JOURNAL OF ANIMAL BEHAVIOUR AND BIOMETEOROLOGY

RESEARCH ARTICLE
Published Online: June 10, 2025
https://doi.org/10.31893/jabb.2025018

Locomotor activity and proximity relationships of nursing cows and their calves

José-Alfonso Abecia[a] | Francisco Canto[b] | Carlos Palacios[c] | Jaime Nieto[c] | Javier Plaza[c] | Elena Pérez-García[c] | Ignacio Torre[d]

[a]Instituto Universitario de Investigación en Ciencias Ambientales (IUCA), Universidad de Zaragoza, Miguel Servet, 177, 50013, Zaragoza, Spain.
[b]Centro Regional de Investigación Remehue. Instituto de Investigaciones Agropecuarias, Ruta 5 km 8, Osorno, 5290000, Región de Los Lagos, Chile.
[c]Departamento de Construcción y Agronomía, Facultad de Ciencias Agrarias y Ambientales, Universidad de Salamanca, Avenida Filiberto Villalobos, 119, 37007, Salamanca, Spain.
[d]CPIFP Montearagón, Ctra. Sariñena, Km 4, 22071, Huesca, Spain.

Abstract Actigraphy uses triaxial accelerometers to study the locomotor activity (LA) of animals and humans, and proximity sensors are used to record interactions between individuals. This study documented the LA of a group of cows and their calves, and their interactions based on data collected by accelerometers that also served as proximity sensors. Mean LA of five cows and their calves, the temporal distribution in LA, and their circadian rhythms were calculated and the statistical significance of differences was assessed by an ANOVA. LA (counts/min) did not differ between cows (60.03±7.96) and calves (51.68±5.48), and were highest at 0900 h, and 1300 h, and 1900 h. Cows exhibited higher ($P<0.001$) LA in the day (96.05±7.99) than at night (38.42±7.48); in calves, the difference between day (63.84±7.67) and night (44.39±6.96) was not statistically significant. Mothers and offspring exhibited a 24-h circadian rhythm in their LA, which had a similar acrophase (12:45 vs. 12:14 h), but different MESOR (60.03 vs. 51.69) and amplitude (41.63 vs. 20.06) ($P<0.05$). On average, 34% of a cow's proximity contacts were with their own calf. Cow-calf proximity contacts occurred throughout the day, but were most frequent around 0100 h, 0600 h, 1100 h, 1700 h, 1900 h, and 2100 h. The closest contacts (shortest distances) occurred at 0500 h, 1100 h, 1900 h, and 2300 h. The devices used in this study proved to be a useful for monitoring proximity between mothers and calves and their daily LA, in which both exhibited a 24-h circadian rhythm.

Keywords: cattle, accelerometer, circadian rhythm, proximity

1. Introduction

An understanding of the behavior of cows and their calves is fundamental to insuring animal welfare, livestock diversification, and productivity in dairy and beef production systems (Orihuela, 2021). The relationship between the cow and her calf is vitally important to the welfare of cattle because it directly affects the survival, growth, and development of the calf, and the health and productivity of the cow (Orihuela & Galina, 2021). Locomotor activity (LA) and social behavior are especially indicative of maternal care, calf dependency, and herd dynamics (Sanz et al., 2024). Those activities are shaped by biological, environmental, and management factors that should be considered in the establishment of practices aimed at serving the natural needs of the animals.

The bond between a cow and her calf is characterized by physical proximity, especially in the early months of the calf's life, and is vital for its nutrition, protection, and social learning (von Keyserlingk & Weary, 2007). Variety of factors such as time of day, environmental conditions, and composition of the herd can influence the frequency and duration of those interactions. For instance, mothers might increase their proximity to calves around feeding and resting periods, but environmental stressors such as extreme temperatures or predator threats can impact such behavior (Costa et al., 2016). Awareness of those dynamics is helpful for implementing management strategies that will enhance mother and calf welfare.

An assessment of proximity relationships between cows and calves can indicate maternal investment and social bonding. Frequent contact implies active maternal care and protection, and reduced proximity indicates that calves are becoming independent (Green, 1992). The interactions that occur between calves and other cows in the herd can provide insights into the broader social structures and communal care behaviors, rather than just one cow caring solely for its offspring, which are important to herd dynamics (de Freslon et al. 2020).

