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Cow and herd-level risk factors associated with mobility scores in pasture-based dairy cows

A.H. O'Connor[a,b,*], E.A.M. Bokkers[b], I.J.M. de Boer[b], H. Hogeveen[c], R. Sayers[a], N. Byrne[a], E. Ruelle[a], B. Engel[d], L. Shalloo[a]

[a] Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland
[b] Animal Production Systems Group, Department of Animal Sciences, Wageningen University & Research, the Netherlands
[c] Business Economics Group, Department of Social Sciences, Wageningen University & Research, the Netherlands
[d] Mathematical and Statistical Methods - Biometris, Department of Plant Sciences, Wageningen University & Research, the Netherlands

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ABSTRACT

Lameness in dairy cows is an area of concern from an economic, environmental and animal welfare point of view. While the potential risk factors associated with suboptimal mobility in non-pasture-based systems are evident throughout the literature, the same information is less abundant for pasture-based systems specifically those coupled with seasonal calving, like those in Ireland. Therefore, the objective of this study was to determine the potential risk factors associated with specific mobility scores (0 = good, 1 = imperfect, 2 = impaired, and 3 = severely impaired mobility) for pasture-based dairy cows. Various cow and herd-level potential risk factors from Irish pasture-based systems were collected and analyzed for their association with suboptimal mobility, whereby a mobility score of 0 refers to cows with optimal mobility and a mobility score ≥ 1 refers to a cow with some form of suboptimal mobility. Combined cow and herd-level statistical models were used to determine the increased or decreased risk for mobility score 1, 2, and 3 (any form of suboptimal mobility) compared to the risk for mobility score 0 (optimal mobility), as the outcome variable and the various potential risk factors at both the cow and herd-level were included as predictor type variables. Cow-level variables included body condition score, milk yield, genetic predicted transmitting ability for 'lameness', somatic cell score, calving month and cow breed. Herd-level variables included various environmental and management practices on farm. These analyses have identified several cow-level potential risk factors (including low body condition score, high milk yield, elevated somatic cell count, stage of lactation, calving month, and certain breed types), as well as various herd-level potential risk factors (including the amount of time taken to complete the milking process, claw trimmer training, farm layout factors and foot bathing practices) which are associated with suboptimal mobility. The results of this study should be considered by farm advisors when advising and implementing a cow/herd health program for dairy cows in pasture-based systems.

1. Introduction

Lameness is an area of increasing concern facing the dairy sector worldwide, being considered one of the most important disease challenges by Huxley (2012). Lameness is the third most important disease related economic loss, after both fertility and mastitis (Bruijnis et al., 2010), whereby lameness has been shown to have negative associations with various aspects of both production and reproduction (Bicalho et al., 2008; Alawneh et al., 2011; O'Connor et al. (in press). With compromised production effects associated with lameness, it is not surprising that recent findings have also reported on the negative environmental consequences, such as increased greenhouse gas emissions (Mostert et al., 2018), acidification, eutrophication and fossil fuel depletion (Chen et al., 2016). As well as this the welfare of lame cows is also at risk due to the pain and behavioral changes associated with this debilitating disease (O'Callaghan, 2002; Navarro et al., 2013).

Most cases of lameness are as a result of various types of claw disorders (Huxley, 2012; O'Connor et al., 2019), with the majority of claw disorders causing lameness found in the hind limbs (Murray et al., 1996). However, it is important to note that cows can become lame as a result of other factors, such as for example udder distention in heifers (Flower et al., 2006). Therefore the use of visual locomotion or mobility scoring rather than visual inspection solely for the presence of claw disorders is a preferred and a less invasive technique for detecting

* Corresponding author.
E-mail addresses: aisling.oconnor@teagasc.ie, aisling.oconnor@wur.nl (A.H. O'Connor).

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lameness. Given the multifactorial nature of lameness and how it is measured, in the present study we use the four-point mobility scoring scale for lameness as defined by the UK Agriculture and Horticulture Development Board (AHDB), whereby a mobility score 0 refers to a cow with good or 'optimal' mobility, and a mobility score 1, 2, or 3 refer to a cow with increasing severities of suboptimal mobility (imperfect, impaired and severely impaired mobility, respectively).

While various cow and environmental type risk factors associated with lameness have been reported in the literature, there is a particular emphasis on housing and management type risk factors (De Vries et al., 2015), including flooring type (Somers et al., 2003), the availability, cleanliness, and type of bedding (Cook et al., 2004; Chapinal et al., 2013), and access to pasture (Hernandez-Mendo et al., 2007; Olmos et al., 2009). There is less known about potential cow and herd-level risk factors in pasture-based systems, specifically during the grazing season (Alawneh et al., 2011; Bran et al., 2018). A reason for this may be the presumed perception that pasture-based cows are less at risk for succumbing to mobility issues. This perception is most likely due to the reported positive effect that access to pasture has for cows compared to confinement type systems (Chapinal et al., 2013). However cows in pasture-based systems are exposed to a variety of potential risk factors such as cow roadway conditions, distance walked each day, and other management type factors.

In north-west Europe, a pasture-based system generally refers to a system in which cows are housed during the winter period and are managed at pasture for the remainder of the year. A key difference between pasture-based systems in Ireland compared to other countries is the seasonal calving aspect, whereby cows are turned out to pasture post calving once ground conditions allow (Shalloo et al., 2014), wherein over 70 % of cows calve between January and March (Irish Cattle Breeding Statistics, 2018). In such a system, it was previously reported by O'Connor et al. (2019), that up to 38 % of cows were recorded as having some form of suboptimal mobility (a mobility score ≥ 0 using the AHDB scale). Therefore, the objective of the present study was to investigate the potential cow and herd-level risk factors associated with suboptimal mobility in spring calving, pasture-based systems.

