Smart Agricultural Technology 8 (2024) 100496

Contents lists available at ScienceDirect

Smart Agricultural Technology

journal homepage: www.journals.elsevier.com/smart-agricultural-technology

Comparison of two tri-axial accelerometers for measuring locomotor activity in ewes and lambs

José Alfonso Abecia *, Carlos Aguerri, Francisco Canto

Instituto de Investigación en Ciencias Ambientales de Aragón (IUCA), Facultad de Veterinaria, Universidad de Zaragoza, Miguel Servet, 177, 50013, Zaragoza, Spain

A R T I C L E I N F O

Keywords:
Sheep
Accelerometer
Locomotor activity
Circadian rhythm

A B S T R A C T

Triaxial accelerometers provide a non-invasive means of recording all small-scale body motions of an animal. The summary metrics that can be extracted from a given accelerometer, and the validity and reliability of the estimates obtained, determine whether a particular accelerometer is suitable for research. The objectives of this study were to compare the performance of two models of triaxial accelerometers in quantifying the behavior of adult ewes and growing lambs, and to compare the circadian rhythms calculated from the locomotor activity data collected by these accelerometers. Ten non-pregnant ewes, and 10 weaned lambs, which were in their fattening period were used in experiment 1 and 2, respectively. Ewes and lambs were fitted with two models of commercially available accelerometers (ActiGraph wGT3X-BT and Axivity AX3), which were attached to a neck collar that remained in place for 10 d The profiles of the mean locomotor activity of ewes and lambs based on the two devices were similar. In addition, the cosinor curves of the two devices fit each other, and their acrophases did not differ significantly. Both accelerometers indicated that all ewes and lambs had a 24 h rhythm in locomotor activity. The coefficient of correlation and the coefficient of determination between the Actigraph and the Axivity data were 0.798 ($P < 0.01$) and 0.6369 ($P < 0.01$), and 0.940 ($P < 0.01$) and 0.8843 ($P < 0.01$), for ewes and lambs, respectively. Given the strong correlations between the Actigraph and the Axivity tri-axial accelerometers in quantifying the activities of ewes and lambs, and the similarity of the circadian rhythmicity curves calculated from data from the two devices, both brands of accelerometers are suitable for measuring the locomotor activity in these animals.

1. Introduction

Actigraphy is the use of an accelerometer to record bodily activity, particularly in assessing sleep quantity and quality and irregular circadian rhythms [1]. The accelerometer senses movement and has a memory unit that stores data, typically, for several days. Accelerometers have been used extensively to assess human sleep, exercise, and other daily activities [2] by recording the quantity, frequency, and duration of the activity. In addition, it provides information on the intensity and patterns of activity in the day and at night. Triaxial accelerometers have improved and provide a non-invasive means of recording all small-scale body motions of an individual in the field [3]; e.g., in veterinary medical research. Accelerometry is a significant advancement over the traditional method of monitoring animals in the field, visually, and provides the most accurate tracking of farm and companion animal activities [3].

The summary metrics that can be extracted from a given accelerometer, and the validity and reliability of the estimates obtained determine whether a particular accelerometer is suitable for research that seeks to objectively assess locomotor activity in livestock. Numerous types of accelerometers are commercially available, and it is uncertain which accelerometer is most suited for estimating activity in subject animals. First, in comparing different triaxial accelerometers it is important to quantify their sensitivity, accuracy, and precision, which will aide in determining which accelerometer is best suited to a particular application. Second, given that accelerometers have to be calibrated, periodically, to maintain their accuracy, by comparing the outputs of two accelerometers, one of which is known to be accurate or calibrated, one can verify the calibration of the other accelerometer. Third, some accelerometers might have been designed for specific applications or environments; therefore, by comparing their performances, one can identify the accelerometer that is best suited for a particular situation based on factors such as species, temperature range, shock resistance, size, and power consumption. Other issues are the cost-effectiveness of different accelerometers, and how each device can

* Corresponding author.
E-mail address: alf@unizar.es (J.A. Abecia).

https://doi.org/10.1016/j.atech.2024.100496
Received 21 May 2024; Received in revised form 25 June 2024; Accepted 25 June 2024
Available online 26 June 2024

