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# Accelerometer-based detection of circadian rhythm disruption in sheep following shearing

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## Abstract

**Background**  . Circadian rhythms regulate physiological and behavioral processes in livestock, influencing welfare, productivity, and adaptation to environmental changes. In sheep, locomotor activity (LA) is a reliable marker of circadian organization and can be continuously monitored using accelerometers. Shearing represents an abrupt management event that alters body insulation and may disturb thermal balance and stress responses, but its effects on circadian rhythmicity have not been quantified. This study aimed to evaluate whether shearing disrupts circadian LA in ewe lambs using continuous accelerometer-based monitoring.

**Results**  . Eleven Rasa Aragonesa ewe lambs were monitored continuously from 48 h before to 72 h after shearing. Circadian parameters were quantified using cosinor analysis, including mesor, amplitude, and acrophase, together with indices of rhythm robustness (Circadianity Index, CI) and day–night differentiation (Diurnality Index, DI). Before shearing ($-48$ h and $-24$ h), sheep displayed robust circadian rhythms, with mesor values of 0.032–0.033 g, high amplitudes (0.011–0.014 g), acrophases clustered around midday (1237–1318 h), elevated CI values (0.19), and pronounced day–night contrasts reflected by high DI values (0.43). At 24 h post-shearing, LA increased significantly, while amplitude (0.009) and CI decreased compared with pre-shearing values ($P < 0.01$), and acrophase was significantly delayed to the evening (1849 h; $P < 0.01$). Day–night differentiation was also significantly reduced ($P < 0.001$). At 48 h post-shearing, amplitude and CI declined further (0.005; $P < 0.001$), indicating a marked weakening of rhythm robustness, with acrophase delayed to approximately 2008 h. By 72 h post-shearing, circadian organization was severely disrupted, with minimal amplitude (0.001), near-zero CI, markedly reduced DI, and a significantly advanced acrophase to early morning hours (0407 h).

**Conclusions**  . Accelerometer-based biotelemetry revealed that shearing strongly alters the circadian organization of LA in sheep. The procedure induces acute behavioral activation followed by dampened rhythmic strength and altered phase expression, likely reflecting combined stress and thermal effects. These findings highlight the sensitivity of circadian monitoring through accelerometry for detecting management-induced disturbances in livestock behavior. Incorporating chronobiological approaches into routine welfare assessment could improve understanding of physiological adaptation and support more welfare-friendly management practices in animal production systems.

**Keywords**  Accelerometer, Shearing, Sheep, Disruptor, Circadian rhythm

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# Background

Circadian rhythms are biological oscillations of approximately 24 h that regulate physiological and behavioral processes in most organisms, including domestic mammals [1]. In farm animals, these rhythms play a fundamental role in regulating feeding, locomotion, thermoregulation, and social behavior, and are an essential component of both welfare and productive efficiency [2].

In ruminants, locomotor activity (LA) is a reliable indicator of internal temporal organization and synchronization with the light–dark cycle [3]. Environmental and management-related factors can modulate the expression of biological rhythms by altering their robustness and phase. Among these factors, shearing is a particularly relevant management practice because it abruptly alters body insulation, thereby affecting thermal homeostasis and potentially modifying the animal's interaction with its immediate environment [4].

In recent years, accelerometry has become valuable tool for monitoring animal behavior and welfare in farm settings [5]. Accelerometers provide continuous, non-invasive, high-resolution data on LA, which can detect subtle changes in behavioral patterns that can reflect underlying physiological states or responses to management practices [6]. In sheep, accelerometers have been successfully employed to assess grazing behavior, lying and standing postures, activity budgets, and responses to environmental challenges [7]. Their capacity to generate objective, time-stamped records makes them particularly suitable for chronobiological studies, where precise temporal resolution is essential for characterizing circadian dynamics. In sheep, triaxial accelerometers have proven to be a powerful tool for studying circadian rhythms in LA, such as in experiments involving the alteration of LA by feed restrictions [8], LA in artificially reared lambs [9], lamb activity during lactation [10], in lambs exposed to different housing [11], and the use of melatonin implants [12], among others. By overcoming the limitations of traditional observational methods, accelerometry offers a reliable means of quantifying activity rhythms and identifying disruptions associated with stressors such as handling, transport, and thermal challenges [13].

