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Measuring liveweight changes in lactating dairy ewes with an automated walk-over-weighing system

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ABSTRACT

Monitoring liveweight (LW) is an important part of sound management practices at the individual and flock level (e.g., controlling for nutritional status based on body condition, reproduction, and health-related issues), but it is time consuming and stressful. To our knowledge, no literature has reported on the evaluation of automated weighing systems in dairy sheep as an alternative to conventional static scales. The objective of this research was to evaluate the practical feasibility of using an automated walk-over-weighing (WoW) prototype to measure daily LW changes in dairy ewes without human intervention. We used adult Lacaune dairy ewes in 2 complementary trials conducted indoors. Trial 1 aimed at evaluating the repeatability, precision, and accuracy of LW measures recorded using WoW scales compared with a static scale (the gold standard). Forty-two adult ewes (LW ± standard deviation = 71.3 ± 10.4 kg) were randomly drafted from the main flock and used in a 1-day session. The trial included 3 passages. In each passage, ewes were weighed first on a static scale; once a static position was achieved and LW recorded, they continued the circuit and immediately traversed the WoW scale for an automated LW record. Trial 2 aimed to demonstrate the feasibility of using the WoW device under real-world conditions in a dairy sheep-farming system. The WoW scale was installed in the exit race of the milking parlor and evaluated over 7 wk with adult ewes in mid lactation (n = 93; LW 78.5 ± 8.1 kg). Once the ewes were acclimated to the WoW system, 1 group of ewes (n = 48) continued to receive the same feeding regimen (controls), and the other group (n = 45) underwent a nutritional challenge [challenged; 2 wk of undernutrition and then back to control regimen (refeeding) for 1 wk]. We evaluated the ability of the WoW to detect small changes in LW. We collected LW data (2 weighings per ewe per day) from the WoW after each of the 2 milking sessions (morning and evening). We also obtained LW values by weighing the ewes using a static scale once a week. The automated WoW system showed substantial agreement with the gold standard when assessed using Lin's concordance correlation coefficient and Bland and Altman's method, largely due to high repeatability. The WoW system was adequate for detecting small daily variations in LW during undernutrition and refeeding periods. Misbehaviors resulted in spurious WoW values in trial 2, requiring us to use filtration methods to exclude outlier weights and allow meaningful assessment of small LW changes. The WoW system evaluated here is an alternative to the static scales conventionally used on dairy sheep farms. If sound filtration of raw data is applied, WoW could contribute to the close (daily) monitoring of individual LW without operator intervention (i.e., voluntary weighing) and taking animal welfare into account (i.e., no stress related to the weighing session on static scales).

Key words: dairy sheep, lactating ewe, automated weighing, liveweight monitoring, precision livestock farming

INTRODUCTION

Sheep milk volumes (10.6 Mt in 2018) represent 1.3% of global milk production (843 Mt; FAOSTAT, 2018). The average milk yield of dairy ewes in Europe (91 L/ewe) is more than double the world's average milk yield, showing the growth potential of the world dairy sheep sector. Countries bordering the Mediterranean and Black Sea regions have 27.1% of the ewes and produce 41.4% of the world's sheep milk. Turkey (21.6%; 60 L/ewe), Greece (16.6%; 106 L/ewe), Syria (15.2%; 56 L/ewe), Romania (14.7%; 89 L/ewe), and Spain (12.6%; 243 L/ewe) are the current leaders, followed by

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Italy (9.9%; 82 L/ewe), France (6.8%; 239 L/ewe), and Algeria (6.6%; 26 L/ewe; Pulina et al., 2018).

France produced 15% (323,758 t) of the whole fresh sheep milk in the commercially and technically developed dairy sheep industries of the Mediterranean Basin countries (i.e., total 2.1 Mt in Greece, Spain, Italy and France; FAOSTAT 2018). However, Lagriffoul et al. (2016) and Pulina et al. (2018) have identified substantial room for improvement in the dairy sheep sectors of these countries. A first priority for the French dairy sheep sector is to increase production of the milk intended for Protected Denomination of Origin sheep milk cheesemaking, which requires a change in the milking season schedule and adaptation of some production techniques. To meet these goals, taking advantage of new precision livestock farming technologies seems to make sense.

A technological revolution in farming led by advances in robotics and sensing technologies looks set to disrupt modern practices (King, 2017). Precision livestock farming, involving the management of livestock production using the principles and technologies of process engineering, is the primary means by which "smart" sensors are used in livestock farming (Wathes et al., 2008). However, apart from the dairy cattle industry, the application of precision livestock farming in current farming systems is still in its infancy (King, 2017) and a cautious approach is needed, requiring considerable research and development in terms of technology design and evaluation, livestock applications, marketing, and bioethics (Wathes et al., 2008).

An increasing number of studies have validated the application of sensor technologies in a broad range of sheep-farming contexts (Fogarty et al., 2018; Caja et al., 2020). Sensors help to categorize and quantify sheep behavior, monitor environmental management, validate data analysis methods, and support health, nutritional, and welfare research. Electronic identification is one of the most established technologies, making a basic contribution to the rational use of time and resources, and optimizing processes in everyday farming practice (Caja et al., 1996; Cappai et al., 2018). However, whereas electronic identification in sheep is mandatory according to European Union regulations (EC Reg. 933/2009; Commission of the European Communities, 2009; Caja et al., 2020), most precision livestock farming technologies are still optional for farmers and other stakeholders.

In this context, some studies have reported the feasibility of using walk-over-weighing (**WoW**) technology, which provides much more information than conventional static weighing scales and enables new ways of using liveweight (**LW**) in farm animal species. With WoW, animals must pass through a crate that is specially designed crate to estimate body mass using continuous averaging techniques; the electronic circuit averages the fluctuating signal while the animal crosses the platform and, once the animal leaves the platform, it registers the average LW value. The weight-averaging circuit involves integration of the incoming electrical signal from the weigher for a period of about 2.5 s (Smith and Turner, 1974). An example of the block diagram of a weighing circuit for a WoW platform used with dairy cows at the exit race of a milking parlor was reported by Filby et al. (1979).

Liveweight is indicative of an animal's current and changing physical state and is affected by factors such as growth or physiological status. It is one of the most conventionally and widely used parameters in livestock because it is easy to collect and understand, it has potential for longitudinal monitoring and comparison within and between animals, it changes in response to a range of stimuli, and the quantitative data it generates can be used for statistical analyses with different purposes (Brown et al., 2015; González-García and Hazard, 2016; Wishart et al., 2017).