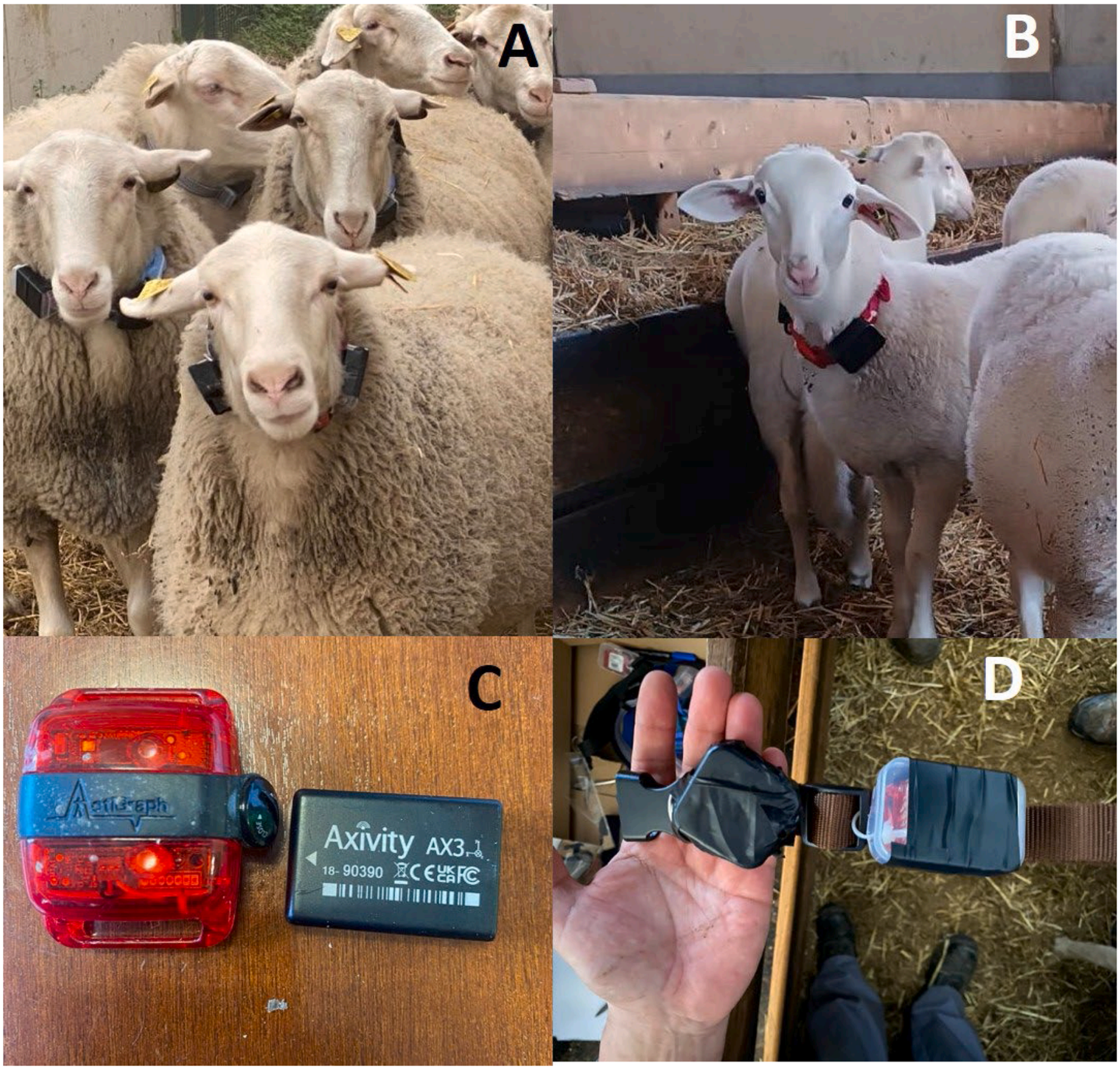

Fig. 1. Ewes (A) and lambs (B) that were fitted with two types of commercially available tri-axial accelerometers sensors (ActiGraph wGT3X-BT and Axivity AX3 3-Axis (C)) that record raw acceleration data, which were attached to a neck collar (D).

provide insights into new technologies, materials, or designs, identifying areas for improvement and innovation, leading to the development of better-performing accelerometers.

In this work we hypothesized that the use of two brands of triaxial accelerometers should conduct to the same conclusions about the locomotor activity of sheep, either adult ewes or fattening lambs. Therefore, the objectives of this study were to compare the performance of two models of triaxial accelerometers (Actigraph wGT3X-BT and Axivity AX3), which have been used to quantify locomotor activity in sheep, in quantifying the behavior of adult ewes and growing lambs, and to compare the circadian rhythms calculated from the locomotor activity data collected by these accelerometers.

2. Material and methods

2.1. Animals

In experiment 1, 10 non-pregnant adult Rasa Aragonesa ewes (mean (± SD) age: 5 ± 2 yr; mean live weight (LW): 65.9 ± 5.7 kg) were used. In experiment 2, 10 weaned Rasa Aragonesa lambs (mean age: 60 ± 4 d; mean LW: 17.4 ± 3.1 kg), which were in their fattening period (from weaning at 45 d of age until slaughter at 90 d of age), were used. Ewes and lambs were fitted with two models of commercially available accelerometers that record raw acceleration data, which were attached to a neck collar that remained in place for 10 d (Fig. 1); however, the analysis excluded data from the first and last days of data collection.

2.2. Accelerometers

The performances of two models of tri-axial accelerometers were compared in the two experiments; the ActiGraph wGT3X-BT (ActiGraph, FL, USA) (46 × 33 × 15 mm in size, mass = 19 g) and the Axivity AX3 3-Axis Logging Accelerometer (Axivity, Newcastle, UK) (23 × 32.5 × 7.6 mm in size, mass = 11 g). Both sensors record accelerations (activity) based on the individual's amplitude (g) and frequency (Hz) of movement along three axes (x for front-to-back, y for side-to-side, and z for up-down). Sensors were programmed to collect data at a rate of 50 Hz, which is equivalent to 50 samplings per second. Activity data from the Actigraph devices were downloaded to the ActiLife software (ActiGraph, LLC, Pensacola, FL) as activity counts per 1 min intervals, and the data from the Axivity devices were downloaded to the OMGUI Configuration and Analysis Tool software (open source) in g (the acceleration of gravity, -9.8 m s^{-2}). The data (counts or g) for the three axes were used to create minute-by-minute activity data values (Vector Magnitude,

