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Research article

Evaluating a Walk-over-Weighing system for the automatic monitoring of growth in postweaned *Mérinos d'Arles* ewe lambs under Mediterranean grazing conditions

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A B S T R A C T

Live weight (**LW**) is a key and conventional indicator for monitoring and assessing overall animal performance and welfare, representing the progress through different physiological stages, while providing close indication of individual physical and health status. Measuring LW in practice is still, however, quite rare and infrequent under commercial sheep farming conditions, mainly because sessions are time-consuming, stressful either for the operator or the animals. A Walk-over-Weighing (**WoW**) system was tested in this experiment lasting 14 weeks (i.e. 3 weeks for acclimation and adaptation and 11 weeks for data collection). We validated its use for routine and frequent monitoring of growth rate in post-weaned *Merinos d'Arles* ewe lambs (n = 100), reared under Mediterranean grazing conditions. The necessity for an initial adaptation period of the animals was confirmed. Also, the importance of conducting an effective data cleaning procedure of the raw database automatically collected by the WoW was corroborated. Adaptation of naive ewe lambs enabled the required voluntary passages across the weighing platform and a high volume of individual and daily data after 2–3 weeks. Close monitoring of individual growth was then possible after performing sound data cleaning. A good agreement was demonstrated between WoW LW and a reference LW value (measured with a standard static scale). At the individual level, even with the lowest number of LW values collected with WoW, it was possible to monitor variations in LW at daily intervals. The establishment of an early warning system to help farmer decision-making could therefore be possible. Our results show interesting prospects for more accurate and frequent monitoring of LW in grazing sheep without human intervention, compared to what is currently carried out on commercial farms.

Implications

We validated the use of Walk-over-Weighing system for the first time under Mediterranean grazing conditions, with post-weaned ewe lambs. The system provides enough quantitative and qualitative data (after performing a sound filtering procedure of the raw data) for effective monitoring of individual daily growth rates of lambs on grassland. Good prospects emerge for developing early warning systems in future with further progress expected in the automatic filtering of raw data and ease of interpretation of the final data and graphs by the farmers and interested end users.

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Specification table

Subject	Livestock Farming Systems
Type of data	Tables, Images, Figures, R-Codes to manipulate datasets and carry out statistical analysis
How data were acquired	Using two different weighing scales i.e. static (Gold Standard) and Walk-over-Weighing (WoW)
Data format	Datasets are presented as Excel files. All results are presented in tables and figures
Parameters for data collection	Individual LW trajectories automatically registered by the WoW platform for ewe lambs after weaning under grazing conditions
Description of data collection	The datasets are provided i.e. the raw database downloaded from the WoW indicator and subsequent datasets after the raw dataset was filtered from outliers, using different cleaning procedures. In each case, the same information is contained including the individual animal identification (**ID**), the experimental group, the week, the date, the exact time of passage through the WoW, the individual WoW_LW measurement, the LW_estimated, the SD_min and SD_max.In the case of the static scale (GS) database, the same information is contained including the individual ID, the date and the static LW value for each individual at that time (i.e. one LW reference value per animal per week)
Data source location	Institution: INRAE City/Town/Region: Salon-de-Provence Country: FranceLatitude and longitude (and GPS coordinates, if possible) for collected samples/data: 43°38′37″.15″ N; 5°00′58.66″ E
Data accessibility	Repository name: Dataverse INRAE Data identification link: https://doi.org/10.15454/IXSHF7
Related research article	González-García, E., Alhamada, M., Pradel, J., Douls, S., Parisot, S., Bocquier, F., Menasol, Llach, I., González, L. A. (2018). A mobile and automated walk-over-weighing system for a close and remote monitoring of liveweight in sheep. *Computers and Electronics in Agriculture*, 153, 226–238. https://doi.org/10.1016/j.compag.2018.08.022.

Introduction

Monitoring live weight (**LW**) of young animals is needed to guarantee adequate growth rates, maintain good health, respect welfare, and for assuring good performances along their productive lifetime. Controlling LW of ewe lambs during the first months could prevent the deterioration of reproductive performance (Kenyon et al., 2014), which is mainly due to the stress of the weaning period after separation from the mother, and the effects of dealing with a new environment and feeding regime (Karakuş, 2014). However, frequent monitoring of LW in commercial sheep farms is rare because it is time-consuming and stressful for both animals and farmers due to the manipulation and restraining of the animals. Furthermore, the picture is poorer when the flock is reared on pasture, because it includes, for example, transportation of animals to the barn/handling area where the weighing platform is located or, *vice versa*, creating weighing and handling facilities within the paddock. Solutions using Walk-over-Weighing (**WoW**) systems have been previously tested on adult ewes to measure LW without human intervention (Brown et al., 2012; González-García et al., 2018a, 2018b, and 2021; Morris et al., 2012; Polat et al., 2013). The WoW has been demonstrated to be less stressful compared with human handling and capable of collecting a much higher volume, and a higher frequency, of LW records per unit of time compared to the standard static weighing system (Brown et al., 2014a; González-García et al., 2018a, 2018b, and 2021). Even if this system seems highly promising, there are still only a few reports on the use of this technology in small ruminants (and here only for sheep) and most of them have tested the WoW only with adult females, sometimes with their lambs (Brown et al., 2012; González-García et al., 2021 and 2018b; Morris et al., 2012; Polat et al., 2013). The objective of the current work was to push forward the state of the art on this matter, by testing the use of the WoW for monitoring the progression of individual LW (growth rate) in recently weaned ewe lambs under grazing conditions. We hypothesised the possibility of collecting a large number of longitudinal LW records with the WoW. Our results show, that after the essential cleaning of raw data (for filtering spurious LW values), it is possible to record LW growth with accuracy over the entire period of interest, either at the flock or individual levels.

Materials and methods

Experimental location and conditions: Animals and farming system

The study was conducted at the Experimental farm of *Domaine du Merle*, Salon-de-Provence, France (43°38′37″.15″ N; 5°00′58.66″ E) which belongs to the Institut Agro–Montpellier SupAgro. One hundred recently weaned *Mérinos d'Arles* ewe lambs (106 ± 6 days old; 24.8 ± 3.44 kg of LW), born in early October (i.e., October 4th ± 6 days) and weaned on January 13th, were chosen for the study, at five days after weaning (i.e., LW > 18 kg; Table 1). The ewe lambs were chosen according to their LW and then further classed into three subgroups: **Light** (LW average: 21.2 ± 1.4 kg; n = 33), **Medium** (average LW: 24.4 ± 0.8 kg; n = 33) and **Heavy** (LW over the average: 28.8 ± 2.0 kg; n = 34). Such subgroups are representative of the three contrasting LW strata typically found in the source flock. During the experiment, one lamb died (belonging to heavy subgroup). The experiment started two weeks after weaning (i.e., on January 25th) and lasted for 14 weeks (i.e., until April 30th).