Recent technological advances have significantly advanced the study of animal behavior because they have allowed researchers to measure activity and social interactions with an unprecedented level of precision. Actigraphy is useful for identifying movement patterns and detecting circadian rhythms of activity based on the combination of three-dimensional accelerometers and Bluetooth (BT) proximity sensors, which provide platforms for real-time measurement of social interactions and spatial relationships within herds that can provide insights into maternal care, social bonding, and hierarchy

 Received: April 1, 2025 | Accepted: May 27, 2025

within the herd. In sheep, studies have used actigraphy to quantify activity, circadian rhythms, and proximity relationships between lambs and their twins based on BT-based accelerometers (Abecia et al. 2022). Those technologies offer an objective and non-invasive approach to studying animal behavior in the field and in semi-natural environments, which has opened new avenues for research. Accelerometry circumvents many of the limitations associated with direct observations of animals in the field, and provides advantages over traditional techniques that have been used to record the activity of farm and companion animals (Brown et al. 2013).

Circadian rhythms are very important in the regulation of mammalian activities; e.g., feeding and resting cycles, and locomotor movements (Refinetti, 2016). In cows, those rhythms are most closely aligned with grazing and social behavior, and peak activity usually occurs in the day (Palacios et al., 2021). The activities of calves differ from those in their mothers because they are highly dependent on maternal care for nutrition. Monitoring a cow's behavior provides information about how maternal behavior varies throughout the calf's development and the way in which the independence of the calf increases.

We hypothesized that nursing cows exhibit higher LA in the day than they do at night, which reflects their grazing and nursing behaviors. It was predicted that cows would spend more time close to their own calves in the day than they would at night, with specific peaks in contact frequency that reflects the periods when caregiving, including feeding and resting, is thought to occur. In addition, we predicted that cows and calves would exhibit synchronized circadian rhythms, although differing activity amplitudes will reflect their respective needs and roles.

The main objectives of this study were to quantify LA of nursing cows and their calves, and the distance relationships between them. Specifically, we quantified activity levels, identified circadian patterns, and assessed the proximity between mother-calf pairs and other conspecifics in the group based on data from BT-enabled triaxial accelerometers.

2. Materials and Methods

2.1. Animals and housing

Five Parda de Montaña cows and their five calves (6 months old) were housed in a 350-m² enclosure that also housed 12 weaned adult cows. The enclosure provided ample space for eating, resting, and social interactions, which simulated a semi-natural environment. Cows were fed a concentrate ration at 0700 and 1400 h, and meadow hay and barley straw *ad libitum*.

2.2. Data collection

Each animal had attached to its neck collar a commercially available sensor (ActiGraph wGT3X-BT; ActiGraph, FL, USA) (46 mm × 33 mm × 15 mm; 19 g) that was capable of capturing and recording high-resolution raw acceleration data and featured Bluetooth (BT) technology, which remained in place for 7 d (Figure 1).

Figure 1 Parda de Montaña cows and calves wearing a collar housing a tri-axial accelerometer (ActiGraph wGT3X-BT; ActiGraph, FL, USA), which was used to measure locomotor activity and proximity contacts.

The sensors recorded acceleration (activity) based on the individual's amplitude (g) and frequency (Hz) of movement along three axes; x (front-to-back), y (side-to-side), and z (up-down). Data were collected at a rate of 30 Hz, which was used to quantify proximity and track spatiotemporal movements between mothers and their calf. Each sensor functioned as both a receiver and a beacon. As receivers, they scanned for and logged the serial numbers and labels of nearby beacons once per minute. As beacons, they broadcast their serial number and label at a frequency of 4 Hz (four times per second).

The activity data (counts) were downloaded to the ActiLife software (ActiGraph, LLC, Pensacola, FL) in 1-min intervals. The output included three columns of counts that indicated activity along the x-, y-, and z-axes, which were used to calculate Vector Magnitude (VM), a reflection of the overall intensity of movement based on the accelerations in all three dimensions. VM is calculated using the following formula:

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

The BT signals received by the sensors were downloaded to the ActiGraph software, and the distance between the beacon and receiver was estimated based on the Received Signal Strength Indicator (RSSI) and a polynomial equation described by Ortmeyer et al. (2018). To calibrate the relationship between RSSI and distance, two sensors were placed facing each other on a flat surface, one sensor remained stationary while the other was moved in 0.1 m increments up to 2 m (the maximum range at which relative distance remains identifiable). The RSSI values were plotted against distance, and a second-order polynomial equation was derived to convert the RSSI data from the sensor carried by the animal into an estimate of the distance between animals as follows:

$$\text{Distance} = (0.0012 \text{ x } \text{RSSI}^2) + (0.0936 \text{ x } \text{RSS}) + 1.9262$$

Where RSSI = Received Signal Strength Indicator.

