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Liveweight loss associated with handling and weighing of grazing sheep

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Abstract

Sheep liveweight and liveweight change are important data both for research and commercial farm management worldwide. However, they can contain errors when procedures in collection are not standardised, including when weighing occurs around other husbandry tasks resulting in varying time delays between removal from grazing and weighing. This research had three stages with different objectives: 1) a liveweight loss study, to quantify liveweight and liveweight change over three and six hours of delay prior to weighing within a handling facility, and to develop a correction equation for delayed liveweights; 2) a validating process, to examine the correction ability of the equation by using it on a different set of delayed liveweights collected under a range of situations; and 3) a management simulation, to explore what impact delayed and corrected delayed liveweights could have when liveweight change was used to assign ewes to feeding levels. Results from each stage showed that: 1) ewes lost a significant amount of liveweight after three (1.8 ± 0.5 kg or 3.5 ± 0.8 % liveweight) and six (2.9 ± 0.6 kg or 5.6 ± 1.0 % liveweight) hours delay during a practical handling operation ($p<0.001$). The following equation was developed to correct delayed liveweights: $y = 100\ (x\ /\ (100 + (-0.9301\ t + 0.07106)))$ where y, x and t are corrected liveweight (kg), delayed liveweight (kg) and time delayed in decimal hours, respectively; 2) the correction equation provided a more accurate and precise estimate of liveweight than a delayed liveweight alone; and 3) use of delayed liveweights, to determine liveweight change over a two month period, resulted in significantly more animals being assigned wrongly to higher feeding levels ($p<0.001$), than if the delayed liveweights had been corrected by time elapsed since gathering from grazing fields. To conclude, a short-term delay prior to weighing associated with a practical handling operation significantly reduces the numerical liveweight recorded for each sheep. Using variably delayed liveweights in research and on commercial farms will have significant consequences for research results and management practices globally. Therefore collection of liveweights should occur without delay. However, when this is not feasible delayed liveweights should be corrected and in the absence of locally formulated correction equation, the one presented in this paper could be used.

Keywords: liveweight; weighing; accuracy; precision; data collection; sheep.

1. Introduction

Liveweights are indicative of an animal's current and changing physical state and measuring changes in liveweight is useful in assessing how an animal is responding to its current situation (Baker et al., 1947). As liveweight is affected by: growth, nutrition, health, stress, pregnancy and genetics (Brown et al., 2015; Coates and Penning, 2000), research exploring these areas in sheep can use liveweight as an important variable. Liveweights are one of the most frequently utilised measurements in livestock research worldwide due to: ease of collection and understanding; comparability within and between animals; changes in response to a range of stimuli; flexibility of quantitative data produced for statistical analyses; and the potential application of methods for monitoring and managing liveweights on commercial farms (Brown et al., 2015; Coates and Penning, 2000).

Liveweight recording and associated management decisions have been identified as key elements for improving productivity and efficiency on commercial sheep farms in Australia and the UK (Brown et al., 2015; Wishart et al., 2015; Young et al., 2011). New applications are being made possible through advances in commercially available weighing equipment. Radio Frequency Identification (RFID) chips within each animals ear tag and readers within the weigh crate allow liveweights to be easily collected and utilised on an individual animal basis (Morgan-Davies et al., 2015). Research and application in the field of Precision Livestock Farming (PLF), which uses technology to manage animals in a more precise individual manner (Banhazi et al., 2012), is expanding. Such weighing equipment has the potential to allow new management systems to be developed using sheep liveweight to aid decision making (Brown et al., 2014; Wishart et al., 2015).

Most research and commercial use of liveweight data involves making comparisons between liveweights at different time points within and between animals and groups. To be able to produce reliable, comparable liveweights the variation and error associated with these data needs to be understood and controlled.

Liveweight is a measure of body mass which is composed largely of muscle, fat, bone and organs. All of these have a relatively stable weight over a short period of time, such as a day, but alter over longer periods in response to environmental and biological conditions (Coates and Penning, 2000). Changes in weight of these components are of most interest within research and industry. However, body water and the fluids and digesta of the gastrointestinal tract (known as gut-fill) also make up total body mass. Levels of these change over the day and result in fluctuations in liveweights being observed. While this is an issue with weighing all animals, gut-fill needs greater consideration with ruminants as the contents of the rumen can account for 10-23% of total liveweight (Hughes, 1976).

The short-term liveweight fluctuations in ruminants are affected by: feed and water consumption (Whiteman et al., 1954); time since last meal (Hughes, 1976); quality and quantity of feed available (Hughes and Harker, 1950); age and size of the animal (Lush et al., 1928); time of day relative to sunrise (Gregorini, 2012); ambient temperature (Lush et al., 1928); and individual differences in grazing behaviour (Hughes and Harker, 1950).

Robust methodology is required to reduce variation in liveweights between animals and weigh points to ensure liveweight data collected are comparable. This requirement becomes more essential as on-going improvements in weighing equipment, software and data management is resulting in liveweight data having greater use in research and management on farm. Methodologies to reduce variation include: fasting prior to weighing (Coates and Penning, 2000); standardising weighing procedure (Watson et al., 2013); taking an average of multiple liveweights across a number of successive days (Koch et al., 1958); weighing at a specific time relative to sunrise (Hughes and Harker, 1950); standardising feed before weighing (Meyer et al., 1960); increasing the number of animals (Hughes, 1976); and repetitions of the study (Lush et al., 1928). However, there is evidence that such methodologies to reduce variation are not being considered or used in research. To illustrate this we examined 35 recent peer-reviewed papers (from Small Ruminant Research 2014, all issues of volume 120) and revealed that of the 11 papers involving liveweights, only 2 clearly stated the method used to control liveweight variation.

