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Interpretive summary: Impact of mobility score on milk yield and activity. Reader

The hypothesis tested was that delay in treatment of lame cows explains the reduction in milk yield before treatment. Delay in treatment was one likely explanation for a reduction in milk yield. Reduced yield occurred before cows were visibly lame; one explanation is that mobility scoring in less than 100% sensitive. An alternative hypothesis is that reduced body condition caused both reduced milk yield and lameness as the digital cushion became thin.

LAMENESS AND MILK YIELD

Impact of mobility score on milk yield and activity in dairy cattle

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ABSTRACT

Previous studies have indicated that lame cows have a reduced milk yield both before and after they are treated. One explanation for the reduction in yield before treatment is that there is a delay to treatment, that is, cows have impaired mobility for some time before they are treated. The aim of this study was to test this hypothesis by investigating temporal associations between change in milk yield and change in mobility score. Mobility score (MS, on a scale 0 to 3), milk yield, treatments for lameness and cow activity were recorded on 312 cows in a dairy herd in Somerset, UK for 1 yr. The MS was scored every 2 wk and compared with the daily yield and activity (steps/h) averaged over the previous 16 d. Approximately 44 % of MS changed within 14 d, usually by 1 score. Overall, milk yields of cows with MS 1 were higher than those of cows with other scores. Cows with MS 2 and 3 produced 0.7 (0.35 - 0.97) kg and 1.6 (0.98 – 2.23) kg less milk / d, respectively, compared with cows with MS 1. In addition, cows with MS 1 were slightly but significantly more active than cows with MS 0, 2 or 3. Cows with MS 2 and 3 were 0.0.02 (0.01 – 0.03) and 0.03 (0.01 – 0.05) mean log steps less active than cows with MS 1.

There was a reduction in yield from 6 - 8 wk before becoming MS 2 0.5 (0.12 – 0.47) or 3 0.9 (0.16 – 1.65) to 4 wk after recovering from MS 2 0.42 (0.09 – 0.75) and non-significantly, score 3. The activity of cows was significantly less but quantitatively small (mean log steps 0.01) with increasing MS; the associations between activity and parity (mean 0.03 – 0.11) and month of lactation (mean 0.03 – 0.36) were quantitatively larger. Results from a multistate model indicated that once cows were lame they remained lame or become lame again despite treatment. We conclude that cows started to reduce milk production before their mobility is visibly impaired. One explanation for this is that MS is not 100% sensitive. An alternative hypothesis, using evidence from other studies, is that reduction in milk yield and development of lameness are on a common causal pathway most likely

linked to loss in body condition and reduced digital cushion thickness as a result of the demands from producing high milk yields.

Key words Dairy cow, Milk yield, Lameness, Treatment, Multistate model

INTRODUCTION

The prevalence and incidence of lameness in dairy cows in intensive systems is unacceptably high with estimates of prevalence in the UK ranging from 21 % (Clarkson et al., 1996) to 36 % (Leach et al., 2010). Lame cows are in pain and their welfare is compromised (Whay et al., 1997).

Lameness is associated with a reduction in milk yield (Juarez et al., 2003; Archer et al., 2010). This reduced milk yield is present before and after a treatment event, but varies by the type of lesion (Green et al., 2002; Amory et al., 2008; Bicalho et al., 2008). The reduction in yield detected before a treatment event with non infectious horn lesions (Amory et al., 2008; Green et al., 2010) might occur because of a long pathogenesis in disease before cows become lame or because of delayed treatment. There is less evidence that infectious claw conditions are associated with reduced milk yield before cows are observed lame, although Warnick et al. (2001) reported that interdigital phlegmon was associated with reduced yield before treatment, possibly because the time to lameness from infection is rapid. For both types of disorders, delay in treatment would probably lead to reduced milk yield because of the increased metabolic demands from pain and reduced feed intake. The treatment of lame cows depends on the ability of farmers to recognize a lame cow and to treat affected cows promptly and appropriately. Most dairy cow farmers underestimate the prevalence of lameness on their farms (Whay et al., 2003) and do so inconsistently compared with a trained researcher (Leach et al., 2010), suggesting that most dairy cow herdsmen do not have a logical way of detecting lameness, in contrast to sheep farmers (King and Green, in press).

