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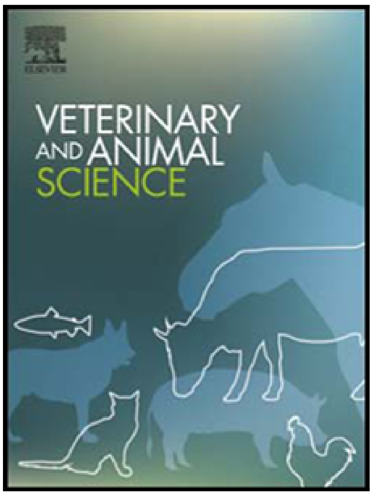

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PII: S2451-943X(26)00113-4
DOI: https://doi.org/10.1016/j.vas.2026.100678
Reference: VAS 100678

To appear in: *Veterinary and Animal Science*

Received date: 27 October 2025
Revised date: 18 April 2026
Accepted date: 4 May 2026

Please cite this article as: Andrea Confessore , Chiara Aquilani , Maria Chiara Fabbri , Pier Attilio Accorsi , Carolina Pugliese , Daily Behavioral Grazing Patterns of Beef Cattle: continuous stocking grazing vs. strip grazing managed by Virtual Fencing, *Veterinary and Animal Science* (2026), doi: https://doi.org/10.1016/j.vas.2026.100678

Highlights:

- Type of grazing management did not affect total rumination, grazing, or resting time.
- Behaviours were driven by period of the day rather than grazing management itself.
- Strip Grazing cows showed shifted daily patterns without stress effects.
- Electric pulses decreased over time, showing effective learning.
- Hair cortisol unchanged, indicating no chronic stress impact.

Daily Behavioral Grazing Patterns of Beef Cattle: continuous stocking grazing *vs.* strip grazing managed by Virtual Fencing

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Acknowledgements

This work was supported by PRIN project "INnovation STrategies IN Cattle grazing managemenT – INSTINCT", grant no. 2022NF3FR9, and by PSR - Regione Toscana sottomisura 16.2 project GAL START – Vistock, grant no. 853175.

ABSTRACT

Virtual fencing is an innovative technology for managing grazing cattle using GNSS collars. Animals were contained through a paired stimulus: when they approach a virtual boundary, the collar emits audio warnings, followed, if ignored, by an electrical pulse as aversive stimuli. This study evaluated whether different grazing management systems and the use of virtual fencing affect the daily activity behavior of Limousine cows under seasonal grazing. Two groups of 13 cows each were managed for 36 days respectively under: i) continuous stocking on a 15-ha pasture (CSG), and ii) by strip grazing (SG) using Nofence® collars to gradually expand areas according to forage availability (five boundary shifts, P1–P5). Each cow wore Allflex® smart ear-tags recording time spent grazing, ruminating, and resting. Data were analyzed with a generalized linear mixed effect model, including group (CSG, SG), period (P1–P5), and time slot (00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, 20:00–00:00) as fixed effects, and distance traveled, temperature, and gestation day as covariates. Animal and day were random effects. Hair cortisol content was also analyzed as chronic stress indicator. SG managed with virtual fencing did not affect the overall time spent grazing, ruminating, or resting, which was similar between groups. However, a significant triple interaction indicated behavioral shifts: SG cows ruminated more during the night and early afternoon, grazing mainly in the late afternoon and evening, while CSG cows showed the opposite pattern. SG managed with virtual fencing could optimize pasture management without altering physiological behaviors or increasing chronic stress measured by hair cortisol content.

Highlights:

Key words: Smart ear-tag sensor, Cattle, Behavioral daily pattern, Hair cortisol content, Activity budgets, Precision Livestock Farming

1. INTRODUCTION

Grazing system provides support for the cow-calf system in several beef-producing regions and countries. For example, in Europe, beef production systems generally include a grassland-based suckler cow–calf phase followed by intensive finishing. Indeed, in intensive finishing systems, cattle are typically housed in confinement and fed predominantly with concentrate-based diets. By contrast, in several regions the finishing phase relies exclusively on pasture, although marked differences in efficiency among grass-based systems have been reported (Claire et al., 2021). Sustaining and promoting the adoption of pasture-based finishing systems is therefore pivotal to address increasing societal demands for improved animal welfare and evolving consumer preferences, while simultaneously reducing competition between feed and human-edible food resources. Furthermore, the maintenance of well-managed pasture-based systems provides substantial benefits in terms of ecosystem services, contributing to environmental sustainability (Wróbel et al., 2023). On the pasture utilization point of view, efficient livestock grazing management is crucial to minimize overgrazing, reduce pasture degradation, and provide adequate recovery time after grazing (Wang et al., 2022). It is well known that more rational grazing systems (i.e., rotational grazing or strip-grazing) offer advantages in terms of carrying capacity and more efficient forage utilization (Sollenberger et al., 2020). For instance, Davies-Jenkins et al. (2024) reported that strip grazing management can increase carrying capacity and gain per hectare during fall and winter compared with continuous stocking. Also, the transition from conventional continuous grazing to rotational grazing system types potentially increase annual forage production, and improve soil health on cultivated grazed paddocks with multispecies forage crops (Harmel et al., 2021). However, higher production costs for building, moving, and maintaining fences may reduce their adoption from farmers (Du et al., 2023).