Reasons why variation reduction methodology is not being followed may be that: broader methodology has not caught up with the improved weighing technology now available; people collecting liveweights are simply not aware of the problem; or such methodologies are not practical when liveweight collection (research or commercial) is carried out in farm situations.

Consideration of the on-farm situation raises concern that not only is variation in liveweight not being controlled but procedures in weighing could also be adding systematic error to the data. On a research or commercial farm, weighing of sheep is likely to occur alongside other husbandry or research procedures. On a large farm, many animals may be gathered from fields of varying distances to be handled and weighed on the same day. Inevitably, this results in delays, where groups of sheep are removed from pasture and then wait varying lengths of time, without access to food and water prior to weighing.

Delays in weighing leads to gut-fill weight loss, with previous literature reporting losses of 0.5 to 2 kg after six hours and 1 to 4 kg after 12 hours (Hughes, 1976). Indeed fasting (removal of feed and water) is well documented as a suitable method to reduce variation in liveweight, where feed and water are removed for fixed long periods of time prior to weighing (e.g. Coates and Penning, 2000; Shrestha et al., 1991; Wilson et al., 2015). Our review of the literature found that only research carried out by Wilson et al. (2015) considered the impact of removal of feed and water for less than six hours; however, this was with the focus of fasting to reduce variation in gut-fill between animals or weigh points. Adjustment of liveweights has previously been used as a method to reduce errors: by Scott (2011), via a moving average of mean liveweights; and by Kane et al. (1987), using assumptions of feed intake and quality. However, both these methods are unsuitable or challenging for single weighings in a grazing sheep system. We found no published studies that attempt to develop a correction equation for liveweights with a known short-term period of delay prior to weighing as a result of a gathering and handling procedure of six or less hours.

The aims of this paper are 1) to determine the extent of liveweight loss in sheep, in a practical environment, as a result of delayed weighing over three and six hours; 2) to explore whether this information can be used to produce a methodology to reliably correct delayed liveweights across different situations; and 3) to demonstrate the potential consequence of not correcting delayed liveweights.

2. Materials and Methods

Data for this research were collected from Scotland’s Rural College (SRUC), Hill and Mountain Research Centre, Kirkton and Auchtertyre Farms in the West Highlands of Scotland. All work involving animals was carried out in accordance with EU Directive 2010/63/EU and was approved by SRUC’s Animal Welfare and Ethical Review Body.

This research was carried out in three stages:

1) A liveweight loss study: to quantify liveweight and liveweight loss over three and six hours delayed weighing within a handling facility and without access to feed or water. Then to use these findings to develop a correction equation for delayed liveweights.
2) A validating process: to examine the precision and accuracy of the correction equation by using it on different sets of delayed liveweight data collected under a range of situations.
3) A management simulation: to explore what impact delayed and corrected delayed liveweights could have when liveweight change is used to assign ewes to feeding levels.

2.1. Animals

All three stages of this research used the same base flock from which sheep and liveweight data were selected. The role of this flock was the long-term recording of 600 Scottish Blackface and 300 Lleyn ewes and their lambs (further details of the flock and research can be found in Morgan-Davies et al., 2015 and Umstätter et al., 2013).

2.2. Weighing Facility

The following weighing setup was used to collect all liveweights discussed in this paper. A Prattley Auto Drafter (Prattley Industries, Temuka, New Zealand), with Tru-Test™ MP600 load bars and XR3000 weigh head (Tru-Test Group, Auckland, New Zealand) recorded all sheep liveweight data automatically. They were then downloaded onto a computer for analysis.

The weigh head and weigh bars collected liveweights at a resolution of 0.1 kg for weights between 0-50 kg; weights between 50-100 kg were recorded to 0.2 kg. The weigh head was set to use the inbuilt system: Superdamp III (Sheep) (Tru-Test Group, Auckland, New Zealand). This used a damping algorithm to allow accurate liveweights to be collected from sheep in the weigh crate standing still or moving, with the liveweight automatically recorded when within tolerance (TruTest XR3000, Tru-Test Group, Auckland, New Zealand).

The liveweights were recorded in the weigh head against each ewe's unique identification number stored on their low frequency RFID, or Electronic Identification (EID), ear tag. This was read in the weigh crate via an Allflex® RFID portal reader (Allflex Australia, Queensland, Australia). The EID tags used were either Ritchey™ RD2000 tags (Ritchey Ltd., County Durham, United Kingdom), Shearwell Data SET Tags (Shearwell Data Ltd., Somerset, United Kingdom) or Allflex® Button tags (Allflex UK Group Ltd, County Durham, United Kingdom). No difference in performance was seen between different EID tags.

2.3. Stage 1: Liveweight loss study

2.3.1. Animals

For the liveweight loss study, 100 Scottish Blackface non-pregnant and non-lactating ewes (25 from each of four age groups; 1.5, 2.5, 3.5 and 4.5 years of age) were randomly selected and separated from the larger flock grazing unimproved hill pasture. The 100 selected ewes were placed in a field of improved pasture overnight prior to the study on the following morning (6th November 2013).

2.3.2. Times and weighing

Three weigh sessions were started at 9 am, 12 pm and 3 pm; each weigh session involved weighing the 100 ewes three times (Table 1). Each time, or round, involved weighing all ewes once before moving on to the next round immediately after the last ewe exited the weigh crate.

Table 1 Actual times for weighing sheep at three weigh sessions, with varying lengths of delay prior to weighing. Each weigh session comprised of weighing 100 ewes three times.