Mobility scoring has been developed to help farmers improve detection of mild lameness and stimulate treatment and prevention as part of a herd health program. The currently accepted system used in the UK is a 4 point mobility scoring (**MS**, on a scale 0 to 3) system (Whay et al., 2003). This system is used by many researchers and veterinary practitioners, but has not been evaluated for repeatability. Some authors have reported that daily activity levels are lower in cows with reduced mobility (O'Callaghan et al., 2003; Mazrier et al., 2006; Walker et al., 2008).

The current study was designed to test the hypothesis that the reduction in milk yield that occurs before lame cows are treated is as a result of delayed treatment. This was tested by investigating the temporal association between change in milk yield and change in locomotion and time to treatment. The MS, milk yield, and activity in cattle from 1 farm was observed every 2 wk for 1 yr to estimate precise relationships between MS and changes in MS, milk yield, and cow activity.

MATERIALS AND METHODS

A dairy herd that calved all year round, located in Somerset UK, with a milking herd of 200 Holstein cows, producing approximately 9,000 kg milk/cow per year was used for the study. The study started on October 24, 2007 and finished on November 5, 2008. Calving was all yr around; The numbers of cows in milk ranged from 168 (November 5, 2008) to 217 (April 23, 2008) with a mean of 197 and median of 200. The herd was divided into 2 groups of about equal size based on milk yield, both housed in 1 building with a floor of concrete and 230 free stalls fitted with mattresses and bedded with sawdust. Milking cows had access to pasture in summer with high yielding cows only on pasture for a limited period each day. Non-lactating cows were kept in a separate building and their locomotion was not scored. The herd was milked twice daily through an 18/36 Westfalia herringbone parlor. Milking cows walked through a 5% formalin footbath as they exited the parlor once each week.

Cows were selected for foot trimming by the herdsman. Approximately 35 cows were trimmed per month; foot trimming was carried out by a paraprofessional foot trimmer from Kingfisher Veterinary Practice (Synergy Farm Health, West Hill Barns, Evershot, Dorset, England. DT2 0LD). The selection criteria for foot trimming were cows that were clinically lame (MS 2 or 3) or cows that were due to be dried off. The farmer intended to trim feet of each cow at least once each year, but this was not cross checked. Lesions were defined using the definitions in the EU Lamecow Project (Barker et al., 2007) and all foot trimming and lameness were recorded on lameness scoring sheets designed by the EU Lamecow project. Cases of lameness treated by the herdsman or veterinarian (who treated severe cases) were recorded in the same way.

All cows were individually identified and fitted with pedometers (Westfalia Dairy Plan C21 (GEA Farm Technologies Australia Pty. Ltd. PO Box 39816 Trade Park Drive Tullamarine VIC 3043). Activity readings for each cow were automatically downloaded to the farm computer in the parlor twice daily and onto a lap top once weekly. The mobility of lactating cows was scored (Table 1) every 2 wk after evening milking by JDR using the system described by Whay et al., (2003). The identity of each cow was recorded as she entered the parlor and mobility was scored and recorded on standardized sheets as the cow exited the parlor. The MS was transferred to an Excel 2003 spreadsheet (Microsoft Corp., Redmond, WA). Milk yield, activity (mean steps/hr), health records, lameness records, and group were downloaded from the farm computer into the spreadsheet.

Data analysis

The mean proportion of cows with each MS by stage of lactation (1 to 90 d, 91 to 180 d, >180 d), mean milk yield, and mean activity over 16 d previously were calculated. The probability of transition between MS from time t to time t + 1, 14 d later, was estimated. Two multilevel statistical models were constructed, using conventional methods (Goldstein, 1995). In the first model the outcome variable was mean milk yield in the 16 d before a MS and the impact of MS before and after this outcome was investigated. In the second model log^{10} mean activity score for the previous 16 d was the outcome and the impact of MS on activity was investigated.