For this reason, the use of emerging technologies that monitor cattle behavior, and facilitate their grazing management can enhance system efficiency while supporting productivity, welfare, and environmental sustainability (Greenwood, 2021). In particular, controlling animals' location and grazing, as well as continuously monitoring welfare, offers significant advantages to farmers, who can be immediately alerted when abnormal behaviors occur and intervene promptly (Aquilani et al., 2022). One of the most promising tools is represented by the virtual fencing system. This system allows a real-time automation of grazing management, ensuring high flexibility in making changes to the fences, reducing both labor and material costs (Goliński et al., 2023). Thus, the system commonly consists of Global Navigation Satellite System (GNSS) collars worn by each animal that communicate with a mobile interface allowing the definition of virtual boundaries on pastures. Control of animal grazing is guaranteed through aversive stimuli delivered by the collars. When animals approach the virtual borders, they first receive an audio warning with increasing tone, followed, if they continue to cross the virtual boundary, by an electrical pulse. The efficiency of virtual fencing in containing cattle at grazing, and consequently, the animals' ability to learn the system quickly, has been demonstrated (Confessore et al., 2022; 2024; Harland et al., 2025). With regard to beef cattle, several studies reported positive responses from the animals, without affecting their welfare status. For instance, a recent study by Harland et al. (2025), showed that both heifers and cows managed with a virtually fenced rotational grazing system, spent 99% of the time within the inclusion zones. Also, this result was reached when cows were coupled by their relative uncollared calves. Furthermore, Confessore et al. (2022) showed that Limousine cows were able to progressively reduce the number of electric pulses received from the collars with time, with no effect on long-term stress, assessed trough hair cortisol content.

At the same time, comparative studies with physical fencing showed no changes in both behavioral and welfare indicators. Thus, Hamidi et al. (2022) reported that none of the Fleckvieh heifers exposed to virtual fencing crossed the virtual boundaries and, when receiving an electric pulse from them, they resumed grazing in a shorter time compared to electrical fenced heifers. Likewise, Fuchs et al. (2024) showed that, among other, milk cortisol and activity behavior did not significantly differ between virtually and physically fenced dairy cows. Verdon, et al. (2021) obtained similar results, with no differences in rumination time during the first three days of virtual fencing compared with electric fencing. Finally, there's evidence that the system enhances flexibility management for lactating grazing dairy cows, making the technology suitable across different herd and farm structures. Hence, it can be used regardless of the age in heifer or lactating cows, without affecting welfare and milk production (Confessore et al., 2024), and can even be used to guide cows form the pasture to the milking parlor (Verdon et al., 2024). However, to the best of our knowledge, no study has investigated whether the use of virtual fencing affects the normal daily behavioral patterns of beef cattle under different grazing management. Cattle grazing behavior, including ruminating, resting and forage searching, is strongly influenced by a lot of variables, such as pasture structure, climate, season, and time of day, with most activity occurring during morning and evening (Caram et al., 2021). In particular, most grazing bouts occur at dawn and dusk, with the latter being more significant in length and herbage intake (Gregorini, 2012).

The primary objective of this study was to evaluate and compare the daily behavioral grazing patterns of beef cattle managed under two different grazing strategies: Continuous Stocking Grazing (CSG) and Strip Grazing (SG). For The latter virtual fencing was used as management tool to implement the change of pasture allocation. Specifically, the study aimed to assess differences in behavioral time budgets (namely grazing, ruminating, and resting activities) between the two grazing management systems.

As a secondary objective, limited to the cows equipped with virtual fencing collars, the study aimed to quantify the number of electrical stimuli delivered by the virtual fencing system and to evaluate potential physiological stress responses. Stress was assessed through the measurement of hair cortisol concentrations, in order to verify that the implementation of virtual fencing-based strip grazing did not induce chronic stress in the animals.

Therefore, we hypothesized that, even if cows were managed under different grazing management, one of them including the use of virtual fencing collars, they would not modify their normal daily behavioral patterns.

2. MATERIALS AND METHODS

2.1. *Study area and climate conditions*

The study was conducted during 36 days from April to early June 2024 on an approximately 33-hectare sown pasture located in Borgo San Lorenzo, Italy (43°57'12.3"N 11°20'55.4"E). The pasture was sown with a commercial mixture of grasses and legumes adapted to local soil and climate conditions. The most abundant species were *Lolium sp., Dactylis glomerata, Festuca arundinacea, Trifolium pratense, Trifolium repens and Lotus corniculatus*. The pasture also contained spontaneous herbaceous species from other botanical families, which contributed to the overall floristic diversity of the study site. As described in Bellini et al. (2023b, 2023a) , this sown pasture was ordinarily used for grazing in the previous years. The temperature data were collected from weather stations operated by the Tuscany region (SIR, Servizio Idrologico Regionale, https://www.sir.toscana.it/) located near the study site. The mean temperature registered varied from 13 C° during the first week (22nd- 29th April), to 18 C° during the last week (20th – 29th May). No heatwaves occurred during the experiment.

