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Associating cow characteristics with mobility scores in pasture-based dairy cows

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ABSTRACT

The quality of dairy cow mobility can have significant welfare, economic, and environmental consequences that have yet to be extensively quantified for pasture-based systems. The objective of this study was to characterize mobility quality by examining associations between specific mobility scores, claw disorders (both the type and severity), body condition score (BCS), and cow parity. Data were collected for 6,927 cows from 52 pasture-based dairy herds, including mobility score (0 = optimal mobility; 1, 2, or 3 = increasing severities of suboptimal mobility), claw disorder type and severity, BCS, and cow parity. Multinomial logistic regression was used for analysis. The outcome variable was mobility score, and the predictor variables were BCS, type and severity of claw disorders, and cow parity. Three models were run, each with 1 reference category (mobility score 0, 1, or 2). Each model also included claw disorders (overgrown claw, sole hemorrhage, white line disease, sole ulcer, and digital dermatitis), BCS, and cow parity as predictor variables. The presence of most types of claw disorders had odds ratios >1, indicating an increased likelihood of a cow having suboptimal mobility. Low BCS (BCS <3.00) was associated with an increased risk of a cow having suboptimal mobility, and relatively higher parity was also associated with an increased risk of suboptimal mobility. These results confirm an association between claw disorders, BCS, cow parity, and dairy cow mobility score. Therefore, mobility score should be routinely practiced to identify cows with slight deviations from the optimal mobility pattern and to take preventive measures to keep the problem from worsening.

Key words: lameness, claw disorder, body condition, parity, grass-based system

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INTRODUCTION

Worldwide, suboptimal mobility in dairy cows is considered to be among the most significant disease challenges throughout the dairy industry (Huxley, 2012). Suboptimal mobility is a major animal welfare concern due to the associated pain (e.g., Rushen, 2001; O'Callaghan, 2002) and is the third most important health-related cause of economic loss, after fertility and mastitis (Bruijnis et al., 2010; Huxley, 2013). In Northwest European pasture-based systems, in which cows are housed during the winter months but managed at pasture for the remainder of the year, suboptimal mobility is often overlooked due to a perception that the quality of dairy cow mobility is better than that of cows in nonpasture systems (Somers and O'Grady, 2015). The incidence of suboptimal mobility, however, has been shown to be similar in both grazing and nongrazing systems (Olmos et al., 2009). This is most likely due to grazing cows being exposed to different risks for suboptimal mobility compared with nongrazing cows. For example, cows in pasture-based systems are exposed to elements identified as risk factors such as poor-quality roadway surfaces, longer walking distances to the milking parlor (Doherty et al., 2014), and poor herding skills or management practices (Westwood et al., 2003), whereas cows managed in non-pasture-based systems are exposed to elements identified as risk factors such as slatted concrete flooring and continuous exposure of claws to slurry (Cook et al., 2004).

It is well known that claw disorders are a major risk to dairy cow mobility and account for the majority of cases of severe mobility problems (Murray et al., 1996). The literature shows that the likelihood of many claw disorders (e.g., sole hemorrhage, white line disease, digital dermatitis) causing mobility problems, such as lameness, is larger in non-pasture-based systems than in pasture-based systems (Olmos et al., 2009). However, the association of claw disorders with less severe forms of mobility problems has been less extensively

researched. Especially in pasture-based systems, the association between presence, type, and severity of claw disorders and mobility score has not been investigated. Studies that do address these associations in non-pasture-based systems mainly focus on lameness. The term "lameness," however, is not defined conclusively. For example, using the 5-point scoring method developed by Sprecher et al. (1997), a cow is often defined as lame when she is scored ≥3 (Solano et al., 2015; Cook et al., 2016). Using the same scoring method, Olechnowichz and Jaskowski (2015) refer to a cow as lame when she is scored ≥2. Other studies refer to a cow as lame only when her score is ≥4 (Kovács et al., 2015). In this study, we use a specific mobility scoring system to describe varying levels of mobility quality rather than focusing on lameness.

The focus of this study is to better understand the quality of dairy cow mobility and the causes behind suboptimal mobility using cow-level attributes in pasture-based systems. Therefore, in addition to examining the effect of claw disorders on mobility scores, we explore the effect of other parameters proven to be related to mobility, such as BCS and parity (Lim et al., 2015). We define suboptimal mobility as any abnormality to a cow's gait that causes a deviation from the optimal walking pattern of a cow (i.e., any deviation that resembles any form of variation so that the cow's mobility can no longer be classified as optimal). Optimal mobility is defined in this study as perfect dairy cow mobility with no abnormalities. Optimal versus suboptimal is not to be interpreted the same as clinical versus subclinical, often used throughout the literature to describe abnormal mobility (Green et al., 2002). Clinical and subclinical can refer to diseases severe enough that they are either associated or not associated with some form of productive or reproductive losses, whereas optimal and suboptimal refer only to the quality of mobility relative to what is accepted as optimal for dairy cows. The severity of suboptimal mobility can vary greatly from slight deviations from normal gait and walking pattern to severe immobility and inability to bear weight on a limb, causing difficulty when walking (Beusker, 2007). Therefore, the objective of this study was to more specifically characterize mobility scores by determining their association with cow-level attributes—namely, the presence, type, and severity of claw disorders, BCS, and cow parity.