The models took the form:

$$Yij = \alpha + \beta_1 X_{ij} + \beta_2 X_j + vj + e_{ij} \; v_j \sim N(0,a^2{}_v)$$

$$eij \sim N(0,a^2{}_e)$$

where the subscripts i, and j denote the ith observation of the jth cow, respectively; α is the regression intercept; X_{ij} is the vector of covariates associated with each observation; β_1 the coefficients for covariates X_{ij}; X_j the vector of covariates associated with each cow; β_2 the coefficients for covariates $X_{j,}$; v_j a random effect to reflect residual variation between cows which is normally distributed with mean = 0 and variance = σ^2; and e_{ij} a random effect to reflect residual variation between MS which is normally distributed with mean = 0 and variance = σ^2. The analysis was carried out using MLwiN 2.02 with penalized quasi-likelihood for parameter estimation (Rasbash et al., 2005). Covariates were left in the model when the significance probability was $P < 0.05$ based on the Wald Test. When mean milk yield was the outcome, DIM, the exponential DIM $^{0.05}$ (Wilmink, 1987) and parity 1, 2, 3, and > 3, and first or second lactation in the study were forced into the model. Then the discrete variable MS (0, 1, 2, and 3) at time **t** was added. The impact of MS at time t - 1, t - 2,.., t - 5 and t + 1, t + 2, .., t + 5, where each time interval i was 14 d, was tested in the model. When log mean activity was the outcome, parity 1, 2, 3, and > 3, second lactation in the study and month in milk were forced into the model and then the mobility score at times t, t - 1, .., t - 5 and t + 1, .., t + 5, where each time interval t was 14 d, were tested in the model. Missing observations were random and so were fitted in the model as discrete variables to minimize loss of data. The model fit was checked.

Finally, a multistate model was set up to test the factors associated with cows becoming lame, remaining lame, becoming sound, and remaining sound. Mobility score was categorized into 2 states: not lame (scores 0 and 1) and lame (scores > 1). A cow was in 1 of 2 states, not lame or lame. An episode was defined as the continuous period of time a cow spent in either state until a transition to the other state occurred. For each episode *j* for cow *k* there was an original state *i* (0 (not lame), 1 (lame)) the duration spent in that state was categorized into discrete time intervals of 14 d, t_i (measured as $t = 1, 2\ldots\ldots n$ with *n* being the maximum duration of an episode) and an outcome event at the end of the discrete time interval, *y*, with 0 = no change in state, and 1 = occurrence of a change in state. A logit link function was used to express the ratio of probability of a change in state to probability of no change in the state and took the form:

$$\text{logit}[\pi_{ik\,(t)}] = \beta_{0\,i} + \alpha_i\,(t) + \beta\; x_{ik\,(t)} + u_k^{(i)}$$

where $\beta_{0\,i}$ is a state specific intercept , $\alpha_i\,(t)$ a set of dummy variables for the discrete time interval *t* depicting duration of state, $\beta\, x_{ik(t)}$ covariates include a vector of explanatory variables varying by time or cow with a dummy variable for original state. The model was run in MlwiN 2.02 (Rasbash et al., 2005) using Markov chain Monte Carlo estimation. The first 5,000 iterations were discarded and then 500,000 iterations until the chains were visually stable.

RESULTS

Mobility was scored on 28 occasions, 312 cows (allowing for additions and removals) were scored with 168 to 217 at each observation, the number of scores arranged from 5 to 28 / cow. The percent of scores 0, 1, 2, and 3 were 23, 45, 27, and 5, respectively, with 1, 20 , 48, and 31% of cows with maximum scores of 0, 1, 2, and 3, respectively. The mean number of observations with MS 2 or 3 was 32%, ranging from 24% in October 2008 to 40% in July

2008. The mean duration of lameness was 5.5 [s.e. 3] wk (median 4 wk, interquartile range 2 to 7 wk). Only 48% of scores remained unchanged from 1 score to the next, but cows were unlikely to move more than 1 score in a 2-wk period. Once cows were a certain MS for 2 observations they were more likely to remain at that MS than change score. Patterns of scores are in Table 2.

The milk yield was highest in cows with MS 1 (Table 3). Cows produced 0.7 kg/d and 1.6 kg/d less milk when MS 2 or 3, respectively, compared with cows with MS 1 ($P < 0.05$). There was a reduction in yield from t – 3 before becoming MS 2 (0.47 CI (0.11 – 0.82) or MS 3 (0.9 (0.15 – 1.65) and t + 2 after recovering from MS 2 (0.85 CI 0.5 – 1.2).