Although numerous studies have addressed the impact of handling stress on ovine physiology [14], knowledge about how shearing influences circadian rhythms in LA has been limited. An understanding of those effects is crucial not only for interpreting circadian plasticity in production contexts, but also for evaluating animal welfare and promoting sustainable management practices.

In this study, chronobiological approaches were used to quantify the LA of sheep before and after shearing. The aim of this study was to evaluate whether shearing alters the circadian organization of LA in ewe lambs using continuous accelerometer-based monitoring.

# Methods

## Animals and experimental design

The study was conducted in early April in Zaragoza, Spain (41.65° N, 0.89° W), where typical spring conditions prevail. In this region at that time of year, daily high temperatures generally range around 20 °C and nighttime lows around 9 °C, with a mean temperature of approximately 14 °C. Average daylight duration increases through April from about 12 h 42 min at the beginning to around 13 h 59 min at the end of the month. Animals were housed indoors during the experiment; however, detailed records of ambient temperature and humidity inside the shed were not available.

The study involved 11 Rasa Aragonesa ewe lambs that were aged 14 mo and maintained under standard farm conditions. Animals were managed under routine indoor husbandry conditions commonly used in the region, including group housing in an enclosed pen (6 × 5 m), *ad libitum* access to water, and feeding with straw and concentrate according to maintenance requirements. Animals had continuous access to straw and water, while concentrate was provided once daily at a fixed morning time (0800 h) according to routine management practices. Feeding times were kept constant throughout the study, ensuring that potential feeding-related activity patterns were comparable across all time windows. Management conditions remained unchanged throughout the experimental period, except for the shearing procedure.

Locomotor activity was recorded continuously from 48 h before to 72 h after shearing. Activity data were analyzed in consecutive 24-h periods that corresponded to −48, −24, +24, +48, and +72 h relative to shearing, which allowed a comparison of pre- and post-shearing rhythms and to identify any acute or delayed effects of the procedure. Shearing was performed manually by professional shearers who used electric clippers and followed the Bowen shearing method, and lasted approximately 2 min per animal. No chemical sedatives or additional handling procedures were applied. The Bowen method involves positioning the sheep on its rump between the shearer's knees to maintain balance and comfort for the sheep. The procedure emphasizes efficient body mechanics and a specific sequence of strokes, starting with the belly and then moving systematically around the body to remove the fleece in one continuous motion. The shearer uses footwork and body pressure to control the sheep's position and balance throughout the shearing process.

LA was recorded by Axivity AX3 3-Axis Logging Accelerometers (Axivity, Newcastle, UK) (23 × 32.5 × 7.6 mm in size, mass = 11 g) that were affixed to the neck of each animal one week before shearing (Fig. 1). 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

**Fig. 1** Ewe lambs that were fitted with commercially available tri-axial accelerometers sensors (Axivity AX3 3-Axis) that record raw acceleration data, before and after being sheared, which were attached to a neck collar

for up-down). Sensors were programmed to collect data at a rate of 50 Hz, and activity data from the 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 (g) for the three axes were used to create minute-by-minute activity data values (Vectorial Dynamic Body Acceleration; VeDBA) [15], 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. VeDBA is calculated as follows:

$$VeDBA = \sqrt{(x^2 + y^2 + z^2)}$$

.

**Circadian analysis**

Mean (± SE) LA across the five-day monitoring period was calculated from the accelerometer data, and hourly averages were subsequently derived. The hourly means were fitted to the cosine curve of a 24 h activity rhythm, which was obtained from the cosinor method. The standard cosinor model fits a cosine function to the time-series data based on the following equation:

$$y(t) = M + A \cos(2\pi t / T + \varphi),$$

where y(t) is the value of the time series at time t, M is the mesor, A is the amplitude, T is the period of the rhythm, which typically is set to 24 h for circadian data, and φ is the acrophase.

The following variables were extracted: MESOR (Midline Estimating Statistic of Rhythm), which is a rhythm-adjusted mean or the average value of the fitted cosine curve, Amplitude (the difference between the MESOR and the peak value of the curve), and Acrophase (the timing of the peak (crest) of the rhythm, expressed as a lag from a defined reference time. In addition, two complementary indices were computed, the Circadianity Index (CI) and the Diurnality Index (DI). The CI is a quantitative descriptor that estimates the relative contribution of the 24 h frequency component to the overall variance of a biological time series. Higher CI values indicate a stronger dominance of the circadian component, rather than an absolute measure of rhythm robustness. It is calculated as the proportion of the total variance in the signal that is explained by the 24 hour (circadian) frequency component, based on a spectral analysis such as a periodogram or Fourier transform. A CI close to 1 indicates a strong, dominant circadian rhythm, and a value near 0 suggests the absence or weakness of a circadian component. The DI reflects the magnitude of the difference in activity between the light (day) and dark (night) periods, and is computed as the normalized difference between mean activity levels recorded in predefined light and dark phases. High DI (close to 1) reflects predominantly diurnal behavior, and low values indicate reduced differentiation between day and night activity.