Proximity to another animal was calculated based on BT signal presence (RSSI between −34 and −91 = 1) and signal absence (no RSSI reading = 0) as described by Clark et al. (2018), and measured as minutes per hour.

2.3. Statistical analysis

First, the distribution of the variable LA was analyzed to determine whether it followed a normal distribution, using the Shapiro-Wilk test. For cows and calves, mean (±S.E.) VM for the 7 d that the animals wore the sensors was calculated at hourly intervals, and significant differences between mothers and calves, and daytime and nighttime, were identified by an ANOVA. Circadian rhythms in VM were graphed by fitting the time-series measurements of each animal to the cosine curve of a 24-h activity rhythm, which was obtained by the cosinor method at the Cosinor on-line platform (Molcan, 2019). Midline Estimating Statistic of Rhythm (MESOR, the average around which the variable oscillates), amplitude (the difference between the peak and the mean value of a wave), and acrophase (the time of peak activity) were calculated for each variable for each individual. To test for rhythmicity, an F-test compared the (re-parameterized) cosine model and the non-rhythmic model. $P < 0.05$ indicated that the time series fit a 24-h rhythm. Thereafter, the data were pooled and the mean 24-h cosinor curves for each of the three parameters were calculated, and the differences in the cosinor values of mothers and calves were compared by ANOVA.

A proximity contact between a cow and her calf or other calves was calculated based on the BT signals (including distances < 2 m, only), and mean hourly frequencies of the proximity contacts were calculated. Mean (±S.E.) distance to the offspring of the close proximity contacts was calculated based on the mean hourly values within the 7-d period.

3. Results

3.1. Locomotor activity

LA did not differ significantly between cows (60.03 ± 7.96 counts/min) and calves (51.68 ± 5.48 counts/min), and activity was highest at 0900 h, 1300 h, and 1900 h (Figure 2). Among cows, LA was significantly ($P < 0.001$) higher in the day (96.05 ± 7.99) than it was at night (38.42 ± 7.48), but it did not differ significantly with time of day among calves (63.84 ± 7.67 vs. 44.39 ± 6.96, resp.). Cows and calves exhibited a 24-hour circadian rhythm in LA, but they differed significantly ($P < 0.05$) in MESOR (60.03 vs. 51.69 counts/min) and Amplitude (41.63 vs. 20.06 counts/min), although not in Acrophase (12:45 vs. 12:14 h) (Figure 2).

3.2. Proximity relationships

On average, 34% (range = 20-48%) of a cow’s proximity contacts were with their own calf, and 18% (range = 9-31%) were with each of the other four calves of the other cows (4.04 contacts/h with their calf and 2.12 contacts/h with the other calves) (Table 1).

Mother-calf proximity was maintained throughout the day, but contact frequency was highest at certain times of day. At 0100 h, 0600 h, 1100 h, 1700 h, 1900 h, and 2100 h, approximately 6% of proximity events occurred at each time (Figure 3).

The frequency of contacts was lowest at 0400 h, 0800 h, 1200 and 2000 h. The closest physical contacts (shortest distances) occurred at 0500 h, 1100 h, 1900 h, and 2300 h.