However, irrespective of the system used and despite the advantages of LW monitoring, most farmers do not weigh their animals at all, primarily because of lack of time and economic issues. Autoweighing technologies could be used in a range of situations, including outdoor grazing systems, to help farmers. In ruminants, studies to date have been conducted mainly in cattle (Alawneh et al., 2011; Dickinson et al., 2013; Aldridge et al., 2017; Menzies et al., 2018; Imaz et al., 2019, 2020; Kedzierski, 2020); in sheep, the only available reports are for meat breeds (Brown et al., 2012, 2014a,b; González-García et al., 2018a,b). To our knowledge, WoW has not been evaluated in dairy sheep, despite the role that monitoring LW could play; weight has often been confirmed as an essential trait by farmers in the French dairy sheep sector, for example (Barillet et al., 2001; Lagriffoul et al., 2016). The routine use of WoW technology in dairy sheep farms would enable an immediate improvement in the individual monitoring of dairy ewe LW without human intervention, and improvements in animal welfare conditions without the stress linked to LW sessions. It would represent a direct contribution to the farm economy (i.e., by reducing labor and time for weighing animals). Furthermore, continuous access to a massive set of individual and daily LW data would give farmers and advisors a better understanding of the nutritional requirements of dairy ewes, aid in decision-making when LW gains or losses occur, facilitate the adoption of precision feeding practices (e.g., individual ration calculations), and help with the monitoring of flock health status (i.e., utility of LW monitoring from a veterinary point of view).

The objective of this research was to evaluate the practical feasibility of using an automated WoW prototype for routine measurement of daily LW changes in Lacaune dairy ewes, under controlled and real-farm conditions. We hypothesized that monitoring LW in Lacaune dairy ewes indoors would be feasible using the WoW platform and could be included in routine farming practices.

MATERIALS AND METHODS

Experimental Location, Animals, and Farming System

The study was conducted at the Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (INRAE), Experimental Farm La Fage, Causse du Larzac (43°54′54.52″ N; 3°05′38.11″ E), Roquefort-sur-Soulzon, Aveyron, France. The experiments were approved by the Regional Ethics Committee on Animal Experimentation number 115 (Région Occitanie) and complied with the Animal Research Act 1985, in accordance with ethical principles established in the European Union Directive 2010/63/EU.

In total, 135 adult multiparous Lacaune dairy ewes from the main dairy flock of La Fage were involved in this study, which consisted of 2 complementary trials to evaluate the feasibility of using an already validated WoW prototype (González-García et al., 2018a,b) for the automated weighing of dairy sheep. Experimental ewes were randomly selected based on their LW and BCS.

Ewes in both trials were housed indoors in the same area and managed identically, following the management routine of the dairy sheep flock in the experimental unit. The routine was representative of the regional breeding system of the Roquefort area of France (Lagriffoul et al., 2016) with respect to breed (Lacaune), flock size, average milk production (250 L/ewe per lactation), reproduction based on estrus synchronization and artificial insemination, lambing season (autumn to early winter), litter suckling length (weaning lambs at 1 mo), exclusive milking length (November–August), machine milking ("casse" system with a herringbone formation and a milking rate of 400–500 ewes per person per hour), feeding system (grazing from spring until lambing; supplementation with concentrate), milk prices according to milk quality (fat and protein rate) and udder health (SCC), and overall feed cost margin (€168/ewe in the flock).

At the beginning of this study, the Lacaune dairy flock of La Fage farm consisted of a semi-intensive confined farming system with 564 ewes, of which 197 were primiparous (35%; LW ± SEM 64 ± 7 kg) and 367 were multiparous (65%; 77 ± 9 kg). Lambing occurred from late November to mid-January, and ewes were machine-milked twice a day, beginning after a suckling period of approximately 28 d (weaning). During the second half of lactation, from April to August, ewes were sent to diurnal pasture, during which they were dried off.

Experimental Sequence: Trials, Design, and Measurements

Two complementary experiments were conducted, the first a 1-d session under controlled conditions, and the second a larger-scale trial with management routines similar to that of real farming situations. The details of the 2 trials are provided below.

Trial 1: Animals, Experimental Design, and Procedures

The trial aimed to validate the feasibility of using the WoW prototype (available at La Fage) for Lacaune dairy ewes fitted with radiofrequency identification ear tags. The latest individual LW data from all ewes belonging to the main flock (n = 564) were available before the trial. We calculated the difference between extreme values (maximum minus minimum) and divided the result by 3 to stablish 3 equivalent strata of LW data distribution (i.e., upper, average, and lower). A sample of 42 adult ewes (14 ewes per level) was chosen using a simple randomization procedure from the sampling option in the data analysis toolpack of Microsoft Excel 2016. The selected ewes [LW ± standard deviation (**SD**) = 71.3 ± 10.4 kg] comprised a subpopulation of animals with a range of LW (60–80 kg), which was representative of the main flock.

Experimental ewes were allocated to a 1-d experiment that evaluated the accuracy, precision, agreement, and repeatability of the LW measures recorded using the WoW system compared to the LW recorded using a static scale (gold standard). At each passage (n = 3), the ewes were first weighed using the static scale (scale 300 kg UO1896; Société AGID); LW was not recorded until the animal was stationary. Then, ewes continued through the WoW prototype, equipped with 2 loads cells for automated walk-over scales (Tru-test XR3000 WoW Scales; Tru-Test Pty Ltd.) and installed in the corridor at the exit race of the electronic static scale. Once a static position was achieved on the scale and the LW was recorded, the door opened, the ewes continued the circuit, and they immediately traversed the WoW platform to yield an automated LW record. This process was repeated 3 consecutive times (i.e., 3 passages) with the same 42 ewes in the 1-d session, resulting in a database of 6 LW values per ewe (3 static plus 3 WoW). The weighing session for this trial started at 1315 h, and the first ewe stepped on the static scale at 1330 h. Once on the static scale, each ewe took approximately 20 s to achieve the static position required to obtain the LW value. Then, ewes took an average of 10 s to traverse the WoW platform during the first passage and 5 s during the second and third passages (i.e., at first passage, ewes took more time to cross because they were less familiar with the device). Approximately 10 to 15 s was required for the transition between ewes (i.e., time taken between 2 ewes getting onto the static scale). Overall, the 42 ewes took approximately 50 min for the first passage and 40 min for the second and third passages. The full weighing session finished at 1600 h (i.e., the trial took 2 h 45 min in total: 1330–1420 h, 1420–1500 h, and 1500–1540 h for passages 1, 2, and 3, respectively).

For this experiment, the static scales were assumed to measure the true LW (gold standard). Each of the 3 automated LW was compared with the 3 static LW for the same ewe to assess agreement between the automated and static scales.

Trial 2: Animals, Experimental Design, and Procedures

The second experiment was carried out to evaluate the feasibility of using the WoW prototype as part of the daily routine (i.e., twice daily, at each milking) and to evaluate the ability of the WoW to detect daily changes in the LW of ewes submitted to undernutrition and refeeding periods.

