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Article

Grazing Cow Behavior and Lameness

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Simple Summary: Associations between cow behavior and lameness (mobility) have been investigated several times with mixed results. The most promising reported associations are evaluated in this paper. Four separate trials were performed with two breeds of cows across two different farms. However, the behaviors studied were found not to be associated consistently and statistically significantly with mild and moderate lameness. These behaviors utility in automated lameness detection may thus be limited.

Abstract: Development of accelerometer-based lameness (mobility) detection has focused on cow behaviors such as lying and walking. Several studies, usually small, have reported levels of accuracy up to 91%. However, there has been limited independent replication of these results. In this study, behavior measures previously identified as being associated with lameness such as lying bouts and walking time are examined in relation to mobility score. On a research farm and a commercial farm, four trials were completed with 65 grazing cows. The cows had differing mobility scores ranging from perfect mobility to impaired mobility. Behavior was monitored using leg worn accelerometers. In general, behavior and mobility associations identified in previous studies were not found. Behavior monitoring with accelerometers as a basis to classify impaired mobility in pasture-based contexts thus remains challenging.

Keywords: accelerometer; lameness; pasture; behavior; dairy cow

1. Introduction

Given its endemic nature and the associated pain, lameness is a major cause of poor welfare [1]. However, lameness is not routinely measured on many farms [1]. When lameness (mobility) is assessed, lameness is usually 3-4 times more prevalent than farmers originally thought [2]. The prevalence of severe lameness aligns with farmers' estimate of total lameness. This indicates many farmers are not conscious of mild and moderate lameness in their herd [2]. This information gap relating to mild and moderate lameness could be a major barrier to lameness management. In particular, many severe cases could be prevented by treatment if they were detected at earlier stages of mobility impairment.

Various approaches for automated lameness detection have been investigated. These include pressure plate-based systems which cows walk over, computer vision-based approaches [3,4] and accelerometers. However, commercially available systems remain rare [5,6] and those that are available

have not been independently validated. Accelerometers are increasingly used on dairy farms for heat detection. Heat detection is achieved by measuring changes in behavior relative to herd mates and relative to individual cows' past behavior. Using similar behavior measures to detect lameness has been a prominent area of research [7,8].

Variables such as walking duration [7], lying bouts and changes in behavior [9–12]; and a gross measure of movement [7] have all been reported as being associated with lameness. Some of these studies have reported lameness classification of up to 91% accuracy using this approach [9]. However, there have also been studies which have found weak, no or conflicting associations, in particular for lying time [11,13–16]. As such, the feasibility of behavior-based approaches for detecting lameness remains an open question. This paper evaluates if these or similar measures are indicative of mildly and moderately impaired mobility for grazing cows.

2. Materials and Methods

The Moorepark Animal Welfare Body was consulted regarding the ethical implications of the present study. As the study was observational in nature with no invasive procedures, formal ethical approval was not required.

The difference in meaning, if any, between locomotion, mobility and lameness is often unclear. A 0 to 3 'mobility' scale was used to score cows. 0 is good mobility, 1 is imperfect mobility, 2 is impaired mobility and 3 indicates severely impaired mobility [17]. To determine the score, asymmetric gait, stride length, reluctance to bear weight, arched back and walking speed are observed [18]. Horseman et al., [19] documented the deliberate moving away from the term lameness to mobility scoring in the UK in order to make the topic more palatable to farmers. However, this sanitizing of the topic might be miss-leading and farmers could be taking 'mobility' less seriously than 'lameness' [19]. We thus use the terms lameness and mobility interchangeably with a preference for lameness and use mobility when referring to the act of scoring the cows. For clarity, we interpret the mobility scores as meaning the following: 0 as non-lame, 1 as mild lameness, 2 as moderate lameness, and 3 as severe lameness. One scorer, mobility scored all the cows as they exited the milking parlor. A stratified sample of cows with healthy, mildly and moderately impaired mobility/lameness was created. Given the particular information gap relating to mild and moderate lameness discussed, score 3 severely lame cows were not included in the study.