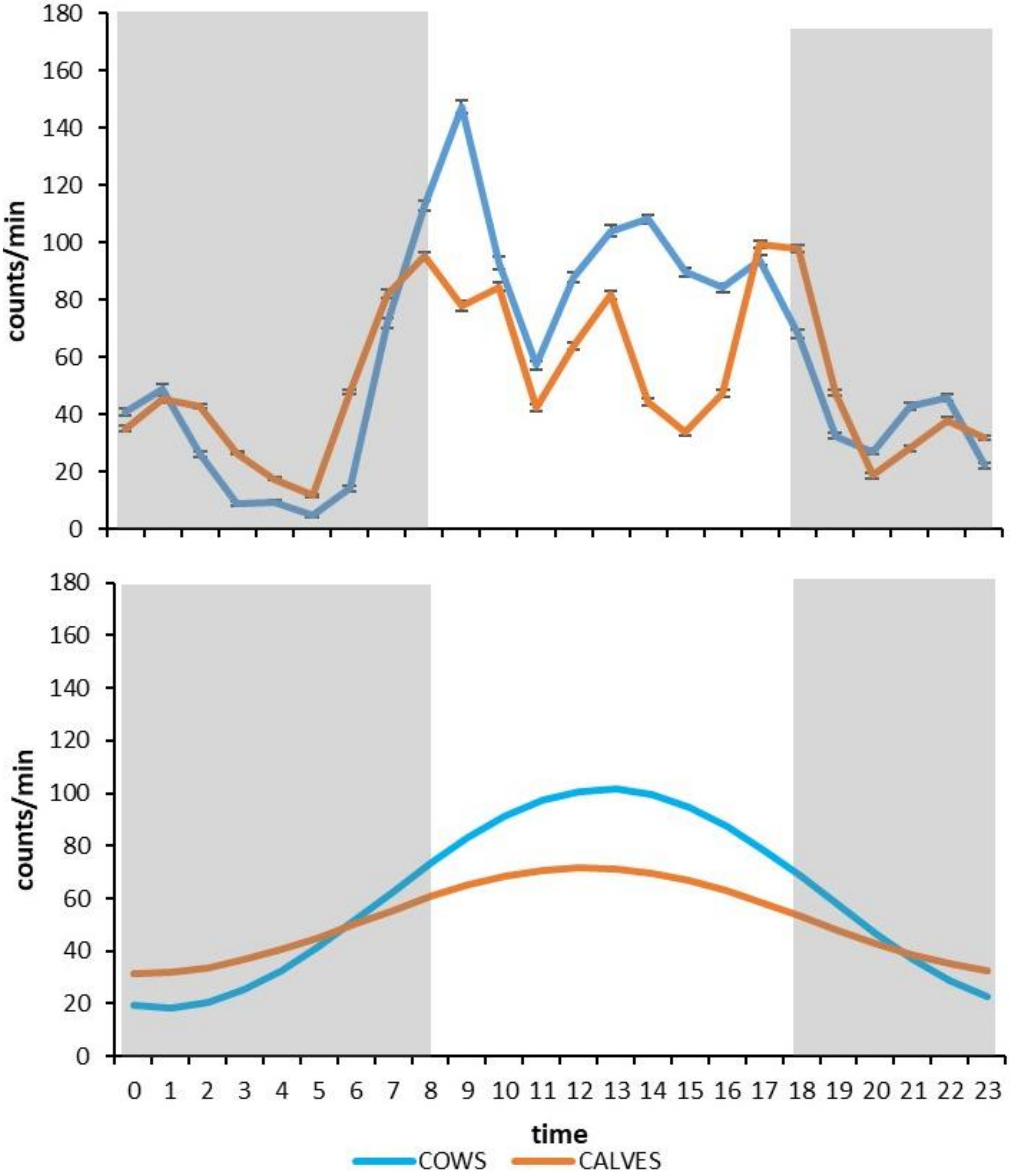

Figure 2 Mean (±SEM) locomotor activity (counts/min) measured by tri-axial accelerometers (upper panel), and the cosine curve of a 24-h activity rhythm (lower panel) of five Parda de Montaña cows and their calves on 7 d. Grey areas indicate night.

Table 1 Proximity contacts between five Parda de Montaña cows and their calves, proportion (%) of contacts with each calf, and mean number of contacts per h over 7 d, measured by triaxial accelerometers that were equipped with Bluetooth technology. The calf of each cow is indicated in bold.

