Lying behaviour of housed and outdoor-managed pregnant sheep

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ABSTRACT

Little is known about the lying behaviour of sheep despite its high value in supporting productivity and welfare in other livestock. The aim of this experiment was to investigate the lying behaviour of pregnant sheep and test for the effects of biological and physical factors on lying behaviour. Data for 96 Mule ewes managed to lamb indoors, and 80 predominantly Welsh Mountain ewes managed to lamb at grass were used for the study. Acceleration values were collected for the two flocks from HOBO Pendant G accelerometers (Onset Computer Corporation, Bourne, MA) fitted vertically to the outside of the rear right leg and set to record at 1-min intervals for at least 14 d prior to parturition. Ewes were simultaneously recorded using video equipment to identify lambing and to verify predictions of lying (total lying time, mean lying bout duration and mean numbers of lying bouts) using 10 randomly selected ewes from the indoor flock on day -10 prior to lambing. Linear regression was used to evaluate predicted behaviours with video footage. Measures of lying (mean daily lying time, mean lying bout duration and mean daily lying bouts) were calculated for all ewes using averages taken across days -10, -9 and -8 prior to lambing and linear regression was used to test for effects of independent variables (pregnancy scan result (single- or twin-bearing), ewe age, ewe BCS, lambing ease, lamb sex and lamb birth weight) on each measure of lying. Predictions of total lying time ($R^2 \geq 0.99$; $P > 0.05$ for slope = 1, intercept = 0), mean lying bout duration ($R^2 \geq 0.99$; $P > 0.05$ for slope = 1, intercept = 0) and mean number of lying bouts ($R^2 \geq 0.98$; $P > 0.05$ for slope = 1, intercept = 0) were strongly associated with video footage ($P < 0.001$), demonstrating that a 1-min sampling interval provides reliable estimates of ewe lying behaviours. Significant associations ($P < 0.05$) were found between measures of lying and pregnancy scan result, ewe age, sex of singleton lambs and twin birth weight for housed, Mule ewes. Only ewe age and twin birth weight were significantly associated ($P < 0.05$) with measures of lying for Welsh mountain ewes managed at grass. This information could help guide further research on sheep behaviour for management purposes (e.g., to optimise stocking densities and welfare for pregnant ewes). Further work should also consider evaluating measures of lying as proxies for imminent parturition.

Keywords

Sheep; Behaviour; Accelerometers; Pregnant; Lying behaviour; Lambing

1. INTRODUCTION

The use of precision sensors to monitor the behaviour and performance of livestock has been shown to be highly valuable, and significant research and development have been undertaken in support of the management of cattle (Caja et al., 2016) and other intensively managed animals (Benjamin and Yik, 2019; Li et al., 2020). Discrete, on-animal sensors are now providing previously unattainable information, allowing for a better understanding of livestock behaviour for managing comfort (Molina et al., 2020) and production disorders (Wagner et al., 2020) using sensors such as pedometers (Edwards and Tozer, 2004) and accelerometers (Reiter et al., 2018). Further development of integrated systems on farms will provide farmers with the information necessary to make management decision at the level of the individual animal as well as at a flock or herd level. Some sectors of the livestock industry have seen a greater emphasis on the development of precision sensors and systems, in-part because of the economic necessity and incentive to do so, such as in the dairy industry (Rutten et al., 2013). For example, the fertility management of cattle has developed greatly in recent years with information such as feeding duration and activity used to support the optimum time for artificial insemination (Mottram, 2016).

More recently, it has been demonstrated that the management of sheep could also be supported by on-animal sensor technology. For example, accelerometers were used to measure the activity of growing lambs showing promise for the early detection of behavioural changes associated with parasitism (Ikurior et al., 2020). Research has also been undertaken to assess the feasibility of recording other measures from sheep including attributes of movement for identifying gait anomalies associated with lameness (Barwick et al., 2018), feeding behaviour (Giovanetti et al., 2017) and also parturition (Fogarty et al., 2020). However, few studies have assessed the behaviour of sheep in commercial settings. This will be needed to effectively differentiate optimal from suboptimal performance. Lambing represents an important period in the production cycle for ewe comfort and welfare but relatively little is known about the behaviour of pregnant sheep. Often, shepherds are in increased contact with sheep during this time and this presents an opportunity to test the feasibility of using well-established activity monitoring techniques. Lying behaviour is a highly valuable metric of behaviour in other species (Jensen, 2012; Blackie et al., 2011) and can be measured and monitored using accelerometers. These methods require low computational power and data processing and have been shown to be highly valuable in identifying indicators to support the management of other livestock (Ito et al., 2009). To our knowledge, no similar exploratory analyses have been undertaken using accelerometers with sheep. This information could be useful to better understand the behaviour of sheep particularly during times of increased stress (e.g., lambing) and provide information on the degree of variability in measures of lying that might be present in a flock and associated factors.