WoW Validation in a Real-Farm Situation for Dairy Ewes. The WoW system was installed at the exit of the milking parlor race and evaluated over 7 wk (i.e., 3.5 wk for adaptation and 3.5 wk for data collection, from February 11 to March 29; Figure 1). Ninety-three adult mid-lactating ewes (LW ± SD 78.5 ± 8.1 kg) were randomly selected to represent the adult ewes from the main flock. Two single sequences of random assignments were performed (i.e., simple randomization with the sampling function of Excel 2016; Microsoft Corp.). At first, 96 ewes were randomly chosen from all available adult lactating ewes in the main flock. Those 96 ewes then underwent a second round of randomization to distribute them equally into 2 experimental treatments (i.e., 48 controls and 48 nutritionally challenged ewes). The sample size of 48 ewes per experimental group was determined by the limited number of automated feed bins available in the experimental facilities (n = 48 for challenged ewes). However, 3 automatic electronic bins were unavailable at the beginning of the experiment, so the final challenged group consisted of only 45 ewes, rather than the 48 ewes initially planned, for a total study population of 93.

Each day, from the start of the experiment, the ewes were loaded twice into the milking parlor (i.e., 2 milking sessions, morning and evening, at approximately 0800 and 1700 h, respectively). The 3.5-wk adaptation period allowed ewes to acclimate to the general environment of the housing facility and be trained to use the electronic and automatic feeders (for the 45 challenged ewes). In addition to helping the ewes adapt to passing through the WoW system, the observer had to force the ewes to cross the WoW platform for the first 3 days of the experiment; after a few days, the ewes adapted to the device and started to cross the WoW platform voluntarily and without interference. During this period, some minor adjustments were made to the WoW platform to ensure that it fit the frame of the Lacaune breed (larger than the Romane breed, used in previous studies from our team; González-García et al., 2018a,b). The WoW prototype was closely monitored to ensure correct functioning. For comparison, ewes were weighed weekly at around the same time (1330 h), using the same static scale as in trial 1. Ewes' BCS were estimated by 2 experienced observers at the same time and with the same frequency (weekly), using the grid proposed by Russel et al. (1969). During this period, all ewes received 100% of their nutritional requirements.

WoW Sensitivity to Detect Small Daily Individual LW Changes. At wk 4 (Figure 1), we began to evaluate the ability of the WoW to detect small LW changes by performing a 2-wk nutritional challenge. One group of ewes received the same feeding regimen (controls, n = 48), but for the other group the feeding system was manipulated (challenged, n = 45), first to a 2-wk undernutrition challenge and then to a 1-wk refeeding period (back to control regimen for last week of the experiment; Figure 1). The rationale for applying the nutritional challenge (hypothesis) was that reducing the diet energy load by 20% (i.e., distributing 80% of the theoretical energy requirements) would induce a negative energy balance with consequent LW losses in the lactating ewes. Once the normal feeding regimen was reestablished (i.e., the refeeding week), we expected the ewes to recover and stabilize both their nutritional energy balance and body condition (LW).

Ewes' average age, BCS, and LW at the beginning of the experiment were similar for the 2 groups (age = 3.5 ± 0.95 vs. 3.3 ± 0.03 years; LW = 79.1 ± 6.52 vs. 74.2 ± 6.44 kg; BCS: 3.1 ± 0.22 vs. 3.1 ± 0.29, for control and challenged ewes, respectively). During this period, ewes were managed in the same way, and milked twice a day at the same time.

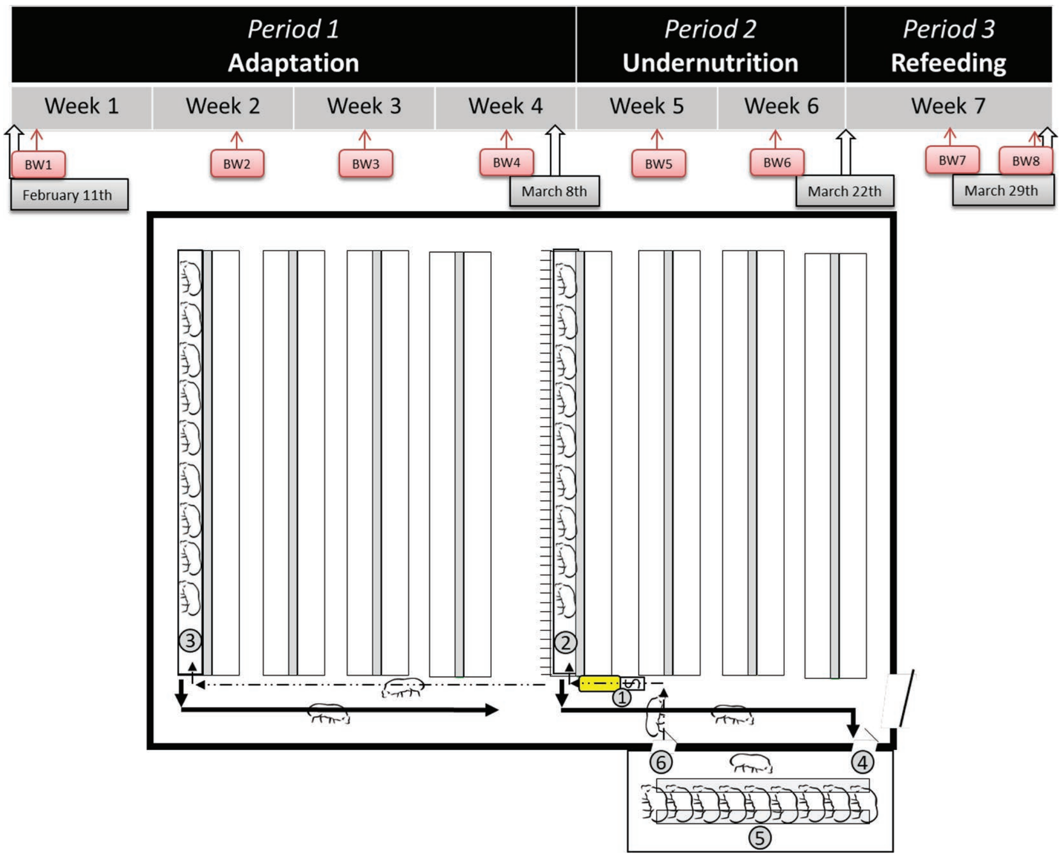

Figure 1. Experimental design followed during trial 2 (45 d) to evaluate the effectiveness of using the walk-over-weighing (WoW) prototype for monitoring liveweight changes in dairy ewes in a real farm situation. The circuit followed by the ewes is shown at the bottom: (1) location of the WoW system in the corridor; (2) pen for nutritionally challenged ewes (n = 45); (3) pen for control ewes (n = 48); (4) entrance to the milking parlor; (5) milking parlor with 2 × 24 capacity; (6) exit door from milking parlor. At the exit race of the milking parlor, after each daily milking session, the ewes crossed the WoW system to return to their pen, and an automated liveweight was potentially registered for each ewe each time they crossed over. Liveweights were also recorded using the static scales (at the beginning of the experiment, BW1; once a week during the experiment, BW2–7; and at the end of the experiment, BW8) to compare findings with the average of the twice-daily (morning and evening) records collected using the WoW system.