Animals were reared under Mediterranean pastureland conditions, grazing a mixed sward composed mainly of ryegrass and other native herbaceous grasses and legumes. A rotational grazing system was established with paddocks (each averaging 0.29 ± 0.0 8 ha) that were grazed on average for 4.7 ± 1.4 days each. Water, molasses, minerals and salt blocks were only provided in an attraction area (around 150 m^2 of average area; Fig. 1). In a similar manner as previously reported by our team (González-García et al., 2018a and 2018b), the access to the attraction area was possible

Table 1
Overall characteristics of the experimental ewe lambs (n = 100), according to their live weight subgroup (Heavy, Medium or Light condition). Data are presented as Least squares means ± Standard Error of the Mean.

Live weight range[1] of experimental ewes (n = 100)	At birth		At weaning	
	Litter size	Live weight, kg	Litter size	Live weight, kg
Heavy (n = 34)	1.2 ± 0.4	5.1 ± 0.8	1.06 ± 6	28.8 ± 2
Medium (n = 33)	1.7 ± 0.5	4.1 ± 0.7	1.07 ± 6	24.4 ± 0.8
Light (n = 33)	1.9 ± 0.3	4.0 ± 0.5	1.05 ± 6	21.2 ± 1.4
Average	1.6 ± 0.5	4.4 ± 0.8	1.06 ± 6	24.8 ± 3.5

[1] The ewe lambs were chosen according to their LW and then further classed into three subgroups: Light (LW average: 21.2 ± 1.4 kg; n = 33), Medium (average LW: 24.4 ± 0.8 kg; n = 33) and Heavy (LW over the average: 28.8 ± 2.0 kg; n = 34). Such subgroups are representative of the three contrasting LW strata typically found in the source flock.

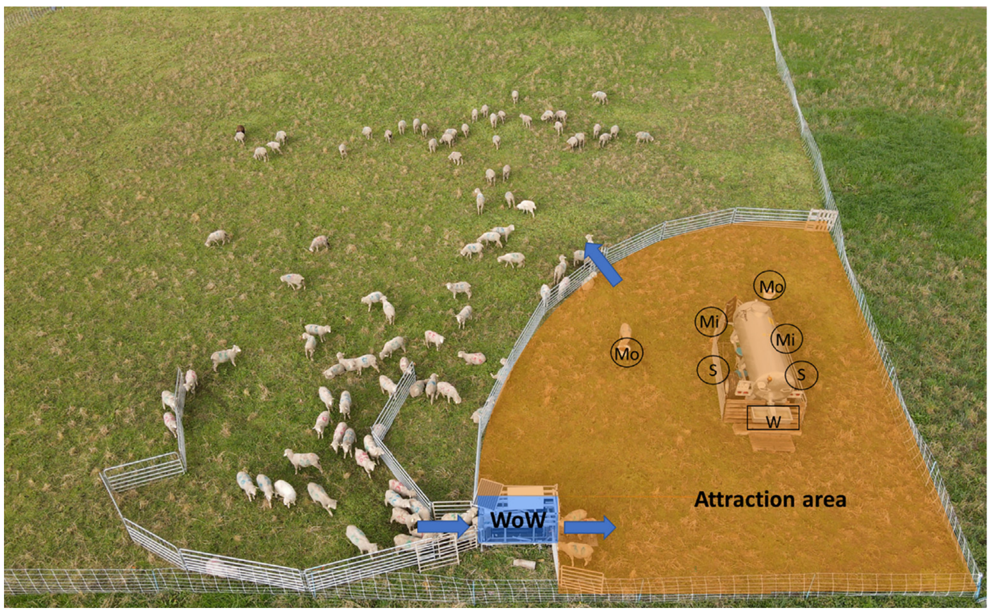

Fig. 1. Schematic representation of the paddock plan and the set-up of the walk-over-weighing system to allow one-way flow of ewe lambs to the attraction area, connected to the rotationally grazed paddock. Mi: mineral blocks; Mo: molasse; S: salt blocks; W: water; WoW: walk-over-weighing.

only by a one-way passage through the WoW, with the exit placed on the other side with a non-return gate. When an animal passed through the platform, the **RFID** (radio frequency identification) ear tag of the animal was read by the antenna placed on the left side of the system, registered to a XRP2 reader (TRU-TEST™, Auckland, New Zealand; released by Marechale Pessage, Chauny, France). This reader was linked by Bluetooth® to the weigh scale indicator **WOW2** (TRU-TEST™, Auckland, New Zealand) which recorded the LW of each animal at each passage, together with their RFID identity and date and the time of passage.

Experimental sequence: trials, design and measurements

Fig. 2 illustrates the experimental design. The study was divided into two complementary periods i.e., (1) the adaptation phase, lasting three weeks (until February 14th), corresponded to the theoretical time required (based on our previous experience) for the ewe lambs to become well-adapted to the system and which involved some interventions by the operator, and (2) the data collection phase without any intervention aimed to facilitate the voluntary individual passages through the WoW.

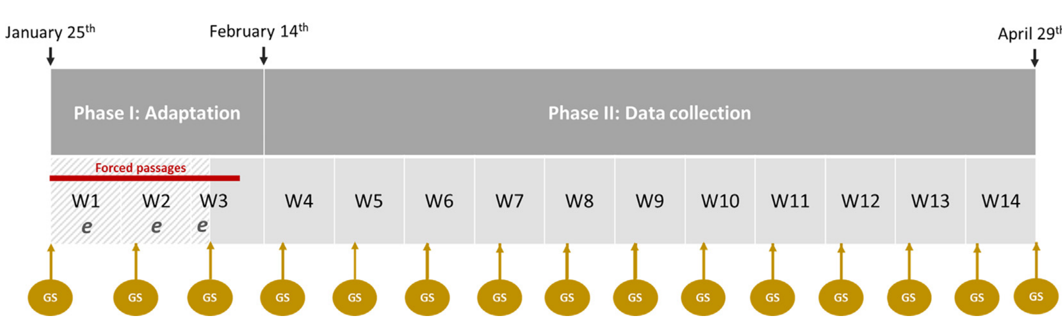

Fig. 2. Schematic representation of the timeline of the experimental design with ewe lambs at grazing. The 3-month experiment started on January 25th and lasted until April 30th with a design including two major experimental periods (Adaptation and Data collection). Wi: week n°i; GS: Gold Standard measurements with the static weight scale indicator XR-5000; e: presence of five WoW-adapted adult ewes to facilitate adaptation of naïve lambs.

Phase I: Adaptation

The Adaptation phase lasted three weeks (Fig. 2) and aimed to prepare the animals and the whole setting of the experimentation in order to achieve the main purpose: getting the animals well-adapted enough to achieve voluntary and daily passages through the WoW without human intervention. At the start of the experiment, the lambs were trained with forced passages three to five days a week with one to four passages per day for the first three weeks of the experiment. During the first 15 days, the training was also accelerated by the presence of five adult ewes which were previously adapted to the WoW in another experiment. During this phase, the progress in voluntary daily number of passages through the WoW was recorded, as was the progress in the number of biologically plausible LW records which were assessed thanks to the comparison with individual LW reference values (i.e., Gold Standard **-GS-** LW measured with the static animal position and recorded once a week, every Tuesday at 0900 am). These GS measurements were performed manually in the field using the same WoW platform but with a weight scale indicator XR-5000 (TRU-TEST™, Auckland, New Zealand). During this first phase, a total of 5411 WoW records were transferred every 1–3 days at the same time (0900 am GTM + 1) through a smartphone linked to the WoW2 with Bluetooth®.