2.2. Animals and Sensors

Twenty-six Limousin beef cows were used for the experiment. Before the study, the animals were housed in an open free-stall barn with permanent access to an outdoor area. The age of the cows ranged from five to fourteen years (9 ± 2 years, mean ± SD). All cows were pregnant at the beginning of the experiment, with gestation days ranged from 62 to 275 days. Animals were divided into two groups, namely CSG and SG, considering their ages and gestation day to obtain homogenous herds. The average age and gestation day were 8.09 ± 2.31 and 274 ± 15.4 for CSG animals and 9.08 ± 2.78 and 243 ± 27.5 for SG animals. During the experimental period, 5 cows in the CSG group and 1 cow in the SG group calved.

All animals were equipped with commercial virtual fencing collars (Nofence, Norway), the functioning of which has been previously described by Goliński et al. (2023). During the experiment, animal behavioral activity was monitored using the SenseHub™ Beef system, which consists of an ear-tag (SCR eSense, Allflex) attached to the left ear of each cow. Equipped with an internal accelerometer, the device could detect and analyze three key behaviors such as: i) grazing (muzzle or tongue physically contacts growing grass, while either standing in place or moving at slow, uneven pace between patches, often but not always followed by visible chewing movements); ii) ruminating (rhythmic circular movements of jaw not associated with grazing, interrupted by brief pauses during time that bolus is swallowed); resting (the animal is standing or lying down motionless and does not ruminate). The SenseHub™ Beef ear tag's accuracy for grazing, ruminating, and resting was 87.1%, 96.1%, and 85.8% respectively as reported by (Merenda et al., 2019). The ear-tags communicated with a base station located on the pasture via radiofrequency. Considering both the internal storage capacity and the communication range of the ear-tag (200m laterally and 500m in frontal direction), the base station was mounted near the only water source of the pasture to ensure at least daily data upload. Once uploaded, the data were transferred to a server via a Wi-Fi router and were also accessible online through the management software. All components of the base station were placed inside a fenced area to prevent contact with the animals, and continuous power supply was ensured by a solar panel connected to a 50 Ah battery.

2.3. Experimental design

The study area was divided into two pastures (Pasture 1 and Pasture 2), each assigned to one of two groups of pregnant Limousin beef cows (13 in the CSG group and 13 in the SG group).

A 90-m buffer zone divided the two experimental areas (Figure 1). The two sown pastures were comparable in terms of aboveground biomass (AGB), botanical composition, and relative abundance of the main herbaceous functional groups (Table S1).

AGB was assessed following the methodology described by Bellini et al. (2023a). Briefly, 1 m² exclusion cages were randomly positioned at four sampling sites in Pasture 1 and four sampling sites in Pasture 2. Herbage was clipped at ground level, and fresh samples were dried in a forced-air oven at 60 °C to determine dry matter yield. Prior to clipping, botanical composition at each sampling site was classified into grasses (Poaceae), legumes (Fabaceae), and forbs (non-grass, non-legume herbaceous species), and expressed as percentage of total biomass.

The mean dry AGB over the grazing season was 886.5 kg/ha in Pasture 1 and 896.8 kg/ha in Pasture 2. The average proportion of grasses, legumes, and forbs was 45.8%, 38.3%, and 15.8% in Pasture 1, and 57.5%, 23.8%, and 18.8% in Pasture 2, respectively.

Overall, forage availability and botanical composition were broadly comparable between pastures, suggesting that substantial differences in animal behavior were unlikely to be primarily driven by forage characteristics.

CSG group was managed using traditional continuous stocking grazing on Pasture 1, which grazed approximately 15 hectares for the entire duration of the study. SG group, meanwhile, was managed according to strip grazing management ("Grazing Management," 2023). The backward fence, typical of this management, was not used to ensure continuous access to the water source which cannot be moved. Animals of SG group were provided with an incrementally expanded grazing area each week by moving the virtual border to progressively enlarge the available grazing area, resulting in five pasture expansions. These expansions were identified as grazing periods (referred to hereafter as P1 to P5). The extent of the grazing area was estimated based on the rate of pasture consumption and production and ranged from 4.5

hectares in P1 to 14 hectares at the final virtual boundary change, in P5. The buffer zone established between the two pastures prevented any influence between the two experimental groups, including potential visual or auditory cues. Animals of SG group were trained to the system one-week before the experiment in a separate paddock following Nofence training protocol (https://www.manula.com/manuals/nofence-as/master-user-guide/1/en/topic/learning).

2.4. Data processing

Data on grazing, ruminating, and resting were collected by the ear-tag sensor on hourly basis. Each record represented a one-hour observation per cow, with behaviors expressed in minutes. To improve the normality of the data distribution for model fitting, and to link these behaviors to key-targeted periods of the day, data were processed on 4 hours intervals, by summing the minutes of each behavior within this interval. This resulted in six time slots: 00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00. Subsequently, data were assigned to the respective grazing period (P1 to P5).