Weigh session	Approx. weigh time	Approx. hours delayed	Actual start time	Actual finish time of 3 rounds
1	9 am	0	08:59	09:43
2	12 pm	3	12:08	12:47
3	3 pm	6	15:04	15:45

A period of 30 minutes elapsed between sheep grazing being halted (by the stockperson and dog entering the field) and liveweight being collected from the first ewe entering the weigh crate for the first weigh session. Between weigh sessions, ewes were housed indoors with no access to feed or water. The first liveweights collected (9 am, round 1 liveweights), are referred to as the “without delay” liveweights. The term “without delay” liveweight will be used throughout this paper to describe any liveweight collected as soon as animals entered the handling facility; these may still contain some delay as a result of gathering from pasture. All other liveweights will be referred to as “delayed” liveweights.

During the day, between weigh sessions, Body Condition Scores (BCSs; scored on a 5 point scale with quarter intervals, according to Russel et al., 1969) were collected. Three different experienced condition scorers assessed each ewe three times; resulting in nine scores per ewe. An average (mode) score per ewe was used in analysis.

2.3.3. Liveweight and liveweight change

The mean liveweight per ewe (from the three liveweights recorded per session) was used to provide the best estimate of liveweight at each weigh session. These were used to consider short-term liveweight change over three (9 am to 12 pm) and six (9 am to 3 pm) hours delay prior to weighing. These periods of delay are comparable to the length of handling operations on a farm. Gathering extensive hill grazing can take three hours (Stott et al., 2005), while six hours is a maximum length of time gathering and handling is likely to occur in one day. The mean liveweights at each weigh session were compared using a one-way ANOVA blocked for animal.

Mean “without delay” liveweight (calculated from all three liveweights collected during the 9 am weigh session), BCS and age were all considered against the actual and the proportion of liveweight change over three and six hours delay. Correlation was used to explore mean “without delay” liveweight and one-way ANOVAs for BCS and age. Liveweight change over the first three hours (9 am to 12 pm) and the second three hours (12 pm to 3 pm) were compared via a paired t-test to determine whether rate of change was the same throughout the six hours delay period.

2.3.4. Delayed liveweight correction equation

All nine liveweights over the three weigh sessions were then used in the development of an equation to correct delayed liveweights. For this, liveweight loss over the whole six hour period was treated as linear. Using all nine liveweights per individual allowed for a greater number of data points in the analysis. The proportion of liveweight loss was analysed via a Linear Mixed Model in GenStat 16th Edition (Payne et al., 2013) to produce a regression equation (the correction equation). The fixed model included decimal hours delayed and the random model included the interaction between the individual sheep and decimal hours delayed. The proportion of liveweight loss was calculated from the “without delay” liveweight for all subsequent delayed liveweights (resulting in 800 data points). Decimal hours delayed since the “without delay” liveweight were calculated for each delayed liveweight as a result of time information automatically recorded by the weigh head.

2.4. Stage 2: Validating process

2.4.1. Dataset

The resulting correction equation from Stage 1 was tested on a different dataset. This validation dataset contained 1581 pairs of liveweights, from 20 groups of sheep. These were collected as part of a larger project being carried out on the research farm, between and including January 2014 and June 2015. Each pair of liveweights was collected from the same sheep over the same day and with a known delay between the two liveweights. These data included sheep from outside the narrow range of conditions of the original liveweight loss study, and encompassed five different categories: breed, sex, stage of production, grazing location and hours delayed prior to weighing (Table 2).

The first of each pair of liveweights was an actual “without delay” liveweight (aWt1), collected as soon as the group of sheep entered the handling facility. The second was an actual “delayed” liveweight (aWt2), collected later the same day after varying lengths of delay within the handling facility, without access to feed and water. While this is secondary data, all liveweights (aWt1 and aWt2) were collected automatically with an individual time and date stamp; therefore the delay between liveweights could be accurately calculated.

Whilst the sheep were first weighed immediately after entry into the handling area, the groups used in the validation dataset came from grazing locations across the large research farm. Three pasture types were identified and classified as: 1) improved field, with good quality pasture, fertilised annually with the potential for silage making, at an altitude of 180 m; 2) semi-improved park, with partially improved semi-natural permanent grassland and wet heath, with an altitude of 180 to 230 m; and 3) unimproved hill, which is a mosaic of semi-natural permanent grassland and wet heath ranging in altitude from 230 to 680 m.

The grazing locations had widely different gathering times compared to the liveweight loss study dataset. Therefore, two stockpersons and one technical staff, all of whom had experience of time taken to gather sheep from each field/location, were asked to estimate the normal gathering time. This was calculated from the moment grazing was halted (by the stockperson and dog entering the field) to the first of the group entering the weigh crate. These estimates were used to determine the pre-gather time for each pair of liveweights. On average time elapsed was 1.21 ± 0.59 hours between pre-gather and aWt1. This length of delay prior to aWt1 was also used in analysis (Table 2).

Table 2 Description of validation dataset containing pairs of actual liveweights (aWt1, liveweight collected without delay and aWt2, delayed liveweight) collected from the same individual sheep on the same day with varying length of delay in weighing between the two, for different categories (SD in brackets).