The aim of the experiment was to investigate the effect of biological and physical factors on the lying behaviour of sheep. The objectives were 1.) to validate the use of leg-mounted accelerometers for measuring lying time and 2.) explore whether commonly measured biological and physical attributes of sheep around the time of lambing contribute to variability in measures of lying time. To achieve this, both indoor- and outdoor-lambing flocks were studied, representing common UK sheep production systems. We hypothesised that variation in economically important attributes of sheep would partly explain variations in lying behaviour during the final trimester of pregnancy.

2. MATERIALS & METHODS

The study was approved by Aberystwyth University Animal Welfare and Ethical Review Board.

2.1. Study farms

Data were collected at two different farms representing lowland (Farm A; Gogerddan Farm, Aberystwyth University, Wales) and upland (Farm B; Llysfasi Farm, Coleg Cambria, Wales) commercial lamb-producing enterprises between February and May 2019. Farm A lies approximately 40 m above sea level and is situated 6 km north-west of Aberystwyth, Ceredigion, Wales. The farm comprises of approximately 1,000 ewes of predominantly Welsh Mule-type sheep (Bluefaced Leicester x Welsh Mountain (WM) crossbred ewes), with a small number of both Beulah and pure-bred Texel ewes that are managed at grass throughout the year and housed in January to lamb between February and March. Lambs are finished at grass. Farm B ranges between 200-300 m above sea level and is situated 6 km south of Ruthin, Denbighshire, Wales and manages approximately 1,000 Welsh WM ewes and 160 Welsh crossbred ewes. The flock is managed at grass throughout the year with ewes lambing between April and May. After weaning, lambs are finished at grass with a proportion finished on silage and concentrate feed.

2.2. General ewe management

The first experiment took place at Farm A. Following a winter tupping period, ewes were pregnancy scanned on the 8th and 15th January 2019 and housed in two barns with capacity for approximately 600 ewes. The remaining 400 ewes would lamb at a later date. Ewes were penned according to their pregnancy status, with single, twin and triplet-bearing ewes managed separately in straw-bedded pens measuring 8.8 m x 6.1 m. On average, each pen contained approximately 40 ewes at any given point. Ewes had *ad-libitum* access to water and a complete ration comprising of grass silage and a protein blend dispensed twice per day at 0800 and 1600 throughout their third trimester of pregnancy. Upon lambing, ewes were moved with their offspring to an individual 1.5 m x 1.5 m pen situated around the inner perimeter of the barn. Both ewes and lambs remained in these single pens for at least 24 h before being moved out to pasture or to a separate larger pen. The second experiment took place at Farm B. Ewes were pregnancy scanned on the 14th February 2019 and those selected for the experiment were brought-in to in-bye fields surrounding the farm buildings on the 9th March 2019 prior to lambing. For the purpose of the experiment, both single and twin-bearing ewes were lambed as mixed groups in two fields (field A; 0.66 ha and field B; 0.87 ha) close to the farm buildings. Ewes were managed at grass throughout the lambing period, had free access to water and were supplemented with *ad-libitum* access to a glucose lick.

2.3. Ewe selection and data collection

2.3.1. Farm A - indoor lambing

Of the 600 Mule ewes that were initially due to lamb at Farm A, 46 single-bearing and 52 twin-bearing ewes were randomly selected from the flock and entered the experiment on the 25th and 26th February 2019 according to availability. Upon selection, the age of each ewe was recorded according to farm records, and its body condition score (BCS = 1-5; Russel, 1984) and locomotion score (locomotion score 0-3; Angell et al., 2015) recorded. No lame ewes were selected for the experiment. Ewes were clearly spray marked on each side with a unique number for identification purposes and randomly allocated to one of six pens. To record the lying behaviour of the experimental ewes, HOBO Pendant G accelerometers (Onset Computer Corporation, Bourne, MA) were fitted to the outside of the right-hind leg of each ewe according to a standard operating procedure (UBC Animal Welfare Program, 2013). The accelerometers were fitted vertically, such that the X-axis was pointing upward and the Z-axis pointing left towards the midplane of the ewe. Accelerometers were configured to sample at 1-min intervals. This sampling interval was selected as it has been previously used to record the lying behaviour of dairy goats (Zobel et al., 2015) and is well-established for use in monitoring the lying behaviour of cattle (Ledgerwood et al., 2010). This sampling interval also allowed for 14 d of continuous data recording which meant that most ewes (n=??) could remain undisturbed other than for daily management. Once accelerometers were fitted, each ewe was placed back into its allocated pen where it remained until it gave birth. In order to visually verify predicted behaviours and the time of lambing, cameras (5MP PoE Security Camera System, Reolink) were fitted to the end of each pen containing focal ewes and were set to record throughout the entire experimental period. During the night, the lights in the building remained on for management purposes. Upon lambing, ewes were moved to individual pens and their accelerometer removed. At this point, the lambing difficulty (0 = no assistance, 1 = slight assistance, 2 = severe assistance, 3 = veterinary assistance), lamb birthweight (kg) and sex were recorded. If ewes had not given birth within the initial 14 d observation period, the original accelerometer was removed and replaced with a second accelerometer which remained in place until the ewe had given birth. Upon removal, data were downloaded from each accelerometer and saved in a spreadsheet program. Other than for specific experimental procedures and data capture, all ewes were managed and monitored 24 h/d by farm shepherds. Data collection was complete by 22nd March 2019 at Farm A. Three single-bearing ewes did not lamb during the trial leaving only pre-lambing variables for testing for these ewes. Behaviour data for two twin-bearing ewes were not available due to the failure of accelerometers and a further two did not give birth during the trial. This left a total of 46 single-bearing ewes (n = 43 for all variables) and 50 twin-bearing ewes (n = 48 for all variables) available for analysis.