2. Materials and methods

This section will describe the data collection, data edits, and statistical analysis for the both the cow and herd-level potential risk factors analysis. For the statistical analyses, a combined cow and herd-level analyses that incorporated repeated cow-level measures was completed.

2.1. Cow-level data collection and edits

Data used in this analysis were collected from a sample of Irish pasture-based dairy cows as part of another research project entitled "Healthy-Genes". Herds were selected for inclusion based on the following criteria: 1) maximum of 100 km from Teagasc, Moorepark in Fermoy, 2) must have been registered to the Irish Cattle Breeding Federation (ICBF) milk recording system, 3) herd owners must have been willing to have their herd genomically tested, and 4) must have been operating a spring calving pasture-based system. The Irish spring calving, pasture-based system refers to compact seasonal calving systems, whereby cows are turned out to pasture post calving. The system focus is to manage the interface between the cow and the pasture, with a focus on maximizing grass intake and grass utilisation (Dillon et al., 2015). Participation was on a voluntary basis. Sixty-eight pasture-based dairy herds (consisting of 11,116 cows) fitted the criteria and were included in the data collection. The average herd size was 169 (standard deviation of 115) cows. However, due to missing or incomplete records the number of cows included in each of the cow-level analyses differed (described in Table 2 and Table 3). No difference in cow or herd-level attributes is known by the authors between the subset of cows used in the analyses (due to deletions of some data) and the excluded cows/herds.

2.1.1. Body condition score and mobility score

Each herd was visited twice by two trained technicians from Teagasc, Moorepark during the 2015 calendar year. The first visit took place during March through May and the second visit took place during June through November. During each herd visit, each lactating cow was assessed for their body condition score (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 1–5 with 0.25 increments, as described by Edmonson et al. (1989). As a categorical variable, BCS data was regrouped based on the median. The categories were < 3, = 3, and > 3 (less the median, the median, and greater than the median). Mobility quality of each cow was scored using the UK Agriculture and Horticulture Development Board four point scale (https://dairy.ahdb.org.uk/technical-information/animal-health-welfare/'lameness'/husbandry-prevention/mobility-scoring/#.WXnhU-LuFOr8; accessed December 16, 2017), using the following definitions.

- A score of 0 describes a cow with good mobility that walks with even weight bearing and rhythm on all four feet, with a flat back. Long and fluid strides are possible.
- A score 1 describes a cow with imperfect mobility (any mobility score > 0 is defined as suboptimal mobility) with uneven steps or shortened strides affecting one or more limbs and it may not be immediately identifiable.
- A score 2 describes a cow with impaired mobility, which is a cow with uneven weight bearing on one or more limbs that is immediately identifiable and/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 to score 2.

2.1.2. Production data and somatic cell count

Production data were extracted from the ICBF database for the full lactation of the calendar year 2015, for all cows. Production data included; milk, fat, and protein yield (corrected for a 305 day lactation), and the average somatic cell count for the entire lactation. To account for variability in fat and protein content of different farms, the functional unit chosen was a kg of fat and protein corrected milk (FPCM) (One kg FPCM = 1 kg milk × (0.337 + 0.116 × Fat% + 0.06 × Protein %) (Yan et al., 2011). The statistical models initially failed to converge when FPCM was used as continuous variable, therefore FPCM was converted into three approximately equal groups; < 6000 kg, 6,000–7,100 kg, and > 7100 kg. Somatic cell count (SCC) data was transformed to somatic cell score ($\log_{10}$ SCC) using a logarithm to the base 10 to normalize the data (Ali and Shook, 1980).

2.1.3. Predicted transmitting ability (PTA) data

The EBI is a breeding index, used to select genetically superior animals to increase profitability within Irish dairy herds (Veerkamp et al., 2002). The EBI and its subindices are described in detail by Berry et al. (2007). The EBI subindices trait values for 'health' were extracted from the ICBF database for the year 2015, for all cows. The health subindex is made up of three traits: 'lameness', mastitis, and $\log_{10}$ SCC, expressed as predicted transmitting abilities (PTAs). The genetic PTA for 'lameness' is used in the cow-level analyses, and is a continuous variable. The higher the PTA for lameness, the more progeny that are expected to become lame during the lactation. Therefore, a PTA for 'lameness' less than 0 translates as a reduced risk for 'lameness', and a PTA greater than 0 translates as an increased risk for 'lameness'. An animal's PTA indicates the amount of a particular trait an animal is expected to pass on to its progeny, relative to the base population (Berry et al. (2007).

The base population performance figures are 5743 kg milk, 224 kg fat (3.9 %), 195 kg protein (3.39 %), a 400 day calving interval and 82.5 % survival (Irish Cattle Breeding Statistics, 2018). The PTA for lameness was put into three groups; < 0, = 0, and > 0.