Categories	*n*	Mean aWt1 (kg)	Mean aWt2 (kg)	Mean Difference aWt2-aWt1 (kg)	Time range between aWt1-aWt2 (hours)
All	**1581**	**40.94 (10.56)**	**40.06 (10.35)**	**-0.88 (0.72)**	**0.3 - 4.9**
Stage of production					
Non-pregnant & non-lactating ewe	455	51.06 (5.91)	50.07 (5.93)	-0.99 (0.59)	2.3 - 4.9
Pregnant ewe	164	50.79 (6.25)	49.25 (6.20)	-1.55 (0.78)	2.2 - 3.65
Lactating ewe[a]	88	47.72 (5.67)	47.04 (5.73)	-0.68 (0.43)	0.85 - 2.62
Suckling lamb[b]	69	26.56 (3.89)	26.09 (3.69)	-0.48 (0.52)	1.28 - 4.72
Weaned lamb[c]	805	33.70 (5.81)	32.97 (5.62)	-0.73 (0.73)	0.3 - 4.72
Sex					
Female	1014	44.12 (11.38)	43.31 (11.04)	-0.81 (0.76)	0.3 - 4.9
Male (lambs only)	567	35.24 (5.36)	34.25 (5.28)	-0.99 (0.65)	0.38 - 4.72
Grazing location					
Improved field[d]	823	39.34 (8.35)	38.33 (8.29)	-1.01 (0.66)	0.38 - 4.72
Semi-improved park[e]	390	33.59 (9.23)	33.29 (9.09)	-0.3 (0.55)	0.3 - 4.57
Unimproved hill[f]	368	52.30 (6.40)	51.12 (6.43)	-1.18 (0.71)	2.2 - 4.9
Breed					
Scottish Blackface	623	39.21 (9.27)	38.32 (9.22)	-0.88 (0.67)	0.37 - 4.72
Lleyn	857	43.57 (10.70)	42.67 (10.40)	-0.9 (0.77)	0.3 - 4.9
Crossbred[g] (lambs only)	101	29.27 (5.57)	28.62 (5.24)	-0.65 (0.57)	1.28 - 4.72
Hours delayed prior to aWt1[h]					
0 to 1	658	41.31 (8.25)	40.28 (8.22)	-1.03 (0.62)	0.6 - 4.72
1 to 2	690	37.11 (10.65)	36.47 (10.4)	-0.64 (0.74)	0.3 - 4.9
2 to 3	233	51.22 (8.95)	50.08 (8.80)	-1.14 (0.75)	1.92 - 4.67

NB: [a]ewes which had been with their lamb immediately before aWt1 but without contact with lamb between aWt1 and aWt2; [b]lambs remained with their ewe between aWt1 and aWt2 and aged three to five months old; [c]lambs aged four to six months old; [d]good quality pasture, fertilised annually with the potential for silage making; [e]partially improved semi-natural permanent grassland and wet heath; [f]a mosaic of semi-natural permanent grassland and wet heath; [g]crossbred lambs with dam of Scottish Blackface or Lleyn and opposite breed sire; and [h]estimated hours elapsed prior to aWt1 (from halting grazing to entering the weigh crate).

2.4.2. Comparing corrected and uncorrected liveweights

The correction equation was used on aWt2 to generate a corrected version of aWt1 (cWt1) using the known length of delay between aWt1 and aWt2. In practice, to account for the varying lengths of delay prior to aWt1, the correction equation could be used to correct aWt2 to a pre-gather liveweight. However this pre-gather liveweight is not known so correction to the “without delay” liveweight (aWt1) allows the correction ability of the equation to be tested. This is possible as the equation treats liveweight loss as linear over this short-term period.

To explore whether cWt1 or aWt2 was a more accurate and precise estimate of aWt1, paired two-way t-tests were used to compare each with aWt1. The distribution of differences between these pairings of liveweights was also examined.

2.4.3. Category differences in correcting

To explore whether the correction equation had the same precision across a range of categories, a Linear Mixed Model in GenStat 16th Edition (Payne et al., 2013) was used on the difference between cWt1 and aWt1. The five different categories (listed in Table 2) were explored. Stage of production and grazing location were the only categories identified as being statistically significant and were included in the final fixed and random models. Predicted means were then generated to compare the different levels within each of these two categories.

2.5. Stage 3: Management simulation

2.5.1. Dataset

A dataset was compiled to simulate the impact of assigning ewes to feeding levels based on liveweight change, comparing when actual delayed liveweights or corrected liveweights were used. This management example involves assigning feeding levels to pregnant ewes based on liveweight change over a period of two months. It was chosen as it is advised that pregnant ewes should be provided with supplementary feeding (e.g. Fthenakis et al., 2012). Assigning individual ewes' feeding levels based on liveweight change over the first two months of pregnancy, is one method that has been shown to be effective at allocating ewes to different supplementary feeding levels (Wishart et al., 2015).

Actual "without delay" liveweights from 395 ewes (Lleyn ewes, *n* = 239, were 1.5 to 7.5 years of age and Scottish Blackface ewes, *n* = 156, were 1.5 years of age) were collected from the research flock at pre-mating as soon as animals entered the handling facility (PreWt, November 2014). "Delayed" liveweights were also collected from the same animals two months later at post-mating after varying periods of time within the handling facility without access to feed and water (PostWt, January 2015). The correction equation was used on both sets of liveweights (PreWt and PostWt) to produce corrected pre-gather sets of liveweights (cPreWt and cPostWt, respectively). Time of pre-gather was calculated from the automatically recorded time stamp and the estimated time to gather each field (same method as previously explained in Stage 2). Overall the average delay prior to weighing for PreWt was 2.6 ± 1.3 hours and for PostWt was 4.9 ± 1.3 hours.

2.5.2. Assigning ewes to feeding levels

Ewes were assigned to feeding levels based on liveweight change between November and January (the period covering mating): low level feeding (LOW) for ewes that had put on liveweight; medium level feeding (MED) for ewes that had lost up to 5% liveweight; and high level feeding (HIGH) for ewes that had lost over 5% liveweight (method adapted from Umstätter et al., 2013).

Two simulations were run with the data, to assign ewes to feeding levels, one using the actual collected "without delay" (PreWt) and "delayed" (PostWt) liveweights to determine liveweight change and the second using corrected versions of these liveweights (cPreWt and cPostWt). Counts of ewes assigned to each feeding level, based on these two alternative simulations, were compared via a chi-squared test.

3. Results

3.1. Stage 1: Liveweight loss study

3.1.1. Times and weighing

Each weigh session (where all 100 ewes were weighed three times) lasted 41.3 ± 2.5 minutes. The weighing rate, over all nine rounds was 7.5 ± 0.5 seconds per ewe.