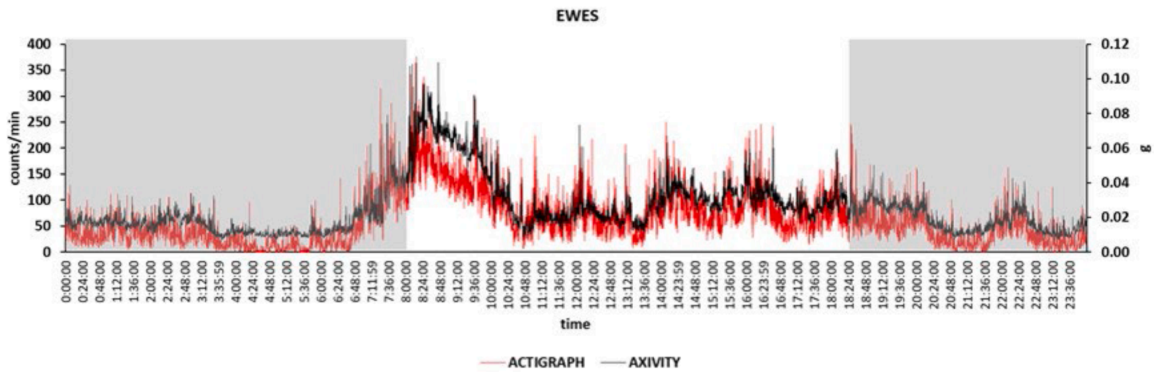

Fig. 2. Locomotor activity of ewes measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) registered every 10 s for 8 d (gray areas represent night).

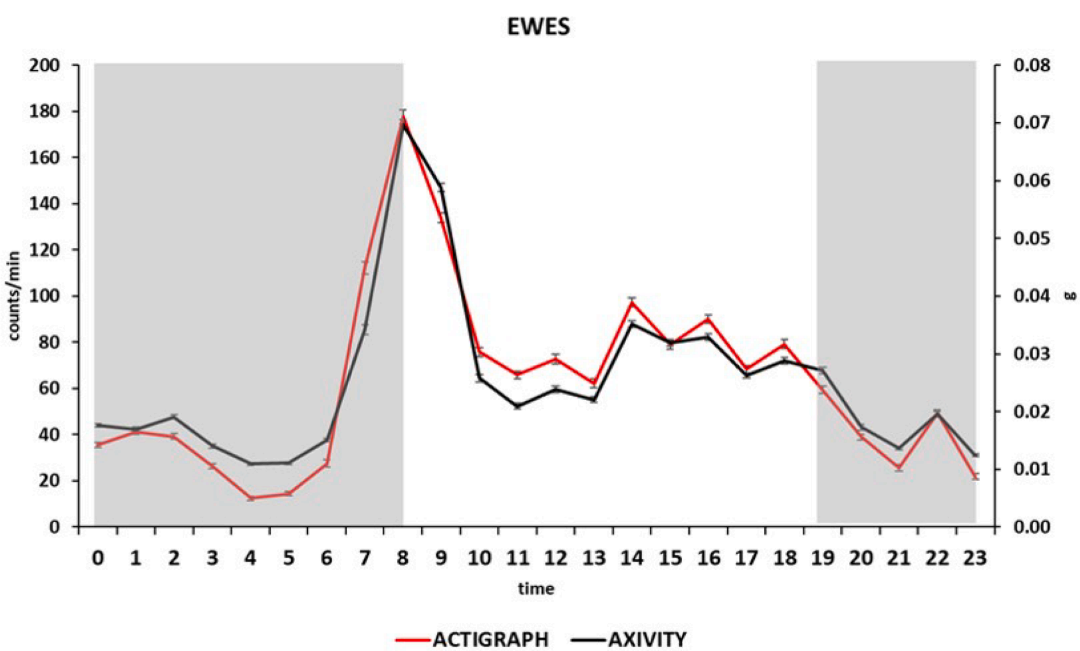

Fig. 3. Mean (±SE) hourly locomotor activity of ewes measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) registered every 10 s for 8 d (gray areas represent night).

VM), which are the magnitudes of the resulting vectors that are formed from the combination of the sampled accelerations from the three axes (x,y,z) on any device. VM is calculated as follows: x^2

$$VM = \sqrt{x^2 + y^2 + z^2}$$

2.3. Statistical analysis

The mean (±SE) estimated locomotor activity from the eight days were calculated based on the data from both devices, and the hourly means were calculated. The hourly means were fitted to the cosine curve of a 24 h activity rhythm, which was obtained from the cosinor method at the Cosinor online platform (https://cosinor.online/app/cosinor.php) [4]. Acrophase, which is the time at which the highest activity occurs under the cosinor model, was calculated based on the data from the two accelerometers. To confirm circadian rhythmicity, an F-test compared the cosine model with the input data. If the null hypothesis was rejected ($p < 0.05$), the input data fit a 24 h circadian rhythm. The acrophases calculated for each ewe and lamb with each of the accelerometers were compared by a *t*-test for related samples. Pearson correlation coefficients between the counts/min values logged by the Actigraph accelerometer, and the g values logged by the Axivity accelerometer measured at the same time were calculated. A linear regression analysis was conducted between the values estimated by the Actigraph and Axivity accelerometers.

3. Results

For both experiments, a description of mean locomotor activity, either based on the 10 s records, or hourly, is described, together with the corresponding cosinor curves adjusted to a 24 h circadian rhythm, and the correlations between both accelerometers.