2.1.4. Calving month, days in milk, cow breed and cow parity

For the year 2015, calving date, days in milk (DIM), cow breed and cow parity records were extracted from the ICBF database. Days in milk refers to the number of days the cow has been producing milk on each day her mobility score and BCS were recorded, therefore each cow has two DIM records. Cows that had not yet calved on the day that mobility score and BCS were collected were recorded as 0 DIM. Days in milk was categorized into three groups; < 60 DIM, 60–120 DIM, and ≥ 120 DIM. Calving dates were grouped into calving months for the analyses, whereby 1371 cows calved in January, 5970 in February, 2509 in March, and 1219 in April or later. Analyzed cows comprise 75 % Holstein, 13 % Jersey, and 9% Friesian cattle, which is representative of the national population (Ring et al., 2018). Cow breed was put into the following groups for the analyses; Holstein-Friesian (HF), Holstein-Jersey (HJ), other Holstein-Friesian cross (HX) i.e. Holstein-Friesian crossed with any other breed that is not Jersey, and other Jersey-Cross (JX), i.e. Jersey crossed with any breed other than Holstein-Friesian. Parity ranged from 1 through 13, whereby parity 1 cows made up 30 % of all the cows, parity 2 cows made up 20 % of all the cows, and Parity 3+ cows made up 50 % of all the cows.

2.2. Herd-level data collection and edits

Herd-level data for this study were collected from a survey completed in 2015 by the farmers via SurveyMonkey. Each farmer completed the survey throughout the calendar year 2015. The objective of the survey was to collect data on the overall health status (not just mobility related) of the herds (including some questions of farmers' perception of their herds' health status). The survey consisted of 38 questions collecting information including; herd identifiers, general farm characteristics, level of concentrate and mineral supplementation, number and type of animals purchased throughout the year 2015, biosecurity measures practiced on farm, milking routine, cow roadway condition, distances walked by the cows, claw trimming and foot bathing routine. Not all data from the survey was deemed biologically relevant for this analyses (e.g. certain biosecurity measures), therefore were not included. Non-binary responses by farmers were re-categorized into binary responses using authors' expertise and expertise of others (including experiences technicians) in the field for the purposes of this analysis in an attempt to have relatively even number of herds within each category and indeed to ensure categories made biological sense. Where it did not make biological sense to categorize to binomial responses and the number of herds in a category was less than five farms, the variable was dropped from any further analysis. These binary responses are outlined in Table 1, describing in detail exactly how the categories were created. Due to missing records, incomplete responses, or failure of farmers to complete the surveys, just 47 of the total 68 had herd-level data available to include in this analyses.

2.3. Statistical analysis

Descriptive statistics and modelling were performed using the R statistical software (RStudio Team, 2016), using binomial logistic regression models (function 'glmer' and 'glmmTMB').

2.3.1. Pre model building

Prior to multivariable model development, variables were tested for collinearity using Fishers-exact test, and variables found to be markedly correlated were not used in the model simultaneously. Correlated variables included; cow parity and FPCM, walking distance and herd size, milking duration and stocking rate, and grazing platform and stocking rate. Pairs of correlated variables were not tested simultaneously, rather each variable was tested for one at a time and the significant variable (P value < 0.05) was kept. Binomial logistic regression was used to model the nominal outcome variables, in which the log odds of the outcomes are modeled as a linear combination of the cow and herd-level variables. Binomial logistic regression was used to investigate the potential risk factors for imperfect, impaired and severely impaired (all forms of suboptimal mobility) mobility (mobility score ≥ 1) together, which were compared to optimal mobility (mobility score 0). Binomial logistic regression was also used to investigate the potential risk factors for impaired and severely impaired forms of suboptimal mobility (mobility score ≥ 2) compared to optimal and imperfect mobility (mobility score 0 and 1).

For the binomial logistic regression analyses the potential cow-level risk factors for suboptimal mobility included in the analyses were; BCS, FPCM, $\log_{10}$ SCC, the PTA for 'lameness', cow breed, calving month and DIM.

2.3.2. Model building

Step 1; all cow and herd-level variables were run together in one multilevel model, with repeated measures using the mobility score and BCS collected during the early scoring period. Biologically relevant interactions were also tested for using author's own expertise. The interactions tested included; walking distance and cow path roughness/maintenance/cleanliness, $\log_{10}$ SCC and cow path cleanliness, and soil type and mineral supplementation. A combined forward and backwards stepwise variable selection method was applied. The step function used selects the variables to be kept based on the AIC of the model. Step 2; step 1 was repeated by replacing the early lactation mobility score and BCS with the late lactation mobility score and BCS. Step 3; all selected variables from step 1 and 2 were inputted together with early and late lactation mobility score and BCS inputted as repeated measures in the model. Cow nested within herd was inputted in the final model as a random effect variable. Step 4; the model created in step 3 was then restricted to significant variables (P value < 0.05) only and each removed variable was retested one at a time again in the model. Removed and retested variables that did not significantly affect the outcome of the model selected in step 3 were excluded from any further analyses. Variables that were removed and retested that were either significant or affected the significance of other variables already in the model were further investigated for their interaction with the other variables.

3. Results

The proportion of cows in each mobility score is previously reported by O'Connor et al. (in press), whereby 35.7 % of cows were scored as having some form of suboptimal mobility (mobility score ≥ 1) during the early and 38.2 % during the late scoring period. The proportion of mobility score ≥ 2 at the cow-level was 4.2 % during the early and 7.1 % during the late scoring period, while the proportion of mobility score = 3 was 0.7 % during the early and 0.6 % during the late scoring period.

The herd-level prevalence (average proportion of cows per herd) of suboptimal mobility (mobility score ≥ 1) was 36.1 % (standard deviation (SD) = 13.15) during the early scoring period and 37.8 % (SD = 7.84) during the late scoring period. The herd-level prevalence of cows with a mobility score ≥ 2 at the herd-level was 11.0 % (SD = 8.61) during the early scoring period and 5.9 % (SD = 5.71) during the late scoring period, while the prevalence mobility score = 3 was 1.3 % (SD = 2.37) during the early scoring period and 0.5 % (SD = 1.17) during the late scoring period.