	Calf 1			Calf 2			Calf 3			Calf 4			Calf 5		
	n	%	cont./h	n	%	cont./h	n	%	cont./h	n	%	cont./h	n	%	cont./h
Cow 1	**574**	**42**	**4.1**	220	16	1.6	234	17	1.7	127	9	0.9	216	15	1.6
Cow 2	240	16	1.7	**698**	**48**	**5.0**	135	9	1.0	222	15	1.6	161	11	1.2
Cow 3	687	31	4.9	465	21	3.4	**436**	**20**	**3.1**	245	11	1.8	381	17	2.7
Cow 4	373	21	2.7	267	15	1.9	323	18	2.3	**535**	**30**	**3.9**	302	17	2.2
Cow 5	313	18	2.3	292	17	2.1	292	17	2.1	277	16	2.0	**567**	**33**	**4.1**

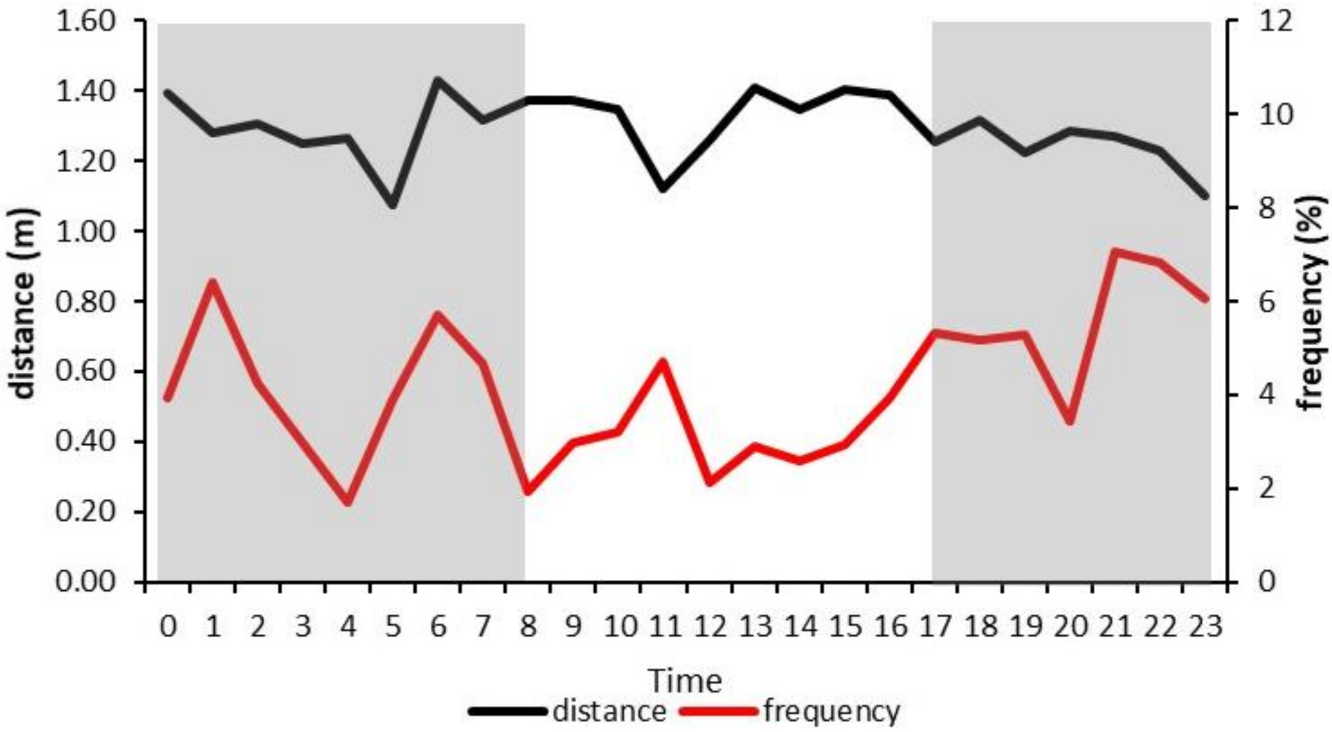

Figure 3 Mean (±SEM) distance (m) between five Parda de Montaña cows and their calves, and the hourly frequency (%) based on data from triaxial accelerometers that were equipped with Bluetooth technology.

4. Discussion

This study has provided insights into the LA and proximity relationships among nursing cows and their calves, which reflect the multifaceted patterns of maternal behavior, circadian rhythms, and social interactions among beef cattle. The circadian rhythm in cow activity, with activity levels highest in the day, reflects the timing of their natural grazing and caregiving behaviors. In an earlier study, we found that beef cows exhibited a 24-h rhythm in LA, and had higher LA and body temperature in the day than they did at night (Palacios et al., 2021). Cattle are diurnal and high activity in the day reflects their need to eat, interact, and care for their calves (Kilgour, 2012). The activities at 0900, 1300 h, and 1900 h probably involved feeding, socialization, and maternal care activities such as suckling and grooming (Nevard et al., 2023), which are necessary for the physical and mental health of the animals.