Phase II: Fully automated data collection

The second phase lasted 10 weeks (Fig. 2) and aimed to evaluate (i) the possibility of using the WoW system for growing animals from this *Mérinos d'Arles* breed under grazing condition and (ii) the feasibility of automatically measuring their LW with accuracy, and the resultant calculations of individual growth rates (Average Daily Gains – **ADGs**, g/d). The progression in the number of passages and biologically plausible LW records variables were also recorded. The GS measurements continued to be performed every Tuesday at 0900 am and the data transmission was performed almost every day at the same hour (0900 h) when no lamb was on the platform. During this second phase, a total of 25 172 WoW records were collected.

Calculation and statistical analyses

Database development and outlier detection

All statistical analyses were performed using R software (R Core Team, 2021). Daily downloaded raw WoW records were registered in CSV file format on a laptop, and data from the GS measurements were added in an individual sheet in the Specification Table. Using the GS, individual lamb ADG between each of the two weekly measurements was calculated. Due to this calculated ADG, each daily LW was estimated for each ewe lamb. Before further analyses, different data filtering procedures were carried out with R using the *dplyr* package to manipulate data. Firstly, records were removed if they did not capture the RFID identity of the individual, or if the registered LW was equal to zero. Then, a three-step data filtering approach was followed to detect and remove lamb misbehaviours and outliers. The first filtering step was performed at the group level. Records falling outside the LW range (i.e., minimum, and maximum) of the group (i.e., classified as misbehaviours) were removed by detecting extremely low and high values as well as data higher than twice the LW mean of the group (e.g. meaning that more than one lamb was on the platform at the same time). The second filtering step was made at the LW subgroup level. All the data outside the interval [group weekly minimum of LW – 2.5 kg; group weekly maximum of LW + 2.5 kg] aimed to take into account LW fluctuations during the day considered to be due to the content of the digestive and urine tracts (INRA, 1989), but exclude weight data beyond this range. Finally, a third filtering step was carried out at the individual level. The daily estimated LW of each individual, used as a reference value, was first calculated after calculating ADG from the available weekly LW records obtained with the GS measurements. Then, all values falling out of the individually accepted range (i.e., daily estimated LW based on GS ± 2 × SD) were removed from the database. At the end of this three-step data filtering approach, the result was a cleaned database able to be further processed and interpreted.

For each step of the filtering process, the concordance of the records obtained with the WoW and the GS data was evaluated using the concordance methodology proposed by Bland and Altman (Bland and Altman, 1999). The bias coefficient of concordance evaluates the repeatability of the system. As the bias between the two methods, it is a measure of the lack of agreement and is estimated by the mean difference (d) and the variation around the bias is estimated as SD (sd). Assuming the differences are normally distributed, the variation of the results is calculated as ± 1.96 × sd and referred to as limits of agreement (Yellareddygari and Gudmestad, 2017). Lin's concordance correlation coefficient (**CCC**) was also calculated to evaluate the extent of agreement between the WoW and the GS method (Lin, 1989). The CCC combines the measurements of accuracy and precision to define how far the WoW data deviate from perfect concordance (i.e., CCC = 1.0). It evaluates the reproducibility of the system. It also provides the correction bias factor to estimate how far the method is from the perfect correlation. These analyses were assessed using the *BlandAltmanLeh* and *DescTools* packages, and the linear models function on R software, with the use of *ggplot2* package, for plotting graphics.

LW data procedure and analysis

A complex mixed model with repeated measurements (Week) was used, applying the *lme4* package (Bates et al., 2015), based on the fixed effects LW measurement System (n = 2; WoW vs GS), the experimental measurement Week (n = 14) and the LW subgroup (n = 3; Heavy, Medium and Light). Data were analysed considering both crossed (not nested) and nested random effects. Crossed random effects (i.e., a given factor appearing in more than one level of the upper-level factor) were considered for the LW subgroup in the different and progressive experimental weeks, and both for the GS and WoW weighing system scales. Nested random effects occurred for each individual ewe lamb within each of the three specific LW subgroup levels. The model was fitted as follows: *lmer(LW ∼ Group + System + Group × Week + Group × System + (1|System) + (1|Week) + (1|Group/RFID), data = data_analysis).* With *data_analysis* using the final database for the statistical analysis (i.e., after the filtering data process was finished) and on the weekly static measurement days, the retained statistical model was as follows:

$$Y_{\mathrm{ijkl}} = \mu + System_{\mathrm{i}} + Week_{\mathrm{j}} + LWGroup_{\mathrm{k}} + LWGroup_{\mathrm{k(EweLamb)}} + LWGroup \times System_{\mathrm{ik}} + LWGroup \times Week_{\mathrm{kj}} + \varepsilon_{\mathrm{ijkl}}$$

where Y_{ijkl} is the observed LW of the ewe, μ is the overall (fixed) mean of the sample population, $System_{\mathrm{i}}$ denotes the main fixed effect of the i_{th} weighing system scale (static vs WoW), $Week_{\mathrm{j}}$ is the fixed effect of the $\mathrm{j_{th}}$ experimental week (1…14), $LWGroup_{\mathrm{k}}$ is the random associated effect of the k_{th} experimental subgroup, according to the LW of the ewes (n = 3; Heavy, Medium and Light), $LWGroup_{\mathrm{k}(EweLamb)}$ is the nested random effect of each individual ewe lamb within each of the three specific LW subgroup levels, $LWGroup \times System_{\mathrm{ik}}$ and $LWGroup \times Week_{\mathrm{kj}}$ are the random interaction effects associated with the $\mathrm{k_{th}}$ LW subgroup and the $\mathrm{l_{th}}$ weighing system and $\mathrm{j_{th}}$ Week, respectively, and $\varepsilon_{\mathrm{ijkl}}$ is the associated residual error.

The weekly individual ADG was calculated for each animal using its LW records collected in a time phase (i.e., between two weekly GS sessions for the LW reference data, and between the same days for the WoW with the measured or estimated Tuesday data). Such ADG, calculated for each week, enabled determination of the individual and daily LW either for calculating the individual daily LW progression shape in turn for either the WoW or the GS scale. The ADGs obtained by both methods were compared and further calculations were performed to estimate the agreement between ADG assessed by the automated (WoW) and reference static (GS) scales.

To evaluate the intra-LW subgroup variability and the use of the WoW at the LW subgroup level, mixed models on LW and ADG are respectively built on the same process that previously explained each group separately. The model was fitted as follows: *lmer(ADG ~ Group + System + Group × Week + Group × System + (1|System) + (1|Week) + (1|Group/RFID), data = data_analysis)*. The retained statistical model was similar to that previously stated, just changing the individual LW by the ADG as a response variable (Y_{ijkl}).

Results

Database filtering outputs

A summary of the number of records obtained in the WoW database before and after the cleaning procedure is shown in Table 2. From the total of 21 days during the adaptation phase, 6 days were excluded due to battery dysfunction issues. A total of 5 411 records were initially downloaded and 1 429 (i.e., 26.4%) were retained after the removal of LW spurious values (misbehaviours and outliers), which represent an average of 95 records/effective day during the adaptation phase. During the second phase of the experiment (data collection), a total of 25 172 records were collected during the 65 effective days (from the total of 74 i.e., 9 days were lost due to battery issues). Of these data, 38.7% were retained after the filtering process, representing on average 150 records/effective day –i.e., 1.5 records/animal/effective day.