MATERIALS AND METHODS

Cow Data

Data for 11,472 cows from 68 pasture-based dairy herds located in the Munster region of Southern Ireland were collected as part of a larger research project. The aim of the project was to collect claw health traits from a large sample of cows, representative of the Irish dairy population, for the estimation of variance components of hoof health for consideration in national genetic evaluations (Ring et al., 2018). The average herd size was 169 (SD = 115) cows. The main breed of the cows was 75% Holstein, 13% Jersey, and 9% Friesian, which is representative of the national population (Ring et al., 2018). Cow parity records were available for only 6,927 of the cows. Herds were selected for inclusion in the study based on the following criteria: (1) maximum of 100 km from Teagasc, Moorepark, in Fermoy; (2) registered in the Irish Cattle Breeding Federation milk recording system; (3) herd owners willing to have their herd genomically tested; and (4) operating a pasture-based system. The Irish pasture-based system refers to one in which cows are turned out to pasture postcalving during the spring once ground conditions allow, whereby more than 70% of cows calve between January and March (Irish Cattle Breeding Statistics, 2018), remain outside grazing for the summer and autumn months, and are partially or fully housed during the winter months (December to January). The mean calving date for the study population was February 23, 2015 (SD = 24). Cows are turned out to pasture directly after calving. The focus of the system is not to maximize milk yield per cow but rather to manage the interface between the cow and the pasture with an ultimate balance to maximize intake while maximizing grass utilization (Dillon et al., 2005). A typical diet for a dairy cow in an Irish pasture-based system consists mainly of grazed pasture, predominantly based on perennial rye grass (accounting for 60.2% of the DMI; O'Brien et al., 2018), followed by concentrate feed, accounting for 19% of the diet on a DM basis (Hanrahan et al., 2018). The remainder of the typical diet is made up of grass silage and alternative forages (O'Brien et al., 2018).

Mobility Score, BCS, and Claw Disorder Data

Mobility Score and BCS. Each herd was visited twice by 2 trained technicians from Teagasc, Moorepark, in 2015. The first visit was conducted in early lactation (March through May) and the second visit was conducted in late lactation (June through November). During each herd visit, every lactating cow was assessed for BCS (by one technician) and mobility score (by the other technician). Body condition of each cow was scored using both visual and tactile appraisal on a scale of 1 to 5 with 0.25 increments, as described by Edmonson et al. (1989). Mobility quality of each cow was scored using the UK Agriculture and Horticulture

Table 1. Descriptions used by the assessors to identify claw disorders

Claw disorder	Type	Description
Overgrown claw	Noninfectious	Significant difference in width, height, or length between outer and inner claw that cannot be balanced by trimming
White line disease	Noninfectious	Separation of the sole from the side wall of the claw and penetration of foreign material; separation of the white line that remains after balancing both soles
Sole hemorrhage	Noninfectious	Clear differentiation between discolored and normal-colored horn
Sole ulcer	Noninfectious	Penetration through the sole horn exposing fresh or necrotic corium or ulcer located at the toe
Digital dermatitis	Infectious	Infection of the digital or interdigital skin with erosion, mostly painful ulcerations or chronic hyperkeratosis and proliferation

Development Board (2019) 4-point scale using the following definitions.

- A score of 0 describes a cow with optimal mobility that walks with even weight bearing and rhythm on all 4 feet, with a flat back. Long and fluid strides are possible.
- A score of 1 describes a cow with imperfect mobility (any mobility score >0 is defined as suboptimal mobility), with uneven steps or shortened strides affecting 1 or more limbs; it may not be immediately identifiable.
- A score of 2 describes a cow with impaired mobility, with uneven weight bearing on 1 or more limbs that is immediately identifiable or shortened strides, usually associated with an arched back.
- A score of 3 describes a cow with severely impaired mobility; a cow with this score is unable to walk as fast as the rest of the healthy herd due to more severe symptoms compared with score 2.

Claw Disorder Data. On a separate third herd visit, claw-trimming professionals from a commercial company (Farm Relief Services, Roscrea, Co. Tipperary, Ireland) lifted both the hind claws of each lactating cow for identification and scoring of claw disorders in 52 of the total 68 herds, amounting to 7,602 cows examined during July through December 2015. The claw disorder data were collected mainly after the second farm visit. The dates for claw disorder data collection ranged from July 14 to December 10, 2015, with an average date of September 18, 2015 (median date of September 28, 2015). The claw disorders were identified and recorded, and severity was scored by 1 of 2 Teagasc technicians (not the same technicians who scored BCS and mobility). Both technicians recorded a similar number of animals and a similar prevalence for each of the claw health traits, differing by only 4% on average (Ring et al., 2018). The claw disorders were identified using the claw atlas of the International Committee for Animal Recording (ICAR, 2015). A scoring method was developed in which the claw disorders were scored based on visual severity of each disorder. Where doubts occurred in severity scoring, the photos of the disorders (which were taken at the time of scoring) were used for clarification with the other technician. Two types of claw disorders were recorded by the assessors: noninfectious and infectious. The noninfectious claw disorders recorded included overgrown claw, white line disease, sole hemorrhage, and sole ulcer, and the infectious claw disorder recorded was digital dermatitis. See Table 1 for a description of each claw disorder. Overgrown claw, sole hemorrhage, and white line disease were each severity scored using a 0-to-3 scale, where 0 = not affected (no visual evidence of the disorder present), 1 = mildly affected (visual evidence of the disorder present in a mild form), 2 = moderately affected (visual evidence of the disorder present in a moderate form), and 3 = severely affected (visual evidence of the disorder present in a severe form). Sole ulcer and digital dermatitis were scored as binary traits, where 0 = not affected (no visual evidence of the disorder present) and 1 = affected (visual evidence of the disorder present in any form). After scoring, the claw trimmer treated the claws if necessary.