3.1. Experiment 1

Mean (±SE) locomotor activity of ewes were 61.67 ± 0.02 counts/min and 0.159 ± 0.001 g, for the Actigraph and the Axivity accelerometers, respectively. The profiles of the mean locomotor activity of the ewes based on the two devices were similar whether based on a 24 h profile, data recorded every 10 s (Fig. 2) or hourly (Fig. 3). Both devices indicated a peak in activity at 0825 h. In addition, the cosinor curves of the two devices fit each other (Fig. 4), and their acrophases did not differ

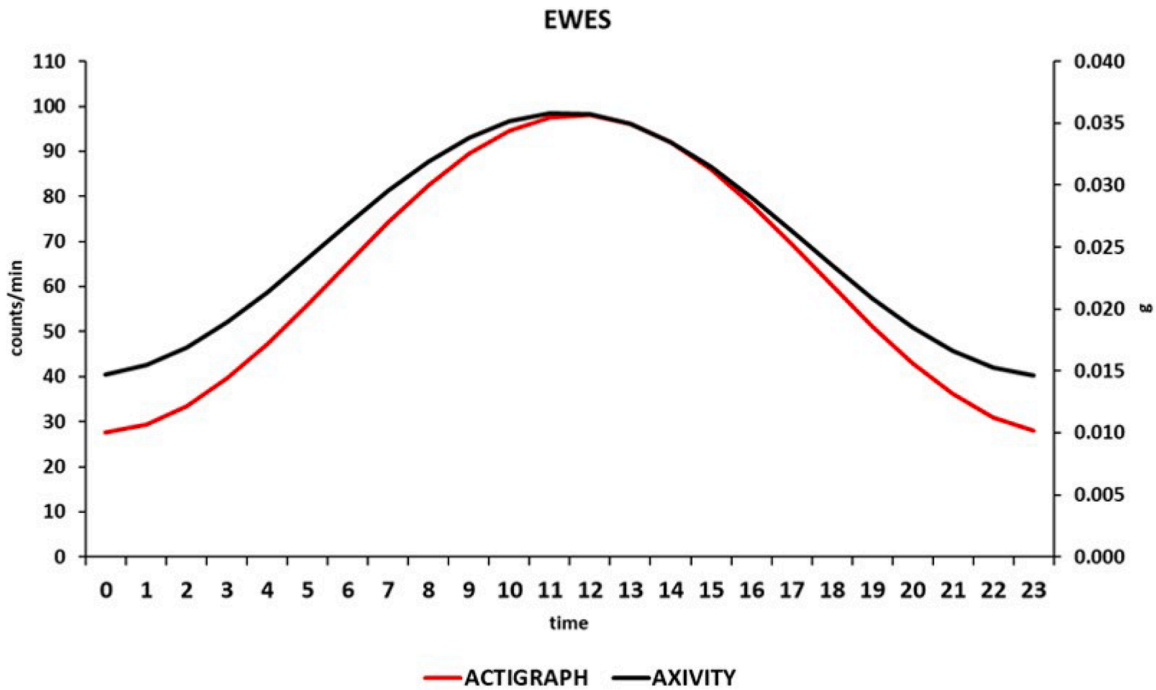

Fig. 4. Cosinor curves of a 24-hour activity rhythm in locomotor activity of ewes measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) measured every 10 s for 8 d (gray areas represent night).

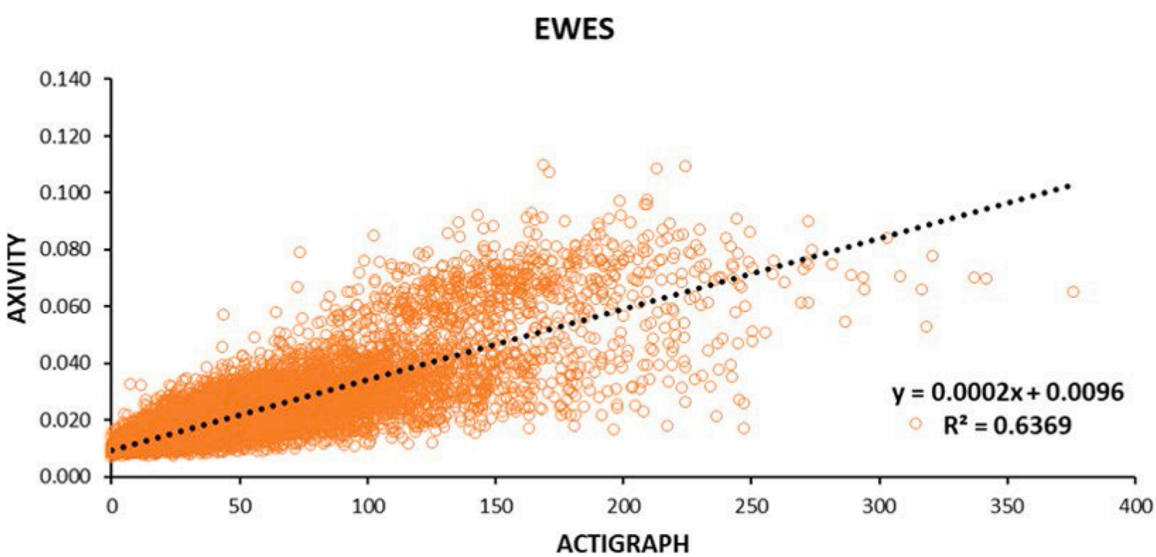

Fig. 5. Linear regression between the counts/min values logged by the Actigraph accelerometer, and the g values logged by the Axivity accelerometer, of the locomotor activity of ewes measured by two types of tri-axial accelerometers for 8 d

significantly (Actigraph: 1144 h; Axivity: 1124 h). Both accelerometers indicated that all ewes had a 24 h rhythm in locomotor activity. The coefficient of correlation and the coefficient of determination between the Actigraph and the Axivity data were 0.798 ($P < 0.01$) and 0.6369 ($P < 0.01$), respectively (Fig. 5).