Validation of the WoW system

Validation of WoW was made after the adaptation of the animals, in the second phase of the experiment. Table 3 presents the descriptive statistics, linear regression and CCC reports. The linear regression coefficient of the LW WoW measured values explained by the GS reference estimated values is about 0.92 with an error of 1.181 kg (Fig. 3). The CCC (0.94) shows moderate agreement between the two LW measurement methods. On the raw database, the Bland and Altman concordance coefficient is −6.95 ± 30.12 kg, which is considerably improved after the full cleaning process (i.e., −0.83 ± 2.32 kg in final clean database after the three-step procedure; Fig. 4).

Adaptive behaviour

Fig. 5 shows the adaptive behaviour of the lambs according to the daily percentage of animals that voluntarily passed across the system. By the end of the adaptation phase, the percentage of ewe lambs that passed across the platform increased. This rate was on average higher during the second phase of the experiment compared to the first one (65.4 ± 32.9% and 90.5 ± 7.4% respectively for the phase I and phase II), which demonstrated the positive impact of time and training on the adaptation of the animals. The number of forced passages did not influence this rate.

Table 2
Summary of a three-step raw database filtering process (for removing spurious live weight –LW- records) performed during the two experimental phases with *Mérinos d'Arles* ewe lambs. Databases were successively cleaned from the primary (raw), to the final database, which was used for comparisons with static LW records.

	Number of animals	Days of automatic LW data collection	Effective days of data collection	Raw database		Database 1 (after misbehaviour removal)		Database 2 (after group outlier removal)		Database 3 (Final) (after individual outlier removal), used for analyses					
				Total of records	Average records/ effective day	Total of records	Average records/ effective day	Total of records	Average records/ effective day	Total of clean records	Average records/ effective day	Average records/ animal/ effective day	% Raw database	% Database 1	% Database 2
Adaptation (Phase I)[a]	100	21	15	5 411	361	3 565	238	1 482	99	1 429	95	0.95	26.4	40.1	96.4
Fully automatic data collection (Phase II)[b]	100 (99 after the 1st of April)	74	65	25 172	387	17 762	273	9 984	154	9 735	150	1.50	38.7	54.8	97.5
Total	100 (99 after the 1st of April)	95	80	30 583	-	21 327	-	11 466	-	11 164	-	-	36.5	52.3	97.4
Average	100 (99 after the 1st of April)	48	40	15 292	374	10 664	256	5 733	127	5 582	123	1.24	32.6	47.5	97.0

*Days with a battery problem preventing correct data collection were deleted.
[a] The adaptation phase, lasting three weeks (until February 14th), corresponded to the theoretical time required (based on our previous experience) for the ewe lambs to become well-adapted to the system and which involved some interventions by the operator.
[b] The data collection phase, without any intervention, aimed to facilitate the voluntary individual passages through the WoW.

Table 3
Descriptive analyses and live weight data validation indicators during the database filtering process in an experiment with *Mérinos d'Arles* ewe lambs at grazing.

		Descriptive analysis										Linear regression		Concordance correlation coefficient (CCC)[¥]	
		GS[a]					WoW[b]								
		n	Mean (kg)	SD	Min (kg)	Max (kg)	n	Mean (kg)	SD	Min (kg)	Max (kg)	R^2	Residual error	Precision (Cb)	Lin's concordance coefficient
Adaptation (Phase I)[c]	Raw database	5 411	26.0	3.7	18.4	35.2	5 411	29.9	19.1	0	79.2	0.025	18.91	0.36	0.06
	Database 1	3 565	26.0	3.6	18.4	35.2	3 565	34.6	8.7	10.2	49.8	0.051	8.47	0.38	0.09
	Database 2	1 482	26.3	3.6	18.4	35.2	1 482	27.4	4.0	16.6	37.6	0.808	1.74	0.96	0.86
	Final database	1 429	26.3	3.6	18.4	35.2	1 429	27.2	3.8	17	37.6	0.885	1.30	0.96	0.91
Fully automatic data collection (Phase II)[d]	Raw database	25 172	30.5	3.9	20.3	42.4	25 172	37.4	15.9	0	80	0.062	15.37	0.40	0.10
	Database 1	17 762	29.7	3.7	20.3	42.4	17 762	36.3	8.4	10.4	49.8	0.044	8.19	0.49	0.10
	Database 2	9 984	30.2	4.0	20.3	42.4	9 984	31.1	4.3	18.2	44.6	0.850	1.66	0.98	0.90
	Final database	9 735	30.3	4.0	20.4	42.4	9 735	31.1	4.2	18.8	44.6	0.921	1.18	0.98	0.94
Total	Raw database	30 583	29.7	4.3	18.4	42.4	30 583	36.1	16.7	0	80	0.077	16.09	0.42	0.12
	Database 1	21 327	29.1	4.0	18.4	42.4	21 327	36.0	8.5	10.2	49.8	0.051	8.23	0.50	0.11
	Database 2	11 466	29.7	4.2	18.4	42.4	11 466	30.6	4.4	16.6	44.6	0.857	1.67	0.98	0.90
	Final database	11 164	29.7	4.2	18.4	42.4	11 164	30.6	4.4	17	44.6	0.924	1.20	0.98	0.94

Data were analysed using the following statistical model and comparisons performed with a threshold of 0.05:

$$Y_{ijkl} = \mu + System_i + Week_j + LWGroup_k + LWGroup_{k(EweLamb)} + LWGroup \times System_{ik} + LWGroup \times Week_{kj} + \varepsilon_{ijkl}$$

where Y_{ijkl} is the observed LW of the ewe, μ is the overall (fixed) mean of the sample population, $System_i$ denotes the main fixed effect of the i_{th} weighing system scale (static vs WoW), $Week_j$ is the fixed effect of the j_{th} experimental week (1…14), $LWGroup_k$ is the random associated effect of the k_{th} experimental subgroup, according to the LW of the ewes (n = 3; Heavy, Medium and Light), $LWGroup_{k(EweLamb)}$ is the nested random effect of each individual ewe lamb within each of the three specific LW subgroup levels, $LWGroup \times System_{ik}$ and $LWGroup \times Week_{kj}$ are the random interaction effects associated with the k_{th} LW subgroup and the l_{th} weighing system and j_{th} Week, respectively, and ε_{ijkl} is the associated residual error.

[a] GS = Gold Standard live weight measures (obtained with the static scales).
[b] WoW = Walk-over-Weighing live weight measures, automatically obtained with the WoW platform.
[c] The adaptation phase, lasting three weeks (until February 14th), corresponded to the theoretical time required (based on our previous experience) for the ewe lambs to become well-adapted to the system and which involved some interventions by the operator.
[d] The data collection phase, without any intervention, aimed to facilitate the voluntary individual passages through the WoW.
[¥] Calculated according to the method proposed by Lin (1989), https://doi.org/10.2307/2532051.