First, second and third lactation cows were 58, 48, and 19%, respectively, less active (took fewer steps) than cows parity >3 ($P < 0.05$; Table 3). Cows were less active in early lactation (mean log 1.38 steps/hr in month 1) and became more active as lactation progressed (mean log 1.74 steps/hr in month 10), e.g., cows that were 9 months into lactation were 42% more active than those in the first month of lactation ($P < 0.05$). Cows with MS 0 were 1% less active than a cow with MS 1 ($P < 0.05$). Cows with MS 2 and 3 were 3 and 5 % less active than a cow with MS 1 ($P < 0.05$). Cows had a decreased activity for 42 d before being MS 2 (mean 0.02 (CI 0.01 – 0.03)): they were 3% less active 2 wk before and 2% less active 4 wk before they became MS 2 compared with a cow with MS 1 ($P < 0.05$). Cows with MS 3 were less active from 28 d before they developed MS 3 (-0.02 CI (0.00 – 0.04)). Similarly, cows that were MS 2 were less active by 3 to 4 % for the following 5 recordings and cows that had MS 3 were less active by 3 to 6 % for the following recordings ($P < 0.05$).

A total 444 lesions (185/100 cows per yr) with 385 primary lesions on 258 feet were recorded by the herdsman, veterinarian, and foot trimmer. Over the 12 mo study period 178 cows (74%) were treated for at least 1 lesion; 72 (30%) cows had more than 1 foot with a lesion and 81 (31%) feet were treated more than once. The lesions recorded were digital dermatitis (39%) sole ulcer (25%), white line disease (**WLD**) (12%), interdigital growth (9%), and other (15%).

From the multistate model (Table 4) the longer the period a cow was not lame (i.e., not MS 2 or 3) the less likely she was to make a transition to being lame and the longer a cow was lame the less likely she was to recover from being lame. Cows < 90 DIM were less likely to become lame than cows ≥ 90DIM (Odds Ratio (**OR**) = 0.66) and cows with milk yield > 15 to ≤ 35 kg in the previous 16 d were less likely to recover from lameness (OR = 0.73) than cows with milk yield > 35 kg.

Cows in parity 1 (OR = 0.49) or 2 (OR = 0.79) were less likely to become lame and they were more likely to recover (OR = 1.26 and 1.32, respectively) once they had become lame compared with cows of parity >2. Lame cows with 'other' lesions that were treated were less likely to recover from being lame (OR = 0.58) than untreated lame cows. Cows treated with a sole ulcer (OR = 1.35), digital dermatitis (OR = 1.51) or 'other' lesions (OR = 1.39) were more likely to become lame again in comparison with non lame cows that had not been treated (Table 4).

DISCUSSION

In the current study, milk yield was reduced in cows with MS 2 or 3 for up to 4 to 8 wk before their locomotion moved from MS 1. This period of time was considerably less than the reduction in yield seen 3 to 4 mo before treatments reported by Green et al. (2002) and Amory et al. (2008) and suggests that there was a delay in treatment in these 2 studies. If MS was used to identify lame cattle and they were treated promptly the duration of both lameness and milk loss might be reduced (Green et al., 2010). From the multistate model and patterns of MS (Tables 4 and 2), treatment in the current study herd was not successful, with treated cattle either not recovering (digital dermatitis) or being more likely to become lame again (sole ulcer and other diseases). Note that WLD was not associated with lameness (Table 4) as in other studies (Tadich et al., 2010). Repeated occurrences of lameness might indicate meager treatment strategy or efficacy, but might also indicate that treatment cannot address intrinsic factors such as a thin digital cushion. Treatment was added to the milk yield model; however, it did not alter the associations between yield and MS and so was excluded.