The milking parlor consisted of 2 × 24 stalls, so each group was milked in 2 consecutive batches at each milking session, and the ewes from each group entered the milking parlor randomly. After milking, which usually took approximately 3 min per batch, ewes came out of the milking parlor and were routed toward their pen, allowing them to voluntarily cross the WoW (placed in the corridor at the exit race of the milking parlor; Figure 1) without intervention from the operator or any other perturbation factor. The pen for the challenged ewes was near the end of the WoW exit, and the pen for the control ewes was at the end of the corridor (about 30 m from where the WoW was placed).

Feed was distributed 50:50 daily around the time of each milking session (i.e., at 0900 and 1600 h) and was composed of the same ingredients for both lots (ryegrass silage and local hay, with barley as a supplement). The 48 ewes in the control group were fed as a group. The 45 challenged ewes were fed individually in the same pen with electronic automatic feeders, each of which was fitted with an electronic "open-close" gate system that controlled access to the feed bins (González-García et al., 2018a) and measured daily individual feed intakes (Hassoun et al., unpublished data). Ewes had constant free access to fresh, clean water and mineral salts.

Data Calculation and Statistical Analyses

Two Filtering Steps for the Raw Database. For both experiments, the first filtering of raw databases consisted of removing misbehaviors (i.e., ewes with an abnormal crossing of the WoW platform causing spurious readings—zero or extremely low or high values—including fast or frantic passage or another ewe on the scale at the same time). In the second filtering, outliers were removed using Grubbs's Outlier Test (Grubbs,

1969) available as part of NCSS Comprehensive Statistics Software (NCSS 12; https://www.ncss.com/software/ncss/). The raw database from trial 2 was downloaded at the end of the experiment and the daily data (containing both milking sessions) were analyzed.

For each trial, after the raw databases were filtered to remove misbehaviors and outliers, the differences between the 2 LW measurement methods were calculated (i.e., automated weight minus static weight). Lin's concordance correlation coefficients (**CCC**) were analyzed according to the methodology proposed by Lin (1989) to assess the extent of agreement between the 2 LW recording methods. The CCC combines measures of both precision and accuracy to determine how far the observed data deviate from perfect concordance (i.e., CCC = 1.0). Suggestions for interpretation of Lin's CCC are almost perfect agreement (>0.99), substantial agreement (>0.95–0.99), moderate agreement (0.90–0.95), and poor agreement (<0.90; Lin, 1989). Static LW values were plotted against their respective automated WoW values to evaluate accuracy [i.e., the closeness of the line of best fit to the 45° line (slope of 1) through the intercept] and precision (i.e., how far observations deviated from the line of best fit). Then, we analyzed the degree to which each automated LW and static LW were identical for the same ewe (i.e., agreement between the 2 methods, which combines accuracy and precision; Lin, 1989). We also analyzed repeatability: the extent to which replicate measurements in identical circumstances were the same—in this case, the degree of similarity of repeated automated weighings using the WoW system on the same ewe.

We also assessed agreement between the 2 methods using the method proposed by Bland and Altman (1999): the 95% limits of agreement and the range within which 95% of differences in weights between the automated and static scales lay. We analyzed the associations between differences and the means of the automated and static weights (Bland and Altman, 1999).

WoW Ability to Detect LW Daily Variations. In trial 2, to evaluate the ability of the automated WoW scale to detect short-term LW changes in the ewes, further statistical analyses were performed by using the SAS statistical package (v. 9.4; SAS Institute Inc.) and the PROC MIXED procedure. Weighing scale, period, week, and their interactions were considered the main fixed effects; experimental group (nutritionally challenged or control), confounded by pen, was considered a random effect. We assumed that the observed LW data would be normally distributed. However, because the data occurred in clusters (experimental groups), it was very likely that observations from the same group were statistically correlated (not independent). To model this correlation, we declared group or pen a random effect to set up a common correlation among all observations with the same feeding level. The interactions group × scale, group × period and group × week were also declared as random effects to model additional correlations between all observations with the same levels of group and scale, group and period, and group and week, respectively. The retained statistical model was as follows:

$$Y_{ijkl} = \mu + Scale_i + Period_j + Group_k + Week_l + Group \times Week_{kl} + Group \times Period_{kj} + \varepsilon_{ijkl},$$

where Y_{ijkl} is the observed LW of the ewe, μ is the overall mean, $Scale_i$ denotes the main fixed effect of the ith weighing scale (static vs. WoW), $Period_j$ is the fixed effect of the jth experimental period (adaptation, undernutrition, or refeeding), $Group_k$ is the random associated effect of the kth experimental group of ewes (nutritionally challenged or control), $Week_l$ is the fixed effect of the lth experimental week, $Group \times Week_{kl}$ and $Group \times Period_{kj}$ are the random interaction effects associated with the kth experimental group and the lth week and jth period, respectively, and ε_{ijkl} is the associated residual error.

RESULTS

In trial 1, the number of automated weighing records increased with the number of weighing sessions (third > second > first; Table 1), indicating that ewes became well adapted as they made more crossings of the WoW prototype. This was reflected in a decrease in misbehavior and outlier values in database filtrations 1 and 2, respectively, as the weighing sessions advanced. In the third weighing, only 1 outlier was detected.

Of the 42 ewes weighed, 41 yielded 3 out of 3 automated readings and 1 yielded only 1 record. From the 41 ewes, 23 yielded 3 valid records for the 3 weighing sessions, 10 ewes yielded 2, and 8 ewes produced only 1. In total, we collected 97 plausible automated weights from a possible 126 readings. At the first, second, and third weighing sessions, 61% (n = 26), 71% (n = 30), and 98% (n = 41) of the 42 ewes, respectively, had valid weights recorded by the automated WoW.