Data Management

There were 52 herds amounting to 6,927 cows (average herd size = 163 cows; SD = 111) used in the analyses (Figure 1). Of the original 11,472 cows from 68 farms (average herd size = 169 cows; SD = 115), 3,870 were excluded from the analyses (leaving 7,602 cows) because no claw disorder data (presence and severity) were present. No difference in herd attributes is known between the subset of 52 herds and the original 68 herds; claw disorder data were collected only from 52 herds due to time and budget constraints. A further 675 cows were excluded from the analyses (leaving 6,927 cows) because no cow parity data were available for these cows. Two mobility scores and 2 BCS were recorded for each cow, and just 1 of each were included in the analyses. The specific mobility score and BCS used in the analyses were chosen based on

the specific date the first and second herd visits occurred relative to the third herd visit. The first herd visit was in early lactation, and the second herd visit was in late lactation, both for mobility score and BCS data collection. The third herd visit (for claw health data collection) might have occurred between visits 1 and 2 or after visit 2. For example, the mobility score and BCS of cow A were recorded twice, both during the early-lactation herd visit on March 3, 2015, and during the late-lactation visit on July 8, 2015. This same cow had her hind claws lifted and recorded for the presence and severity of any claw disorder present during the third herd visit on July 21, 2015. For this example, the recorded mobility score and BCS used in the analysis were the scores taken on July 8, 2015 (the late-lactation visit) because they were closer in time to the third and final visit. As another example, the mobility score and BCS of cow B were recorded only once—namely, during the early-lactation herd visit on March 3, 2015. Her mobility score and BCS are not available for the second herd visit, during the late-lactation period, possibly because she was removed from the herd. In this instance, the available mobility score and BCS are used irrespective of the date on which her claws were lifted and recorded for the presence and severity of any claw disorders. The mean date for mobility score and BCS used in the analysis was July 22, 2015 (SD = 49 d). The time difference (in days) between the date on which mobility score and BCS data were collected and the date on which claw disorder data were collected ranged, whereby claw disorder data were collected up to 29 d before or 252 d after the recording of mobility score and BCS data (mean = 58 d; SD = 51).

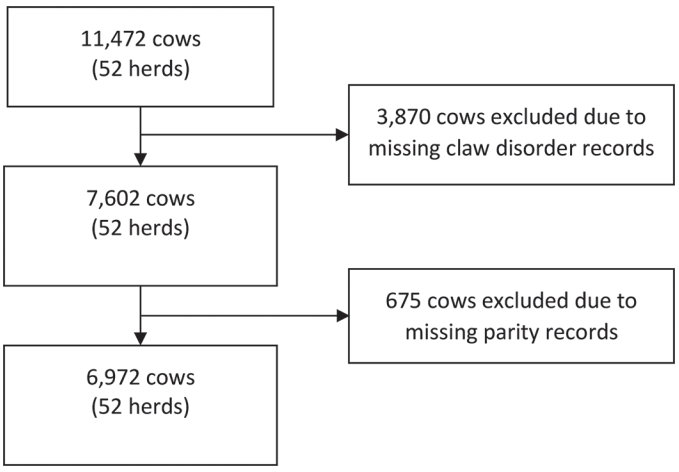

Figure 1. Flow chart illustrating the number of cows deleted from the original data set.

Statistical Analysis: Mobility Score, BCS, Claw Disorders, and Cow Parity

Analyses were performed using R statistical software (RStudio Team, 2016; function "multinom" for multinomial logistic regressions).