Results for the analysis of the cow and herd-level potential risk factors for suboptimal mobility are presented in Table 2 and Table 3.

Table 1
Herd-level factors and observed number of herds per factor level (n = 50 pasture- based dairy farms).

Factor[1]	Herd-Owner response	Farms, n[2]	Binary categories	Farms, n[2]
Grazing platform	Single platform	10	Single platform	10
	≤ 3 platforms	32	> 1 platform / use public road	40
	> 3 platforms	8		
Walking distance[3]	< 0.4 km	2	< 0.8 km	16
	0.4 – 0.79 km	14	≥ 0.8 km	33
	0.8 – 1.59 km	21		
	≥ 1.6 km	12		
Collecting yard procedure after milking	Not retained, allowed walk freely back to pasture	38	Not retained, allowed walk freely back to pasture	38
	Retained until all cows are milked	10	Retained until all cows are milked	10
Milking duration[4]	≤ 60 minutes	4	< 90 min	29
	61 – 90 min	25	≥ 90 min	20
	91 – 120 minutes	12		
	121 – 150 min	4		
	≤ 151 minutes	4		
Cow path roughness (ranked 1 – 5)	1 = Smooth	16	Smooth (1)	16
	2 = less smooth than 1	22	Relatively not smooth - very rough (> 1)	34
	3 = less smooth than 2	11		
	4 = less smooth than 3	1		
	5 = Very Rough	0		
Cow path cleanliness (ranked 1 – 5)[5]	0.75	1	Clean (1 – 1.5)	27
	1.00	6	Relatively not clean - significant mud and dung build up (> 1.5)	22
	1.25	13		
	1.50	7		
	1.75	11		
	2.00	7		
	2.25	3		
	2.50	1		
Cow path maintenance	Completed within the past year	20	Completed within the past year	20
	Completed within the past 3 years	13	Completed more than 1 year ago	28
	Completed within the past 6 years	11		
	Completed more than 6 years ago	4		
Soil type (ranked 1 – 4)	1 = very dry	14	Very dry (1 – 2)	32
	2 = less dry than 1	18	Moderately dry - moderately wet (> 1)	17
	3 = less dry than 2	13		
	4 = less dry than 3	4		
	5 = very wet	0		
Foot bathing frequency	Never	23	Never	23
	Once per 2 weeks	4	At least once per year	24
	Once per month	4		
	Once per 2 months	8		
	Once per 6 months	5		
	Once per year	3		
Claw trimmer training	Trained personnel	30	Trained personnel	30
	Non-trained personnel	18	Non-trained personnel	18
Mineral supplementation	Via bolus	8	Provided	37
	Via concentrate feed	22	Not provided	11
	Via water	7		
	Not provided	11		
Herd size		25	< 130 lactating cows	25
		24	≥ 130 lactating cows	24
Stocking rate[6]	≤ 2.5	9	< 3.0	32
	2.5 – 2.74	9	≥ 3.0	17
	2.75 – 2.99	14		
	3.00 – 3.24	11		
	≥ 3.25	6		

[1] All data presented is for the lactation during the calendar year 2015.
[2] The number of farms does not always equal to 50 due to missing observations.
[3] Refers to the distance cows have to walk to the furthest away grazing ground.
[4] Refers to the average time from when the cows leave the paddock until they return to the paddock after milking.
[5] Cow road cleanliness was scored on a five point scale each season (spring, summer, autumn and winter). These scores were averaged across all seasons.
[6] Livestock units per hectare on the milking platform.

3.1. Cow-level risk factors for mobility score ≥ 1

Results for the analyses of the potential cow-level risk factors for all forms of suboptimal mobility (mobility score ≥ 1) are presented in Table 2. Having a BCS = 3 and > 3 (compared to BCS < 3) was associated with a decreased risk of occurrence for having a mobility score ≥ 1 compared to mobility score 0. A FPCM yield between 6,000–7,100 kg, and > 7100 kg (compared to < 6000 kg) were found to be associated with an increased risk of occurrence for having a mobility score ≥ 1. Elevated $\log_{10}$ SCC was also associated with an increased risk of occurrence of a cow being scored as mobility score ≥ 1.Similarly, a PTA for 'lameness' = 0 and > 0 (compared to a PTA < 0) increased the risk of occurrence of mobility score ≥ 1 compared to mobility score 0. Cow breeds; HJ and JX cows (compared to HF cows) were found to be associated with a decreased risk of occurrence of mobility score ≥ 1, while there was no significant association between

Table 2
Results[1] of the final binomial logistic regression model of the cow (n = 6062) and herd (n = 44) level risk factors associated with mobility score[2] ≥ 1.