The indices are calculated as follows:

$$CI = \frac{\text{Power at } 24 - \text{h frequency}}{\text{Total spectral power}}$$

.

$$DI = \frac{(\text{Mean activity during light } - \text{ Mean activity during dark})}{(\text{Mean activity during light } + \text{ Mean activity during dark})}$$

### Statistical analysis

For each animal, circadian parameters were calculated separately for each non-overlapping 24 h time window relative to the shearing event (− 48 h, − 24 h, + 24 h, + 48 h, and + 72 h). The parameters analyzed included LA, MESOR, amplitude, acrophase, CI, and DI. Data are presented as mean ± standard error of the mean (SE). Normality of the residuals was assessed using the Shapiro–Wilk test. For each circadian parameter, individual animal values were analyzed using a repeated-measures ANOVA, with time window relative to shearing as the within-subject factor. When a significant main effect was detected, pairwise comparisons between time windows were performed using Bonferroni-adjusted post hoc tests. Statistical significance was set at $P < 0.05$.

### Results

Continuous monitoring of the LA of ewe lambs revealed clear temporal changes in circadian organization in response to shearing. Prior to the procedure (− 48 h and − 24 h), sheep exhibited a well-defined daily rhythm that was characterized by higher activity levels in the light phase and reduced activity in the dark phase (Fig. 2). The fitted cosinor curves confirmed the presence of clear circadian oscillations, which were quantitatively supported by high amplitude and CI values, with relatively high amplitudes and acrophases that were clustered around midday (Table 1; Fig. 2).

Activity amplitude in the experimental period was highest at − 48 h, when the CI was 0.192 and the DI was 0.430, which reflected a stable and coherent daily pattern. At − 24 h, CI and DI did not differ significantly with those at −8 h, and acrophase remained close to midday, which suggested that phase alignment was preserved.

Immediately after shearing (+ 24 h), LA increased (Fig. 2) and, although MESOR remained similar to that of the previous two days, amplitude and CI decreased significantly ($P < 0.01$) (Table 1; Fig. 2). Acrophase shifted
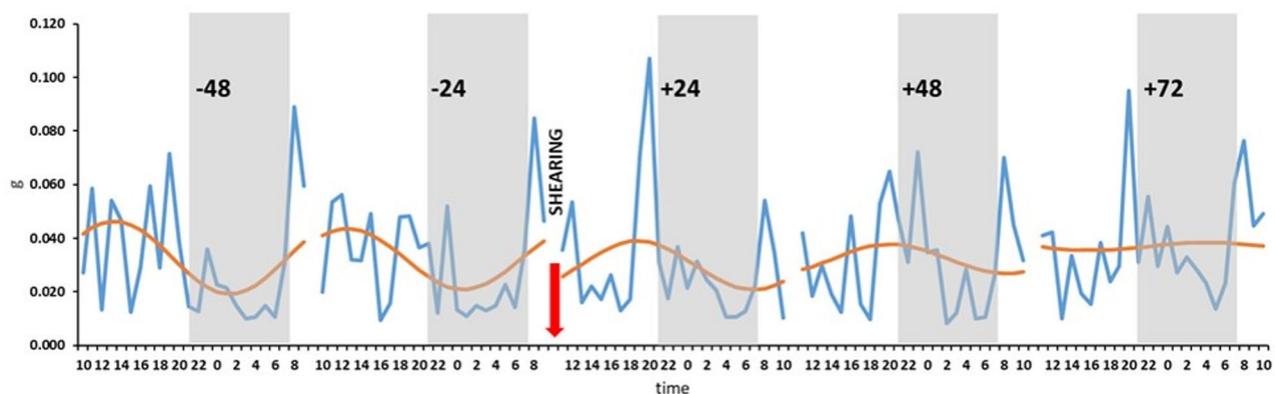