Data from the virtual fencing collars were downloaded upon request from Nofence. Each raw data record contained a time-stamped GNSS position (latitude and longitude) of the cow every 15 minutes. In addition, a time-stamped GNSS position was recorded each time a stimulus was delivered by the collar (data not included). Data on electrical pulses received by the SG group were extracted and processed for each time slot within each day of each grazing period. For the CSG group, collar data were used only to track GNSS positions.

The distance travelled by each cow during the experiment was calculated by summing the Euclidean distances between consecutive GNSS positions recorded by the collars, using the *geosphere* R package (Hijmans et al., 2025). The cumulative distance expressed in meters was then assigned to each time slot of each day of grazing periods.

In order to evaluate differences in chronic stress exposure between the groups during the experiment, cortisol content was assessed in hair samples. At the beginning of the experiment (22th April 2024), hair samples were collected from the forehead of each cow, clipping an area approximately 5 cm wide. The procedure was repeated, sampling the same area, one week after the experimental period (5th June 2024) in order to adequate catching the hair regrowth. Each sample was stored in a dark place and subsequently analyzed. Cortisol (17-α-hydroxycorticosterone) concentrations were determined by RIA based on binding of ^{3}H-steroid by competitive adsorption as described by Accorsi et al. (2008). All concentrations were expressed in pg/mg of hair shaft.

2.5. Statistical analysis

Data handling and statistical analysis were carried out using R software v. 4.2.2. (R Core team, 2021). Repeated observations of a single cow over each experimental day (i.e., from days 1 to 38) in which data was collected from the ear-tags, were analyzed to evaluate the differences in the activity behaviors between the two experimental groups. Our dependent variables were grazing time, ruminating time, and resting, expressed as total daily minutes on 4 hours time slot.

Generalized linear mixed effect models were fitted with fixed effects of groups (two levels: CSG and SG), grazing period (five levels: P1 to P5), time slot (six levels: 00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00), and their three-way interactions. Moreover, the effect of the distance travelled, as well as both the mean daily temperature and gestation day of each cow were included as additional covariates. Animal data and the experimental day were included as random effects. Data gathered from the ear-tags on the activity budgets were modelled using a Gaussian likelihood distribution.

Regarding the analysis conducted on the SG group, the total number of electrical pulses within the 4-hour intervals of each grazing period were modelled fitting a negative binomial

Generalized mixed effect models with the fixed effects of the grazing period (five levels: P1 to P5), time slot (six levels: 00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00), and their two-way interactions. In addition, random effects of animal and experimental day were added to the model. To assess the potential influence of calving events occurred during the experimental period, an additional analysis was performed at the individual animal level. Activity behaviors were averaged per animal within each experimental period, and linear models were used to test the effect of calving status (calved vs. not calved) and the occurrence of a calving event within the corresponding experimental period, including their interaction with experimental period.

Hair cortisol concentration was analyzed using a linear model including group, gestation day and calved status as fixed effects. Model assumptions were evaluated by inspection of residual plots and by the Shapiro–Wilk test for normality.

Model parameters were estimated using the *"glmmTMB"* R package (Brooks et al., 2017). Differences among target dependent variables were tested using post hoc tests with Sidak adjustment using the *"emmeans"* package (Searle et al., 1980). In addition, model diagnostic assumptions were conducted using the R package *"DHARMa"* (Hartig, 2022). To explore the correlation's coefficients between all the variables of the dataset, correlation matrix was constructed using the *corrplot* R package (Wei et al., 2025). All the figures were generated using *ggplot2* R package. A P-value < 0.05 was considered significant. To better visualize and quantify the significance of P values, three significance levels are presented in the figures and tables: $P < 0.05$, $P < 0.01$, and $P < 0.001$.

Due to the lack of data from the EarTag sensors, records of 3 cows from CSG group were deleted from the dataset.

2.6. Ethical approval

Ethical approval was obtained from the Committee of Ethics in Animal Experimentation of the University of Florence (protocol no. 0056846, 12/03/2024).

3. RESULTS

3.1. Animal behavior

The output of generalized linear mixed effect model for animal activity budgets is shown in Table 1. The triple interaction between period, group, and time slot was significant in all the three behaviors analyzed. The main factors affecting animals' time budgets were the time slot and period effects for grazing and resting behaviors. For the covariates, distance covered had a significant effect on all the time budget variables, as well as temperature for the ruminating and grazing behavior. Group effect (CSG vs. SG) was never significant.

Correlations between the variables studied are shown in Figure 2. Independently by the management, grazing was negatively correlated to both ruminating and resting behaviors, whereas ruminating and resting behaviors showed negative correlation with distance covered and 4 hours/mean temperature. Contrariwise, grazing behavior was positively correlated with both distance covered and 4 hours/mean temperature.