The associations between the predictor variables (BCS, presence and severity score of specific claw disorders, and cow parity) and mobility score (outcome variable) were assessed using a forward stepwise regression approach. Each individual predictor variable was first modeled alone (a univariate analysis) to predict mobility score. As each predictor variable was statistically significant ($P < 0.05$), they were all kept and included in the final model (a multivariate model; Hosmer and Lemeshow, 2000). Multinomial logistic regression was used to model nominal outcome variables, in which the log odds of the outcomes are modeled as a linear combination of the predictor variables. The outcome variable was mobility score (a categorical variable). The predictor variables were BCS (a categorical variable put into 3 groups: BCS <3.00, BCS = 3.00, and BCS >3.00; i.e., less than the median, the median, and greater than the median BCS, respectively), the presence and severity of each claw disorder (a categorical variable), and cow parity 1, 2, or 3+ (a categorical variable). The time difference in days (a continuous variable) between the visit for mobility score and BCS recording and the visit for claw disorder recording was included as a confounding factor in the model. Farm was included in the model as a random effect. Output variables were analyzed with multinomial logistic regressions. The assumption of proportional odds was tested for the data and was violated; thus multinomial logistic regression was used, assuming no order in the categories. Three multinomial logistic regression models were run with the same predictor and confounding variables; one model used mobility score 0 as a reference category, a second model used mobility score 1 as a reference category, and a third model used mobility score 2 as a reference category. In each of the 3 regression analyses, 3 of the 4 output categories (mobility score 0, 1, 2, or 3) were compared with a different reference category (mobility score 0, 1, and 2). In all 3 regression analyses, all of the claw disorders, BCS, and cow parity were included as predictor variables. The association between the reference categorical outcome variables and 3 other categorical outcome variables (e.g., mobility score 1, 2, or 3 in reference to mobility score 0) and the predictor variables was expressed as odds ratios. The interpretation of odds ratios differs when considering categorical predictor variables and continuous predictor variables. For the categorical predictor variables (claw disorder presence and severity, cow parity, and BCS), an odds

ratio >1 indicates that an increase in the predictor variables increases the risk of occurrence of a specific category rather than the occurrence of the reference category, whereas an odds ratio <1 indicates than an increase in the predictor variable decreases the risk of occurrence of a specific category rather than the occurrence of the reference category. For the continuous predictor variable (time difference, in days) between the first farm visit when mobility score and BCS were recorded and the farm visit when claw disorders were recorded and severity was scored, an odds ratio >1 indicates that a 1-unit increase in the predictor variables increases the risk of occurrence of a specific category rather than the occurrence of the reference category, whereas an odds ratio <1 indicates than a 1-unit increase in the predictor variable decreases the risk of occurrence of a specific category rather than the occurrence of the reference category. An odds ratio = 1 indicates that the outcome is the same for all mobility scores. For example, in a multinomial logistic regression predicting the occurrence of mobility score 1, 2, or 3 or the occurrence of the reference category mobility score 0, an odds ratio (for mobility score 3 vs. mobility score 0) >1 indicates an increase in the risk of occurrence of mobility score 3 rather than mobility score 0 in these multinomial models. The reference category is thus important for the interpretation of the results, bearing in mind that the reference category can be altered to reduce bias interpretations from the results. Predicted probabilities for mobility score were used to assess model fit by visual comparison with observed data (Gelman et al., 1996) and using the Hosmer-Lemeshow test statistic (Hosmer and Lemeshow, 1989). This test compares how well the observed data matches the predicted probabilities calculated from the model. Results from the test ($P > 0.05$) indicated good model fit.

RESULTS

Mobility Score, BCS, and Cow Parity

Figure 2 presents the distribution of mobility score, BCS, and cow parity for all cows analyzed. Of all cows, 38% were scored as 1, 2, or 3 for mobility and thus defined as suboptimally mobile. The BCS followed a normal distribution, with 91% of all the cows falling within the range of 2.75 to 3.25. Cow parity ranged from 1 to 13, with 30% in parity 1, 21% in parity 2, and 49% in parity 3 or greater.

Claw Disorder Prevalence

The distributions of severity scores for each claw disorder for all cows are presented in Figure 2, specifically for overgrown claw, sole hemorrhage, white line disease, sole ulcer, and digital dermatitis. Cows were on average 207 (SD = 53) DIM when claws were assessed. Noninfectious claw disorders (overgrown claw, sole hemorrhage, white line disease, and sole ulcer) were the most prevalent, with 84.5% (5,850) of all cows scoring >0 for having at least 1 of these disorders (further referred to as the noninfectious claw disorder group). Of the noninfectious claw disorder group (5,850 cows), sole hemorrhage was the most prevalent, with 3,639 of the noninfectious group scoring >0; this was followed by overgrown claw, with 3,537 of the noninfectious group scoring >0, then white line disease, with 3,420 of the noninfectious group scoring >0, and finally sole ulcer, with just 80 of the noninfectious group scoring >0. Digital dermatitis was found in 194 (2.8%) of the cows. The remaining cows (1,044, or 15.1%) had none of the assessed claw disorders on the day of recording.