3.1.2. Liveweight and liveweight change

The analysis showed that ewes lost liveweight (*p*<0.001) over both three and six hours delayed prior to weighing (Fig. 1). They lost 1.8 ± 0.5 kg or 3.5 ± 0.8 % liveweight and 2.9 ± 0.6 kg or 5.6 ± 1.0 % liveweight at three and six hour delays, respectively.

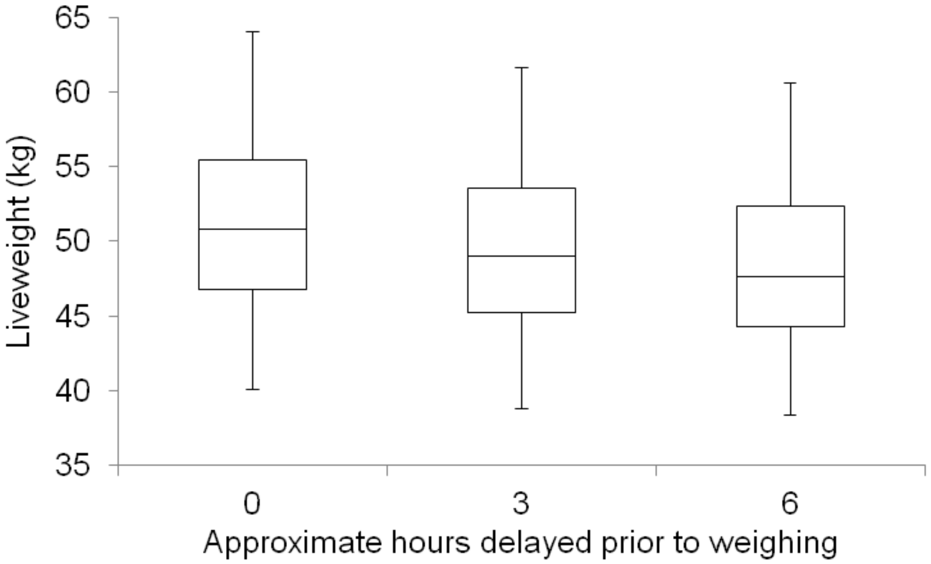

Fig. 1 Liveweights at the three weigh sessions where 100 ewes were weighed three times per session with a time delay between sessions. Box and whisker plot shows median, upper quartile, lower quartile (box) and range of liveweights (whiskers).

The mean “without delay” liveweight was found to be correlated (*p*<0.001) with actual liveweight change over three and six hour delays (*r* = -0.48 and -0.63, respectively), with heavier ewes losing more liveweight. However, there was a non-significant poor correlation between the mean “without delay” liveweight and proportion of liveweight change over both delay intervals ($r = -0.05$ and -0.18 for three and six hour delays, respectively). BCS did not impact on actual or proportion of liveweight change. However, age impacted at both three and six hour delay intervals for actual ($p<0.001$) and proportion ($p<0.05$) of liveweight change. The youngest ewes (aged 1.5 years old) lost less than all other age groups; they were also lighter than all other ages.

Over the first three hours (9 am to 12 pm) ewes lost more liveweight compared to the second three hours (12 pm to 3 pm) delayed ($p<0.001$, 1.8 kg compared to 1.1 kg liveweight lost, respectively).

3.1.3. Delayed liveweight correction equation

The equation developed during Stage 1, to correct delayed liveweights when length of delay is known ($p<0.001$), was:

$$y = 100\ \left(\frac{x}{\big(100 + (-0.9301\ t + 0.07106)\big)}\right)$$

Where:

y = corrected liveweight (kg)

x = actual delayed liveweight (kg)

t = time difference in decimal hours delayed

3.2. Stage 2: Validating process

3.2.1. Comparing corrected and uncorrected liveweights

In comparing liveweights, aWt2 and cWt1 were both different to aWt1 ($p<0.001$). However, cWt1 was a more precise estimate of aWt1 compared to aWt2, demonstrated by 72% of aWt1 liveweights being closer to cWt1 than to aWt2. Figure 2 illustrates how correction reduces the error that would occur if the delayed liveweight (aWt2) were used as the only liveweight for these sheep. Simplifying this data, the counts of sheep with a cWt1 that was: close to (-0.24 to 0.25 kg); higher than (>0.25 kg); or lower than (<-0.24 kg) aWt1, were very different (with a chi-square statistic of 1172.6, $p<0.001$) to the equivalent groupings of aWt2 to aWt1.

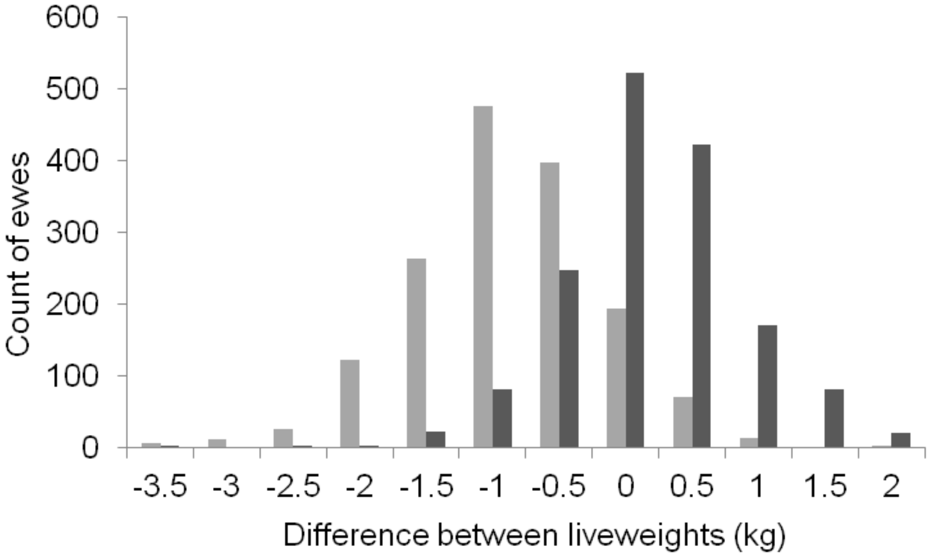

Fig. 2 Distribution of difference between two sets of liveweights: 1) grey bars, actual delayed liveweight (aWt2) minus actual “without delay” liveweight (aWt1); and 2) black bars, corrected from aWt2 to the time of aWt1 (cWt1) minus aWt1. X axis labelling is the mid-point of the group difference (i.e. 0 kg means difference fell between -0.24 and +0.25 kg).