Grazing activity of the two experimental groups, among different grazing periods of trial, and within each time slot, is reported in Figure 3. Animals belonging to both groups showed the highest estimated means for grazing activity during 12:00-16:00 hours; the values ranged from 71.64 ± 36.18 in P1 to 106.55± 37.85 min/4hr in P4. On the other hand, time slots 16:00-20:00 and 20:00-00:00 were the least preferred for grazing, with the lowest level for this activity registered in P1 with 6.38± 10.55 min/4hr, and reaching the highest during P5 (53.87 ± 26.56 min/4h).

Confronting the estimated means of time spent grazing during each period, a slightly increasing trend can be observed in all time slots, especially when comparing P1-P3 to P4-P5, indeed, both groups showed higher grazing activity in P4 and P5 when compared with the other periods of trial. CSG group showed a preference for grazing in the time slots 00:00-04:00, 08:00-12:00, and 12:00-16:00. In time slot 08:00-12:00 a higher grazing activity of CSG animals was observed during P5. SG animals showed a consistent tendency for grazing more in time slots 16:00-20:00 and 20:00-00:00, being statistically significant for P3, P4, and P5 in the first time slot. In time slot 04:00-08:00 no significant difference in time spent grazing was observed, except for P4 in which CSG group grazed significantly more.

The estimated means of rumination time of each experimental group (CSG vs. SG), within each period and time slot, as well as the contrasts statistically significant between groups, are shown in Figure 4. Both groups showed a preference for ruminating (89.85 ± 20.72 min/4 hours or above) during the late afternoon and early evening (16:00 to 20:00 and 20:00 to 00:00 hours), while the lowest level of activity (< 51.65 ± 18.28 min/4 hours) is reported for the early afternoon (12:00 to 16:00 hours). From 00:00 to 12:00 hours, ruminating showed values between 55.75± 24.29 (P1, time slot 08:00 – 12:00) and 75.72± 20.34 (P1, time slot 00:00-04:00) min/4h in all the experimental periods.

Significant differences in time spent ruminating between the two experimental groups were observed across several periods and time slots. SG-managed animals generally spent more time ruminating during the 00:00–04:00 and 12:00–16:00 intervals, except in a few periods where differences were not significant (P2 in time slot 00:00–04:00 and P1, P2, and P5 in time slot 12:00–16:00). In contrast, during the 16:00–20:00 time slot of P2, and P5**,** CSG animals spent significantly more time ruminating than SG animals. Conversely, in the 20:00–00:00 interval of P5**,** SG animals ruminated more than CSG animals**.** Overall, rumination patterns varied between groups mainly during nighttime and early afternoon hours.

The estimated means and contrasts' significances of time spent resting of each experimental group (CSG vs. SG), within each period and time slot, are shown in Figure 5. Resting activity was mainly concentrated during the night hours from 20:00 to 08:00. During these hours, time spent resting ranges between 55.08 ± 22.39 (P5, time slot 04:00-08:00) and 96.58 ± 23.74 min/4h (P1, time slot 20:00 - 00:00). However, in the 12:00 - 16:00 interval, animals rested the least, showing an average of 41.62 ± 20.53 min/4h for P5 or lower for P1-P4 grazing periods. Within each time slot, there was at least one significance of the groups among periods, partially reflecting those observed for rumination activity. Compared with ruminating activity, SG animals rested more than CSG in P1 during 04:00-08:00 time slot and in P2, P3, and P5 during 08:00-12:00 time slot; contrariwise, CSG animals spent significantly more time resting in P1, P3, and P5 between 16:00-20:00 and in P3, and P5 during 20:00-00:00, if compared to SG ones.

The interaction between these factors and experimental period was not significant for any behavioral variable (rumination $p = 0.91$, grazing $p = 0.86$, resting $p = 0.12$), indicating that calving events did not affect the temporal behavioral patterns observed during the experiment.

3.2. Virtual fencing

The output of generalized linear mixed model describing virtual fencing performance, based on the number of electrical pulses emitted by the collars, is shown in Table 2. The overall average number of electrical pulses emitted per animal within time slots remained relatively stable across periods ranged between zero and a maximum of 7 (P5, 12:00-16:00 time slot), despite considerable inter-individual variability.

The examined variable was significantly affected by time slot and their interaction (period * time slot). Adjusted means of electric pulses released by virtual fencing collars during each period of trial and within time slots are shown in Figure 6. The mean number of electrical pulses recorded for each period tended to decrease from P1 to P5 in all the time slots examined, except for the ones related to the daytime hours (e.g., time slot 12:00-16:00 and 16:00-20:00). Indeed, During these time windows, the number of electric pulses increased significantly from P1 and P4 to P2 and P5, respectively (Table S2). Conversely significant decrease were showed from P1 and P2 to P5 in time slot 04:00-08:00 and from P1 and P2 to P3 in time slot 08:00-12:00 (Table S2).

3.3. Hair cortisol content

In Table 3 the results from the Hair cortisol content linear model are summarized. Hair cortisol concentration did not differ significantly between groups. However, model estimates indicated numerically higher values in the CSG group (0.871 ± 0.159 pg/mg; 95% CI: 0.538–1.204 pg/mg) compared with the SG group (0.400 ± 0.169 pg/mg; 95% CI: 0.045–0.755 pg/mg). Results showed that the hair cortisol was not affected by the management, either by gestation day or calving event, which occurred in 9 CSG cows and in 1 SG cow after one week from the end of the experiment.