2.3.2. Farm B - outdoor lambing

Of the ewes brought-in to in bye fields at Farm B on the 9th March 2019, 44 were single-bearing and 45 were twin-bearing WM ewes. At this point, the age of all ewes was determined, and their body condition and locomotion scores recorded as described previously. Ewes were also fitted with an accelerometer and equally and randomly split between fields A and B. Six cameras (5MP PoE Security Camera System, Reolink) were fitted around the boundary of field A to record as much information as possible such as the time of lambing which may have been missed by the shepherd. Once ewes in field A had given birth, they were replaced with ewes from field B in order to maximise the number of ewes captured on video giving birth. Ewes were regularly monitored by a shepherd at least 3-times daily between 06:30 h-08:30 h, 11:30 h-13:30 h and 16:00 h-18:00 h. All observations were made from the boundary of the field and intervention (e.g., for reasons of birthing difficulty) was only undertaken when necessary according to farm protocols. Shortly after lambing, measures were recorded for each lamb as described for Farm A, and if required, video footage was used to verify the time of birth (no ewes required any level of birthing assistance in the flock monitored at Farm B and so this factor was not used for analysis). At this point, accelerometers were removed, and data downloaded. Accelerometers were replaced on ewes that had not given birth within the initial 14 d observation period before being returned to their respective field. Data collection was complete by 1st May 2019 at Farm B. Data for three single-bearing ewes were missing due to a fault with the accelerometers. One other single-bearing ewe did not lamb during the trial and so analysis of post-birth data was not possible for this ewe. For twin-bearing ewes, three did not lamb during the trial and three accelerometers failed to function. In total, there were behaviour data for 41 single-bearing and 39 twin-bearing ewes available for analysis.

2.4. Data processing

Accelerometer data (*g*-force values) for each ewe were processed using R statistical software (R Core Team, 2019) in a program adapted from that developed by UBC Animal Welfare Program (2013) based on the method of Ledgerwood et al. (2010). The guidance provided by Zobel et al. (2015) for accelerometer cut-off values were used to determine whether the ewe was in a lying (or standing) position and these values were incorporated into the program. Lying laterality was not explored in this work. Behaviours computed from the raw accelerometer data included lying time (min/d), lying bouts (n/d) and lying bout duration (min/bout) using the X-axis data only. These behaviours were calculated for each ewe, for each day that the accelerometer remained in place. For ewes that had not given birth in the initial 14 d observation period, two spreadsheets were processed. For all ewes, the first day of accelerometer data was ignored, as were data recorded on the day of accelerometer changeover (if necessary). This was to allow for a 24 h settling-in period.

It has been shown previously that at least 3 d of behaviour data are required to obtain a reliable estimate of the behaviour of cattle (Ito et al., 2009) and a similar method has been applied to dairy goats (Zobel et al., 2015). In order to reliably estimate the behaviours of each ewe, the computed values for measures of lying were standardised by averaging three days of data in the 10 d period prior to the day of lambing. These were days -10, -9 and -8 prior to lambing for each ewe as it was hypothesised that the behaviour of ewes may be influenced by the onset of lambing (behaviour change within 24 hrs of birth) (Echeverri et al., 1992; Fogarty et al., 2020). This procedure was repeated for all ewes at both farms. A total of 10 ewes (n = 5 single-bearing, n = 5 twin-bearing) from

Farm A were randomly selected to verify lying behaviours with recorded camera footage (24 h for each ewe).

2.5. Statistical analysis

To validate the accuracy of the accelerometer measurements, estimates of total lying time, number of lying bouts and mean bout duration were compared with video footage taken on day -10 before lambing for 10 randomly selected ewes (24 hrs each for 5 single- and 5 twin-bearing ewes) using linear regression. Transitions between lying and standing were recorded on a per-second basis and rounded to the nearest minute in a spreadsheet program for analysis with predicted behaviours. Regression slopes and intercepts were evaluated to see whether they differed significantly ($P \leq 0.05$) from 1 and 0 respectively.