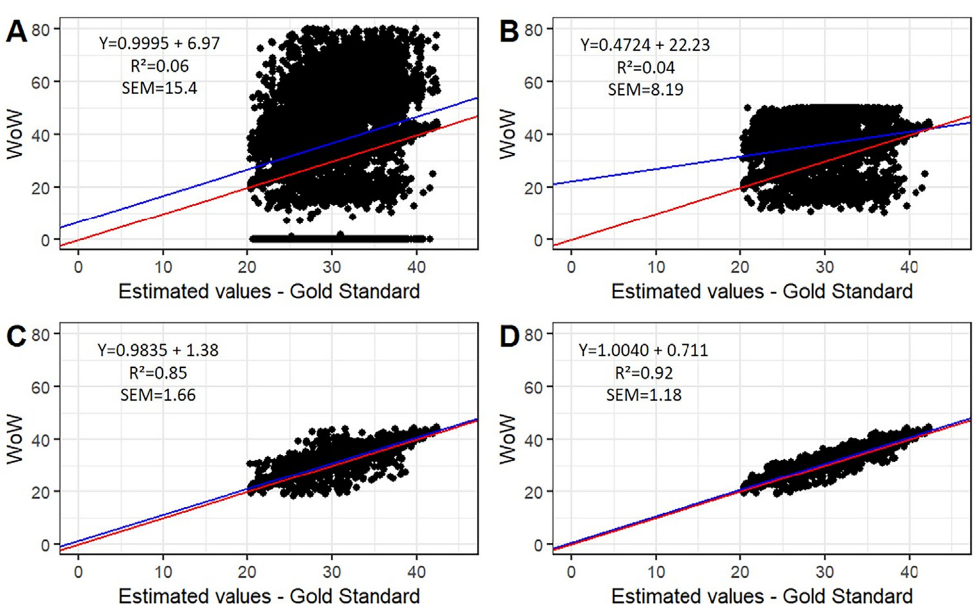

Fig. 3. Illustration of the effects of using a three-step cleaning method to eliminate extreme and outliers from phase II of the experiment, on the correlation between static weighing (traditional) and the automatic Walk-over-Weighing (**WoW**) system in ewe lambs at grazing. Linear regression (blue line): A: from the raw database; B: after step 1 of data cleaning; C: after step 2 of data cleaning; D: after step 3 of data cleaning, final database. R^2: linear regression coefficient; Error: residual error. The red line shows the perfect correlation (45° line).

Growth rate monitoring

Flock level

The LW values collected by each weighing system are presented in Table 4. At the beginning of the data collection phase, the ewe lambs were 127 ± 6 days old and weighed 28.5 ± 3.9 kg. After 74 days (i.e., at 201 ± 6 days), the average LW of the flock measured by the WoW was 34.3 ± 3.8 kg. During this phase II of the experiment, the ewe lambs gained 6.1 ± 1.9 kg (as measured with the WoW system). The *p*-values of the variables Group, System and their interaction are also presented in Table 4. At a threshold of 0.05, there was no influence of the interaction Group × System: the effect of LW subgroup on the LW was the same regardless of the weighing system. There was no significant difference of the

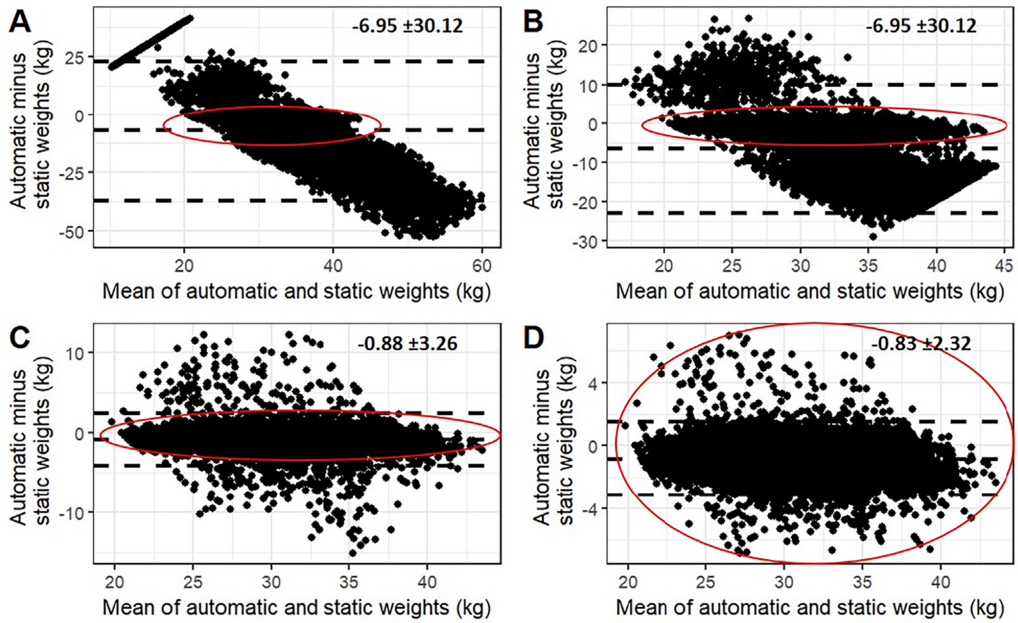

Fig. 4. Bland and Altman graphics during the data cleaning process of the second phase of the experiment with ewe lambs at grazing. The two outer dashed lines represent the 95% limits of agreement (repeatability) between automatic and static weighing scales. The middle dashed line shows the mean of the difference between automatic and static weights. Bland and Altman graphic: A: from the raw database; B: after step 1 of data cleaning; C: after step 2 of data cleaning; D: after step 3 of data cleaning, final database. The red circle represents the data retained after the cleaning process.

Fig. 5. Daily percentage of ewe lambs (n = 100, 99 after April 1st) passing along the platform of the Walk-over-Weighing system during phases I and II of the experiment (i.e., Adaptation and Collect, $P < 0.001$). indicates days with a battery problem.

weighing system on the LW values. Moreover, the weighing system had no significant impact ($p > 0.05$) when analysing the initial and final LW values and the LW gain during phase II. Table 5 shows an average ADG of 0.08 kg/d with a high variability (0.21) for the whole flock. There were no significant differences between the LW subgroups, the weighing systems and their interactions. There is also no significant difference between weeks on the ADG values ($p = 0.72$).

LW subgroup level

LW subgroup growth rates are shown in Fig. 6 for each weighing system. Globally, the LW increased during the experiment without difference between WoW and GS scales (variation of 3 kg in each subgroup, Table 4; $p > 0.05$). The ADG variation of 227, 196 and 195 g/d within each LW subgroup (respectively Heavy, Medium, and Light) was observed without any inter-individual effect between WoW and GS.

Table 4
Initial, average and final live weight (LW, kg), and LW gain (ΔLW) during the second experimental phase (fully automatic data collection), as measured by the two weighing systems. The experimental grazing *Mérinos d'Arles* ewe lambs were grouped according to their body condition (Heavy, Medium, Light).