4. DISCUSSION

4.1. Animal behavior

Estimating the time animals spend ruminating, grazing, and resting using commercial sensors has proven to be useful metrics for monitoring animal welfare and early detection of health issues (Halachmi et al., 2019). Animal-mounted sensors appeared promising to classify also grazing (Obermeyer et al., 2025; Werner et al., 2019), ruminating and eating (Leso et al., 2021; Obermeyer et al., 2025) behaviors for grazing cattle. The current research selected these three main activities (e.g., grazing, ruminating, and resting) performed by cattle to evaluate whether type of grazing management, namely continuous stocking or strip grazing, had an impact on the normal behavior of pregnant suckler cows during spring grazing.

Most daily activity of grazing cattle (>90%) is represented by ruminating, resting, or eating behaviors (Andriamandroso et al., 2016; Hamidi et al., 2022; Kilgour, 2012). Thus, significant changes in time spent ruminating, lying, or eating can be associated with discomfort and stress (Bristow & Holmes, 2007). The intercorrelation between active behaviors, such as standing/walking/grazing and stationary ones, such as lying/ruminating/resting, has been largely reported in literature, showing opposite trends between lying and standing/walking (Hejcmanová et al., 2009; Marini et al., 2020; Wilms et al., 2024). Grazing activity was positively correlated with the distance covered by the animals, suggesting active spatial exploration of the pasture during grazing. Previous studies reported that cattle at pasture may cover distances ranging from 1.7 to 12.6 km per day, with greater walking activity typically occurring during daylight hours (Kilgour, 2012). Furthermore, factors such as herbage allowance, stocking rate, and pasture heterogeneity have been shown to influence the distance traveled by animals during grazing events (Hamidi et al., 2021, 2022, 2023). However, CSG and SG animals travelled a globally similar daily distance (4.6±1.6 km and 5.0±1.5 km, respectively) although different stocking rates were used. The low pasture heterogeneity and adequate herbage allowance even for the SG managed groups, which had a higher stocking rate, could explain our result.

The triple interaction among type of management, period, and time slot was significant, indicating that some differences between grazing managements may occur during diverse periods of trial and on specific time windows. Several authors tried to disentangle the effect of grazing management, stocking rate, daily pattern, and seasonal pasture variability on animal's activity budgets. Venter et al. (2019) have observed how grazing management did not affect how much time was spent on grazing, resting, and walking which, in reverse, mainly followed daily patterns. Similarly, the total duration of the grazing or ruminating/resting phases in non-lactating cows under different grazing managements (Scotton & Crestani, 2019) and under different grazing intensities (Hejcmanová et al., 2009) resulted unaffected.

The evolution of biomass availability and nutritional value over time and seasons, as well as the daytime hour, resulted in the two factors that most affected animals' time budgets. A decrease in the number of lying bouts was observed throughout the experimental weeks on both virtual fencing and electric tape-managed animals (Campbell et al., 2019; Hejcmanová et al., 2009). Authors attributed this change to the reduction of pasture availability, which may have induced both groups to stand more for grazing. In our study, a similar pattern for grazing was observed, specifically in daylight time slots, which are linked to major grazing activity (Chopra et al., 2025; Kilgour, 2012). However, a slight increase in grazing activity over grazing periods can also be appreciated in the other time slots, especially comparing P1-P3 to P4-P5, while resting showed a reverse trend. The shift from resting behavior towards increased grazing activity was likewise documented by Hejcmanová et al. (2009), who compared two groups of beef heifers managed under different grazing intensities. Indeed, grazing time is expected to increase as the summer season advances, and biomass growth rate consistently decreases, requiring a greater effort of walking (Hamidi et al., 2023). Changes in grazing activity during seasonal grazing may have been linked also to changes in temperature. Daily temperature has been recognized to impact cattle behavior (Pinto et al., 2020) and time spent grazing (Hejcmanová et al., 2009). However, in the present study, temperature remained below the established threshold for heat stress; thus, changes in grazing time are more likely to be linked to the reduction of biomass and its quality along the trial.

Resting and ruminating are often performed preferentially at the same time and during night hours, whereas grazing takes place during daylight (Kilgour, 2012). In our study, a similar pattern emerged. Thus, animals in both types of management grazed the most during daylight hours (time slot 12:00-16:00) and ruminated preferentially at dusk and in late evening. Our results for grazing are partially in accordance with Caram et al. (2021) who studied cattle grazing behavior during daylight hours (07:00-19:30). Comparing their results with ours, within the same timeslot, a similar increase of grazing time during the afternoon at the expense of ruminating and idling was observed. Caram et al. (2021) hypothesized that cattle perform this behavior in order to maximize intake and maintain rumen fill in preparation for the night, when grazing activity is reduced.