Unlike cows, the activity levels of calves were similar in the day and at night, which suggests that calves, still reliant on maternal care, have not yet developed the same activity patterns as adult cows. Probably, nutritional needs, e.g., suckling, and the need for maternal protection and comfort strongly influence their activity. In humans, the infant's circadian rest–activity rhythm has been established at 3 wks of age, and the mother's circadian rhythm at that time was disrupted by their night-time broken sleep caused by the need to care for their babies (Nishihara et al., 2002).

The similarity in acrophase (activity peak time) in cattle and calves (1245 h for cows, 1214 h for calves) reflects the strong influence of maternal behavior on calf development; i.e., calves synchronize their activities with those of their mothers, probably, to maximize suckling opportunities and social contacts. In fact, synchronization of mother and infant probably is the earliest expression in infant circadian sleep–wake entrainment (Nishihara et al., 2002).

In our study, the proximity data showed that cows remained closer to their own calf than they did to other calves in the herd, which reflects the intense maternal bond. Cows were in proximity with their own calf more than they were with other calves. Research has shown that mother cows pay more attention to their own calves than they do to caregiving behaviors such as suckling, grooming, and guarding (von Keyserlingk and Weary, 2007). Elevated frequencies of proximity contacts at certain times of day indicates that maternal care does not occur in an evenly throughout the day but, rather, in distinct episodes. The closest physical contacts (shortest distances) occurred at certain times of day might reflect the periods of maximum dependence on their mothers by calves; e.g., when being fed or requiring protection against environmental stress. Such peaks in dam-calf proximity probably is correlated with major caregiving activities, for example, suckling and resting (Turner et al., 2020). That study showed that the closest distances between kinship cow–calf pairs occurred around sunrise, between 1000 h and 1200 h, and close to sunset; however, only 17% of the proximity contacts involved suckling, with the rest involving mere caring behaviors of the cow towards her calf

In our study, the frequency of proximity contacts involving non-filial calves and cows (18% of interactions) suggests that communal care activities play a part in herd dynamics. Studies have shown that cows in herds will occasionally engage in allomothering, for example, when non-maternal cows will care for calves that are not their own (Mota-Rojas et al., 2021). Possibly, some of the cows in our study had developed that behavior to a greater extent than did other cows; e.g., Cow 3, which almost evenly distributed their intimacy with all five of the calves.

Although we acknowledge that the small sample size (n=5 pairs) limits the statistical power of the study, our findings of have practical implications for livestock production and animal welfare. An understanding of the natural activity patterns and spatial relationships of cows and their offspring can help producers in designing management practices in accordance with the requirements of the animal's behavior (Mandel et al., 2016). For example, providing enough space and resources at times of maximal activity (e.g., feeding) can reduce competition and stress, making it easier for cows to interact healthily and for calves to receive proper maternal care.

In addition, technologies such as accelerometers and proximity sensors provide non-invasive and accurate methods of real-time animal behavior monitoring, which can be integrated into precision livestock farming systems to track the health and welfare of individual animals, detect early warning signs of stress or disease, and optimize management practice.

5. Conclusion

The results of our study improve our understanding of the proximity and space-related nursing behaviors of cows and calves, and provides insight into maternal care, circadian rhythms, and social structure. Cows and their calves exhibited strong associations and their behavior suggested that herd members engage in communal care behaviors. Incorporating the inherent natural behaviors of cows and calves in management practices favors animal welfare, productivity, and sustainability of livestock.

Acknowlegments

We thank Bruce MacWhirter for the English revision of the manuscript, and the students of the CPIFP Montearagón, Huesca, Spain, for their help with the animals. F. Canto was funded by the National Agency for Research and Development (ANID)/Scholarship Programme / Doctorado becas Chile/2020 - 72210031.

Ethical Considerations

The study was performed at the experimental farm of the CPIFP Montearagón (Huesca, Spain; latitude 42° 06'N) following a protocol that was approved by the Ethics Committee of the University of Zaragoza based on the requirements of the European Union for Scientific Procedure Establishments.

Conflicts of Interest

The authors have no conflicts of interest to disclose.

Funding

This work was not funded by any particular project.

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