**Fig. 2** Mean locomotor activity (g) (blue lines), and their corresponding 24 h adjusted cosinor curves (orange lines), of ewe lambs before (−48 h, −24 h) and after being sheared (+ 24, + 48, + 72 h). Red arrow indicates moment of shearing (gray areas indicate night)

**Table 1** Mean (± SE) MESOR (Midline estimating statistic of Rhythm) (a rhythm-adjusted mean or the average value of the fitted cosine curve), amplitude (difference between the MESOR and the peak value of the curve), and acrophase (timing of the peak of the rhythm) of Ewe lambs before and after being sheared (a, b,c indicate significant differences among moments, $P < 0.01$)

| Time (h) relative to shearing | MESOR (g) | Amplitude (g) | Acrophase (h) |
|---|---|---|---|
| −48 h | 0.033 ± 0.001 | 0.014 ± 0.001[a] | 1318 ± 0.18[a] |
| −24 h | 0.032 ± 0.001 | 0.011 ± 0.001[a] | 1237 ± 0.09[a] |
| +24 h | 0.030 ± 0.001 | 0.009 ± 0.001[b] | 1849 ± 0.22[b] |
| +48 h | 0.032 ± 0.001 | 0.005 ± 0.001[c] | 2008 ± 0.34[b] |
| +72 h | 0.037 ± 0.001 | 0.001 ± 0.001[c] | 0407 ± 0.10[c] |

towards the evening (1849 h), which indicated a phase delay relative to the pre-shearing condition, and the DI decreased significantly ($P < 0.001$) (Fig. 2), which reflected a reduction in the differences between day and night activity.

By + 48 h, rhythmicity had been further disrupted. Amplitude decreased significantly ($P < 0.001$), and CI decreased markedly (0.041). The fitted curve (Fig. 2) indicated a more fragmented and irregular oscillation, and acrophase was shifted significantly ($P < 0.01$) to approximately 2008 h. Those results indicate a progressive dampening of rhythm strength and a pronounced shift in phase.

At + 72 h, the circadian rhythm appeared highly degraded. Although the MESOR increased slightly, amplitude nearly disappeared, and CI approached zero (0.003). Acrophase advanced abruptly to early morning (0407 h), and the DI fell to 0.086. That pattern corresponded to a flattened rhythm that had very weak day–night differences, which reflected severe circadian disruption (Fig. 3).

## Discussion

Although the ewe lambs displayed robust rhythms before the procedure distinct amplitudes and stable acrophases around midday, shearing induced an acute increase in activity that was followed by a progressive reduction in amplitude, loss of rhythm robustness, and pronounced phase shifts. By +72 h post-shearing, the circadian rhythm of LA was severely weakened, as indicated by near-zero amplitude and CI values, together with reduced day–night differentiation and an advanced acrophase.

Studies have shown that management practices in livestock can be powerful modulators of biological rhythms. For example, handling and transport can disrupt circadian organization in sheep [16]– [17], often through acute stress responses that are mediated by the hypothalamic–pituitary–adrenal (HPA) axis [18]. In our study, the surge in activity at + 24 h might reflect a similar hyperarousal state, which is associated with glucocorticoid and catecholamine release, a mechanism found in goats that had been subjected to transport stress [19], and in lambs that had experienced repeated handling [20].

Beyond the stress response itself, shearing produces an immediate and drastic change in body insulation, which alters thermal homeostasis and can persist [4]. Temperature is a significant modulator of circadian rhythms [21]. In rodents, acute cold exposure induces fragmentation of LA rhythms and phase shifts [22]– [23]. In humans, abrupt temperature changes can be associated with
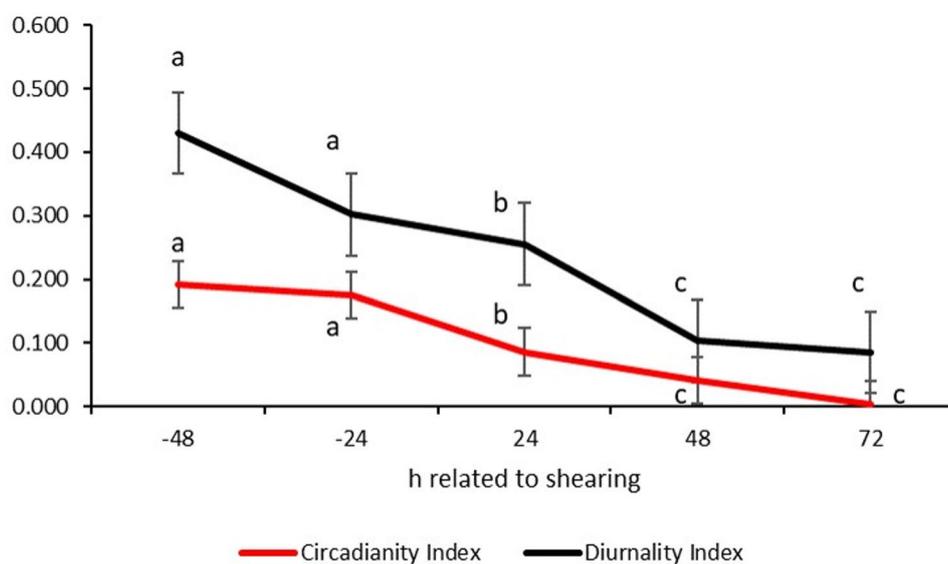