3.2. Experiment 2

Mean (±SE) locomotor activity of ewes were 87.53 ± 0.03 counts/min and 0.246 ± 0.001 g, for the Actigraph and the Axivity accelerometers, respectively. The 24 h profile, whether based on data recorded every 10 s (Fig. 6) or hourly (Fig. 7), showed that the two devices indicated similar mean locomotor activity by the lambs. Both accelerometers indicated that the animals had crepuscular peaks in activity at 0749 h and 1925 h. The cosinor curves derived from the two devices matched each other quite well, and their acrophases (Actigraph: 2316 h; Axivity: 2246 h) did not differ significantly (Fig. 8). The two brands of accelerometers indicated that all lambs had a 24 h rhythm in locomotor activity. The correlation coefficient and the coefficient of determination between the data from the Actigraph and the Axivity accelerometers were 0.940 ($P < 0.01$) and 0.8843 ($P < 0.01$), respectively (Fig. 9).

4. Discussion

Previous comparisons of the performance of the ActiGraph and the

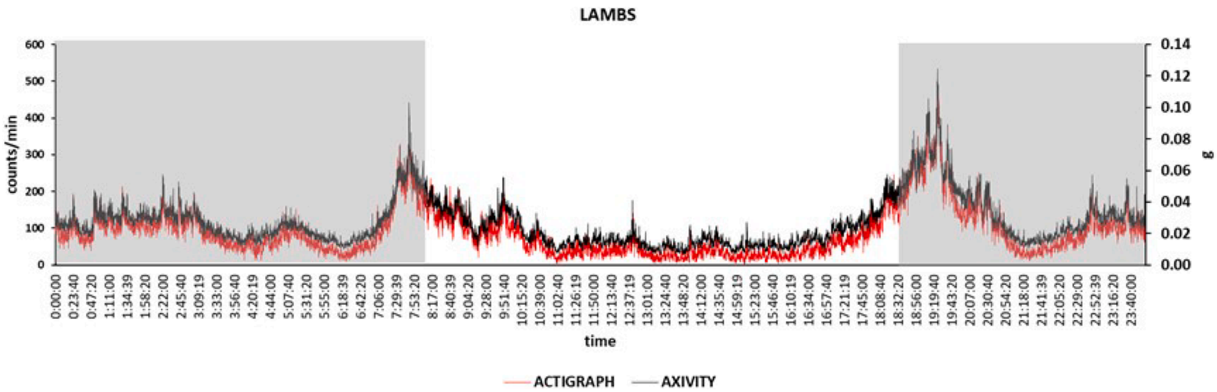

Fig. 6. Locomotor activity of lambs measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) registered every 10 s for 8 d (gray areas represent night).

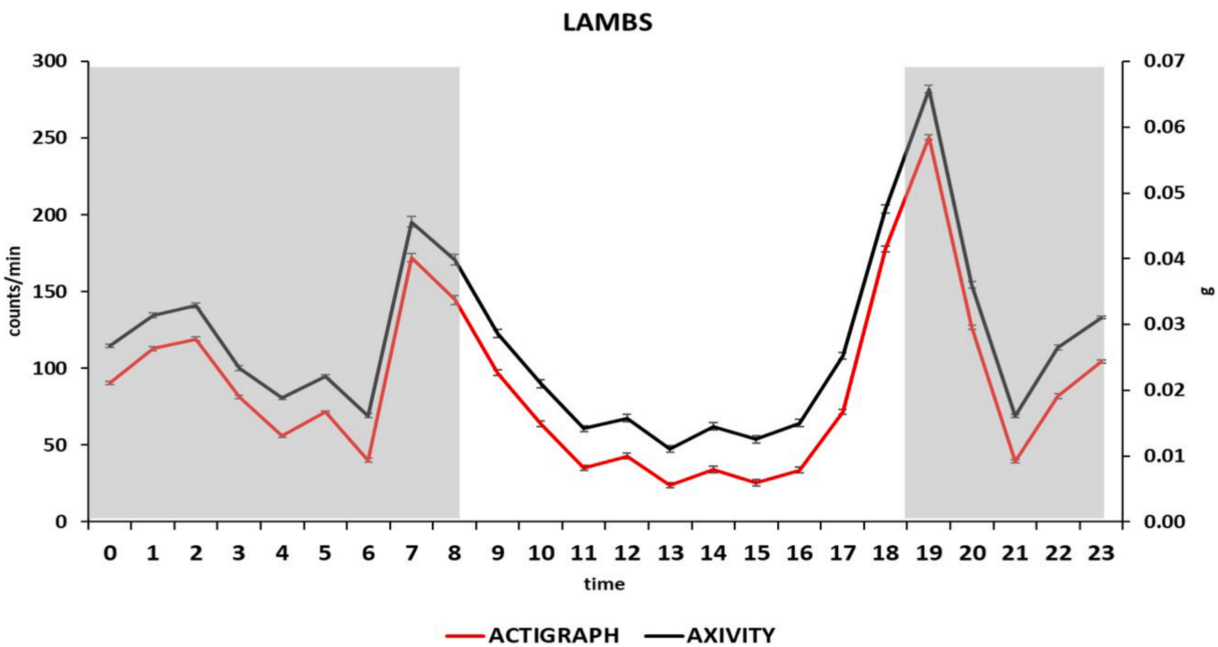

Fig. 7. Mean (±SE) hourly locomotor activity of lambs measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) registered every 10 s for 8 d (gray areas represent night).