Variable[3]	Category	*P*-Value	Odds Ratio	SE	*P*-Value pairwise comparison	95 % CI
Intercept			0.03	1.54	< 0.001	0.02 – 0.06
BCS	< 3	< 0.001	1.00			
	= 3		0.62	1.05	< 0.001	0.57 – 0.67
	> 3		0.54	1.06	< 0.001	0.49 – 0.60
FPCM	< 6000	< 0.001	1.00			
	6,000–7,100		1.59	1.06	< 0.001	1.45 – 1.75
	> 7100		2.40	1.07	< 0.001	2.17 – 2.67
$\log_{10}$ SCC		< 0.001	1.53	1.08	< 0.001	1.34 – 1.74
PTA	< 0	< 0.001	1.00			
	= 0		1.18	1.07	0.015	1.06 – 1.33
	> 0		1.41	1.06	< 0.001	1.28 – 1.54
Breed	HF	< 0.001	1.00			
	HJ		0.47	1.07	< 0.001	0.42 – 0.53
	HFX		1.11	1.07	0.138	0.99 – 1.25
	JX		0.37	1.16	< 0.001	0.29 – 0.47
Calving Month	January	< 0.001	1.00			
	February		1.30	1.08	< 0.001	1.15 – 1.48
	March		1.66	1.09	< 0.001	1.44 – 1.91
	April or later		1.40	1.11	0.001	1.18 – 1.66
DIM	< 60	0.066	1.00			
	60–120		1.10	1.06	0.118	1.00 – 1.22
	> 120		1.12	1.05	0.028	1.03 – 1.22
Milking duration	< 90 min	0.006	1.00			
	≥ 90 min		1.34	1.11	0.006	1.13 – 1.60
Claw trimmer training	Trained personnel	0.006	1.00			
	Non-trained personnel		0.74	1.11	0.006	0.62 – 0.89
Grazing platform	Single platform	0.089	1.00			
	> 1 platform / use of public road		1.27	1.15	0.089	1.01 – 1.59

BCS = body condition score; FPCM = fat and protein corrected milk; PTA = 'lameness' predicted transmitting ability; $\log_{10}$ SCC = log 10 transformation of somatic cell count; HF = Holstein-Friesian; HJ = Holstein Jersey; HFX = Holstein-Friesian cross; JX = Jersey cross; CI = confidence interval.
***, **, *, † odds ratio is significantly or tends to be different from 1 (P < 0.001, 0.01, 0.05, 0.10).
[1] All data presented is for the lactation during the calendar year 2015.
[2] Mobility score 0 = optimal mobility; mobility score 1 = imperfect mobility; mobility score 2 = impaired mobility; mobility score 3 = severely impaired mobility.
[3] Cow nested within herd accounted for as a random variable.

HFX cow breed and suboptimal mobility. Cows that calved in February, March, or April or later (compared to cows that calved in January) were associated with an increased risk of occurrence of mobility score ≥ 1 versus mobility score 0. Similarly, cows > 120 DIM were also associated with an increased risk for the occurrence of mobility scores ≥ 1 compared to mobility score 0.

3.2. Herd-level risk factors for mobility score ≥ 1

Milking duration ≥ 90 min was found to be a potential risk factor for the increased occurrence of mobility score ≥ 1 compared to mobility score 0. When routine claw trimming was undertaken by non-specifically trained personnel there was a decreased risk of occurrence of mobility score ≥ 1. There tended to be an increased risk for the occurrence of mobility score ≥ 1 for herds with at least two grazing platforms for the lactating herd, or herds that use public roads in order to travel between grazing paddocks and the milking parlor.

3.3. Cow-level risk factors for mobility score ≥ 2

Similar to the potential risk factors at the cow-level for mobility score ≥ 2, a BCS = 3 and > 3 were associated with a decreased risk for the occurrence of mobility score ≥ 2 compared to mobility score < 2 (mobility score 0 and 1). Having a PTA for 'lameness' = 0 was not significantly associated with an increased risk for mobility score ≥ 2, while having a PTA for 'lameness' > 0 was. Cows later in their lactation (> 120 DIM) were also associated with an increased risk for mobility score ≥ 2, however being 60–120 DIM was not associated with an increased risk for mobility score ≥ 2. Fat and protein corrected milk yield, calving month, $\log_{10}$ SCC, and breed were dropped from this model during the model building procedure as they were not significantly associated with a mobility score ≥ 2.

3.4. Herd-level risk factors for mobility score ≥ 2

Collecting yard procedure whereby herds are retained in the collecting yard until all cows are milked (rather than not being retained and allowed walk freely back to pasture) was significantly associated with an increased risk for the occurrence of mobility score ≥ 2 compared to mobility score < 2. Foot bathing frequency of at least once per year (compared to never) was also significantly associated with an increased risk for the occurrence of mobility ≥ 2 at the herd-level.

4. Discussion

The proportion of suboptimal mobility (a cow with a mobility score > 0, using the UK AHDB 4-point scale) in the present study was 35.7 % during the early scoring period and 38.2 % during the late scoring period. Although this appears quite high it is important to note the scoring method used, whereby suboptimal mobility includes cows with mobility levels ranging from imperfect to severely impaired. As reported by O'Connor et al., 2020 (in press), cows with a mobility score 2 and 3 (impaired and severely impaired mobility) made up 4.2 % during the early and 7.1 % during the late scoring period, while just 0.7 % of the cows had a mobility score 3 (severely impaired mobility) during the early and 0.8 % during the late scoring period. Somers et al. (2015) reported a 'lameness' prevalence of between 11.6 % and 14.6 % throughout the lactation in 10 pasture-based Irish dairy farms, whereby 'lameness' refers to a cow with a mobility score ≥ 3 (described as moderately lame) using the 5-point scale described by Sprecher et al. (1997). Comparing the prevalence in our study to the study of Somers et al. (2015) (and indeed many other studies reporting the incidence of mobility issues) is fraught with difficulties due to the variation between mobility scoring scales used. However, if we assume a mobility score ≥ 3 using the scoring method described by Sprecher et al. (1997) is comparable to a mobility score ≥ 2 described in our study; the prevalence reported in our study (4.2 % and for the early and 7.1 % for the late scoring period) is substantially lower. The lower prevalence of a possibly comparable level of suboptimal mobility found in our study could be explained by differences in genetics, farm management practices and/or the comparison between the studies.