The pedometers used to record behavior in this study were the RumiWatch 10 Hz pedometer (Itin + Hoch GmbH, Liestal, Switzerland). A pedometer was attached to a rear leg at the metatarsus position for each cow. Sample size was constrained by the number of pedometers available (21). To overcome this restraint, four trials were implemented using the pedometers multiple times. Three trials were at Dairygold research farm, Cork, Ireland. Of the Dairygold trials, one was with purebred Jersey and two were with Holstein Friesian cows. The fourth trial was at a nearby commercial farm with Holstein Friesian cows. Despite 21 pedometers being used in each trial, technical faults resulted in increasing numbers of pedometers failing to record. The final trial thus resulted in only 11 useable data sets. The gap between initial scoring and final scoring of three trials varied from 4 to 14 days (Table 1). All cows were lactating and grazing with minimal supplementation. They walked to and from the paddock twice daily for milking. Paddock to parlor distance varied from day to day but did not exceed 1.5 kilometers.

Daily behavior summaries were generated using the RumiWatch Converter 7.3.36, algorithm V00_56 [20]. For trials 1, 3 & 4, cows were mobility scored at the beginning and the end of these trials and each scoring event is referred to as 'a' and 'b' respectively (Table 1). In trial 2, cows were scored once. Mean and standard deviation of the 24-hour summaries for each of the 14 measures for each of the seven scoring events is presented (Table 3). Spearman's Rho correlation analysis was used to assess associations between variables and mobility score. The data and the r code used in this study is available at https://github.com/nialloleary/Behavior-Lameness.

Table 1. Trial descriptions.

Trial, location & date	N	Breed	Analysis period relative to when cows were scored.
1. A Dairygold (01/06/2017)	18	Jersey	Scored in morning. Pedometers attached in the evening. Next day (24-hour summary) analyzed.
1.B Dairygold (15/06/2017)	19	Jersey	Pedometers were removed a day before scoring. 24-hour summary analyzed from 2 days before scoring.
2 Dairygold (16/06/2017)	16	Holstein Friesian	Scored pedometers attached morning of 16th. Next day's behavior analyzed.
3.A Dairygold (08/08/2018)	17	Holstein Friesian	Scored morning. Pedometers attached in the evening. 24-hour summary from 2 days later analyzed.
3.B Dairygold (13/08/2018)	17	Holstein Friesian	24 hour summary from the same day analyzed. Pedometers removed day after.
4.A Commercial farm (16/08/2018)	11	Holstein Friesian	Scored and pedometers attached in the morning. Next day (24-hour summary) analyzed.
4.B Commercial farm (20/08/2018)	11	Holstein Friesian	Scored in the morning. 24 hour summary on the day of scoring analyzed.

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Table 2. Variables analyzed and definitions.

Variable	Definition	Reference
Activity	Activity index (without dimension), proportional to the variability of the 3 acceleration axes.	(Alsaaod et al., 2015)
Laydown	Lie down instances (which the pedometer angle changes its position from a vertical angle towards a horizontal angle for a duration of at least 50 s) within the summary time frame.	(Alsaaod et al., 2015; Werner et al., 2018)
Laying Counter	Number of periods with the pedometer in a horizontal position >50 s. Interruption of this pedometer position for less than 50 s is identified and calculated as one stand-up and one lying-down event but not as a separate standing bout.	
Laying Index	Activity index while lying.	
Lay Time	Sum of the duration of all lying bouts within a given recording period.	(Alsaaod et al., 2015; Werner et al., 2018)
Limb Events	Movements of the legs or < 3 strides, no./ time frame.	(Kohler et al., 2016)
Standing Counter	Number of periods during which the cow is in an upright position but not walking; temporary change of the pedometer to vertical angle for less than 50 s is neither rated as lying-down and standing-up events nor as an additional lying bout.	
Standing Index	Activity index while standing.	
Stand Time	Standing time slice (time sum in minutes) within the summary time frame.	(Alsaaod et al., 2015; Werner et al., 2018)
Stand Up	Get up instances count within the summary time frame.	(Alsaaod et al., 2015; Werner et al., 2018)
Strides	One forward or backward movement of the limb within a walking bout.	(Alsaaod et al., 2015)
Walking Counter	Number of periods characterized by at least 3 consecutive strides in the same direction (forward or backward). The period between 2 strides must not exceed 4 s. Walking bouts are rated as separate if the time between 2 strides exceeds 10 s	
Walking Index	Activity index while walking.	(Zehner et al., 2015)
Walk Time	Walking time slice (time sum in minutes) within the summary time frame.	(Alsaaod et al., 2015; Werner et al., 2018)

Table 3. 24 hour summary statistics for cows in each trial.