Axivity accelerometers in the field of human medicine have reveals some contradictory results. De Craemer and Verbestel [5] investigated the feasibility and suitability of using outcomes derived from those devices to measure 24 h movement behaviors (i.e., sleep, sedentary behavior, and physical activity) in adults in free-living conditions. In that study, the ActiGraph and the Axivity accelerometers could not be used interchangeably to measure 24 h movement behaviors because the differences in the results from the two devices were clinically relevant and unpredictable. In another study [6], however, the sleep estimates based on data from Axivity, GENEActiv, and ActiGraph accelerometers that had been worn on the non-dominant or dominant wrists were compared, and with or without a sleep log to guide the algorithm, which produced results that were similar among the three accelerometer brands and wear protocols. Another experiment evaluated the validity of using the ActiGraph GT3X+ and the Axivity AX3 to measure physical activity intensity and body postures when direct observation was the criterion measure, and concluded that differences in the results from the two accelerometers were greatest when comparing sitting/standing, sedentary/light intensity, and moderate/light intensity [7]. In addition, the performance of accelerometers in the study of human movement have been compared [8–10]. Although other studies have used the ActiGraph GT3X+ and the Axivity AX3 accelerometers, simultaneously, to quantify sheep behavior, they were used to create algorithms, rather than to compare their performances. Turner et al. [11] argued that sheep behavior is inherently imbalanced (e.g., more ruminating than walking), which results in an underestimation of infrequent activities that are important nevertheless; therefore, they used ewes that had been fitted with jaw-mounted ActiGraph and ear-mounted Axivity accelerometers to build Deep Learning models, which are appropriate for sequential data, from imbalanced data. Their results demonstrated the effectiveness of those models for classifying sheep behavior under grazing conditions. To our knowledge, no other studies have compared the performance of accelerometers, simultaneously, in the same animals. Three body parts (head, neck, and back) for the Actigraph accelerometer by using head halter, a neck collar and a body harness, respectively, were compared [12]. Gurule et al. [13] used the Axivity device to investigate sheep behavior before and after illness caused by mold-contaminated feed.

Although the accelerometers evaluated in our study were designed for use with human subjects, to be worn either on the wrist, waist, ankle,

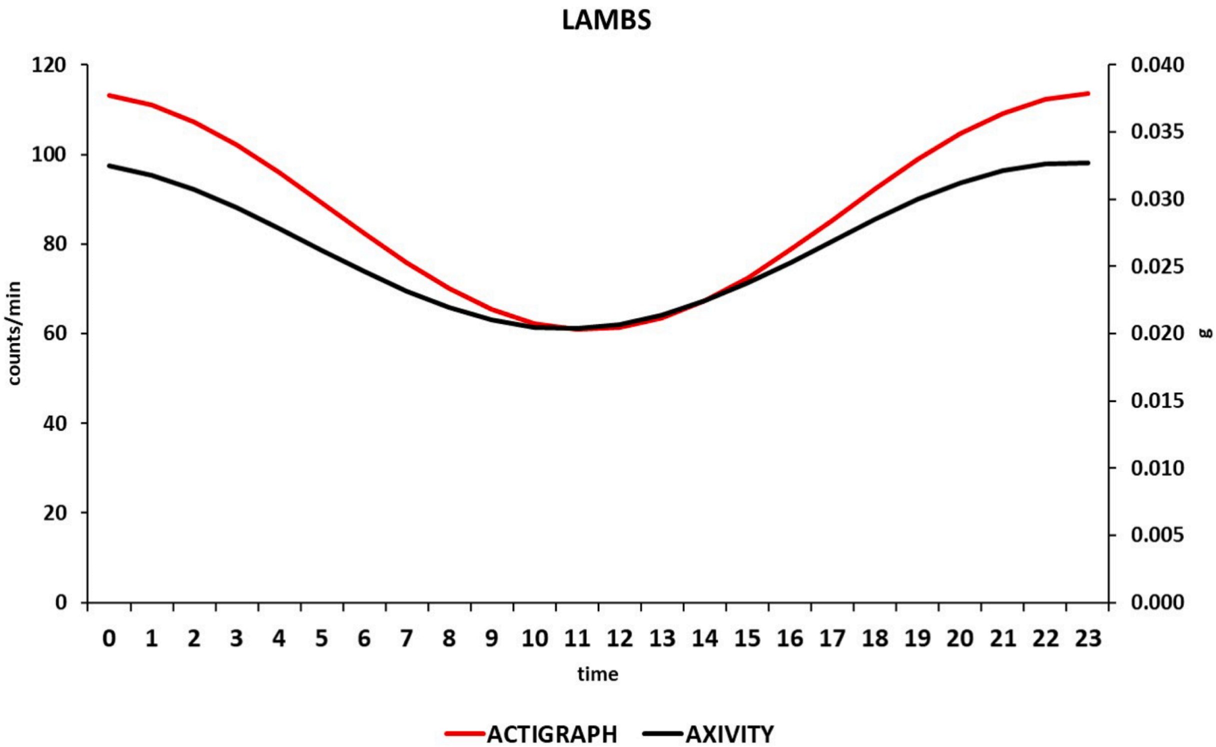

Fig. 8. Cosinor curves of a 24-hour activity rhythm locomotor activity of lambs measured by two types of tri-axial accelerometers (ActiGraph, counts/min, and Axivity, g) measured every 10 s for 8 d (gray areas represent night).