3.2.2. Category differences in correcting

Considering the ability of the correction equation to predict for different categories (listed in Table 2) of sheep revealed that out of the five originally explored (stage of production, sex, grazing location, breed and hours delayed prior to aWt1), only stage of production and grazing location had an impact ($p<0.001$) accounting for 24.6 % of variance. Of these categories, pregnant ewes, semi-improved park, and improved field had the best correction ability with the difference between predicted means cWt1 and aWt1 being within 0.4 kg (Fig. 3).

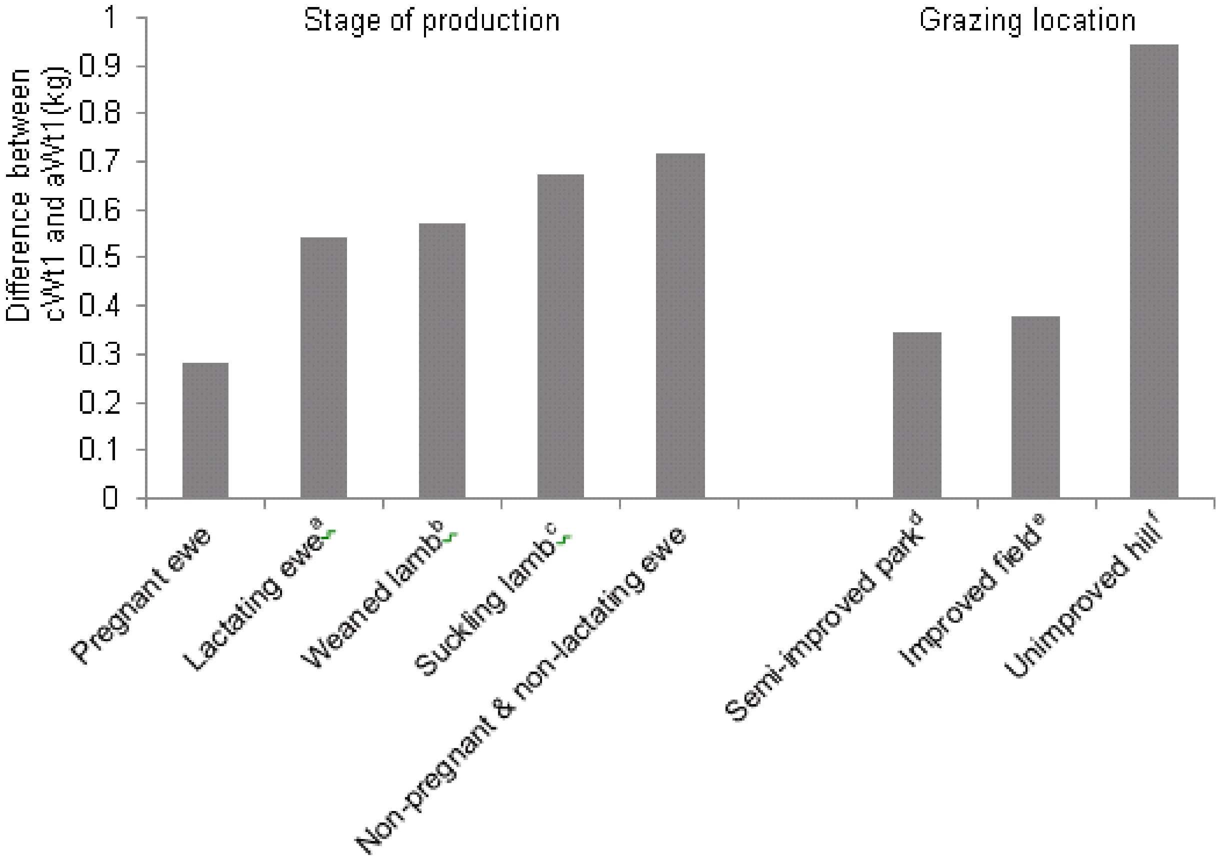

Fig. 3 Difference (in absolute value) between a "without delay" liveweight collected as soon as the group entered handling facility (aWt1) and a delayed liveweight corrected to the time of aWt1 (cWt1), displayed as predicted means, for different categories. NB: [a]ewes which had been with their lamb immediately before aWt1 but were delayed without contact with lamb; [b]lambs aged four to six months old; [c]lambs remained with their ewe during delay and aged three to five months old; [d]partially improved semi-natural permanent grassland and wet heath; [e]good quality pasture, fertilised annually with the potential for silage making; and [f]a mosaic of semi-natural permanent grassland and wet heath.

3.3. Stage 3: Management simulation

Comparing each actual delayed liveweight (PreWt and PostWt) to their respective corrected liveweight at pre-gather (cPreWt and cPostWt) showed a mean liveweight loss of 1.2 ± 0.7 kg and 2.4 ± 0.8 kg for PreWt and PostWt, respectively.