Median values were used to describe the distribution of the three measures of lying (lying time (h/d), lying bouts (n/d) and lying bout duration (min/bout)) separately for both farms. The outcome variables "lying bouts per day" and "lying bout duration" were log transformed to achieve data normality. Single variables were then tested for their association with the 3 measures of lying using simple linear regression separately for both farms. For ewes at Farm A, single variables included pregnancy scan result (single or twin), age (1-≥ 5), BCS (1-5) and pen (1-6). These were the same for ewes at Farm B other than that pen was not recorded. Variables associated with lambs at Farm A and B included lambing ease (0-3), lamb sex and lamb birthweight (kg). Lambing ease was not recorded at Farm B given the nature of the system. The statistical significance of a relationship was declared when the probability of the regression slope differing from zero fell below 0.05. All statistical analyses were undertaken in R (R Core Team, 2019).

3. RESULTS

3.1. Associations between accelerometer predictions and video recordings

Results for linear regression models between predicted measures of lying and those verified by video recordings for 10 sheep at Farm A are shown in Table 1. A strong linear relationship was found for all three measures of lying ($P < 0.001$) with coefficients of determination ≥ 0.99, 0.99 and 0.98 for total lying time (min/d) mean lying bout duration (min/bout) and the mean number of lying bouts (n/d) respectively. With the accelerometer set to sample at 1-min intervals, accurate estimates of lying behaviours were obtained with each regression slope and intercept not differing significantly from 1 and 0 respectively ($P > 0.05$).

3.2. Measures of lying behaviour of housed and outdoor managed ewes

Ewes ($n = 96$) studied at Farm A (Figure 1A) spent a median duration of 13.1 h/d lying down (25^{th} – 75^{th} percentile = 11.9 – 14.3 h/d), had a lying bout frequency of 26.8 bouts/d (25^{th} – 75^{th} percentile = 23.3 – 31.1 bouts/d) and a median bout duration of 29.5 min/bout (25^{th} – 75^{th} percentile = 25.2 – 33.6 min/bout). Ewes ($n = 80$) at Farm B (Figure 1B) spent a median duration of 11.7 h/d lying down (25^{th} – 75^{th} percentile = 10.3 – 12.9 h/d), had a lying bout frequency of 19 bouts/d (25^{th} – 75^{th} percentile = 15 – 23.8 bouts/d) and a median bout duration of 35.9 min/bout (25^{th} – 75^{th} percentile = 30.8 – 45.4 bouts/d).

Univariate results for Farm A (Table 2) found that pregnancy scan foetus number was significantly positively associated ($P = 0.02$) with the daily duration of lying of ewes. On average, twin-bearing ewes lay down 48.51 min/d longer than single-bearing ewes. However, no significant differences were found for the frequency of lying bouts ($P = 0.60$) or lying bout duration ($P = 0.46$) between the groups.

There was no overall effect of age ($P = 0.15$) on the daily lying duration of ewes, but age was significantly associated with the number of daily lying bouts ($P = 0.01$) and the duration of each bout ($P = 0.04$). The duration of lying bouts for three and four-year old ewes was shorter, and the number of daily bouts was higher compared to other ewes.

A significant association (*P* = 0.03) was found between the sex of singleton lambs and the daily lying time of ewes. Ewes carrying male lambs lay down for a shorter (-67.07 min) daily duration. No associations were found between the sex of singletons and the other two measures of lying. For twin-bearing ewes, no associations were found between the sex of lambs (male, female or mixed-sexed groups) and any of the three measures of lying. Similarly, no associations were found between the birthweight of singletons and any of the three measures of lying. However, of the twin-bearing ewes, as twin birthweight increased there was a highly significant reduction (*P* < 0.001) in the daily duration of lying (-43.07 min/d). This effect could not be accounted for by significant changes to lying bout duration (*P* = 0.54) or lying bout frequency (*P* = 0.22). No other significant associations were found between any of the other factors measured at Farm A and the three measures of lying.

In contrast to ewes managed indoors at Farm A, no significant effect of pregnancy scan result was found for the three measures of lying behaviour for the ewes managed at the outdoor system at Farm B (Table 3). Furthermore, the frequency of lying bouts was found to be positively associated with ewe age (*P* = 0.02) only. In agreement with Farm A, no associations were found between ewe BCS and measures of lying at Farm B.

In contrast to the Mule ewes at Farm A, no significant effect was found for the sex of singleton lambs on the three measures of lying, but similarly, no effect of the sex of twin lambs was found. As with ewes at Farm A, a negative effect of lamb birth weight on lying bout duration, only, was found for twin-bearing ewes. However, with ewes at Farm B, as twin birth weight increased, lying bout duration decreased (*P* = 0.03) and the daily frequency of lying bouts increased significantly (*P* < 0.01). Despite these associations, no significant relationship was found between twin birthweight and daily lying duration for WM ewes at Farm B.