4.1. Cow-level risk factors associated with suboptimal mobility

Our study analyzed BCS of each cow recorded at two time points (during early lactation and during late lactation) as repeated measures, as described in the materials and methods. It has been reported by Lim et al. (2015) that, as the level of BCS loss of cows increased between at least two recordings, that the probability of becoming 'lame' increases. Somers et al. (2019) reported on the effect of BCS at the time of calving on the risk for 'lameness', which refers to a cow with a locomotion score ≥ 3 using a five point scale. Somers et al. (2019) found that BCS loss

Table 3
Results[1] of the final binomial logistic regression model of the cow (n = 6675) and herd (n = 47) level risk factors associated with mobility score[2] ≥ 2.

Variable[3]	Category	*P*-Value	Odds Ratio	SE	*P*-Value pairwise comparison	95 % CI
Intercept			0.00	1.47	< 0.001	0.00 – 0.00
BCS	< 3	< 0.001	1.00			
	= 3		0.37	1.27	< 0.001	0.25 – 0.55
	> 3		0.46	1.33	0.007	0.29 – 0.74
PTA	< 0	0.014	1.00			
	= 0		1.57	1.49	0.257	0.82 – 3.03
	> 0		2.33	1.33	0.003	1.46 – 3.72
DIM	< 60	< 0.001	1.00			
	60–120		1.12	1.35	0.701	0.69 – 1.83
	> 120		12.75	1.27	< 0.001	8.62 – 18.84
Collecting yard procedure	Not retained, allowed walk freely back to pasture	0.011	1.00			
	Retained until all cows are milked		2.26	1.38	0.011	1.33 – 3.84
Foot bathing frequency	At least once per year	0.019	1.00			
	Never		0.53	1.32	0.019	0.34 – 0.83

BCS = body condition score; PTA = 'lameness' predicted transmitting ability; CI = confidence interval.
***, **, *, † odds ratio is significantly or tends to be different from 1 (P < 0.001, 0.01, 0.05, 0.10).
[1] All data presented is for the lactation during the calendar year 2015.
[2] Mobility score 0 = optimal mobility; mobility score 1 = imperfect mobility; mobility score 2 = impaired mobility; mobility score 3 = severely impaired mobility.
[3] Cow nested within herd accounted for as a random variable.

around the time of calving was associated with reduced 'lameness', while BCS loss after calving was associated with an increased risk for 'lameness'. In the current study each cows BCS and mobility score were recorded on the same day, therefore no cause and effect between BCS and mobility score can be concluded, rather an association. The present study reports that cows with a BCS ≥ 3 were at a lower risk of being identified as having all levels suboptimal mobility (mobility score ≥ 1) compared to mobility score 0 (Table 2) and for having impaired and severely impaired mobility (mobility score ≥ 2) compared to mobility score < 2 (Table 3). This finding is in agreement with Solano et al. (2015) reporting that cows with low BCS had the highest 'lameness' prevalence (referring to a locomotion score ≥ 3 using a five point scale). Green et al. (2014) also reported that cows with a BCS < 2.5 were associated for an increased risk to be treated for 'lameness' (defined by the presence of certain claw disorders), which implies cows with less body condition have an increased risk to have mobility issues.

The present study also reports that milk yield (expressed as FPCM) ≥ 6000 kg is a potential risk factor associated with an increased risk for a cow to have any form of suboptimal mobility (mobility score ≥ 1 compared to mobility score 0) (Table 2). This finding is in agreement with much of the research published over the past number of years (e.g. (Green et al., 2002; Bicalho et al., 2008; Archer et al., 2010)), reporting that various forms of 'lameness' or in this case; all forms of suboptimal mobility are indeed associated with higher milk yield (Huxley, 2013). In the present study FPCM yield was dropped during the model building process (results presented in Table 3) because it was found not to be significantly associated with an increased risk for the occurrence of mobility scores ≥ 2 compared to mobility score < 2 (Table 3). Similar results are reported in this study for other cow-level potential risk factors including; $\log_{10}$ SCC, cow breed and calving month, whereby these potential risk factors appear to pose significant risk for increased mobility scores ≥ 1 (compared to mobility score 0) (Table 2), but not significantly associated with an increased risk for mobility score ≥ 2 (compared to mobility scores < 2) (Table 3). We are not aware of any research that analyzed cow and herd-level risk factors in a similar way as to how we have done in the current study. Therefore, we hypothesized that perhaps these cow-level risk factors mentioned, that are significant when analyzing the risk for mobility scores ≥ 1 compared to mobility score 0, are not associated with a risk for mobility scores ≥ 2, because the number of cows scored with a mobility score ≥ 2 is relatively low compared to the number of cows with a mobility score ≥ 1.

As mentioned, the current study also found that increased SCC is associated with mobility score ≥ 1, whereby cows with relatively higher $\log_{10}$ SCC are associated with an increased risk for the occurrence of mobility scores ≥ 1 compared to mobility score 0. This finding is in contradiction with the study by Archer et al. (2011) using the same mobility score method as used in the current study, which reported that cows with a mobility score = 2 on some farms, and mobility score = 3 on other farms, actually had a lower geometric mean $\log_{10}$ SCC compared to cows with a mobility score 0 or 1. One of the main differences between the study of Archer et al. (2011) and the present study is the distribution of the number of cows per mobility score. Archer et al. (2011) reports that just 1.7 % of all cows were scored as mobility score 0, while in the present study ~ 60 % of all cows were scored as mobility score 0 during both the early and late scoring period. Finally, there is also a difference in the type of data analyzed between the study of Archer et al. (2011) compared to the present study, whereby Archer et al. (2011) used repeated measures for SCC and mobility scores, whereas average lactational SCC data was analyzed in the present study which may be a cause for contradicting results between both studies. Archer et al. (2011) goes on to discuss the findings of Cook et al. (2004) that lame cows may spend more time standing compared to non-lame cows, therefore reducing the exposure of teat ends of lame cows to pathogens residing in the bedding material of cubicles. However, in contradiction to this, it is also reported by Navarro et al. (2013) that 'lame' cows (defined as cows scored as locomotion score 3 using the Sprecher et al., 1997 scale) stood on average for shorter periods compared to 'non-lame' cows. The findings of Navarro et al. (2013) could imply that the teat end is exposed to more pathogens due to more time spent lying of lame cows. If it is true that lame cows do spend more time lying down then this could be an explanation for the results reported in the present study that elevated SCC associated with mobility scores ≥ 1, due to the teat end being exposed to pathogens more often. However, it seems fair to say the casual relationship between time spent standing and suboptimal mobility is not yet completely understood and beyond the scope of the current study.