Rumination time has been used to predict the time of calving, with a reduction occurring about two hours before parturition and resuming approximately 6 hours after (Pahl et al., 2014). Furthermore, Jensen (2012) showed that in dairy cows the first hours after calving involve most cow–calf interactions and reduced feeding activity, with a recovery during the subsequent hours and on the following day. These results suggest that the influence of calving events is mainly concentrated within the first 24 hours. This is consistent with our results, which showed no influence on the activity behaviors recorded across the experimental periods.

4.2. Virtual fencing

Virtual Fencing supported strip grazing management, helping the farmer to perform weekly pasture changes without additional labor efforts in shifting the physical fences. Indeed, most authors agree on the effectiveness of virtual fencing systems (i.e., Nofence, E-shepard, and Vence) in containing cattle inside virtual boundaries (Confessore et al., 2024; Fuchs et al., 2025; Hamidi et al., 2022; Harland et al., 2025; Staahltoft et al., 2023).

Studies conducted on both grazing beef cattle (Jeffus et al., 2025) and dairy goats (Wilms et al., 2025), outlined that standing time and lying bouts did not differ between physical fences or virtual fencing. Similarly, when comparing dairy cattle behavior before and after activating a virtual fence with a front-virtual line, standing and lying behaviors were similar (Fuchs et al., 2024; Verdon et al., 2021b), as were lying and grazing behaviors in lactating goats (Eftang et al., 2023). On the contrary, slightly less time spent lying (<20 min of difference) and an increase in standing were observed in virtual fencing-managed Angus cattle as compared to electric tape managing (Campbell et al., 2019).

Several studies investigating the effects of virtual fencing on animal welfare and behavior have highlighted that significant outcomes are predominantly associated with interactions among the main predictors, rather than with SG as the main factor alone (Fuchs et al., 2024; Hamidi et al., 2022; Jeffus et al., 2025; Wilms et al., 2025), concluding that this technology has any or minimal impact on animal behavior and welfare.

Indeed, when the learning process is successful, the number of electric pulses decreases over days as the animal acquires the capacity to correctly react to the acoustic warning and avoid the electric pulse (Wilms et al., 2024). The appropriate length of training may vary according to different companies and experiments, ranging from 72 hours (Gerhardt et al., 2025; Langworthy et al., 2021; Verdon et al., 2021a) to 12 days (Fuchs et al., 2025; Hamidi et al., 2022). Generally, animals reach a success rate of at least > 60% (given by the ratio between electrical pulses and audio warnings) after 3-5 days of training (Fuchs et al., 2024, 2025; Harland et al., 2025). However, Hamidi et al. (2

024), observed that learning can be separated into two phases consisting of gaining the ability to avoid the electric pulse and then to correctly interact with the acoustic signal emitted by virtual fencing collars. The second type of learning typically occurs when the animal becomes sufficiently confident with the system to voluntarily test the virtual boarder relying only on acoustic cues. The herd used in the present study had already been trained before the start of the trial, so a low number of electrical pulses were expected, since the animals have learned to avoid the aversive stimuli. However, a slight decrease in electrical pulses over periods can be observed for most time slots. This may be due to a further improvement in animal learning capacity over time, which became more confident in testing the virtual boundaries without receiving aversive stimuli, as suggested by Hamidi et al. (2024). Otherwise, the larger pasture surface available from P1 to P5 could have reduced the occurrence of animals testing the virtual fencing. A similar decrease in the number of electrical pulses over 5 weeks of trial is also reported by Campbell et al. (2019). Additionally, Fuchs et al. (2025) recorded a decrease in electrical pulses over days and after every new pasture allocation. Moreover, the same authors found a negative correlation between electrical pulses and grass height, advocating that the herbage allowance was an important factor in driving cows to test and, possibly, surpass virtual boundaries. These findings are consistent with the results shown in Figure 6 for time slots 12:00-16:00 and 16:00-20:00. In this timeframe, an increasing trend from P1 to P5 was recorded for the number of electrical pulses emitted by the collars. Considering the positive correlation between grazing activity and distance covered (Figure 2b), as well as the greater time spent grazing (Figure 3), the increase in the number of electrical pulses can be explained by higher chance of encountering the virtual boundaries during time slots 12:00-16:00 and 16:00-18:00, which are dominated by grazing activity rather than stationary behaviors, such as resting and ruminating. Consistent with our results, Harland et al. (2025) identified a positive correlation between the number of steps and electric pulses received by grazing beef heifers. Moreover, the additional effect of pasture depletion due to grazing and seasonality may have pushed the animals to test the virtual border to reach the fresh pasture in the exclusion zone (Fuchs et al., 2025). Daytime affecting the number of electrical pulses received by beef heifers was also reported by Verdon et al. (2021a), who observed fewer interactions with the virtual fencing system overnight.