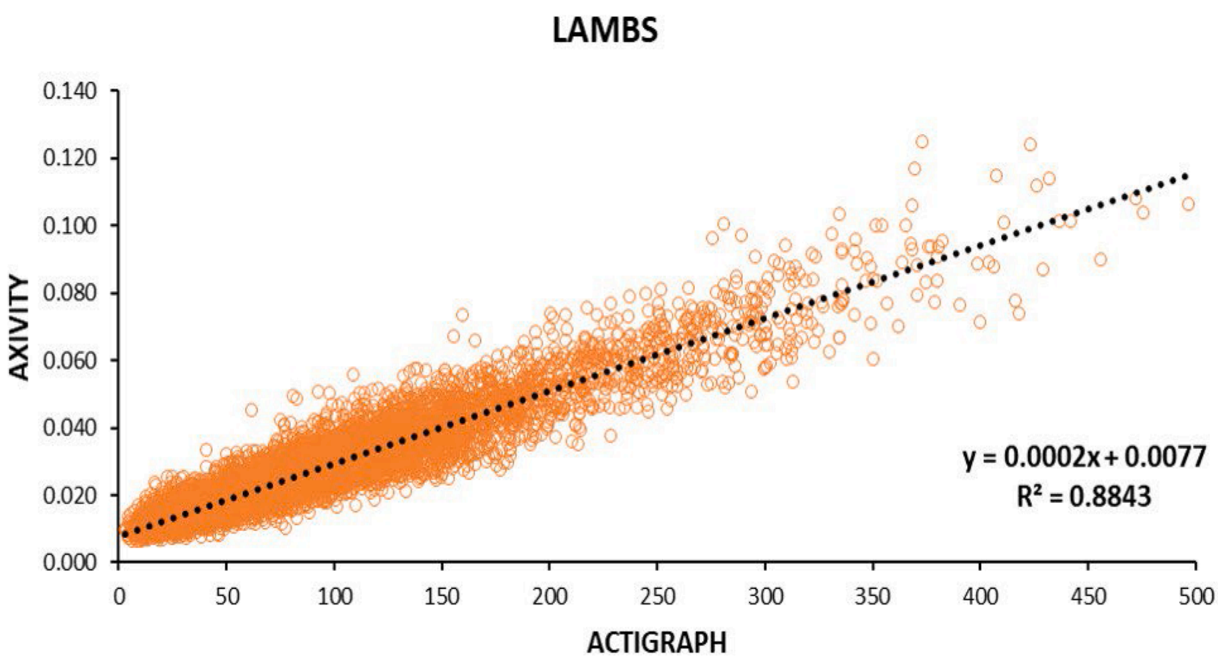

Fig. 9. Linear regression between the counts/min values logged by the Actigraph accelerometer and the g values logged by the Axivity accelerometer, of the locomotor activity of lambs measured by two types of tri-axial accelerometers for 8 d

or lumbar region, they have proven to be suitable in sheep behavioral studies. In other studies, we have used the Actigraph accelerometer to quantify the locomotor activity of lambs in the lactation period and to confirm its circadian rhythm by comparing the sexes and birth type (twin or singleton) in lambs [14], to quantify the locomotor and feeding activities of lambs in the first three weeks of artificial rearing and to confirm their circadian rhythms [15], to compare the locomotor activity of fattening lambs that have or have not received melatonin implants [16], to detect changes in locomotor activity as a means of assessing stress caused by social mixing and stocking density in commercial lambs [17], to quantify the locomotor and circadian behavior of sexually activated rams in spring [18], and to quantify the effects of hoof trimming on sheep welfare as measured by changes in the locomotor activity of the animals after excessive hoof growth has occurred [19].

5. Conclusion

Given the strong correlations between the Actigraph and the Axivity tri-axial accelerometers in quantifying the activities of ewes and lambs, and the similarity of the circadian rhythmicity curves calculated from data from the two devices, both brands of accelerometers are suitable for measuring the locomotor activity in these animals.

Ethics statement

The study was conducted at the experimental farm of the University of Zaragoza, Spain (41° 63 N), following procedures approved by the Ethics Committee for Animal Experiments at the University of Zaragoza. The care and use of animals were in accordance with the Spanish Policy for Animal Protection (RD 53/2013), which meets the European Union Directive 2010/63 on the protection of animals used for experimental and other scientific purposes.

Funding

This research was funded by Instituto de Investigación en Ciencias Ambientales de Aragón (IUCA). F. Canto was funded by the National Agency for Research and Development/Scholarship Program/Doctorado Becas Chile/2020 - 72210031.

CRediT authorship contribution statement

José Alfonso Abecia: Writing – original draft, Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization, Supervision, Resources, Project administration, Funding acquisition, Formal analysis. **Carlos Aguerri:** Methodology, Investigation. **Francisco Canto:** Writing – review & editing, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We thank Bruce MacWhirter for the English revision of the manuscript. The authors acknowledge the use of the Servicio General de Apoyo a la Investigación-SAI, Universidad de Zaragoza, and José Antonio Ruiz and Antonio Barrio for their help in the care of the animals.