When corrected liveweights (cPreWt and cPostWt), rather than actual delayed liveweights (PreWt and PostWt), were used to determine liveweight change over the mating period, a different distribution of ewes to three feeding levels was seen (Fig. 4), with a substantial proportion (24.3%) of ewes being assigned to different management feeding levels (p<0.001).

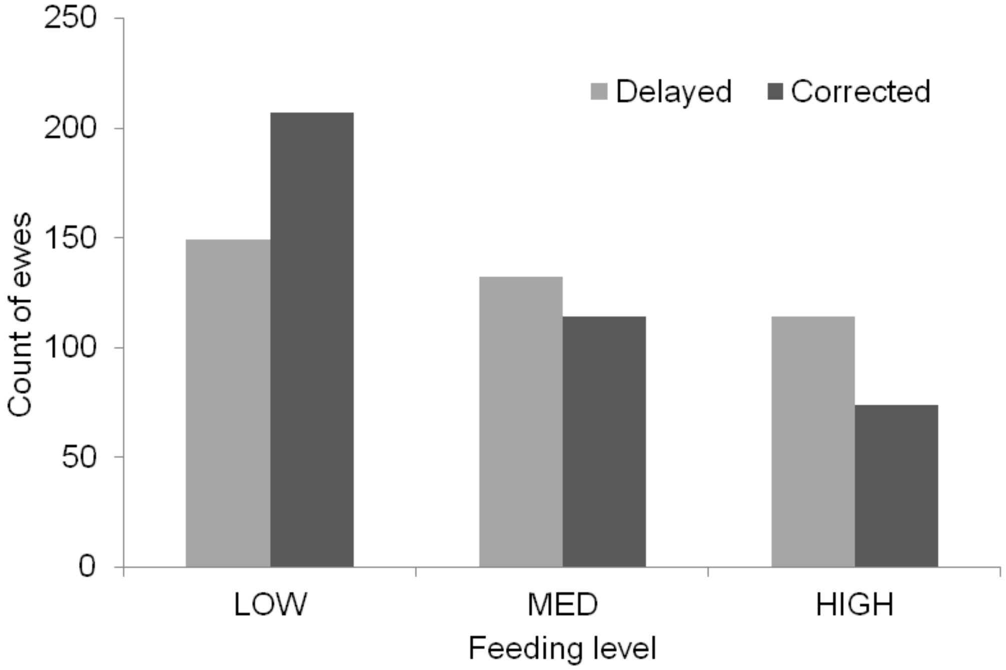

Fig. 4 Number of ewes per feeding level based on the same decision rules but different liveweight calculations used to determine liveweight change between November and January. Three feeding levels available: LOW, ewes gained weight; MED, lost up to 5% liveweight; and HIGH, lost over 5% liveweight. Two different pairing of liveweights were used; Delayed, where collection of liveweights was delayed; and Corrected, where delayed liveweights were corrected to a pre-gather time point.

4. Discussion

4.1. Stage 1: Liveweight loss study

The first stage of this research found that ewes lost a significant amount of liveweight after a delay of three and six hours within a handling facility. The magnitude of liveweight loss found is likely to impact on research findings and management decisions on-farm, unless it can be accounted for.

Although previous literature reported losses of 0.5 to 2 kg and 1 to 4 kg after six and 12 hours, respectively (as reviewed by Hughes, 1976), our study found greater losses. These losses were closer in agreement to findings by Wilson et al. (2015). The ewes in our study moved from poor quality unimproved hill pasture to improved field grazing the night before the liveweight loss study commenced. This allowed for near-by, easy access of the animals to commence work the following morning and is a typical management practice for any extensive sheep system. Change in pasture quality has been suggested to alter liveweight loss (Hughes and Harker, 1950). Therefore, while this change may result in higher liveweight loss compared to Hughes (1976), it is representative of a real-life situation.

It is interesting to note that ewes lost liveweight at a slightly higher rate over the first three hours compared to the second three hours, which is in agreement with previous research of liveweight loss (reviewed by Hughes, 1976). This could be explained by daily biological rhythms where the previous day's digesta is passed from the animal in the early morning (Whiteman et al., 1954) but could also simply be a result of diminishing returns. Both linear and non-linear correction equations were explored, as liveweight loss was not linear over the six hour period. However, a linear equation was ultimately used as it was both simpler to carry out and the alternatives provided no additional precision to the correction of delayed liveweights.

There was negative correlation between mean "without delay" liveweight and liveweight change, therefore heavier ewes lost more liveweight than lighter ewes. However, this was not to the same degree when liveweight loss was considered as a proportion of liveweight. The difference is explainable as larger animals would have a larger holding potential for water and digesta and therefore have a greater potential for loss. Nevertheless this appears to be at a similar rate of loss proportional to body size, which is why the correction equation uses proportion of liveweight.

This study demonstrated that liveweight can be collected at a rate of 480 ewes per hour with modern weighing facilities using EID technology, making it an attractive option for collection of liveweights both for research and on farm. This increases the potential of managing sheep according to liveweight and liveweight change.

4.2. Stage 2: Validating process

Weighing without any delay would clearly provide liveweights with the least error. However, when this is not possible the validating process demonstrated that the correction equation could be used to provide corrected liveweights (cWt1) that were a more accurate and precise estimation of an actual liveweight (aWt1) than a delayed actual liveweight (aWt2).

Given the wide range of factors, as well as period of delay, that can impact on gut-fill and short-term liveweight variation (as described in Coates and Penning, 2000; Hughes, 1976), it is encouraging that the correction equation worked well across the different categories of sheep. This is evidenced as breed, sex and hours delayed prior to aWt1 did not have a significant impact on the precision of correction, adding strength to the application potential of the equation.