	LW subgroup (Group)[1]			Weighing scale (System)		Group × System Interaction						*P*-value		
	Heavy	Medium	Light	GS	WoW	GS-Heavy	GS-Medium	GS-Light	WoW-Heavy	WoW-Medium	WoW-Light	Group	System	Group× System
Initial LW	31.6 ± 2.3[a]	27.2 ± 1.4[a]	23.7 ± 1.8[a]	27.0 ± 3.5	28.5 ± 3.9	30.9 ± 1.9	26.8 ± 1.3	23.2 ± 1.5	33.0 ± 2.6	28.0 ± 1 0.3	24.7 ± 2.1	<0.0001	0.22	0.120
Average LW	34.5 ± 3.1[b]	30.5 ± 2.7[b]	27.6 ± 3.1[b]	30.4 ± 4.1	31.3 ± 4.1	34.0 ± 3.1	30.1 ± 2.7	27.1 ± 2.7	35.0 ± 3.1	30.9 ± 2.7	28.0 ± 3.0	<0.0001	0.56	0.57
Final LW	37.3 ± 2.9[c]	33.4 ± 2.3[c]	30.9 ± 2.6[c]	33.4 ± 3.6	34.3 ± 3.8	36.9 ± 2.8	33.0 ± 2.1	30.4 ± 2.6	37.9 ± 2.9	33.8 ± 2.4	31.3 ± 2.6	<0.0001	0.45	0.40
ΔLW	6.0 ± 2.2	6.1 ± 1.9	7.0 ± 1.9	6.5 ± 2.1	6.1 ± 1.9	6.0 ± 2.2	6.2 ± 1.7	7.2 ± 2.1	6.0 ± 2.2	5.8 ± 2.1	6.6 ± 1.4	0.85	0.73	0.96

Data were analysed using the following statistical model and comparisons performed with a threshold of 0.05:

$$Y_{ijkl} = \mu + System_i + Week_j + LWGroup_k + LWGroup_{k(EweLamb)} + L \times System_{ik} + L \times Week_{kj} + \varepsilon_{ijkl}$$

where Y_{ijkl} is the observed LW of the ewe, μ is the overall (fixed) mean of the sample population, $System_i$ denotes the main fixed effect of the i_{th} weighing system scale (static vs WoW), $Week_j$ is the fixed effect of the j_{th} experimental week (1…14), $LWGroup_k$ is the random associated effect of the k_{th} experimental subgroup, according to the LW of the ewes (n = 3; Heavy, Medium and Light), $LWGroup_{k(EweLamb)}$ is the nested random effect of each individual ewe lamb within each of the three specific LW subgroup levels, $L \times System_{ik}$ and $L \times Week_{kj}$ are the random interaction effects associated with the k_{th} LW subgroup and the l_{th} weighing system and j_{th} Week, respectively, and ε_{ijkl} is the associated residual error.

GS = Gold Standard live weight measures (obtained with the static scales); WoW = Walk-over-Weighing live weight measures.

[1] The ewe lambs were chosen according to their LW and then further classed into three subgroups: Light (LW average: 21.2 ± 1.4 kg; n = 33), Medium (average LW: 24.4 ± 0.8 kg; n = 33) and Heavy (LW over the average: 28.8 ± 2.0 kg; n = 34). Such subgroups are representative of the three contrasting LW strata typically found in the source flock.

[a,b,c] LSMeans in a row with different superscripts differ at $p = 0.05$.

Table 5
Effects of live weight (LW) range of the ewe lambs (Group), the weighing system (conventional, Gold Standard –GS– vs Walk-over-Weighing live weight measures - WoW) and their first-order interaction on the calculated average daily gain (ADG, g/d).

	LW range (Group)[1]			Weighing System		Group × System Interaction						*P*-value		
	Heavy	Medium	Light	GS	WoW	GS-Heavy	GS-Medium	GS-Light	WoW-Heavy	WoW-Medium	WoW-Light	Group	System	Group× System
ADG, g/d	97 ± 227	103 ± 196	116 ± 195	123 ± 200	84 ± 213	116 ± 218	122 ± 188	132 ± 189	74 ± 233	82 ± 203	98 ± 199	0.35	0.29	0.91

Data were analysed using the following statistical model and comparisons performed with a threshold of 0.05:

$$Y_{ijkl} = \mu + System_i + Week_j + LWGroup_k + LWGroup_{k(EweLamb)} + LWGroup \times System_{ik} + \text{LWGroup} \times Week_{kj} + \varepsilon_{ijkl}$$

where Y_{ijkl} is the observed ADG of the ewe, μ is the overall (fixed) mean of the sample population, $System_i$ denotes the main fixed effect of the i_{th} weighing system scale (static vs WoW), $Week_j$ is the fixed effect of the j_{th} experimental week (1…14), $LWGroup_k$ is the random associated effect of the k_{th} experimental subgroup, according to the LW of the ewes (n = 3; Heavy, Medium and Light), $LWGroup_{k(EweLamb)}$ is the nested random effect of each individual ewe lamb within each of the three specific LW subgroup levels, $LWGroup \times System_{ik}$ and $LWGroup \times Week_{kj}$ are the random interaction effects associated with the k_{th} LW subgroup and the l_{th} weighing system and j_{th} Week, respectively, and ε_{ijkl} is the associated residual error.

GS = Gold Standard live weight measures (obtained with the static scales); WoW = Walk-over-Weighing live weight measures.

[1] The ewe lambs were chosen according to their LW and then further classed into three subgroups: Light (LW average: 21.2 ± 1.4 kg; n = 33), Medium (average LW: 24.4 ± 0.8 kg; n = 33) and Heavy (LW over the average: 28.8 ± 2.0 kg; n = 34). Such subgroups are representative of the three contrasting LW strata typically found in the source flock.

Individual level

Due to the validation of the WoW data and the absence of significant differences between WoW and the GS reference scale for the flock and subgroup data, individual growth monitoring with the WoW is considered possible. Three extreme ewe lambs were chosen as examples of the individual growth monitoring i.e., the individuals identified as number 3 537 (with the higher number of correct LW recorded), 3 601 (with the smaller number of correct LW recorded) and 3 954 (ewe lamb that died during the experiment; Fig. 7). The graphs show the LW monitoring with all data measured. For the lambs 3 537 and 3 954, there were more LW values obtained with the WoW than with the GS. Their growth rate curves showed similar shapes whatever the LW measurement system. The graph for ewe lamb 3 954 showed an abrupt LW decrease after March 19th using the WoW, whereas visual information of death was only recorded after March 25th with the weekly LW data recorded with the GS scale. The LW progress of ewe lamb 3 537 followed a similar shape as the growth rate of the flock, with its final LW being higher than the average LW of its subgroup. Ewe lamb 3 601 remained in a stable LW during the experiment, with similar LW values collected irrespective of the LW scale.