	1.a Jerseys		1.b Jerseys		2 Holstein Friesian 2017		3.a Holstein Friesian 2018a		3.b Holstein Friesian 2018b		4.a Farm		4.b Farm	
Variable	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Activity	245	27	159	21	197	29	146	19	149	22	108	12	132	10
Laydown (n/day)	7	2	8	2	9	2	9	1	9	2	10	6	10	4
Laying Counter	7	2	8	2	9	2	9	1	8	2	8	3	9	3
Laying Index	6	2	7	2	10	3	35	75	36	74	19	35	23	48
Lay Time (min/day)	628	89	629	122	564	91	664	116	597	159	682	229	720	94
Limb Events (n/day)	2873	635	2034	494	1982	345	1736	683	2070	809	1545	561	1692	563
Standing Counter	305	43	249	40	209	38	195	78	204	87	191	61	181	61
Standing Index	249	59	143	25	119	21	107	43	112	43	96	33	108	35
Stand Time (min/day)	677	88	704	118	748	89	689	88	756	130	588	108	642	77
Stand Up (n/day)	7	2	8	2	9	2	9	1	9	2	10	5	9	4
Strides (n/day)	4338	726	3212	501	4402	333	2574	1030	2508	1039	1975	688	2607	175
Walking Counter	301	43	243	40	201	39	201	62	198	87	186	63	190	27
Walking Index	1336	119	1179	104	1479	183	1248	247	1122	114	1023	341	1294	146
Walk Time (min/day)	135	19	107	17	128	12	93	27	87	37	70	25	85	8

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3. Results

Table 3 summarizes the mean and standard deviation of each variable for all mobility scoring events across the four trials. It shows that mean behavior varied between and within trials. This was likely due in part to day to day management differences (e.g. distance to paddock). Table 4 shows that none of the 24-hour behavior measures were consistently associated with mobility score. Lying measures had rather inconsistent associations with mobility score. Limb events were highly associated with mobility score for one mobility scoring event (4.a) but were not statistically significantly associated with mobility score (0 to 2) in the other mobility scoring events. Standing Counter (number of times a cow stood) had the highest average correlation (Rho) with mobility score across the trials but these associations were non-statistically significant. Walking time had non-significant correlations of Rho >0.2 with mobility score in five of the seven mobility scoring events, similar to some previous findings [7]. In summary, the assessed 24-hour behavior summary values were not statistically significantly or consistently associated with mobility score. There were only non-statistically significant associations with standing counter and walking time.

Table 4. Spearman's Rho correlation between behavior and mobility score. All values between -0.2 and 0.2 are not reported (blank spaces).

Variable	1.a Jerseys	1.b Jerseys	2 Holstein Friesian 2017	3.a Holstein Friesian 2018a	3.b Holstein Friesian 2018b	4.a Farm	4.b Farm	Average Rho
n	18	19	16	17	17	11	11	
Activity	†-0.4	-0.21	-0.62	0.22	-0.23	0.42	0.35	
Laydown		0.34	0.22	-0.2		-0.33		
Laying Counter		0.26	0.21	-0.22		-0.37		
Laying Index	0.26	0.22	-0.26	0.2		-0.31	0.49	
Lay Time	0.24	0.35		-0.21		-0.23		
Limb Events	-0.27				0.24	**0.82		
Standing Counter	-0.33	-0.31			-0.31		-0.41	-0.2
Standing Index		0.21	†-0.48			*0.75	-0.33	
Stand Time	-0.26	-0.33		0.21		0.75		
Stand Up		0.26		-0.26		-0.36		
Strides		-0.34	-0.22		-0.33	-0.21		
Walking Counter	-0.32	-0.3			-0.29		-0.37	-0.2
Walking Index			†-0.47	0.43		0.47	0.55	
Walk Time		-0.33	-0.27		-0.35	-0.21	-0.27	-0.24