That cows with MS 1 had a lower milk yield for 4 to 8 wk before there was a change in mobility score from MS 1 to MS 2 or 3 suggests that the reduction in yield occurred before lameness was detectable. One possible explanation for the reduction in yield before MS changed is that MS was not sufficiently sensitive to detect the initial stages of disease. In other studies of dairy cow lameness authors have reported lesions on sound cows (Manske et al., 2002; Tadich et al., 2010; Bicalho et al., 2008). One hypothesis, drawing evidence from Bicalho et al. (2009), is that lameness and foot lesions are positively associated with a thin digital cushion which is associated with low body condition, this might cause sub clinical disease that is not detectable externally or by MS, but is sufficiently painful to reduce food intake, increase metabolic rate and so reduce milk yield. Low body condition *per se* could also lead to reduced milk yield. It is unfortunate that we did not score the body condition of the cattle in the current study but one could speculate that the cattle that moved from MS 1 to MS 2 or 3 lost body condition before the transition whilst those that remained at MS 1 did not.

The fact that high yielding cattle at greater risk of lameness (Green et al., 2002; Amory et al., 2008; Green et al., 2010) might help explain why cows with MS 1 produced more milk than cows with scores 0, 2 or 3. These cows are producing high yields and their locomotion is impaired (they are marginally lame). Over time, a proportion remain at MS 1 (Tables 2 and 5) and continue to produce high yields (Table 3) but some move to MS 2 or 3 and the pattern of lower yield and higher mobility score ensues. Once a cow is lame, she might continue to have a further reduction in yield because extra energy is required to cope with the pain of the foot lesion and energy is directed to this rather than milk production.

Depending on farm layout, lame cows might also feed less frequently and so reduce feed intake, exacerbating the disease process. If this was so, then successful treatment might increase mobility and stabilize milk yield, as seen in Green et al. (2010).

A large numbers of transitions in MS were seen between fortnightly scores for individual cows in our study. In the UK farmers often MS their cattle annually or biannually to comply with assurance scheme standards e.g. Tesco scheme, the current results suggest that infrequent MS would give a snap shot of prevalence, but have little value in management of lameness. Cows that had a MS of 2 or 3 had a high probability of remaining a 2 or a 3 (Table 2) and becoming lame again (Tables 2 and 4). The effects of this may be seen in terms of milk production, but the effects on cow welfare are not so easy to quantify, although these cows did have lower activity.. This suggests that prevalence, incidence, and repeat cases should be standard recordings.

The results demonstrate that it is not only the MS on the day of recording that is important, but that the length of time that a cow has been at a particular MS is highly relevant. Our examples demonstrate that a cow that had been MS 2 for 6 wk lost 4.5 kg of milk per d while at MS 3 lost 6 kg/d of milk . These results support Juarez et al. (2003) who demonstrated a drop in milk yield of 4 kg/d for a lame cow. Extrapolating these results to a cow that is lame for 12 wk equates to 610 kg milk lost, supporting Amory et al. (2008).

Results from this herd suggest that activity data may not play a useful role in early identification of lameness because the absolute changes were so small: parity and stage of lactation had a much greater effect on activity than MS (Table 3). Cows became steadily more active as lactation progressed and with increasing parity, contrary to the findings of O'Callaghan et al. (2003) who reported a decreased level of activity as lactation progressed. The average change in activity associated with mobility score was less than 1%/d in our study, while they reported that cows that were lame were 24% less active than non lame cows.

Comment [FCG1]: Over what period of time?

There might be large variations in activity between herds, this might depend on the farm layout, and this might be very important when considering the necessary and unnecessary activity of cows.

The results suggest that a decrease in milk yield could have a role as an early indicator of lameness, while change in activity is a less sensitive measure. In order to be practically applied on farms, algorithms for milk yield, correcting for parity and stage of lactation, would need to be incorporated into on-farm software alongside daily milk recording. In conjunction with fortnightly MS this could alert the farmer that cows need early intervention. Before this could be achieved, research needs to be repeated across many farms and systems to validate the findings. In addition, unexpected reduction in milk yield might indicate that a cow is not metabolically stable (Bicalho et al., 2009) and lameness is only one of the risks for such cattle.

The advantage of this study was the large amount of detailed data that were collected. This farm was chosen because it was similar to many farms in the UK with Holsteins producing large quantities of milk under intensive conditions; the patterns within cow are useful additions to our understanding of the associations between milk yield, MS, activity, and lameness. A disadvantage of this study was that the data were from only 1 farm. It is not possible to generalize prevalence, incidence, and transitions between MS. Whatever the factors initiating lameness it appears that changing external management (Barker et al., 2007, 2009) is likely to be only part of the story to prevent lameness in dairy cows, possibly explaining part of the limited success of intervention studies (Bell et al., 2007; Barker 2007). Further work is required to elucidate when biochemical and pathological changes occur in the development of lameness. If these changes can be identified, then we can move forward in preventing lameness in dairy cows.