We calculated Lin's CCC to assess the agreement between the 3 automated weighings and the static weights (Table 1), including its 2 components (accuracy and precision). Overall, for the 3 pooled weighings, Lin's CCC increased substantially when misbehaviors (from 0.383 to 0.965) and outliers (from 0.965 to 0.982) were removed from the raw database. This was related to a proportional increase in intraclass correlation coefficient for differences between LW on the automated and

Table 1. Accuracy, precision, agreement, and repeatability for liveweights collected (statically and automatically) from 3 consecutive weighing sessions in 42 adult Lacaune dairy ewes during a 1-d trial

	Weighing session											
	First			Second			Third			Pooled		
Item[1]	Raw	Filtration 1[2]	Filtration 2[3]	Raw	Filtration 1	Filtration 2	Raw	Filtration 1	Filtration 2	Raw	Filtration 1	Filtration 2
Ewes (n)	42	42	42	42	42	42	42	42	42	42	42	42
Automated weighings obtained (n)	41	33	26	41	33	30	42	42	41	124	108	97
Agreement												
Lin's CCC	0.193	0.947	0.986	0.355	0.968	0.978	0.980	0.980	0.981	0.383	0.965	0.982
r[4] (95% CI)	0.266	0.963	0.997	0.427	0.979	0.988	0.999	0.999	0.999	0.450	0.981	0.995
Accuracy (Cb coefficient)	0.397	0.972	0.993	0.553	0.983	0.989	0.987	0.987	0.988	0.500	0.976	0.987
Precision (r)	−0.011	0.904	0.974	0.138	0.941	0.959	0.969	0.969	0.970	0.262	0.952	0.975
Lower, 1-sided 95.0% CL of ρc	0.007	0.909	0.975	0.158	0.944	0.961	0.970	0.970	0.971	0.273	0.954	0.975
Upper, 1-sided 95.0% CL of ρc	0.397	0.972	0.993	0.553	0.983	0.989	0.987	0.987	0.988	0.500	0.976	0.987
Lower, 2-sided 95.0% CL of ρc	−0.030	0.899	0.972	0.118	0.937	0.957	0.968	0.968	0.969	0.251	0.951	0.974
Upper, 2-sided 95.0% CL of ρc	0.397	0.972	0.993	0.553	0.983	0.989	0.987	0.987	0.988	0.500	0.976	0.987
Repeatability												
Difference from static weight (kg; mean ± SD)	−5.4 ± 22.1	1.8 ± 3.2	−1.7 ± 1.0	−1.5 ± 17.5	1.4 ± 2.1	−1.46 ± 1.62	−2.0 ± 0.6	−2.0 ± 0.6	−2.0 ± 0.6	−1.6 ± 16.3	−1.8 ± 2.1	−1.8 ± 1.1
Range of difference (kg; 95% limits of agreement)	−1.6 to 12.3	−2.9 to −0.7	−2.1 to 1.3	−4.0 to 7.0	−2.2 to 0.7	−2.1 to 0.9	−2.2 to 1.8	−2.2 to −1.8	−2.2 to 1.8	−1.3 to 4.5	−2.2 to −1.4	−2.0 to −1.5

[1]Cb = bias correction factor, measuring how far the best-fit line deviates from the 45° line (measure of accuracy). No deviation from the 45° line occurs when Cb = 1. CCC = concordance correlation coefficient (Lin, 1989); CL = confidence limits; ρc = Pearson correlation coefficient.

[2]Misbehaviors removed.

[3]Outliers removed, according to Grubbs's test (Grubb, 1969).

[4]Intraclass correlation coefficient for differences between automated and static scale weights.

static scale (0.450, 0.981, and 0.995), accuracy (0.500, 0.976, and 0.987), and precision (0.262, 0.952, and 0.975) when comparing LW collected on the automated and static scales for the raw, misbehaviors removed, and outliers removed pooled databases, respectively (Table 1).

The repeatability coefficient for the automated LW, measured as the difference from the static LW (kg; mean ± SD), improved with weighing sessions and database filtration. Differences between static and WoW weights are illustrated in Figure 2. The WoW system tended to overestimate LW by approximately 1.8 ± 1.6 kg (Figure 2). Except for a small proportion of records (<3%), we found an absolute tendency for LW overestimation (see the % total frequency of difference between values recorded with both scales in Figure 2).

The range of difference between the 2 weighing methods (95% limit of agreement) decreased substantially as the ewes became more adapted to the WoW system (i.e., weighing sessions) and with the removal of misbehaviors and outliers (Table 1). The relationship between static and automated LW records from the 3 pooled weighings is displayed in Figure 3. The proximity of record values to the line of perfect concordance was consistent across the weight range of the experimental population.

The results from trial 2 are shown in Table 2. In contrast to trial 1, which used a controlled situation, trial 2 used a real situation, and the proportion of missing automated LW was considerably higher (~80%). The main causes of this difference included the passage of ewes at excessive speed and the close proximity between ewes when they exited the milking parlor and headed to the pen, where their meal was waiting. These factors were barriers to an ideal, slower passage through the WoW platform.

Nevertheless, after database filtration, the number of LW automatically registered by the WoW system increased with time (Table 2). During the first week, the ewes were new to the system and yielded only 375 LW records, of which 29 were removed for misbehaviors and another 227 were outliers; therefore, only 119 records were plausible, representing 32% of the total expected for this first week. These figures improved with time. At the end of the experiment (i.e., in week 6), the WoW produced 798 raw LW records, of which 47% (375) were plausible: 3 times as many as the first week (375 vs. 119). The proportion of plausible records increased over time (Table 2), from 32% (119/375) in the first week to 40% (185/460) in the last week of the adaptation period (week 4), to 57% (131/230) at the end of the experiment (week 7; Table 2). However, the percentage as a function of the optimal number expected continued to be low. Overall, we collected 20% of possible LW

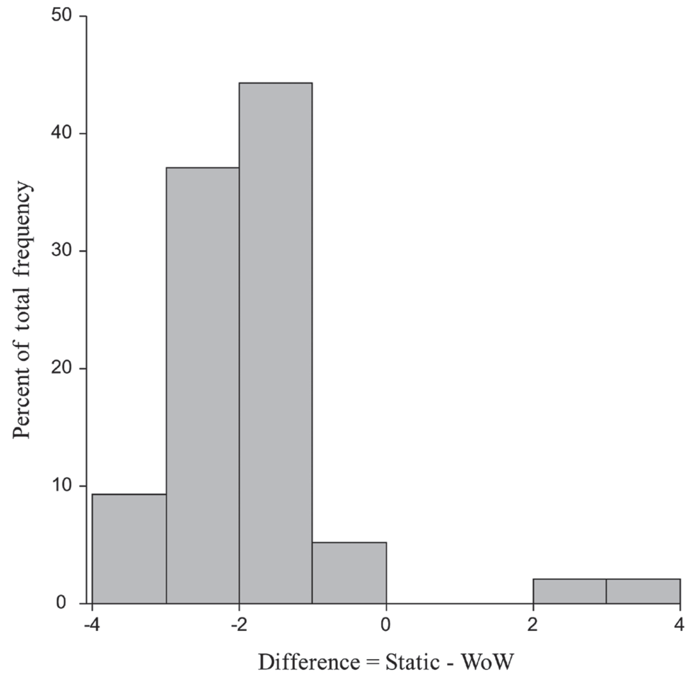

Figure 2. Frequency of difference between automatic and static weighings of liveweights from 42 adult Lacaune dairy ewes (trial 1).

records during the experimental period of 7 weeks (i.e., 1,458 effective readings from 7,500 expected); considering only the last 3.5 weeks (once ewes were adapted), percentages were higher.