Mobility Score, BCS, Claw Disorders, and Cow Parity Associations

Claw Disorders: Mobility Score 0. When the risk of having mobility score 1 versus the reference category mobility score 0 was evaluated, the odds ratios for all severities of overgrown claw, sole hemorrhage, and white line disease (severity score 1, 2, or 3) or sole ulcer and digital dermatitis (severity score 1) were consistently >1. This indicates that all severities of each claw disorder increase the risk of occurrence of a cow being scored mobility score 1 versus mobility score 0 and that even the mild forms of these claw disorders (severity score 1 for overgrown claw, sole hemorrhage, and white line disease) increased the risk of occurrence of mobility score 1 rather than mobility score 0 (Table 2). When the risk of having mobility score 2 versus the reference category mobility score 0 was compared, moderate (severity score 2) and severe (severity score 3) forms of overgrown claw, severe forms (severity score 3) of sole hemorrhage, and all severities (severity score 1, 2, and 3) of white line disease had odds ratios >1, indicating an increased risk for the occurrence of mobility score 2 rather than mobility score 0 (Table 2). When the risk of having mobility score 3 versus the reference category mobility score 0 was compared, only the severe forms of overgrown claw and white line disease (severity score 3) had significant odds ratios (odds ratios >1; white line disease severity score 1 and 2 had a tendency for odds ratio values >1), indicating an increased risk for the occurrence of mobility score 3 rather than mobility score 0 associated with cows that had these specific severities of these claw disorders. The mild and moderate forms (severity score 1 and 2) of overgrown claw and white line disease and all forms (severity score 1, 2, and 3) of

sole hemorrhage did not have an effect when comparing the risk of occurrence of mobility score 3 versus mobility score 0 (Table 2).

The binary severity-scored claw disorders were sole ulcer (noninfectious type) and digital dermatitis (infectious type). The odds ratios for both sole ulcer and digital dermatitis were relatively greater compared with the other claw disorders across all levels of mobility (1, 2, and 3) versus the reference category mobility score 0 (Table 2).

Claw Disorders: Mobility Score 1. When the model was run with the reference category mobility

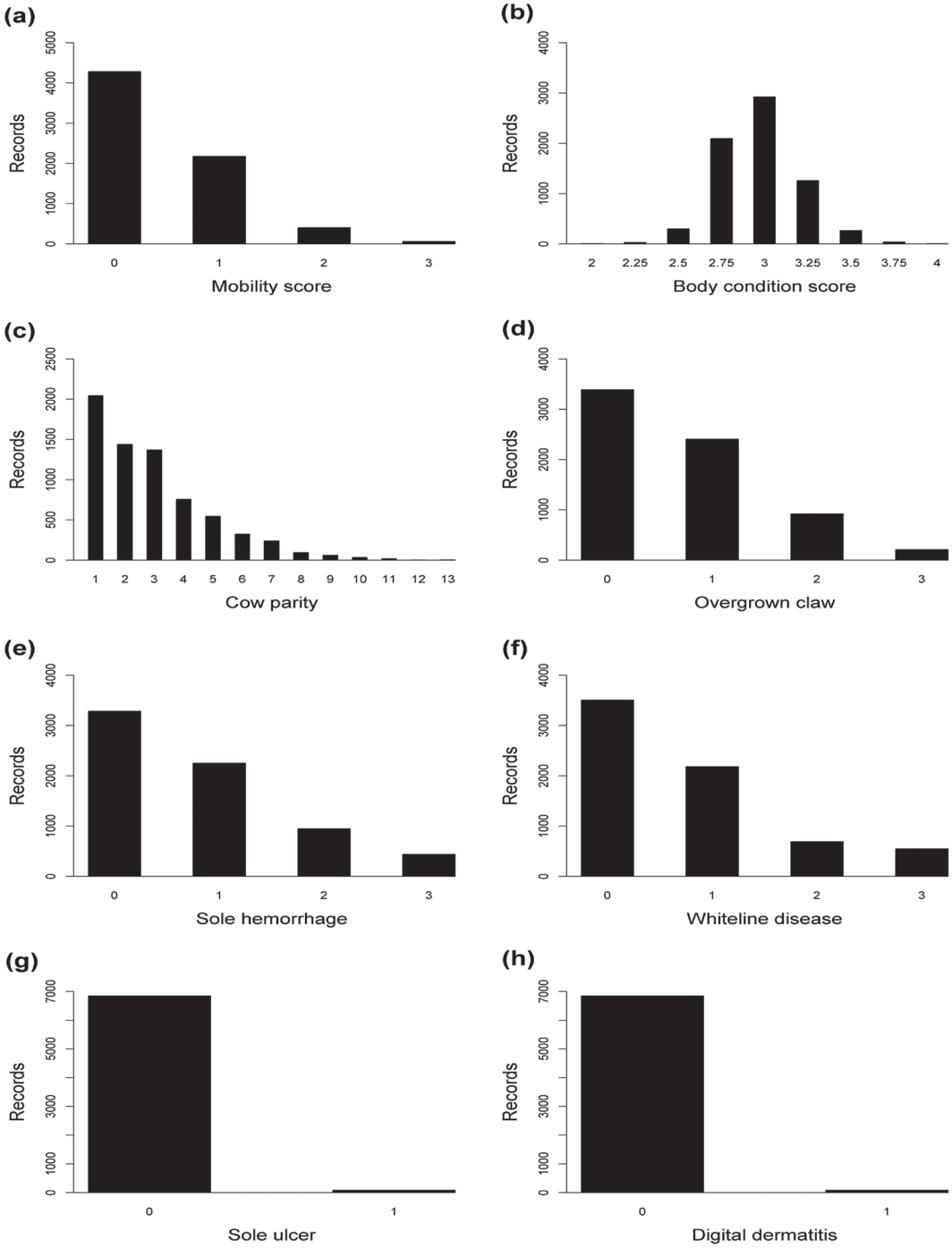

Figure 2. Distribution of (a) mobility scores (0–3 scale), (b) BCS (1–5 scale), (c) cow parity, (d) overgrown claw, (e) sole hemorrhage, (f) white line disease, (g) sole ulcer, and (h) digital dermatitis.