†P < 0.10, *P < 0.05, **P < 0.01

4. Discussion

Behavior changes as measured by accelerometers have been the most studied accelerometer approach to measure lameness. However, adding to a literature which has reported mixed results, the behavior measures assessed were found not to be associated with mobility score in this study. Based on the present and other results [11,13–16], lying time appears to be of limited value for lameness detection. Only Standing Counter and Walking Time had a non-significant tendency to be associated with mobility score across the four trials. These weak results indicate these behavior variables could only play a small part in a mild and moderate lameness detection system for grazing cows.

If a behavior is to be used as the basis of detecting lameness, the association should be at least strong enough to be consistently and statistically significantly associated with mild or moderate mobility score in normal grazing conditions like those in this study, even with sample sizes between 11 and 19. The trial sample sizes in this study were smaller than intended but not unusual with some studies reporting total sample sizes of 9 [26] or 10 [27]. In aggregate, the four trials with 65 unique cows are more than sufficient to gauge if behaviors will be useful or not for mild and moderate lameness detection for grazing cows. That the associations might have been statistically significant with a larger sample is possible but is largely immaterial. This is because the small size of the association and inconsistency of the association would mean they are of limited value for automated lameness detection.

Other aspects of this study could also explain the null results. Only some of the previous studies have been with grazing cows [8,12,16,24,25]. Cows in grazing systems experience greater variation in management, in particular distances walked, than indoor systems which will confound behavior-based approaches. The between and within trial differences in this study (Table 3) illustrate the variation in behavior from day to day when cows are grazing.

Other studies have used the mean of multiple scorers' assessments, worked to improve alignment between scorers [28,29], recorded video of the cow walking for thorough observation with the benefit of replay and playback speed adjustment and have performed hoof inspections [30]. Future research should consider using multiple scorers, video and including severely lame cows in preference to the single highly trained and skilled manual mobility scorer approach used here. The severity of lameness and how easily it can be detected using behavior are likely associated. Some studies, e.g. Blackie et al., (2011), have studied a greater range of lameness severity than the present study focused on mildly and moderately lame grazing cows.

The null findings here might indicate that severe lameness detection may be more easily achieved, and so automated detection of severe lameness should be developed first. Severe lameness detection alone would be of significant value for animal welfare auditing. However, as severely lame cows are usually readily identified by untrained staff, automated detection of severely lame cows may be of relatively lower value for lameness management specifically than mild and moderate lameness detection.

This study set out to test the generalizability of previous findings from a range of contexts to mild and moderately lame grazing animals. However, consistent patterns of association were not found. In grazing systems at least, and potentially zero grazing systems also, there are still significant challenges to be overcome to create effective automated lameness detection systems. Replication of these same findings with non-grazing animals has also not been achieved to any significant extent in previous studies. It appears that behavior monitoring is insufficient or potentially even unhelpful in detecting mild and moderate lameness [31].

A study of measures of gait by the authors (to be submitted for publication) complements this study. It is hypothesized that measures of cow gait such as stride duration [9] may be more indicative of lameness than measures of behavior. This is based on the assumptions that gait measures are less

influenced by management and that measures of gait are closer proxies of lameness than behavior. This appears logical if one considers that it is upon gait that manual mobility scoring is based [32], not on measures of behavior.

5. Conclusions

This study set out to test the generalizability of associations reported in previous studies to lameness. Specifically, this study assessed if grazing cows' behavior was associated with lameness status ranging from non-lame to moderately lame. The variables assessed included measures of lying time, walking time, behavior changes and bout durations of behavior. None of the tested associations were found to be consistently statistically significant. The failure to replicate any associations was unexpected. Smaller than expected associations might have been explained by some of the study limitations – but that lack of any associations raises questions about the usefulness of using behavior to assess mild or moderate lameness of grazing cows.

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