**Fig. 3** Circadianity Index (CI) and Diurnality Index (DI) of the circadian rhythm of locomotor activity of ewe lambs before (−48, −24 h) and after being sheared (+ 24, + 48, + 72 h). The CI reflects the strength or robustness of a circadian rhythm within a biological time-series, and the DI reflects the magnitude of difference in activity between the light (day) and dark (night) periods (**a**, **b,c** indicate significant differences among moments, $P < 0.01$)

circadian misalignment, sleep disturbances, and reduced cognitive and physical performance [24]. In our study, the progressive reduction in amplitude and robustness exhibited by the ewe lambs might reflect an adaptive reorganization of circadian outputs in order to cope with the altered thermal environment.

The shifts in acrophase after shearing suggest attempts by the circadian system to realign with modified physiological states. Phase shifts and rhythm fragmentation can occur in sheep that have been exposed to environmental perturbations such as farm management [25], and feed restrictions [8]. Sheep possess considerable circadian plasticity, although it can lead to rhythm coherence if challenged by stressors.

From an applied perspective, those findings are highly relevant to animal welfare and productivity. Robust circadian rhythms are associated with high immune competence and metabolic efficiency [26], and disruption has been linked to immune suppression, energy imbalance, and disease susceptibility [27]– [28]. Although the behavioral changes that occurred in ewe lambs appeared transient, that they occurred immediately after a routine management procedure emphasizes the need to minimize circadian disruption in livestock. Practical recommendations include scheduling shearing for periods of mild environmental conditions, avoiding the accumulation of multiple stressors in the immediate post-shearing period, and monitoring behavior and physiology in the days that follow.

We recognize that our study focused exclusively on behavioral activity and did not include an assessment of complementary variables such as cortisol, body temperature, or metabolic indicators, which would have enabled a more integrated interpretation of circadian disruption. In addition, the observation window was limited to 72 h, which prevented confirmation of whether full recovery of circadian rhythms occurred later, or whether subtle alterations persist for longer than 72 h. Future research should combine chronobiological approaches with endocrine and thermal variables, which would provide a comprehensive assessment of the impact of shearing. Furthermore, exploring the interaction between shearing and environmental factors (ambient temperature, humidity, photoperiod) would shed light on the ecological determinants of circadian plasticity in livestock.

In our study, the progressive reduction in amplitude and circadian dominance observed after shearing may reflect an adaptive reorganization of circadian outputs following the abrupt removal of fleece, although external thermal conditions were not directly measured and their potential contribution cannot be disentangled.

## Conclusion

In conclusion, accelerometer-based monitoring showed that shearing strongly alters the circadian organization of LA in ewe lambs. The procedure was followed by a significant dampening of rhythm strength (reduced amplitude and circadian dominance), decreased day–night differentiation, and pronounced phase shifts relative to the pre-shearing condition. Rather than a complete loss of rhythmicity, the post-shearing pattern reflects a marked weakening and reorganization of circadian output over the subsequent 72 h. These findings underscore the value of chronobiological metrics derived from accelerometry for identifying management-related disturbances relevant to livestock welfare.

### Data availability
Data will be made available on request.

## Declarations

### Ethics approval and consent to participate
The study was carried out at the experimental farm of the University of Zaragoza (Spain) under a protocol approved by the Ethics Committee and in accordance with EU Directive 2010/63/EU.

### Consent for publication
Not applicable.

### Competing interests
The authors declare no competing interests.

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## Publisher's note