Table 2. Odds ratios and 95% CI for the multinomial logistic regression models used to predict mobility score (n = 6,927) by each claw disorder and BCS[1]

	MS0						MS1				MS2	
	Odds ratio		Odds ratio		Odds ratio		Odds ratio		Odds ratio		Odds ratio	
Risk factor	MS1	95% CI	MS2	95% CI	MS3	95% CI	MS2	95% CI	MS3	95% CI	MS3	95% CI
OG1	1.24***	1.12–1.37	0.86	0.64–1.09	0.82	0.42–1.59	0.69*	0.54–0.88	0.66	0.34–1.24	0.96	0.48–1.91
OG2	1.50***	1.31–1.73	2.20***	1.71–2.83	1.49	0.74–3.00	1.47*	1.14–1.89	0.99	0.49–2.00	0.68	0.33–1.38
OG3	3.09***	2.23–4.29	12.28***	8.36–18.03	23.60***	12.29–45.31	3.97***	2.84–5.55	7.63***	4.10–14.20	1.92†	1.04–3.55
SH1	1.27***	1.15–1.41	0.94	0.75–1.19	0.92	0.49–1.71	0.74*	0.59–0.94	0.72	0.39–1.34	0.97	0.51–1.85
SH2	1.38***	1.20–1.58	1.28	0.98–1.69	1.55	0.82–2.93	0.93	0.71–1.22	1.13	0.60–2.12	1.21	0.63–2.32
SH3	1.54***	1.27–1.87	2.21***	1.61–3.05	1.13	0.49–2.62	1.44†	1.05–1.97	0.73	0.32–1.70	0.51	0.22–1.18
WL1	1.15*	1.03–1.27	1.40*	1.10–1.78	0.56†	0.27–1.16	1.22	0.95–1.56	0.49	0.24–1.01	0.40*	0.19–0.85
WL2	1.32**	1.13–1.54	1.97***	1.45–2.69	1.06†	0.44–2.56	1.49*	1.10–2.03	0.8	0.34–1.93	0.54	0.22–1.32
WL3	1.50***	1.24–1.80	4.90***	3.71–6.46	4.61***	2.63–8.08	3.27***	2.49–4.30	3.08***	1.76–5.38	0.94	0.53–1.66
SU1	1.97*	1.13–3.44	7.94***	4.32–14.58	16.43***	7.15–37.78	4.03***	2.39–6.81	8.35***	3.86–18.04	2.07†	1.02–4.19
DD1	1.95***	1.42–2.67	6.94***	4.35–9.58	26.08***	14.08–44.70	3.32***	2.28–4.83	12.88***	7.34–22.60	3.89***	2.24–6.75
Parity 2	1.43***	1.25–1.64	1.88***	1.26–2.80	2.21	0.72–6.83	1.31	0.87–1.97	1.55	0.50–4.78	1.18	0.37–3.81
Parity 3	2.58***	2.30–2.89	5.45***	3.93–7.57	6.70***	2.76–16.24	2.11***	1.51–2.95	2.59†	1.07–6.30	1.23	0.49–3.07
BCS 3	0.71***	0.64–0.79	0.48***	0.39–0.59	0.26***	0.15–0.44	0.68**	0.55–0.84	0.37**	0.21–0.63	0.54†	0.31–0.94
BCS >3	0.61***	0.54–0.69	0.36***	0.27–0.47	0.09***	0.04–0.23	0.59**	0.43–0.77	0.15***	0.06–0.38	0.26	0.10–0.66
FV	1.00†	0.99–1.00	1.00***	0.99–1.00	0.99***	0.99–1.00	1.00**	0.99–1.00	0.99**	0.99–1.00	1.00†	0.99–1.00

[1]MS = mobility score (0 = optimal mobility; 1 = mild suboptimal mobility; 2 = moderate suboptimal mobility; 3 = severe suboptimal mobility); OG = overgrown claw (1 = mild; 2 = moderate; 3 = severe); SH = sole hemorrhage (1 = mild; 2 = moderate; 3 = severe); WL = white line disease (1 = mild; 2 = moderate; 3 = severe); SU = sole ulcer (1 = present); DD = digital dermatitis (1 = present); FV = farm visit (time in days between claw disorder recording date and mobility score and BCS recording date).

Odds ratio is significantly different or tends to be different from 1: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; †0.10.

score 1 (Table 2), the results in terms of odds ratios indicated (i.e., odds ratios >1) that overgrown claw severity scores 1, 2, and 3, sole hemorrhage severity score 1 (and a tendency for sole hemorrhage severity score 3), and white line disease severity scores 2 and 3 had an increased risk for the occurrence of mobility score 2 rather than the occurrence of the reference category, mobility score 1. Comparing mobility score 3 with the reference category mobility score 1, overgrown claw severity score 3, and white line disease severity score 3 resulted in odds ratios >1, indicating an increased risk for the occurrence of mobility score 3 rather than mobility score 1. Sole ulcer and digital dermatitis had odds ratios >1 when comparing the risk of occurrence for mobility scores 2 and 3 versus the reference category mobility score 1 (Table 2).