4. DISCUSSION

The HOBO accelerometer showed accurate estimates of lying behaviour when verified against video recordings of housed sheep. A 1-min sampling interval was sufficient in recognising 96% of lying events in the 10 sheep used for verification at Farm A. Across the 10-test sheep, the average (± SD) number of missed lying bouts was 1.5 ± 1.1. All missed lying bouts were those that from the video footage had a duration of between 30-59 s, which upon rounding were logged as a lying bout. However, all lying bouts lasting < 1-minute were occasions where a displacement activity had occurred between the focal sheep and another or a disturbance had occurred where farm staff were operating. All lying events lasting ≥1-min were identified by the accelerometer in the verification group. Shortening the sampling interval to 30 s would likely capture all such events but this would also have the effect of reducing the duration of total data capture. With this, we believe that a 1-min sampling interval, providing 14 d of continuous data capture is sufficient and provides highly accurate estimations of measures of lying of sheep as has been shown in studies of cattle (Ledgerwood et al., 2010; Mattachini et al., 2013). Lying laterality was not explored in this work. More work is required in examining the importance of laterality in the study of sheep behaviour as has been done with cattle (Gibbons et al., 2012; Miller-Cushon et al., 2019) and goats (Zobel et al., 2015). Subsequently, work will be needed to accurately estimate measures of lying laterality in sheep, using appropriate thresholds from accelerometer data.

To our knowledge, this is the first time that measures of lying behaviour for both housed and outdoor-managed pregnant sheep have been recorded using this method. The results of the exploratory analyses provide an objective insight into the daily lying times of pregnant ewes and show that significant variation exists between individuals for measures of daily lying behaviour in each of the studied flocks. The median daily lying duration, lying bout frequency and bout duration for housed sheep was 13.1 h/d, 26.8 bouts/d and 29.5 min/bout respectively. For the outdoor flock these values were 11.7 h/d, 19 bouts/d and 35.9 min/bout respectively. In a previous study, Arnold (1984) used direct visual observations to measure the lying behaviour of sheep co-grazing with cattle and horses in a Mediterranean environment. The average daily lying duration of sheep was 11.6 h per day which broadly coincides with the results of the current study, particularly for the WM ewes at grass. Others have assessed lying time as a proportion of total time using visual observations. A mean daily lying proportion of 66% was found in a study examining the effect of pen size (mean = 0.75 m^2 per ewe) on lying behaviour of pregnant, Norwegian Dala sheep (Bøe et al., 2006) and a lying proportion of 70% in a study allowing for 1.5 m^2 per pregnant ewe (Jørgensen et al., 2009). In the current study, Mule ewes at Farm A spent 55% of their time lying (~1.3 m^2 per ewe) whereas WM ewes at Farm B spent 49% of their time lying which substantially differs to the studies noted. A low daily lying proportion might have been expected for the housed flock at Farm A given the high level of staff interaction and that lying space is more limited compared to when ewes are at grass. At Farm A, approximately 1.3 m^2 was available for each ewe which is within the guidelines required for lowland, pregnant ewes (DEFRA, 2003). To our knowledge, little information is available on the expected resting times of ewes in both housed and outdoor conditions, but some exploratory work has been undertaken to assess the behaviour of pregnant ewes in relation to the amount floor space available in housed conditions (Averós et al., 2014). Although the lying bout duration of sheep at Farm B was longer than those of the housed sheep, they spent less time lying each day and had fewer daily lying bouts compared to the housed flock. These sheep may have spent more of their time foraging throughout the paddocks.

Some of the measured variables were shown to be significantly associated with measures of lying time in both systems. In the current study, housed sheep carrying twin-lambs had a greater daily lying duration compared to single-bearing ewes, but this was not found for the ewes managed at grass. This may have been linked to the combined weight of the developing foetuses. The average (± SD) combined twin birthweight of lambs born to Mule and WM ewes was 9.55 kg (± 1.26) and 7.34 kg (± 1.73) respectively. Proportionally, however, the birthweight of single lambs relative to the combined weight of twin lambs was similar (65% and 64% for Mules and WM respectively). A better comparison would be to assess birthweights with respect to maternal weights as has been undertaken previously (Gardner et al., 2007), but these data were not available. It was also shown in that study that the proportional increase in litter size relative to ewe weight was greater in Mules compared to WM ewes, but it is also reported that hill breeds carry a significantly heavier litter proportional to their body weight (Dwyer and Lawrence, 2005). Both breed (e.g., ewe survival strategy) and managerial factors (displacements and interventions by staff) may have contributed to the differences seen between systems for daily lying time. In the housed system, although the lying time of twin-bearing ewes was not explained by significant changes to bout duration or the number of daily bouts, these insignificant, yet marginally higher figures for twin-bearing ewes likely led to higher lying times. Over the course of 24 hrs, the lying time accrued amounted to significantly higher levels compared to the single-bearing ewes. One hypothesis for this finding is that housed sheep behave more like a flock and are probably highly influenced by factors external to their pen environment as compared to sheep in a field environment. Anecdotally, the footage for the verification study demonstrated just how receptive the housed ewes were to human movement and intervention, frequently moving as entire groups in response to various stimuli.