During trial 2, which lasted 45 d, the average number of plausible LW records collected per ewe was 16 (i.e., 16 LW records per ewe could be interpreted). From the 1,458 automated LW obtained after the second filtration (Table 2), the minimum number of valid passages was 8 times per ewe and the maximum was 41 times per ewe. Overall, 50% of the ewes (47/93) produced fewer than 13 plausible LW records (i.e., 8–13, or at least 1 plausible automated LW every 4 d); 31% (29/93) produced between 13 and 24 plausible records (i.e., at least 1 plausible LW every 3 d); and 18% (17/93) yielded more than 25 plausible LW records (i.e., 1 every 2 d). These data also included the adaptation period.

Similar to trial 1, Lin's CCC, accuracy, precision, agreement, and repeatability increased over time (Table 2). However, although the number of plausible records increased, as was the case for the quantity of records expected and the decrease in the number of outliers, the proportion of misbehaviors remained stable throughout the experiment (i.e., 7 to 19% of data were removed in the first database filtration).

Similar to trial 1, the WoW system tended to overestimate the LW of ewes by approximately 0.8 kg. Figure 4 illustrates the good relationships between LW from the 2 scales (Figure 4A), as well as the good repeatability observed (i.e., 95% limits of agreement plot for LW differences between the 2 scales; Figure 4B).

In this real-farm situation, a further objective was to evaluate the sensitivity of the WoW system for detecting small changes in the LW of ewes in the control and challenged groups. The experimental design and diet manipulation yielded the results we expected: the challenged ewes lost and gained weight during the undernutrition and refeeding periods, respectively (Table 3).

The ewes' LW were primarily affected ($P < 0.05$) by the experimental period (average LW: 76.9, 73.9, and 76.4 kg for the adaptation, undernutrition, and refeeding periods, respectively; Table 3) and by the interaction of group × week ($P = 0.004$; Figure 5). We found a trend for the interaction of group × period ($P = 0.069$). Ewes in the challenged group had lower LW from wk 4 to 6 (the induced undernutrition phase; Figure 5). When challenged ewes were refed, the differences in LW disappeared. These results were irrespective of the scale used; LW recorded using the static scale (gold standard; 75.61 ± 0.685 kg) and the WoW scale (75.86 ± 0.702 kg) were not significantly different ($P = 0.591$).

DISCUSSION

We confirmed our hypothesis about the feasibility of using WoW technology with a Lacaune dairy flock reared indoors. To our knowledge, this is the first such report in dairy sheep. The WoW platform used in the current study was the same as that used in previous studies (González-García et al., 2018a,b) conducted with the Romane meat sheep breed.

In the first trial, we found substantial agreement between the 2 weighing methods, even without filtering the raw data. This was mainly because of the controlled conditions of the test; the passage of animals through the scales was monitored by the observers. The repeated passage of animals through the controlled circuit (3 repetitions) did not create significant disturbances in the recorded weights. This finding was in agreement with previous findings (Alawneh et al., 2011) for dairy cows, with a perfect association (r = 0.998) between LW values measured using the WoW system and those measured statically when cow flow over the platform was controlled.

In contrast, in trial 2, using a real-farm situation, we collected a significant number of abnormal readings or extreme values. This part of the experiment demonstrated the need for a significant period of adaptation to the WoW platform—probably at least 3 wk—to reduce animal behavior constraints, although the length of adaptation will depend on the conditions of the experiment (e.g., number of animals, weather, indoor or outdoor conditions). Alawneh et al. (2011) reported that 75% of outlier values were due to animal misbehavior.

In agreement with previous reports (Alawneh et al., 2011; Dickinson et al., 2013; Brown et al. 2014a,b; González-García et al., 2018b), our results also indicated that routinely using the WoW required a method

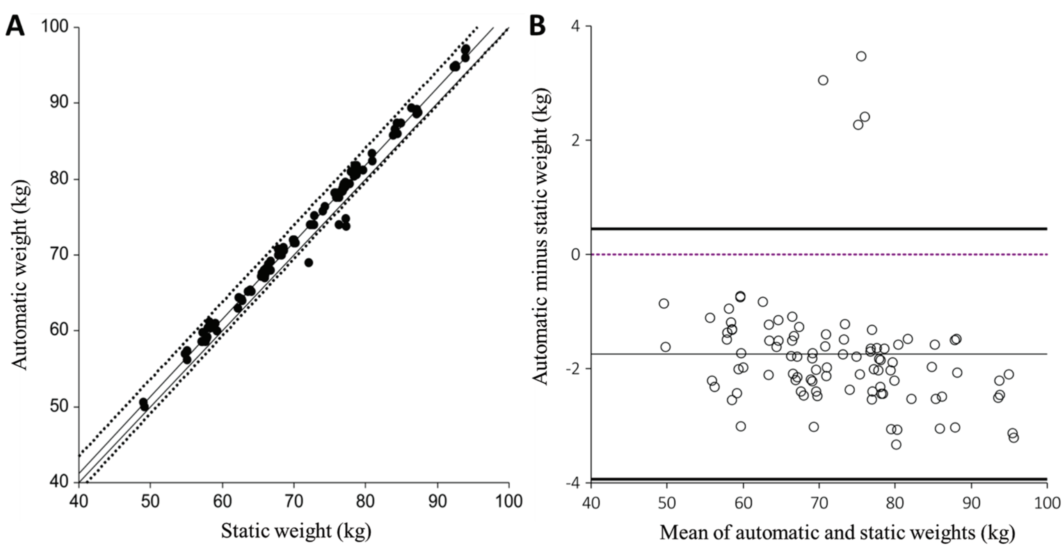

Figure 3. Relationships between liveweights from automated and static scales from 3 pooled automated weighings of 42 adult Lacaune dairy ewes (trial 1). (A) The 45° line (slope of 1) through the intercept (the line of perfect concordance; solid line), the line of best fit (regression; solid line), and the prediction limits (dotted lines). (B) The 95% limits of agreement (repeatability; heavy solid lines) plot for liveweight differences between automated and static scales.