The present study also examined the association between the potential risk factors; 'PTA for lameness' which is the genetic predictive transmitting ability for lameness, whereby the higher the PTA, the more progeny that are expected to become lame during the lactation. Therefore, a cow with a 'lameness' PTA < 1 is less likely to have been visibly lame throughout the lactation, a PTA = 0 is more likely to have been visibly lame throughout the lactation that a cow with a PTA < 1, but less likely compared to a cow with a PTA > 1 for 'lameness'. Therefore, the results of the present study found that when a cows PTA for lameness was ≥ 0 (compared to < 0) there was an increased risk for mobility scores ≥ 1 (Table 2). For the analysis examining the potential risk factors for mobility score ≥ 2 compared to mobility scores < 2, there was only an increased risk associated with a PTA > 0 (Table 3). What is most interesting from our findings is that even with the inclusion of the genetic PTA values for "lameness" in our analysis in an effort to correct for a genetic predisposition for suboptimal mobility, the associated effect of cow breed on mobility prevailed.

The main breeds of the cows used in this study were Holstein (75 %), Jersey (13 %), and Friesian (9%), which is representative of the national population (Ring et al., 2018). As reported in this study, the Jersey breed and Jersey cross breeds are less likely to be associated with mobility scores ≥ 1 (Table 2), which is in agreement with earlier studies (Chesterton et al., 1989; Alban, 1995). Both studies reported that Jersey breed cows had a lower risk for 'lameness' compared to heavier breeds, which is comparable to the present study whereby Jersey breed cows (referring to Holstein Jersey and Jersey crossed with any other breed) were less likely to have suboptimal mobility compared to Holstein-Friesian breed cows, which are a heavier breed. There are also some suggestions that cows with less pigmented claws (mainly Friesian breeds) are more susceptible to claw problems (Toussaint Raven et al., 1985), which have been shown to be associated with suboptimal mobility (O'Connor et al., 2019). This is in agreement with the results of the present study whereby Holstein-Friesian breed are more at risk for having suboptimal mobility. Chesterton et al. (1989) suggests that this could be due to different growth and wear rates of hoof horn, while Webster (1987) states that black claws are harder than white claws. Although the results presented in the current study show that Jersey breed (including HJ and JX) are associated with a decreased risk for suboptimal mobility compared to Holstein-Friesian breed, we also tested the associated effect of breed by changing the reference value from Holstein-Friesian breed to Jersey breed. This resulted in the confirmation that Holstein-Friesian breed is a potential risk factor for the increased risk for suboptimal mobility compared to JX (Jersey crossed with any breed other than Holstein-Friesian). This increased risk for suboptimal mobility associated with the Holstein-Friesian breed could potentially be explained by their predisposition to having higher milk yield, which has been reported throughout the literature to be associated with mobility issues (O'Connor et al., 2019; Archer et al., 2010). However, given that FPCM was also included in this model, this predisposition for high yield associated with Holstein-Friesian breed should in theory be accounted for.

One of the key performance indicators in typical Irish spring calving, pasture-based dairy systems is cow fertility. Performance in terms of cow fertility is vital in order to ensure compact calving, which is a requirement to manage the interface between the cow and the pasture with an ultimate balance to maximize intake while taking cognisance of grass utilisation (Dillon et al., 2005; Shalloo et al., 2014). Interestingly, the results of the present study indicate that calving in February or later (compared to calving in January) is a potential risk factor for mobility scores ≥ 1. This could be due to cows with suboptimal mobility being associated with lower reproductive efficiency as reported by Somers et al. (2015). Another explanation for this, could be due to the fact that in typical Irish spring calving, pasture-based systems, cows remain indoors until they calve, therefore cows with later calving dates have to wait longer periods to access pasture, and pasture has been shown to be positive for mobility, and reduce the risk of suboptimal mobility (Chapinal et al., 2013). However, it is possible that cows could have had suboptimal mobility prior to housing, and could have recovered during the housing period, prior to calving and prior to when their mobility scorings took place, which is not accounted for in the model due to not having this data.