Claw Disorders: Mobility Score 2. When the model was run with the reference category mobility score 2 (Table 2), white line disease severity score 1 increased the risk of occurrence of mobility score 3 versus mobility score 2, and overgrown claw severity score 3 had a tendency for an increased risk in mobility score 3 compared with the reference category. Digital dermatitis was associated with increasing the risk of occurrence of mobility score 3 versus mobility score 2, whereas sole ulcer had a tendency for an increased risk of occurrence of mobility score 3 versus mobility score 2 (Table 2)

BCS. The odds ratios for BCS across all models (except the model run in which mobility score 2 was the reference value) were consistently <1 (Table 2), indicating that (1) cows with a high BCS (BCS $\geq$ 3.00) are associated with a decreased risk of occurrence of mobility scores 1, 2, and 3 rather than the reference category (mobility score 0) compared with cows with a BCS <3; (2) cows with a high BCS are associated with a decreased risk of the occurrence of mobility scores 2 and 3 rather than the reference category, mobility score 1; and (3) cows with BCS = 3.00 have a tendency for a decreased risk for having mobility score 3 rather than the reference category, mobility score 2.

Cow Parity. Cow parity was also included in the model as a predictor variable for mobility. The odds ratios for cow parity across all models were mainly >1 (Table 2), indicating that (1) parity 2 and 3+ cows are associated with an increased risk of the occurrence of mobility scores 1 and 2, and just parity 3+ cows are associated with an increased risk of occurrence of mobility score 3 rather than the reference category, mobility score 0 (compared with parity 1 cows); (2) parity 3+ cows are associated with an increased risk of occurrence of mobility score 2 and a tendency for an increased risk of occurrence of mobility score 3 rather than the reference category, mobility score 1 (compared with parity 1 cows); and (3) parity was not significant in the model with mobility score 2 as the reference category.

Days Between Farm Visits. The number of days between the farm visit when mobility score and BCS were recorded and the farm visit when claws were assessed was included in the model as a confounding effect. The odds ratios for this variable were consistently between 0 and 0.99, resulting in odds ratio values equal to 1.00 (rounded to 2 decimal places), indicating that the outcome of this variable is the same for all levels of mobility score.

DISCUSSION

Claw Disorders

Noninfectious claw disorders were by far the most prevalent for the cows included in this study, wherein about 85% of all cows had some form of noninfectious claw disorder (a severity score >0 for an overgrown claw, sole hemorrhage, white line disease, or sole ulcer) on the day they were recorded. The prevalence of noninfectious claw disorders was relatively higher than what is reported throughout the literature. This high prevalence is most likely due to the method of data collection used in this study, wherein claw disorders were recorded using a severity score, which resulted in extremely mild cases of claw disorders being recorded as disorders. Other studies may have overlooked these mild forms of claw disorders. This is in agreement with another study based on dairy cows in similar pasture-based systems (Somers and O'Grady, 2015). The infectious claw disorder digital dermatitis affected only 2.8% of all cows. It is widely accepted that infectious claw disorders are less prevalent in pasture-based systems compared with confinement systems, primarily because the cows are exposed to different environments and risks. For example, cows in zero-grazing systems have increased exposure of their claws to slurry and thus develop different types of claw disorders (Cook et al., 2004).

Ideally, mobility score, BCS, and claw disorders would have been scored and recorded on the same day by the same people; however, this was not possible due to time and budget constraints. An interesting finding from this study was that the claw disorders with severity score 1 (e.g., overgrown claw, sole hemorrhage, and white line disease) increased the risk of occurrence of mobility score 1 versus mobility score 0. Mobility score 1 in this study was essentially a cow with imperfect gait; thus, these cows were generally not picked up as being lame due to the mild nature of their imperfect mobility. Mobility score 2 or above was more likely to be what is described as "lame" in many other studies.

Thus, the results of this study found that mildly scored claw disorders were associated with mobility score 1 (cows with imperfect mobility). It is important to note that the level of mobility associated with mobility score 1 described in this study is likely to be equivalent to the level of mobility that would not have been reported in many other studies. This is because more often than not, only severely suboptimally mobile cows (often referred to as clinically or visually lame cows) are reported throughout the literature (Norring et al., 2014). This finding could be similar to the findings reported by Manske et al. (2002) and O'Callaghan (2002) in which an association between nonlame cows and claw disorders was reported. On the flip side, severely scored versions of the same claw disorders (severity scores 2 and 3 of overgrown claw and white line disease) increased the risk of occurrence of mobility score 3 versus 0, but the mild forms (severity score 1) did not increase the risk of occurrence of mobility score 3 versus 0. This finding indicates that the severity of the claw disorder had a direct association with mobility score; therefore, mildly severity-scored claw disorders (severity score 1 or 2) were not associated with severe suboptimal mobility (mobility score 3) but were associated with mild suboptimal mobility (mobility score 1). In other words, cows with an overgrown claw severity score 3 had an increased risk of being classed as mobility score 3 instead of mobility score 0 but did not have a significantly increased risk of being classed as mobility score 1 instead of 0. Therefore, it could be anticipated that the associated effects would follow a similar pattern.