Effects of age on measures of lying were found in both flocks although the relationships were different. In the WM flock, only the frequency of lying bouts was associated with age with more bouts undertaken in older ewes compared to younger ewes. In the housed ewes, both lying bout duration and lying bout frequency were associated with age, but the relationship was not completely clear between the variables. The duration of lying bouts for three and four-year old ewes were shorter with a greater number of daily lying bouts compared to other ewes. Parity effects on lamb birth weight, litter weight and placenta weight have been reported previously with significant increases in each from parities 1-3 (Dwyer et al., 2005). The authors also reported that although lamb birth weights and litter weights were greater for Suffolk ewes compared to Blackface ewes, litter weight expressed as a percentage of maternal weight was significantly greater for Blackface ewes. Breed and environment may play a role in the behaviour of older ewes but given the relatively few numbers available for inclusion in the higher age categories, further work would be needed to fully evaluate these findings.

Interestingly, and for the housed sheep only, ewes carrying a male singleton lamb had significantly lower daily lying times compared to ewes carrying female singleton lambs. Again, this effect could not be fully explained by significant changes to the other two measures of lying and may again be a cumulative effect of marginal reductions in lying bout duration as well as the number of bouts. The average birth weight (± SD) of male and female singletons was 6.54 kg (± 0.99) and 5.98

kg (± 0.97) respectively and this may have explained the differences recorded in ewe lying time. It is known that bearing male lambs can lead to increased labour duration and birthing difficulty (Dwyer, 2003), which can ultimately affect lamb survival. However, to our knowledge, little is known about the prepartum behaviour of the ewe with respect to the sex of the lamb. This effect was not found for twin-bearing ewes and it may be that for these ewes, the combined foetal weight is a more important factor in defining measures of lying compared to lamb sex.

In both flocks, effects of increasing combined twin birthweights were found, but no effect of singleton birthweight was found on any measure of lying. For housed ewes, daily lying times decreased significantly with higher combined twin birthweights but neither lying bout duration or the frequency of lying bouts was significantly affected. This may again relate to group behaviour in a housed environment. Ewes with heavier twin-foetuses may only be losing marginal lying time per lying bout compared to ewes with lighter twin-foetuses resulting in an overall significant reduction in lying time with increasing twin-birthweight. One explanation may be that heavier twin foetuses lead to greater lying discomfort during the final stages of pregnancy leading to the increased time spent standing. There are advantages to increased litter weights such as lamb survival, and other studies have measured pre- and postnatal behaviours of several breeds and their associations with lamb survival (Lynch et al., 1980; Rachlow and Bowyer, 1998) as well as biological factors (e.g., placental efficiency) that may favour increased litter weight in hill breeds (Dwyer et al., 2003). For ewes at grass, although there was no significant relationship between twin birth weight and daily lying time, the duration of lying bouts decreased and the number of daily lying bouts increased significantly as twin birthweight increased. This could again be a coping strategy for ewes with heavier twin foetuses and may also reflect a greater level of behavioural independence compared to housed ewes who may have been more influenced by their environment.

For housed ewes at Farm A, lambing ease was assessed, and it is perhaps unsurprising that there were no significant associations between any of the three measures of lying and each level within this factor. Measures of the lying time were assessed more than a week prior to lambing and at this point at least, no differences in lying behaviour were detected that may be associated with difficult parturition. It is likely that assessments would be required closer to the day of parturition and it would be worthwhile to explore this as indicators of birthing difficulty would be useful for shepherds.

To our knowledge, the descriptive statistics and associations found here have not been reported previously for sheep. In this work, measurement days were standardised (days -10, -9 and -8 prepartum) for comparison between individuals and it may be the case that the associations found could change again with proximity to birth (e.g., postural changes). This work could also be extended to other flocks to further evaluate these predictions and to inform further exploratory analyses such as assessing the impact of stocking density on ewe behaviour. Further studies should also seek to identify whether one or more of these measures of lying could be used as alternatives to more computationally intensive strategies to identify parturition or ill health.

5. CONCLUSION

HOBO accelerometers accurately recorded measures of lying time at a 1-min sampling interval showing wide variation between individual sheep. This method can be recommended for recording flock lying behaviour over short durations. For Mule sheep managed indoors, significant associations were found between measures of lying and pregnancy scan result (single or twins carried), age of ewe, male singleton lambs and the birth weight of twin lambs. For WM sheep managed at grass, associations were only found for ewe age and twin lamb birth weight. Further studies should seek to identify any further implications of these findings such as the impact of stocking density on lying behaviour given pregnancy status. In addition, work should be undertaken to assess whether simple measures of lying can be used to evaluate health status or to predict imminent lambing which would be particularly useful for flock managers in extensive systems.