Variations of the ADG per week for the three individuals are illustrated in Fig. 8. The first ADG obtained with WoW for ewe lamb 3 601 was in week 8, because no LW value was obtained

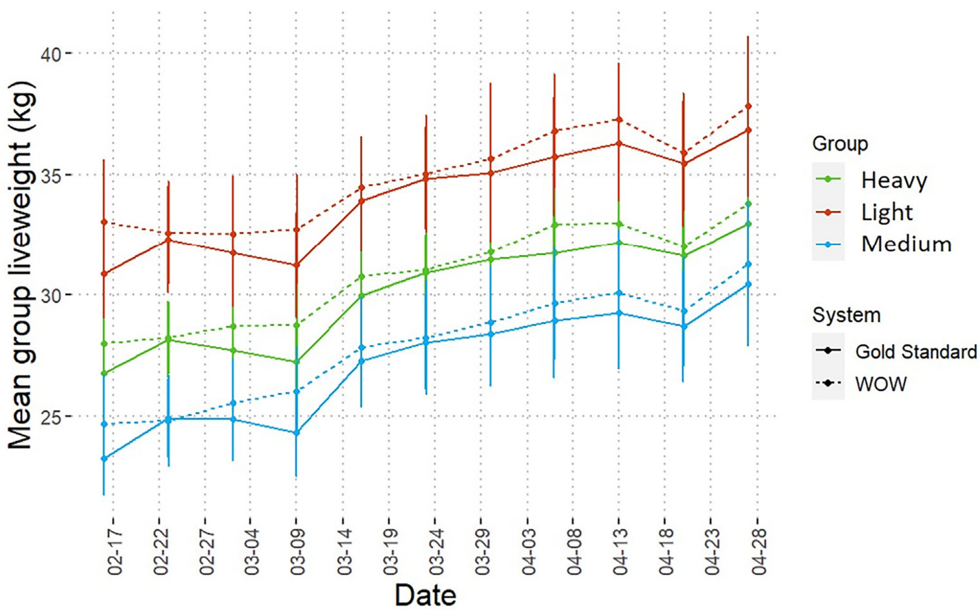

Fig. 6. Growth curves obtained for each group of ewe lambs (Heavy, n = 34 then 33 from 04/01; Medium, n = 33; Light, n = 33) with each of the two measurement systems. The Gold Standard curve represents the mean daily live weight values measured from the weekly static measurements. WoW: walk-over-weighing. The WoW curve represents the mean daily live weight values calculated from the measured or estimated (i.e. when the measured value does not exist on that specific day) automatic scale values on the weekly static measurement day. Bar errors are standard errors of the means.

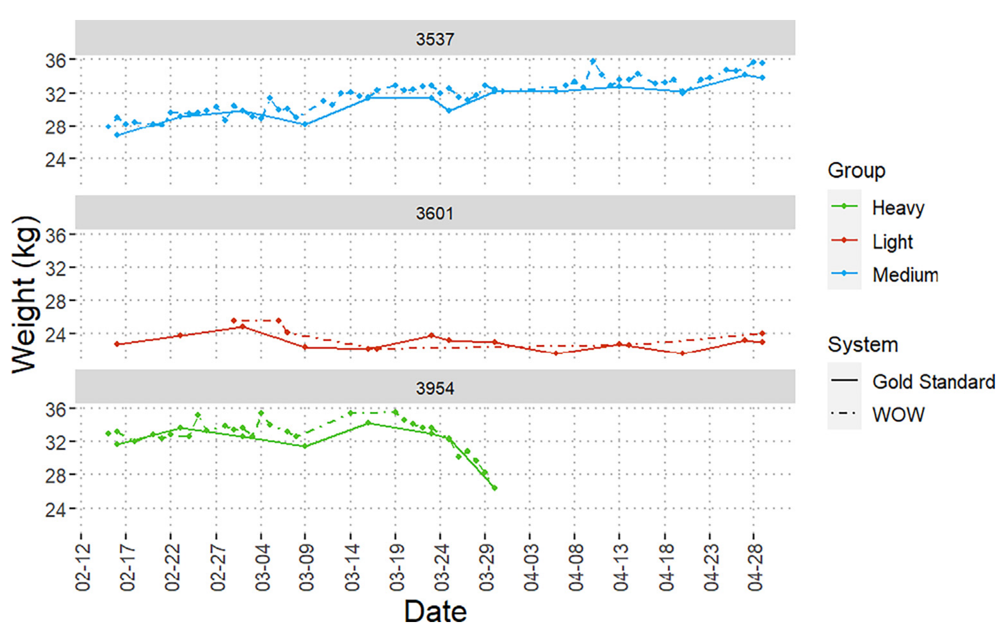

Fig. 7. Growth curves of 3 individual ewe lambs obtained with each of the two measurement systems. The Gold Standard curve represents the weekly live weight values measured statically. WoW: walk-over-weighing. Individual 3 954 died during the experiment (04/01).

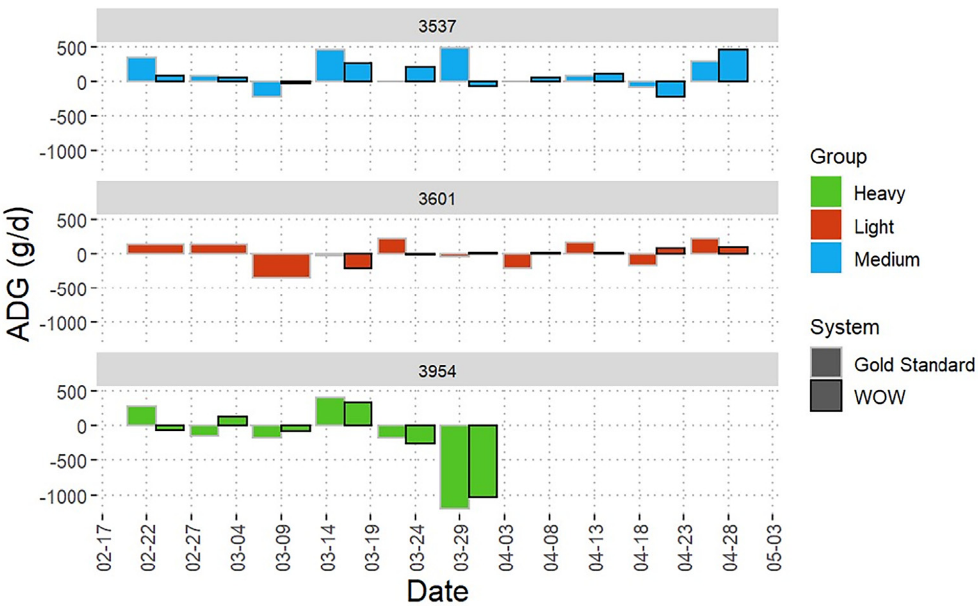

Fig. 8. Average Daily Gain (ADG) of 3 individual ewe lambs obtained with each of the two measurement systems. WoW: walk-over-weighing. Individual 3 954 died during the experiment (04/01).

before the 15 first days of phase II. Its ADG per week did not vary and was low (around 0 g/day). The ADG of the ewe lamb 3 537 was around 200 g/day during the experiment. Concerning ewe lamb 3 954, the decrease in LW observed results in a loss of more than 1 000 g/d during week 10. For the three individuals, no differences were detected linked to the weighing system that estimated the individual ADG during this period. The initial raw database is available in the Data Repository https://doi.org/10.15454/IXSHF7.