4.2. Herd-level risk factors associated with suboptimal mobility

Longer milking durations (≥ 90 min) are reported in our study to be a potential risk factor for mobility scores ≥ 1. Milking duration in this study refers to the time from when cows leave the paddock prior to milking until they return to the grazing paddock after milking as outline in Table 1. Longer milking time could potentially imply that cows are standing longer periods in the collecting yard before or after milking, or that cows are walking longer distances to and from pasture to be milked, or both. Walking distance and collecting yard procedure were other potential risk factors also analyzed separately in these analyses; however they were dropped during the model building process due to a lack of significance with suboptimal mobility. As all combinations of pairs of variables were tested for collinearity, distance walked and collecting yard procedure were not found be correlated with milking duration. Similarly, herds with more than one grazing platform/use of a public road i.e. with fragmented land implying cows must walk longer distances and potentially make use of public road, were found to be associated with an increased risk for the occurrence of mobility scores ≥ 1 (Table 2). Similar to a longer milking duration, herds with more than one grazing platform/use of a public road could also imply that cows are walking longer distances between pasture and the milking parlor as well as increased time spent standing in the collecting yard before and after milking. There was however, an association between collecting yard procedure and the risk for mobility scores ≥ 2 (Table 3), whereby herds that cows are retained in the collecting yard until all cows are milk was found to be a potential risk factor for an increased occurrence of mobility score ≥ 2 compared to mobility scores < 2.

Prior to the analyses we hypothesied that potential risk factors such as; walking distance, cow path roughness, cow path cleanliness, cow path maintnance would be associated with an increased risk for suboptimal mobility, however none of these mentioned variables were significant and were thus dropped during the model building procedure. Chesterton et al. (1989) reported on the association between road quality and mobility issues in pasture-based systems, and found a strong link between the average maintenance and condition of cow paths and the prevalence of suboptimal mobility, however cow path cleanliness, maintenance, and roughness (or their interaction with walking distance) were not significantly associated with suboptimal mobility in the present study and were therefore dropped in the model building process. It is possible that the reason for these variables not affecting the risk for suboptimal mobility could be explained by number of herds analyzed in our study, which was less than the number analyzed in the study of Chesterton et al. (1989). This could potentially be a limitation of the current study, as it was not possible to collect data from a greater number of farms due to the time constraints and availability of staff. Another possible reason for the cow path variables not being significant could also be due to a potential bias in the survey results collect for each herd, as they are self-reported by the farmers themselves.

Our study also found a decreased risk for mobility scores ≥ 1 associated with herds wherein cows' claws were trimmed by non-trained personnel (Table 2). Non-trained personnel refer to anyone (including the herds' person) who has not undergone any formal claw trimming training. On one hand, we hypothesized that herds wherein claw trimming was carried out by untrained personnel implied that it is most likely the herds' person undertaking the claw trimming of the herd. Therefore this could likely mean that claw trimming is being carried out at more regular intervals or more promptly when required, compared to herds wherein claw trimming is only carried out by trained personnel. On the other hand, our finding that herds wherein claws were trimmed by non-trained personnel is associated with a decreased risk for suboptimal mobility could also imply that trained personnel are only called in to complete claw trimming when there is a relatively large number of cows with suboptimal mobility. Therefore, when cows have imperfect mobility, the untrained personnel is sufficient, however when cows have impaired and severely impaired mobility, it is likely a trained professional is required. Similarly, as presented in Table 3, farms that do not use a foot bath are associated with a decreased risk of occurrence of mobility scores ≥ 2 compared to mobility scores < 2. In other words, our study reports that the use of footbaths (ranging from once per month to once per year) is associated with an increase in the herd-level prevalence of suboptimal mobility in this study. Similar findings have been reported throughout the literature, whereby the use of footbaths was associated with higher 'locomotion scores' which one of the possible explanations provided is that the use of footbaths may be indicative of elevated levels of infectious type disorders (which are associated with suboptimal mobility) (Chesterton et al., 1989; Amory et al., 2006). However, the level of infectious type disorders in our data and indeed Irish pasture-based systems is quite low (O'Connor et al., 2019). Amory et al. (2006) also argues that the benefit of footbath use is dependent on their correct use, i.e. it is possible that footbaths were used incorrectly. Incorrect usage of footbaths ranged from not changing the footbath solution as frequently as recommended, which can result in contaminated footbaths, or using footbaths in which the solution is either too diluted or concentrated. There is a perception among Irish farmers that the use of footbaths is associated with harder hooves which is unproven as far as the authors are aware. Based on this perception, we hypothesize in our study that the association between the lack of foot bath use and decreased herd-level suboptimal mobility could be explained due to the assumption that when cases of suboptimal mobility arise within a herd, foot baths may be implemented in an effort to harden hooves to reduce the prevalence of non-infectious type disorders associated with suboptimal mobility. Again, besides a short communication by (Doherty et al., 2014) and the study of (Chesterton et al., 1989), no other studies investigated the use of foot bathing frequency in pasture-based dairy farms to the best of our knowledge.

5. Conclusions

From the findings in this study we conclude that there are both cow-level and herd-level potential risk factors associated with suboptimal mobility in pasture-based dairy production systems. Cow-level potential risk factors associated with all forms of suboptimal mobility (mobility scores $\geq$ 1) include low BCS, higher yield (in terms of FPCM), elevated $\log_{10}$ SCC, stage of lactation, and a genetic predicted transmitting ability for 'lameness' and Holstein-Friesian breed. While cow-level potential risk factors for mobility scores $\geq$ 2 include BCS, stage of lactation, and a genetic predicted transmitting ability for 'lameness'. Therefore, this suggests that there is potential to manage the prevalence of suboptimal at the cow-level through improved breeding strategies, for example. Herd-level potential risk factors for mobility scores $\geq$ 1 include longer milking times, the use of trained personnel for on farm claw trimming and fragmented grazing platforms, herd-level potential risk factors for mobility scores $\geq$ 2 include the use of footbaths, as well as cows being held in the collecting yard after milking. Therefore, reducing the time spent milking and the amount of time a cow spends in the collecting yard could potentially reduce the prevalence of suboptimal mobility at the herd-level.

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