DECLARATION OF COMPETING INTEREST

The authors declare no competing interest.

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REFERENCES

Angell, J.W., Cripps, P.J., Grove-White, D.H. and Duncan, J.S., 2015. A practical tool for locomotion scoring in sheep: reliability when used by veterinary surgeons and sheep farmers. *Veterinary Record*, *176*(20), pp.521-521. doi: 10.1136/vr.102882.

Arnold, G. W. "Comparison of the time budgets and circadian patterns of maintenance activities in sheep, cattle and horses grouped together." *Applied Animal Behaviour Science* 13, no. 1-2 (1984): 19-30. https://doi.org/10.1016/0168-1591(84)90048-0.

Averós, X., Lorea, A., de Heredia, I.B., Arranz, J., Ruiz, R. and Estevez, I., 2014. Space availability in confined sheep during pregnancy, effects in movement patterns and use of space. *PLoS One*, *9*(4), p.e94767. https://doi.org/10.1371/journal.pone.0094767.

Barwick, J., Lamb, D., Dobos, R., Schneider, D., Welch, M. and Trotter, M., 2018. Predicting lameness in sheep activity using tri-axial acceleration signals. *Animals*, *8*(1), p.12. https://doi.org/10.3390/ani8010012.

Benjamin, M. and Yik, S., 2019. Precision livestock farming in swine welfare: a review for swine practitioners. *Animals*, *9*(4), p.133. https://doi.org/10.3390/ani9040133.

Blackie, N., Amory, J., Bleach, E. and Scaife, J., 2011. The effect of lameness on lying behaviour of zero grazed Holstein dairy cattle. *Applied Animal Behaviour Science*, *134*(3-4), pp.85-91. https://doi.org/10.1016/j.applanim.2011.08.004.

Bøe, K.E., Berg, S. and Andersen, I.L., 2006. Resting behaviour and displacements in ewes—effects of reduced lying space and pen shape. *Applied Animal Behaviour Science*, *98*(3-4), pp.249-259. https://doi.org/10.1016/j.applanim.2005.10.001.

Caja, G., Castro-Costa, A. and Knight, C.H., 2016. Engineering to support wellbeing of dairy animals. *Journal of Dairy Research*, *83*(2), pp.136-147. https://doi.org/10.1017/S0022029916000261.

DEFRA 2003, Code of Recommendations for the Welfare of Livestock – Sheep, viewed 11 January 2021, < https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69365/pb5162-sheep-041028.pdf >.

Dwyer, C.M., 2003. Behavioural development in the neonatal lamb: effect of maternal and birth-related factors. *Theriogenology*, *59*(3-4), pp.1027-1050. https://doi.org/10.1016/S0093-691X(02)01137-8.

Dwyer, C.M., Calvert, S.K., Farish, M., Cotham, S., Donbavand, J., Chirnside, J. and Pickup, H.E., 2003. Breed and parity differences in ovine placentation: implications for placental efficiency and lamb vigour. In *Proceedings of the British Society of Animal Science* (Vol. 2003, pp. 5-5). Cambridge University Press. https://doi.org/10.1017/S1752756200011649.

Dwyer, C.M., Calvert, S.K., Farish, M., Donbavand, J. and Pickup, H.E., 2005. Breed, litter and parity effects on placental weight and placentome number, and consequences for the neonatal behaviour of the lamb. *Theriogenology*, *63*(4), pp.1092-1110. https://doi.org/10.1016/j.theriogenology.2004.06.003.

Dwyer, C.M. and Lawrence, A.B., 2005. A review of the behavioural and physiological adaptations of hill and lowland breeds of sheep that favour lamb survival. *Applied Animal Behaviour Science*, *92*(3), pp.235-260. https://doi.org/10.1016/j.applanim.2005.05.010.

Echeverri, A.C., Gonyou, H.W. and Ghent, A.W., 1992. Preparturient behavior of confined ewes: time budgets, frequencies, spatial distribution and sequential analysis. *Applied Animal Behaviour Science*, *34*(4), pp.329-344.

Edwards, J.L. and Tozer, P.R., 2004. Using activity and milk yield as predictors of fresh cow disorders. *Journal of Dairy Science*, *87*(2), pp.524-531. https://doi.org/10.1016/S0168-1591(05)80093-0.

Fogarty, E.S., Swain, D.L., Cronin, G.M., Moraes, L.E. and Trotter, M., 2020. Can accelerometer ear tags identify behavioural changes in sheep associated with parturition? *Animal Reproduction Science*, p.106345. https://doi.org/10.1016/j.anireprosci.2020.106345.