CONCLUSIONS

A reduction in mobility occurred 4 to 8 wk after cows had started to reduce milk yield and an increase in milk yield occurred approximately 6 wk after a cow returned to MS 0 or 1, suggesting that either mobility scoring is insufficiently sensitive to detect lameness, that cattle mask lameness despite being diseased, or that a lameness and reduction in yield are linked by a common intrinsic event. Once lame, cows were likely to remain lame or become lame again, suggesting that either treatment was unsuccessful or that the internal origin of lameness overrode treatment. Further work investigating body condition, biochemical profiles, mobility, and lameness longitudinally could have a huge impact on our understanding of the etiology of lameness.

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Table 1. Definitions of mobility scores (Whay et al., 2003)

Mobility score	Definition	Description of cow mobility
0	Good mobility / sound	Walks with even weight bearing and rhythm on all 4 feet with a flat back. Long fluid strides possible.
1	Imperfect mobility	Steps unevenly or shortened strides. Affected limbs not immediately identifiable.
2	Impaired mobility	Uneven weight bearing on limb immediately identifiable and/or obviously shortened stride. Usually arched back.
3	Severely impaired mobility	Unable to walk as fast as brisk human pace plus signs of score 2.

Table 2. Transitions in mobility score from time t – 3 to time t where t = 14 d intervals illustrating that 50 – 60% of cows remain at a score for 8 weeks but that 40 – 50% cows move mobility score

t[1] - 3	t - 2	t - 1	t	Probability of score at t	N[2] sequence observed
0	0	0	0	0.57	244
0	0	0	1	0.41	244
1	0	0	1	0.51	182
1	0	0	0	0.44	182
1	1	1	1	0.65	665
1	1	1	0	0.19	665
2	2	2	2	0.64	390
3	3	3	3	0.67	54
3	3	3	1	0.02	54
3	3	3	2	0.31	54
3	3	3	3	0.67	54
3	3	2	1	0.16	31
2	3	2	1	0.09	54
1	3	2	1	0.20	10

[1]t = time, t +/- i = time from / to t in 2 wk intervals [2]N = number of occasions,

Table 3. Random effects model of mean 16 d yield and 16 d mean log activity in 312 cows from 1 dairy herd in Somerset, UK

	Mean yield	lower 95% CI[3]	upper 95% CI	mean Log activity	lower 95% CI	upper 95% CI
intercept	41.9	40.685	43.115	1.384	0.972	1.796
parity >3	reference	reference	reference	reference	reference	reference
parity 1	-5.78	-7.113	-4.447	0.113	0.072	0.154
parity 2	-2	-3.078	-0.922	0.039	0.006	0.072
parity 3	-2.4	-3.282	-1.518	0.072	0.047	0.097
2nd lactation	-0.7	-1.366	-0.034	0.237	0.217	0.257
DIM	-0.05	-0.052	-0.048			
Wilmink	-15.7	-17.013	-14.387			
month in milk 1				reference	reference	reference
month in milk 2				0.033	0.011	0.055
month in milk 3				0.065	0.043	0.087
month in milk 4				0.078	0.056	0.100
month in milk 5				0.113	0.089	0.137
month in milk 6				0.125	0.101	0.149
month in milk 7				0.157	0.132	0.182
month in milk 8				0.205	0.180	0.230
month in milk 9				0.244	0.217	0.271
month in milk 10				0.304	0.277	0.331
month in milk 11				0.361	0.330	0.392
at t[1]						
MS[2] 1	reference	reference	reference	reference	reference	reference
MS 0	-0.45	-0.764	-0.136	-0.004	-0.014	0.006
MS 2	-0.66	-0.974	-0.346	-0.016	-0.026	-0.006
MS 3	-1.61	-2.237	-0.983	-0.025	-0.045	-0.005
at t+1						
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.76	-1.093	-0.427	-0.007	-0.017	0.003
MS 2	-0.43	-0.763	-0.097	-0.012	-0.022	-0.002
MS 3	-0.5	-1.147	0.147	-0.011	-0.031	0.009
at t+2						
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.85	-1.203	-0.497	-0.005	-0.015	0.005