Table 2. Accuracy, precision, agreement, and repeatability for liveweights collected (statically and automatically at the exit race of the milking parlor) in 93 adult and lactating Lacaune dairy ewes, during a 45-d trial

	Experimental period							
	Adaptation				Challenge		Refeeding	
Item[1]	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7[2]	Pooled
Ewes (n)	93	93	93	93	93	93	93	93
Automated weighings [no. (% from initial raw database)]								
Raw	375	357	473	460	666	798	230	3,359
Filtration 1[3]	346 (92)	290 (81)	387 (82)	371 (81)	586 (88)	722 (90)	215 (93)	2,917 (87)
Filtration 2[4]	119 (32)	100 (28)	227 (48)	185 (40)	321 (48)	375 (47)	131 (57)	1,458 (43)
Agreement								
Lin's CCC	0.9490	0.9550	0.9458	0.9639	0.9625	0.9517	0.9642	0.9579
r[5] (95% CI)	0.9662	0.9710	0.9549	0.9653	0.9626	0.9583	0.9698	0.9620
Accuracy (Cb coefficient)	0.9676	0.9714	0.9624	0.9757	0.9725	0.9638	0.9773	0.9634
Precision (r)	0.9228	0.9320	0.9243	0.9482	0.9500	0.9371	0.9458	0.9520
Lower, 1-sided 95.0% CL of ρc	0.9256	0.9345	0.9265	0.9498	0.9513	0.9386	0.9477	0.9526
Upper, 1-sided 95.0% CL of ρc	0.9676	0.9714	0.9624	0.9757	0.9725	0.9638	0.9773	0.9634
Lower, 2-sided 95.0% CL of ρc	0.9200	0.9296	0.9221	0.9466	0.9488	0.9357	0.9438	0.9515
Upper, 2-sided 95.0% CL of ρc	0.9676	0.9714	0.9624	0.9757	0.9725	0.9638	0.9773	0.9634
Repeatability								
Difference from static weight (kg; mean ± SD)	−1.4 ± 2.05	−1.4 ± 1.84	−1.1 ± 2.34	−0.4 ± 2.11	−0.1 ± 2.15	−0.9 ± 2.46	−0.6 ± 2.25	−0.8 ± 2.26
Range of differences from static (kg; 95% limits of agreement)	0.88 to 1.89	0.94 to 1.84	0.62 to 1.52	−0.01 to 0.84	−0.24 to 0.44	0.53 to 1.28	0.08 to 1.18	0.60 to 0.92

[1]Cb = bias correction factor, measuring how far the best-fit line deviates from the 45° line (measure of accuracy). No deviation from the 45° line occurs when Cb = 1. CCC = concordance correlation coefficient (Lin, 1989); CL = confidence limits; ρc = Pearson correlation coefficient.

[2]Unlike the other weeks (7 d), the last week of the trial lasted only 3 d.

[3]Misbehaviors removed.

[4]Outliers removed, according to Grubbs's test (Grubb, 1969).

[5]Intraclass correlation coefficient for differences between automated and static scale weights.

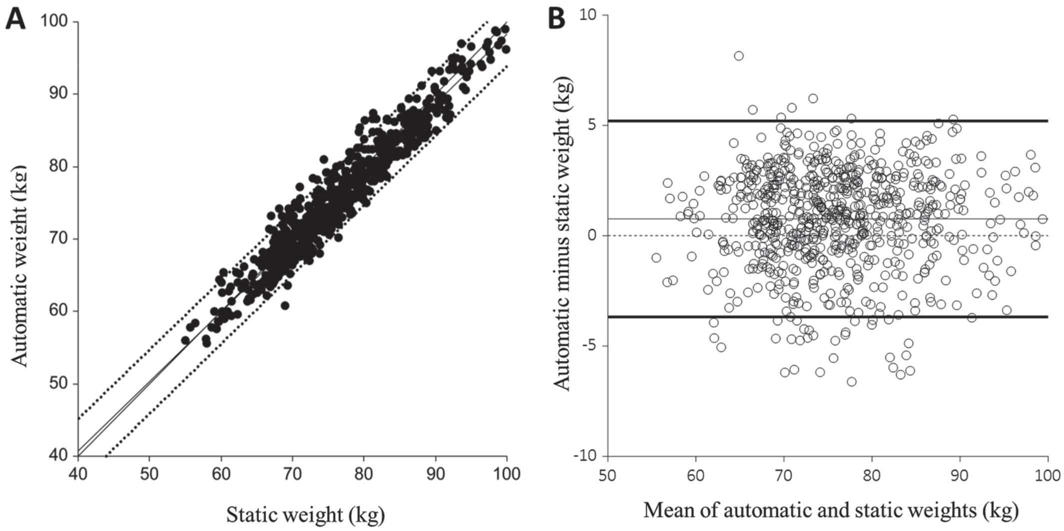

Figure 4. Relationships between liveweights from automated and static scales from 3 pooled automated weighings of 93 adult Lacaune dairy ewes (trial 2). (A) The 45° line (slope of 1) through the intercept (the line of perfect concordance; solid line), the line of best fit (regression; solid line), and the prediction limits (dotted lines). (B) The 95% limits of agreement (repeatability; heavy solid lines) plot for liveweight differences between automated and static scales.

for identifying and removing spurious values (outliers) before interpretation of small LW changes at the individual level. Implementing filtration methods to remove erroneous and extreme values provoked by misbehaviors and other factors allowed the WoW system to detect LW changes in these Lacaune dairy ewes in the short term.

In trial 2, we were able to collect only 20% of the total possible records over the duration of the experiment (1,458 effective readings from 7,500 possible readings). The effective readings were considered plausible LW records that could be used for further database analyses and interpretations after data filtration. Even with such a significant loss of data because of misbehaviors and other sources of outliers (80%), we were able to detect LW changes in ewes. The nutritionally challenged ewes yielded two-thirds of the plausible records (948/1,458), likely related to the practical setting and the location of the WoW platform in the building, which was closer to the pen of the challenged ewes and allowed for slower passage (i.e., the pen of the challenged ewes was much closer to the WoW exit than the pen of control ewes, which was approximately 30 m away).

Having 80% of values removed in our real-farm situation was very high compared to other studies. Alawneh et al. (2011) reported that 12% (9,298) of individual LW records were outliers from a total of 79,697 available for analysis. Kedzierski (2020) reported that 24% (405/1,624) of the initial data were classified as outliers. Brown et al. (2012) showed that the percentage of missing data is related to the applied filter; the 25% filter level removed 25% of weight records on average, and the 10% filter level removed 60% of weight records.

After we filtered the data for misbehaviors and outliers, the WoW automated scales showed substantial agreement with the gold-standard static scales, demonstrated by Lin's CCC and the Bland and Altman's 95% limits of agreement for the pooled weighings. The proximity of data points to the line of perfect concordance were distributed across the weight range of the experimental population used, which was representative of the main Lacaune flock at La Fage experimental farm. Similar to a previous study (Dickinson et al., 2013), the WoW system tended to yield LW values that were biased upwards, but the extent of the mean difference from the static weight decreased with time, illustrating the importance of an adaptation phase before the routine use of this technology. Furthermore, the removal of outliers improved repeatability, confirming that the implementation of a filtration system allowed us to substantially increase the sensitivity of the WoW for detecting small individual LW changes in the ewes.