In terms of the odds ratios for the various severities of the claw disorders included in the analysis, a trend was apparent in which the more severely scored claw disorders (overgrown claw, sole hemorrhage, and white line disease) had odds ratios (for an increased risk of having suboptimal mobility vs. optimal mobility) greater than their mildly scored forms. For example, for cows with an overgrown claw severity score 3, the odds ratio was 3.09, whereas the odds ratio for an overgrown claw severity score 1 was 1.24 when comparing the risk of occurrence of mobility score 1 versus the reference category mobility score 0. Similarly, when comparing the risk of occurrence of mobility score 2 versus mobility score 0, the odds ratio was 12.28 for an overgrown claw severity score 3 and just 0.86 for an overgrown claw severity score 1. When comparing the risk of occurrence of mobility score 3 versus mobility score 0, the odds ratio for an overgrown claw severity score 3 was 23.60, whereas the odds ratio for an overgrown claw severity score 1 was 0.82. This increase in odds ratio associated with the severely scored forms of these claw disorders indicates the greater effect they have on the risk of occurrence of suboptimal mobility in dairy cows in a pasture-based system.

Sole ulcer and digital dermatitis are both considered to be severe forms of claw disorders associated with a substantial amount of pain and inability to bear weight on the affected limbs (ICAR, 2015). The results from our study were in agreement with this inability to bear weight and increased pain, which may be associated with these more severe types of claw disorders. This is seen in our results, whereby a cow with some form of sole ulcer or digital dermatitis had relatively greater odds ratios, compared with cows with the other claw disorders, for an increased risk of having suboptimal mobility (mobility score 1, 2, or 3) versus optimal mobility (mobility score 0). These results are similar to those reported by Manske et al. (2002), in which the risk of lameness was increased for a cow with a sole ulcer or digital dermatitis.

BCS

The results presented in Table 2 provide evidence that a relatively low BCS is associated with the increased likelihood of the occurrence of suboptimal mobility (mobility score 1, 2, and 3) versus optimal mobility (mobility score 0). These results are in agreement with findings of Green et al. (2014), who reported that a BCS of <2.5 was a risk factor particularly for noninfectious claw disorders, which was by far the most prevalent type of claw disorders in the present study. Lim et al. (2015) reported that a loss of BCS increased a cow's probability of becoming identifiably lame and decreased her likelihood of recovery. This predisposition for cows with relatively lower BCS to be classed as suboptimally mobile could be explained by a low BCS being associated with a reduction in the depth of the digital fat cushion, which in turn is associated with suboptimal mobility as a result of claw disorders (Bicalho et al., 2008). In contrast to the findings of this study, however, Lim et al. (2015) also reported that an increase in BCS increases the risk of becoming lame. Regular condition scoring of cows to allow for research into regular changes in BCS is urgently required in this field to fully understand the effect of variation in BCS and mobility score in dairy cows in pasture-based systems.

Cow Parity

The findings of this study indicate a clear association between increased cow parity and an increase in the risk of occurrence of suboptimal mobility score versus optimal mobility score across both types of models

(Table 2). This is in agreement with the findings of Wells et al. (1993), in which parity was reported to be associated with clinical lameness (referred to as suboptimal mobility in this study), with higher prevalence of clinical lameness (similar to mobility score ≥2 in this study) found in cows of higher parity. Interestingly, our study also showed an increase in the risk of occurrence of suboptimal mobility even when comparing parity 1 cows and parity 2 cows in terms of odds ratios (Table 2).

Model

The model created for this study uses various cow health traits to characterize mobility score for dairy cows in pasture-based systems. The health traits used as predictors in this model include claw disorders and their severity scores, BCS, and cow parity. The model created in this study is different from others in that it uses dairy cow health traits to determine associations directly to a mobility score rather than to terms such as lame, subclinically lame, and clinically lame. This reduces the likelihood of misinterpretation of the results. This model could be included in other models, for example, to determine various effects of production at each level of mobility.

CONCLUSIONS

From the findings of this study, we conclude that there is an association between claw disorders (including both type and severity) and mobility score in dairy cows in pasture-based systems as well as an association between BCS, cow parity, and mobility score. Mild severity-scored claw disorders, such as overgrown claw, sole hemorrhage, and white line disease, increased the risk of occurrence of mobility score 1 versus mobility score 0, whereby mobility score 1 was similar to cows referred to as nonlame or subclinically lame in other studies. More severely scored claw disorders, such as overgrown claw, white line disease, and sole hemorrhage severity scores >2, were associated with an increased risk in the occurrence of mobility score 3 versus mobility 0. Low BCS and an increase in cow parity were also associated with suboptimal mobility score versus optimal mobility score. Mobility scoring can be used to identify problem cows (i.e., cows with mild forms of claw disorders) relatively earlier.

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