The two categories that significantly impacted on precision of the equation were stage of production and grazing location. For these, corrected liveweights had a high level of precision for pregnant ewes and sheep previously grazing improved fields and semi-improved parks compared to all other stages of production and sheep from unimproved hill grazing. Pregnancy did not hamper the ability of the correction equation. Indeed, these ewes were all in mid-pregnancy, at around 90 days gestation, at which point the conceptus weight has very little impact on ewe liveweight (Henderson, 2002).

It is understandable that delayed liveweights of ewes from unimproved hill grazing corrected with a lower level of precision compared to improved fields and semi-improved parks given that sheep on hill grazing vary greatly in their time to gather (Morgan-Davies et al., 2006; Stott et al., 2005), adding to the variation on liveweight. However as hours delayed prior to aWt1 did not have a significant impact in the correction ability, it is considered that the grazing type was the most important factor. As previously mentioned, quality and quantity of pasture impact on liveweight variation (Hughes and Harker, 1950; Hughes, 1976) which may be contributing to the differences seen between sheep from different grazing types. Future research in the field of liveweight variation would benefit from collecting pasture data such as quality and quantity available. Also, having two categories (stage of production and grazing location) impacting on the correction ability of the equation suggests that alternative correction equations could be developed for different situations.

To be able to quantify the precision of the correction equation, as previously explained, the delayed liveweight (aWt2) was corrected back to the time of the actual "without delay" liveweight (aWt1) and not the time of pre-gather. This allowed for a comparison of cWt1 and aWt2 to a known liveweight (aWt1). Due to the distribution of ewes being gathered from fields of varying distances from the handling facility, different delays would already be impacting on the aWt1. The majority of aWt1 were collected within two hours of grazing being disturbed (85% of 1581 liveweight pairs). It is likely that as time elapsed, since gathering increased, the correction precision would change. In reality, to be able to produce comparable liveweights, the delay period caused by gathering should also be included in the hours delayed prior to weighing (as it was in the Stage 3: Management simulation). Therefore the correction equation should be used to correct delayed liveweights to a pre-gather time point.

There were a small number of individual sheep within the validation dataset whose liveweights actually increased from aWt1 to aWt2, contradicting what would be expected. As no food or water would have been provided during this time, the increase is likely to be an impact of random error of weighing. The weigh equipment described in this research used a damping algorithm that allowed collection of the liveweight of a moving sheep. While this allows for some inaccuracy it is more accurate than using more traditional scales where the location of the needle needs to be read by eye (Hirsch, 1985). This may also explain the overestimation of the correction equation when comparing cWt1 to aWt1.

Overall, however, the comparison between corrected delayed and “without delay” liveweights highlights the reliability of the equation to correct delayed liveweights to a specific time point. There are no known published attempts of developing a correction equation for liveweights subjected to this short-term period of delay prior to weighing. Therefore, the success of this correction equation is important and could be useful to all practitioners collecting and utilising liveweights where delay is unavoidable.

4.3. Stage 3: Management simulation

The final stage showed that when delayed liveweights were used, ewes appeared to lose more liveweight, which considerably altered the identity and number of ewes in each feeding level compared to if these liveweights had been corrected to a pre-gather liveweight. It should be noted that the pre-defined liveweight change boundaries for each feeding level constrains the example. Any alterations to these boundaries would impact on the number of ewes that would move from one feeding level to another. However it does serve to demonstrate that greater delay in weighing at PostWt (January) suggests a greater loss in liveweight, causing a higher proportion of ewes to be assigned to higher feeding levels. This in turn would increase the amount of feed provided, resulting in a significant cost to the farm that would not be required if more accurate (i.e. corrected) liveweights had been used. A higher level of feed could also lead to over-supplementation with the risk of dystocia and lamb death.

The larger correction or error on January liveweights (PostWt), which were collected after delay compared to liveweights in November (PreWt) collected without delay, highlights the advantage of collecting without delay. Depending on the time delay associated with gathering, collecting liveweights without delay may be sufficient in reducing error, and a correction equation might not be required.

Within each handling, we know from the equipment time stamps that there is further variation in the delay between the first and last ewe weighed. Therefore if correction equations cannot be used, weighing as quickly as possible from the first to the last sheep, to reduce delay during the weighing session, is essential.

4.4. Wider implications of improved liveweight reliability

While feeding management has been explored by this research, there are other farm practices which could also benefit from correcting delayed liveweights: firstly, achieving a target carcass weight at the abattoir, by more accurately selecting finishing lambs to sell based on liveweight; secondly, producing more accurate Estimated Breeding Values (EBVs) when they are generated from liveweights; and thirdly, providing a more appropriate level of anthelmintic based on liveweight bands, as widely recommended as best practice (for example, Henderson, 2002).

Current advice for reducing liveweight variation in research includes increasing animal numbers (Hughes, 1976) and weighing multiple times (Koch et al., 1958). However, correcting delayed liveweights may allow fewer animals and weighings required to reduce error and thereby follow the principles of the 3Rs (Replacement, Reduction and Refinement; Russell and Burch, 1959).

Finally, variation in liveweight may become less of a concern with the development of weighing technology that can collect liveweights in real-time, without extra handling or gut-fill issues, for instance walk-over weighing (Brown et al., 2014).

5. Conclusions

We have shown that sheep lose a significant amount of liveweight over a short-term delay prior to weighing, as a result of practical handling operations. When this delay is uncontrollable, one method to improve reliability and comparability is by correcting delayed liveweights (via correction equations such as the one presented in this paper). Alternatively, since the value of correction increases as the length of delay increases, collecting liveweights immediately (without delay) may be sufficient in producing reliable liveweights. Such approaches will reduce error in liveweights which, if used, can lead to incorrect conclusions in research and negative consequences for management practices of grazing sheep systems globally. Finally, research papers should provide sufficient details of weighing procedures, particularly with respect to time delays between removal from feed and grazing, to actual weighing.

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