The most important factor determining spurious values in this work was the excessive speed of ewes when crossing the WoW and the coincidence or proximity of 2 or more ewes on the platform. Apart from these factors, other reasons could have increased the limits of agreement between the automated and static scales: for example, the loss or gain of gut fill between the 2 milking sessions of the day and during the study, as well as other elements related to the specific design and functionality of the WoW system, likely requiring

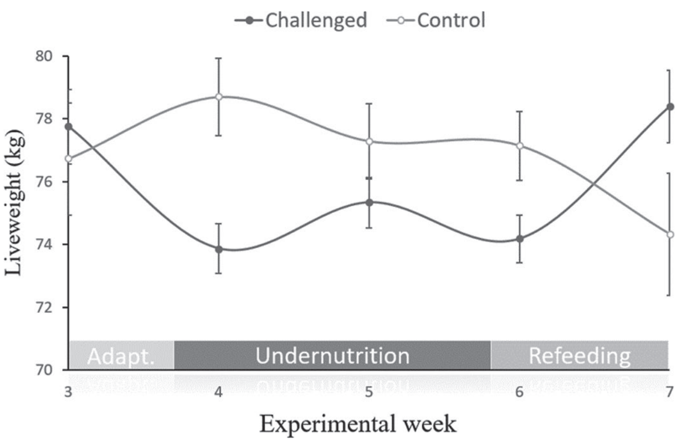

Figure 5. Weekly liveweight progression of mid-lactating Lacaune dairy ewes that underwent a nutritional challenge, including undernutrition and refeeding (challenged) and nonchallenged ewes (control). Errors bars are SEM for each weekly average point.

further adjustments for a better fit to the particular anatomic characteristics of the breed (larger frame in Lacaune compared with Romane ewes) and to the specific location of the platform in the indoor system.

The WoW system was placed in the corridor of the sheepfold (Figure 1) connecting the milking parlor with the pens. This point should also be taken into account when using this WoW system indoors. A suitable place for the device should be chosen, and another type of calibration must be considered so that LW values are not recorded without the animals crossing the platform. Kedzierski (2020) observed that anormal LW values due to shaky behavior of the scale could reach 25% of expected results; Wishart et al. (2017) showed that ewes lost a significant amount of LW (3.5%) after a delay of 3 h during a practical handling operation.

Dickinson et al. (2013) discussed the increase in the number of load cells placed under the WoW platform as a possible improvement to give the weighing system better capability of generating a weight as close as possible to the true weight. They stated that using 4 cells instead of 2 could substantially increase repeatability. We speculate that in sheep this is probably less relevant than in large cattle, considering the differences in how animals step over the platform, the nature of their gait, or their weight distribution on 4 legs, producing different oscillating curves when the animal cross the scale.

Whatever the source of the abnormal records, these data should be deleted and the database filtered before analysis. Brown et al. (2012) demonstrated that the relationship between WoW and static weight changed according to the data manipulation method applied; data from WoW technologies needed to be filtered to achieve better accuracy. Several methods have been

Table 3. Effects of weighing scale, experimental period, group (control or nutritionally challenged), and their first-order interactions on the liveweight (LW) measure of adult mid-lactating Lacaune dairy ewes during a 45-d trial[1]

Item	Scale[2]		Period[3]			Group[4]		Effect, P-value				
	Static	WoW	1	2	3	Control	Challenged	Scale	Period	Group	Group × week	Group × period
LW (kg)	75.61 ± 0.685	75.86 ± 0.702	76.91 ± 1.193	73.94 ± 0.949	76.36 ± 1.091	75.56 ± 0.467	75.90 ± 0.278	0.591	0.047	0.534	0.004	0.069

[1]Outputs of LW are least squares means (±SEM) from the analyses of the final database, containing pooled data after raw database filtration.
[2]Weighing scale used to measure the LW of ewes: static or automated walk-over-weighing (WoW).
[3]Periods: 1 = adaptation [only data from the last adaptation week (wk 3) were included in the ANOVA); 2 = challenge (underfeeding); 3 = refeeding.
[4]Groups: at the end of wk 4, ewes were divided into 2 groups: challenged (submitted to 2 wk of undernutrition, then to 1 wk of refeeding; n = 45) or control (n = 48).

suggested for cleaning the database; the most common ones depend on the SD calculated using each animal's individual LW records. Alawneh et al. (2011) excluded values as outliers if they varied by more than 4 SD above or below the estimated LW, whereas Kedzierski (2020) used a threshold of 3.5 SD. In our study, we used Grubbs's test (Grubbs, 1969) to detect outliers, excluding values if they varied by more than 2 SD above or below the expected LW for a given animal on a given day. It is expected that the lower the threshold used, the more accurate the data will be.

Some studies have suggested grouping data for several days to increase precision. Brown et al. (2012) suggested grouping WoW data (in sheep) over 5 d, and Alawneh et al. (2011) suggested grouping data over 7 d in dairy cattle in pastures to effectively monitor significant changes in recorded daily LW measurements. In our study, we obtained high agreement between the 2 LW recording methods by grouping data from the same day after each milking. To increase the number of observations per week and the precision, we suggest that LW records be grouped every 3 days to monitor small but important daily LW changes in dairy ewes.

Using the WoW allowed us to more closely monitor LW changes at the individual level by adding a higher quantity of individual LW values collected during the week, without requiring human intervention, compared to the single weekly LW record per ewe obtained with the static scale. Based on our results, daily LW changes could be measured at the individual level, to be used as a management tool when making decisions about dairy sheep. For example, this information would allow for more frequent individual adjustment of nutrient requirements with the help of the new INRA feeding system for sheep (Hassoun et al., 2018a) and using radiofrequency identification and automatic feeders for sheep reared indoors (Hassoun et al., 2018b).

Nevertheless, it would be useful to replicate the real-farm experiment developed here using other conditions to reduce the number of records lost (e.g., different settings and WoW platform locations in the building could be evaluated, or avoiding the time of meal distribution for crossing the WoW platform).

CONCLUSIONS

Under the conditions of this study, we were able to demonstrate the feasibility of using an automated WoW system to monitor the individual LW of dairy ewes indoors. Nevertheless, our study showed the need to carry out raw database filtration procedures to remove outliers provoked by ewes' misbehavior (e.g., excessive speed) when crossing the WoW platform. After filtering the databases, however, our results showed high levels of agreement, accuracy, precision, and repeatability between the automated weights yielded by the WoW platform and the static weights collected using the gold standard static scale. Furthermore, we observed no differences between the variation of daily individual LW registered using the static scale and those using the WoW platform during the nutritional challenge induced under real-farm conditions. Further research is warranted to explore alternative settings and determine the best location of the WoW platform on the farm, aiming to decrease the number of outliers to be removed from the original database.

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