.37	0.2425
Front Claw Shape^2	13.59059	2.43	0.1191	8.477908	1.53	0.2166
Rear Hoof Angle^2	10.1058	1.81	0.1789	32.80539	5.91	0.0151
Rear Hoof Depth^2	3.988864	0.71	0.3984	20.62953	3.72	0.0540
Rear Claw Shape^2	60.35309	10.8	0.0010	55.26466	9.96	0.0016
Size of Hoof^2	3.549543	0.64	0.4256	3.223832	0.58	0.4460
Front Side View^2	0.327319	0.06	0.8088	0.468352	0.08	0.7714
Knee Orientation^2	5.254721	0.94	0.3324	0.001047	0.00	0.9890
Front Hoof Orientation^2	0.648682	0.12	0.7334	4.715532	0.85	0.3567
Rear Leg Side View^2	22.88101	4.09	0.0432	26.8439	4.84	0.0280
Rear Leg Rear View^2	5.935402	1.06	0.3029	6.105317	1.10	0.2943

Table 3.5 Estimated Breeding Value (EBV) and Absolute Value of EBV's Relationship of 6 Feet and Leg Traits and Stayability EPD, Type III Sum of Squares (Pr>F)

	Original EBV			EBV Absolute Value		
Variables	Type III SS	F-Value	Pr>F	Type III SS	F-Value	Pr>F
Herd/Year (n=48)	4944.8604	20.68	<.0001	4922.3715	20.26	<.0001
Sex	7.937195	1.46	0.2271	8.460777	1.53	0.2160
Age	8.64823	1.59	0.2074	8.783293	1.59	0.2075
Body Condition Score	0.618941	0.11	0.7358	0.765151	0.14	0.7098
Size of Hoof	16.043667	2.95	0.0860	11.616369	2.10	0.1472
Rear Heel Depth	0.263192	0.05	0.8259	2.804558	0.51	0.4762
Rear Claw Shape	102.31452	18.82	<.0001	11.271172	2.04	0.1533
Rear Leg Side View	20.601606	3.79	0.0517	20.989916	3.80	0.0514
Rear Leg Hind View	5.694044	1.05	0.3062	2.746318	0.50	0.4808

Table 3.6 Age Covariate for BCS, FS, RHD, RC, RSV, RH and SE the 1-9 scale and 1-100 scale

	1-9 Scale		1-100 Scale[a]	
	Covariate on Age in Months	SE	Covariate on Age in Months	SE
Body Condition Score	-0.0247	0.0072	-0.03	0.01
Foot Size	0.0231	0.0081	0.22	0.07
Rear Heel Depth	0.0103	0.0080	-0.12	0.07
Rear Claw Shape	0.0190	0.0089	0.16	0.08
Rear Leg Side View	0.0239	0.0085	0.25	0.08
Rear Hind View	-0.0112	0.0063	-0.18	0.06

[a]Jensen (2017)

Table 3.7 Pearson Correlation Coefficients and associated P values with Stayability EPD, and the Absolute Value of EBV's for BCS and 5 Feet and Leg Traits

	STAY	BCS	FS	RHD	RC	RSV	RH
STAY							
BCS	0.11352 <.0001						
FS	0.03385 0.1850	0.07018 0.0059					
RHD	0.04889 0.0555	0.05648 0.0269	0.16374 <.0001				
RC	0.20786 <.0001	0.10519 <.0001	0.10731 <.0001	0.19247 <.0001			
RSV	0.05143 0.0439	0.04030 0.1145	0.01857 0.4671	0.14829 <.0001	0.15652 <.0001		
RH	0.06890 0.0069	0.12693 <.0001	0.02100 0.4109	0.06477 0.0111	0.10262 <.0001	0.06139 0.0161	

Traits: Stayability EPD (STAY), Body Condition Score (BCS), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Rear Leg Side View (RS), Rear Leg Rear View (RH).

Table 3.8 Stayability EPD Regression Model Comparison of Scoring Methods

	# of Traits	Number of Observations	R^2
Phenotypic scores using 1-9 scale [a]	14	1720	0.426
Phenotypic scores using 1-100 scale [a]	14	1724	0.430
EBV's using 1-9 scale [b]	6	1535	0.428
Absolute value of EBV's using 1-9 scale [b]	6	1535	0.419

[a] Traits: Body Condition Score (BCS), Front Hoof Angle (FA), Front Hoof Depth (FHD), Front Claw Shape (FC), Rear Hoof Angle (RA), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Front Side View (FSV), Front Hoof Orientation (HO), Knee Orientation (KO), Rear Leg Side View (RS), Rear Leg Rear View (RH), and Composite Score (CS). All traits included in model.
[b] Traits: Body Condition Score (BCS), Rear Hoof Depth (RHD), Rear Claw Shape (RC), Foot Size (FS), Rear Leg Side View (RS), Rear Leg Rear View (RH). All traits included in model.

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