Author's point of views

The main objective of this study was to validate the feasibility of setting the WoW system to provide a significant contribution of this Precision Livestock Farming technology to the precise monitoring of growth of ewe lambs reared on pasture. The first phase of the experiment allowed the calibration of the system and the adaptation of the ewe lambs. The importance of the adaptation phase and the data cleaning steps has been previously reported by several authors (Alawneh et al., 2011; Brown et al., 2014a and 2014b; Dickinson et al., 2013; González-García et al., 2018a; 2021). Filtering of outliers has been carried out using individual variations. Alawneh et al. (2011) removed all values outside the mean ± 4 × SD interval, which corresponded to only 12% of outliers. The process used in this study was carried out in three stages, the last stage corresponded to the removal of outliers at the individual scale according to the mean interval ± 2 × SD. In a previous report by our team (González-García et al., 2018a), 80% of the raw data was eliminated with this method at the individual animal scale. In the current study, fewer (61.3%) of the initial raw data were removed. Brown et al. (2012) reported retention of harvested WoW records within an interval of ± 10% of the predetermined LW.

Data eliminated in our study corresponded to misbehaviour of the lambs on the platform. Despite the "S" structure designed for the animals to pass one by one (González-García et al., 2018a), often two animals were weighed together on the platform. For Brown et al. (2014a), these misbehaviours caused low repeatability of the system when they were not removed. In our study, data cleaning decreased the number of records actually available but according to the Bland and Altman coefficient (−0.83 ± 2.32), enabled considerably increased repeatability of WoW data (Grenier et al., 2000). The reproducibility, evaluated by Lin's CCC (= 0.94), also increased as the cleaning process progressed. This coefficient showed however that only was moderate agreement between the two weighing systems. This could be explained by the lack of controlled flow of animals crossing the platform (Alawneh et al., 2011; González-García et al., 2021). Even with an individual level of data cleaning, some misbehaviour data were still present and seemed undetectable. Despite this moderate agreement, the values obtained show a good distribution around the perfect correlation line at 45°. However, after the entire three-step data cleaning process, the resulting data corresponded to plausible values of LW that could be used for monitoring ewe lamb growth. They allowed the recording of many LW values over a short period of time. The minimum frequency of correct data obtained (1 LW every 9 days) still allowed regular monitoring of the individual LW and with greater frequency than typical in conventional, commercial farming, and importantly, without human intervention. The adaptation phase of the animals strongly assisted to the quality of these results.

One of the main objectives of this study was to adapt the ewe lambs for voluntary and frequent passages on the platform. The ewe lambs from the *Domaine du Merle* were reared on pasture with their mother until weaning, and they did not have to adapt to a new environment for the study. Nevertheless, they had to deal with the separation from the dam and the new feeding regime (i.e., from a mixture of maternal milk and grass to a 100% grass diet). Finally, they also had to manage with a new object in their environment (WoW system). The design of the system was the same for all paddocks, only the orientation changed. This regularity in the configuration of the WoW system may have helped the ewe lambs to learn and adapt rapidly to pass across the platform (Hutson, 1980). In order to have more daily passages, more frequently or quicker, adaptation to the WoW could be carried out during the preweaning period (Brown et al., 2014b). The adaptation time defined by González-García et al., (2018a) is still sufficient to obtain an acceptable percentage of ewe lambs crossing the system in a relatively short period of time.

In our study, it was then possible to accurately estimate the LW of the flock. Individual LW values that were close to those measured with the GS reference static weighing, and without significant difference, were obtained. Using the WoW, it is possible to observe variations over time more precisely due to the quantity of data recorded. At the beginning of phase II, the ewe lambs were in good physical condition i.e., the LW at 127 ± 6 days corresponded to a LW slightly higher than those expected at this age for the *Merino d'Arles* breed (Bénévent et al., 1971). The growth rates of the animals, estimated at 123 g/d and 84 g/d respectively by the static GS weighing scale, and the WoW, are similar to the ADG reported for *Merino d'Arles* lambs between 130 and 160 days (Bénévent et al., 1971). Without a good adaptation of the ewe lambs, the different result could have been observed, due to the stressful factors of such a change (Karakuş, 2014). These results showed no apparent problem with the growth and health of the flock or the strata of LW subgroups. In contrast, the progress of LW growth curves showed LW decreases that were observed on March 9th and April 20th. This is likely related to the fact that animals were weighed just before changing the paddock on these same days. Grass availability was very limited and the animals therefore may have had the rumen filled less compared to the other weighing days, so influencing their LW (Brown et al., 2015). Monitoring the LW growth rates of subgroups (or the whole flock) would then make it possible to improve the feed management of the animals as proposed by Brown et al. (2014b), with a precision nutrition strategy. This monitoring could also help the overall health management of the flock by identifying events with dramatic LW losses in the flock due to e.g. parasitism or limited herbage availability in the grassland due to dry season effects. But detecting a decrease in the average flock LW could also be the result of a problem with a limited number of individuals. The ultimate goal and big challenge using the WoW system are to be able to follow the individual and daily growth rate of the animals. Here, we approached this issue and advanced in a good direction, with the three extreme groups of animals chosen. The more frequent LW records obtained with the WoW for the dead ewe lamb, for example, allowed us to identify much earlier than the GS measures, the significant daily LW losses, which signalled a health problem in the animal at least 6 days before the measurement with the GS was performed. This shows that the production of robust early warning systems could help farmer decision-makings, with the possibility, for example, of sending early warning signals by phone along with daily individual LW rates deployed by each member of the flock. Therefore, fine-scale monitoring of individual growth is considered a possibility. However, uncertainty could occur for animals that have only a few correct passages across the platform in a short period of time.

In summary, the importance of both the initial adaptation period of the animals, and essential data cleaning procedures for data automatically collected by the WoW, were confirmed. Adaptation and training of naive ewe lambs enabled the required level of voluntary passages across the platform and a high volume of individual and daily data after 2–3 weeks. Close monitoring of individual growth was then possible after performing robust data cleaning. A strong concordance of WoW LW data with the gold standard (static scale) LW reference data was demonstrated. At the individual level, even with the low number of LW values collected for some lambs with WoW, it is possible to monitor variations in LW at a daily periodicity. The establishment of an early warning system to help farmer decision-making would therefore be possible. Our results show interesting perspectives for a more precise and frequent monitoring of the LW in grazing sheep without human intervention, compared to what is currently carried out on commercial farms. Good perspectives emerge for developing early warning systems in future; therefore, further research and development efforts are warranted for achieving future advances on these aspects.

Ethics approval

This study was approved by the Regional Ethics Committee on Animal Experimentation number 115, Languedoc-Roussillon and followed the European Convention of the Protection of Vertebrate Animals used for Experimental and Scientific Purposes, directive 86-609 of November 24, 1986 of the Council of the EU and Directive 2010/63/EU. The study also complied with the Do No Significant Harm principle, as the research was conducted within the respect of climate and environmental priorities of the Union, without causing harm to them. The study did not imply any injury or invasive measure compromising the health of the experimental animals. We complied with the “3Rs” (Refinement, Reduction, Replacement) principles: (i) the experiment reduced as much as possible the number of involved animals to the minimum necessary; (ii) Refined experimental protocols were settled in order to diminish to an absolute minimum the amount of stress imposed on the ewe lambs used. (iii) Replacement of lambs by *in vitro* investigations or *in silico* simulations was not possible as the goal of the project was to validate the WoW system in the growth category of this species' animal experiments whenever necessary.

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Declaration of interest

The authors declare the full originality of this work and that there is no conflict of interest for the publication of this paper.

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