References

[1] Merriam-Webster, Merriam-Webster Medical Dictionary, Merriam Webster, Springfield, MO, 2022.
[2] E.E. Emery, E.L. Woodhead, V. Molinari, M.G. Hunt, P.A. Lichtenberg, Treatment adherence in late-life, editor. Handbook of Assessment in Clinical Gerontology, Academic Press, NY, 2010, pp. 427–457.
[3] D.D. Brown, R.W. Kays, M. Wikelski, R.P. Wilson, A.P. Klimley, Observing the unwatchable through acceleration logging of animal behavior, Anim. Biotelemetry. 1 (2013) 1–16.
[4] L. Molcan, Time distributed data analysis by cosinor, bioRxiv. 805960 (2019), https://doi.org/10.1101/805960. Online application.
[5] M. De Craemer, V. Verbestel, Comparison of outcomes derived from the ActiGraph GT3X+ and the Axivity AX3 accelerometer to objectively measure 24-hour movement behaviors in adults: a cross-sectional study, Int. J. Environ. Res. Public Health 19 (2022) 271, https://doi.org/10.3390/ijerph19010271.
[6] T. Plekhanova, A.V. Rowlands, T. Yates, A. Hall, E.M. Brady, M. Davies, et al., Equivalency of sleep estimates: comparison of three research-grade accelerometers, J. Meas. Phys. Behav. 3 (2020) 294–303, https://doi.org/10.1123/jmpb.2019-0047.
[7] L. Hedayatrad, T. Stewart, S. Duncan, Concurrent validity of ActiGraph GT3X+ and Axivity AX3 accelerometers for estimating physical activity and sedentary behavior, J. Meas. Phys. Behav. 4 (2021) 1–8, https://doi.org/10.1123/jmpb.2019-0075.
[8] A.V. Rowlands, E.M. Mirkes, T. Yates, S. Clemes, M. Davies, K. Khunti, C. L. Edwardson, Accelerometer-assessed physical activity in epidemiology: are monitors equivalent? Med. Sci. Sports Exerc. 50 (2018) 257–265, https://doi.org/10.1249/MSS.0000000000001435.
[9] J.C. Brønd, L.B. Andersen, D. Arvidsson, Generating actigraphy counts from raw acceleration recorded by an alterantive monitor, Med. Sci. Sports Exerc. 49 (2017) 2351–2360, https://doi.org/10.1249/MSS.0000000000001344.
[10] P. Crowley, J. Skotte, E. Stamatakis, M. Hamer, M. Aadahl, M.L. Stevens, et al., Comparison of physical behavior estimates from three different thigh-worn accelerometers brands: a proof-of-concept for the Prospective Physical Activity, Sitting, and Sleep consortium (ProPASS), Int. J. Behav. Nutr. Phys. 16 (2019) 65, https://doi.org/10.1186/s12966-019-0835-0.
[11] K.E. Turner, A. Thompson, I. Harris, M. Ferguson, F. Sohel, Deep learning based classification of sheep behaviour from accelerometer data with imbalance, Inf. Process. Agric. 10 (2023) 377–390, https://doi.org/10.1016/j.inpa.2022.04.001.
[12] S.J. Ikurior, N. Marquetoux, S.T. Leu, R.A. Corner-Thomas, I. Scott, W.E. Pomroy, What are sheep doing? Tri-axial accelerometer sensor data identify the diel activity pattern of ewe lambs on pasture, Sensors 13 (21) (2021) 6816, https://doi.org/10.3390/s21206816.
[13] S.C. Gurule, V.V. Flores, K.K. Forrest, C.A. Gifford, J.C. Wenzel, C.T. Tobin, et al., A case study using accelerometers to identify illness in ewes following unintentional exposure to mold-contaminated feed, Animals 12 (2022) 266, https://doi.org/10.3390/ani12030266.
[14] J.A. Abecia, C. Canudo, C. Palacios, F. Canto, Measuring lamb activity during lactation by actigraphy, Chronobiol. Int. 39 (2022) 1368–1380, https://doi.org/10.1080/07420528.2022.2108715.
[15] J.A. Abecia, F. Canto, Circadian, feeding, and locomotor activities of artificially reared lambs measured by actigraphy, J. Appl. Anim. Res. 51 (2023) 234–241, https://doi.org/10.1080/09712119.2023.2186884.
[16] I. Viola, F. Canto, J.A. Abecia, Effects of melatonin implants on locomotor activity, body temperature, and growth of lambs fed a concentrate-based diet, J. Vet. Behav. 68 (2023) 24–31, https://doi.org/10.1016/j.jveb.2023.08.004.
[17] J.A. Abecia, J.M. Bello, L. Marco, I. Viola, F. Canto, G. Miranda de la Lama, Locomotor activity measured by actigraphy as a means of estimating social mixing and animal density-induced stress in lambs, Large Anim. Rev. 30 (2024).
[18] J.A. Abecia, C. Palacios, J. Plaza, F. Canto, Actigraphy reveals higher circadian activity in light-induced sexually active rams in spring than in rams subjected to the natural photoperiod, in: US Precision Livestock Conference; Knoxville, Tennessee, 2023.
[19] F. Canto, J.A. Abecia, in: Trimming extremely overgrown hooves in sheep does not improve their welfare as measured by actigraphy. US Precision Livestock Conference; Knoxville, Tennessee, 2023.