Gardner, D.S., Buttery, P.J., Daniel, Z. and Symonds, M.E., 2007. Factors affecting birth weight in sheep: maternal environment. *Reproduction*, *133*(1), pp.297-307. https://doi.org/10.1530/REP-06-0042.

Gibbons, J., Medrano-Galarza, C., de Passillé, A.M. and Rushen, J., 2012. Lying laterality and the effect of IceTag data loggers on lying behaviour of dairy cows. *Applied Animal Behaviour Science*, *136*(2-4), pp.104-107. https://doi.org/10.1016/j.applanim.2011.12.005.

Giovanetti, V., Decandia, M., Molle, G., Acciaro, M., Mameli, M., Cabiddu, A., Cossu, R., Serra, M.G., Manca, C., Rassu, S.P.G. and Dimauro, C., 2017. Automatic classification system for grazing, ruminating and resting behaviour of dairy sheep using a tri-axial accelerometer. *Livestock Science*, *196*, pp.42-48. https://doi.org/10.1016/j.livsci.2016.12.011.

Ikurior, S.J., Pomroy, W.E., Scott, I., Corner-Thomas, R., Marquetoux, N. and Leu, S.T., 2020. Gastrointestinal nematode infection affects overall activity in young sheep monitored with tri-axial accelerometers. *Veterinary Parasitology*, *283*, p.109188. https://doi.org/10.1016/j.vetpar.2020.109188.

Jensen, M.B., 2012. Behaviour around the time of calving in dairy cows. *Applied Animal Behaviour Science*, *139*(3-4), pp.195-202. https://doi.org/10.1016/j.applanim.2012.04.002.

Jørgensen, G.H.M., Andersen, I.L. and Bøe, K.E., 2009. The effect of different pen partition configurations on the behaviour of sheep. *Applied Animal Behaviour Science*, *119*(1-2), pp.66-70. https://doi.org/10.1016/j.applanim.2009.03.001.

Li, N., Ren, Z., Li, D. and Zeng, L., 2020. Automated techniques for monitoring the behaviour and welfare of broilers and laying hens: towards the goal of precision livestock farming. *Animal*, *14*(3), pp.617-625. https://doi.org/10.1017/S1751731119002155.

Lynch, J.J., Mottershead, B.E. and Alexander, G., 1980. Sheltering behaviour and lamb mortality amongst shorn Merino ewes lambing in paddocks with a restricted area of shelter or no shelter. *Applied Animal Ethology*, *6*(2), pp.163-174. https://doi.org/10.1016/0304-3762(80)90067-X.

Miller-Cushon, E.K., Horvath, K.C., Fabris, T.F., Dahl, G.E. and Laporta, J., 2019. Effects of mammary biopsy in the dry period on activity and feeding behavior of dairy cows. *Journal of Dairy Science*, *102*(12), pp.11453-11458. https://doi.org/10.3168/jds.2019-17007.

Molina, F.M., Marín, C.C.P., Moreno, L.M., Buendía, E.I.A. and Marín, D.C.P., 2020. Welfare Quality® for dairy cows: towards a sensor-based assessment. *Journal of Dairy Research*, *87*(S1), pp.28-33. https://doi.org/10.1017/S002202992000045X.

Mottram, T., 2016. Animal board invited review: precision livestock farming for dairy cows with a focus on oestrus detection. *Animal*, *10*(10), pp.1575-1584. https://doi.org/10.1017/S1751731115002517.

Rachlow, J.L. and Bowyer, R.T., 1998. Habitat selection by Dall's sheep (Ovis dalli): maternal trade-offs. *Journal of Zoology*, *245*(4), pp.457-465. https://doi.org/10.1017/S0952836998008097.

R Core Team (2019). A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org/.

Reiter, S., Sattlecker, G., Lidauer, L., Kickinger, F., Öhlschuster, M., Auer, W., Schweinzer, V., Klein-Jöbstl, D., Drillich, M. and Iwersen, M., 2018. Evaluation of an ear-tag-based accelerometer for monitoring rumination in dairy cows. *Journal of Dairy Science*, *101*(4), pp.3398-3411. https://doi.org/10.3168/jds.2017-12686.

Russel, A., 1984. Body condition scoring of sheep. *In Practice*, *6*(3), pp.91-93. https://doi.org/10.1136/inpract.6.3.91.

Rutten, C.J., Velthuis, A.G.J., Steeneveld, W. and Hogeveen, H., 2013. Invited review: Sensors to support health management on dairy farms. *Journal of Dairy Science*, *96*(4), pp.1928-1952. https://doi.org/10.3168/jds.2012-6107.

Wagner, N., Antoine, V., Mialon, M.M., Lardy, R., Silberberg, M., Koko, J. and Veissier, I., 2020. Machine learning to detect behavioural anomalies in dairy cows under subacute ruminal acidosis. *Computers and Electronics in Agriculture*, *170*, p.105233. https://doi.org/10.1016/j.compag.2020.105233.