Table 3. Two level random effects model of mean 16 d milk yield and log activity in 312 cows from one herd in Somerset, UK *continued*

	Mean yield	lower 95% CI	upper 95% CI	mean Log activity	lower 95% CI	upper 95% CI
MS 2	-0.42	-0.753	-0.087	-0.002	-0.012	0.008
MS 3	0.26	-0.387	0.907	0.002	-0.018	0.022
at t+3						
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.84	-1.212	-0.468	0.001	-0.011	0.013
MS 2	-0.26	-0.613	0.093	0.007	-0.003	0.017
MS 3	0.47	-0.196	1.136	0.009	-0.011	0.029
at t+4						
MS 1	reference	reference	reference			
MS 0	-0.65	-1.022	-0.278			
MS 2	-0.1	-0.453	0.253			
MS 3	0.28	-0.406	0.966			
at t-1		0.000	0.000			
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.4	-0.733	-0.067	-0.005	-0.015	0.005
MS 2	-0.95	-1.283	-0.617	-0.015	-0.025	-0.005
MS 3	-2.67	-3.336	-2.004	-0.031	-0.051	-0.011
at t-2						
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.44	-0.773	-0.107	-0.010	-0.020	0.000
MS 2	-0.69	-1.043	-0.337	-0.170	-0.180	-0.160
MS 3	-1.39	-2.096	-0.684	-0.019	-0.041	0.003
at t-3						
MS 1	reference	reference	reference	reference	reference	reference
MS 0	-0.25	-0.603	0.103	-0.013	-0.023	-0.003
MS 2	-0.47	-0.823	-0.117	-0.015	-0.025	-0.005
MS 3	-0.9	-1.645	-0.155	0.010	-0.225	0.245
at t-4						
MS 1	reference	reference	reference			
MS 0	0.09	-0.282	0.462			
MS 2	-0.41	-0.782	-0.038			
MS 3	0.31	-0.474	1.094			

[1]t = time, t +/- i = time from / to t in 2-wk intervals

[2]MS = mobility score

[3]CI = confidence interval

Table 4: Multivariable multistate model of transitions between lame (mobility score 2 or 3) and non lame (mobility score 0 or 1) states in 312 cows from 1 dairy herd observed for 1 yr in Somerset, UK

	Transition			
	Non lame to lame		Lame to non lame	
variables				
intercept	-5.15	0.21	-4.58	0.37
	OR	CI	OR	CI
Duration spent in state				
≤ 2 wk	4.06	2.96-5.55	3.63	1.90-6.94
> 2-4wk	3.16	2.22-4.49	2.51	1.29-4.89
> 4-18 wk	1.80	1.32-2.47	1.93	1.01-3.69
> 18 wk	reference		reference	
DIM				
0-90	0.66	0.57-0.78	1.25	0.93-1.67
91-180	1.00	0.79-1.26	1.15	0.91-1.46
>180	reference		reference	
Past treatments				
Sole ulcer				
yes	1.35	1.11-1.64	0.84	0.69-1.02
no	reference		reference	
Digital dermatitis				
yes	1.51	1.29-1.76	0.86	0.72-1.03
no	reference		reference	
White line disease				
yes	1.15	0.91-1.46	0.83	0.65-1.05
no	reference		reference	
Other				
yes	1.39	1.10-1.76	0.58	0.45-0.74
no	reference		reference	
Pregnant				
yes	0.87	0.70-1.08	1.67	1.34-2.07
no	reference		reference	
Mean milk yield in previous 16 d				
missing	0.90	0.46-1.80	1.16	0.50-2.70
≤15	1.22	0.84-1.77	0.81	0.54-1.22
>15-35	1.15	0.89-1.48	0.73	0.55-0.98
>35	reference		reference	

Parity				
1	0.49	0.39-0.62	1.26	1.00-1.59
2	0.79	0.63-0.98	1.32	1.05-1.67
3	0.94	0.74-1.19	1.15	0.89-1.48
>3	reference		reference	