4.3. Hair cortisol assessment

Several studies focused on the impact of virtual fencing on animal welfare by using cortisol on hair (Confessore et al., 2022; Jeffus et al., 2025), feces (Hamidi et al., 2022; Jeffus et al., 2025; Sonne et al., 2022), milk (Confessore et al., 2024; Fuchs et al., 2024; Verdon et al., 2021), and changes in behavior to assess whether this new technology has repercussions on animal well-being. Few research has been conducted on chronic stress related to the use of virtual fencing for several weeks, such as happening during seasonal grazing (Fuchs et al., 2025). Focusing on the hair cortisol content, our results on 5 weeks-length grazing period using virtual fencing are consistent with Jeffus et al. (2025) and Confessore et al. (2022). Both studies agreed that virtual fencing does not affect animals' chronic stress. These findings confirm that this technology does not represent a stressor when cows are managed for several weeks, as typically occurs during seasonal grazing.

5. CONCLUSIONS

This study demonstrates that different grazing management practices do not alter key physiological behaviors, as both groups displayed comparable overall time budgets for rumination, resting, and grazing. At the same time, some modifications of daily behavioral grazing pattern were shown. Thus, cows displayed a different daily preference in performing these physiological behaviors. SG cows ruminated more during the night and early afternoon, while grazing mainly occurred in the late afternoon and evening. Conversely, CSG cows grazed more at night and early afternoon and ruminated in the late afternoon. Hair cortisol content did not reveal evidence of chronic stress in the cows during the experimental period regardless of their type of management.

In conclusion, our findings indicate that shifting from traditional continuous stocking grazing management to strip grazing using virtual fencing did not affect animal activity's budgets. Virtual fencing can represent a valuable and innovative approach to apply improve grazing management in extensive beef cattle systems. The use of virtual fencing can promote the adoption of efficiency-oriented grazing managements without increasing farmers' labor. Furthermore, the absence of chronic stress responses confirms that virtual fencing can be applied over prolonged grazing periods without compromising animal welfare.

A limitation of the present study is that the effects of virtual fencing cannot be fully disentangled from those of the grazing management strategy. Consequently, the observed differences in daily behavioral patterns should be interpreted as the outcome of an integrated management approach (i.e., strip-grazing management implemented through virtual fencing) rather than the fencing system alone.

Future research should address this limitation by experimentally disentangling the effects of grazing management strategies from those of fencing systems (virtual vs. physical), and by evaluating additional key behavioral parameters and pasture utilization metrics, such as forage intake or grass consumption rate.

Acknowledgements

Removed for double-blind peer reviewing process. This information has been provisionally added to the Title page

Research data on this article

Due to confidentiality agreement between the research project's principal investigator and the provider of the smart ear-tag technology, raw data would remain confidential and would not be shared.

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Tables

Response variable	Effect	Df	Chi-square	p-value	Signif.
Rumination	(Intercept)	1	827.80	< 0.001	***
	Period	4	9.915	0.058	
	Group	1	1.14	0.240	
	Time slot	5	2,530.68	< 0.001	***
	Temperature	1	5.71	0.0167	*
	Distance	1	5.60	0.0180	*
	Gestation Day	1	0.02	0.083	
	Period x Group	4	33.27	< 0.001	***
	Period x Time slot	20	242.68	< 0.001	***
	Group x Time slot	5	155.28	< 0.001	***
	Period x Group x Time slot	20	155.88	< 0.001	***
Grazing	(Intercept)	1	347.20	< 0.001	***
	Period	4	86.19	< 0.001	***
	Group	1	0.22	0.634	
	Time slot	5	979.71	< 0.001	***
	Temperature	1	36.52	< 0.001	***
	Distance	1	213.93	< 0.001	***
	Gestation Day	1	0.02	0.870	
	Period x Group	4	3.12	0.536	
	Period x Time slot	20	326.74	< 0.001	***
	Group x Time slot	5	193.33	< 0.001	***
	Period x Group x Time slot	20	146.16	< 0.001	***
Resting	(Intercept)	1	530.63	< 0.001	***
	Period	4	39.61	< 0.001	***
	Group	1	1.08	0.298	
	Time slot	5	2,269.21	< 0.001	***

Response variable	Effect	Df	Chi-square	p-value	Signif.
	Temperature	1	0.84	0.355	
	Distance	1	14.28	< 0.001	***
	Gestation Day	1	0.012	0.918	
	Period x Group	4	12.24	0.01578	*
	Period x Time slot	20	311.77	< 0.001	***
	Group x Time slot	5	346.10	< 0.001	***
	Period x Group x Time slot	20	123.17	< 0.001	***

*Table 1. Output of the generalized linear mixed-effects models for the total minutes per four-hour time slot of rumination, grazing, and resting. The models evaluate the effects of Period (P1 to P6), Group (CSG and SG), Time slot (00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00), and their three-way interaction, as well as the mean daily temperature, the gestation day of each cow, and the distance covered by the cows during the experiment. Degrees of freedom (DF) and Chi-square values (Chisq) are reported. Significance (Signif.) levels are indicated as * P < 0.05, ** P < 0.01, and *** P < 0.001.*

	Effect	Df	Chi-square	p-value	Signif.
Total number of electric pulses	(Intercept)	1	0.0001	0.99	
	Period	5	0.0001	1.00	
	Time slot	5	95.71	< 0.001	***
	Period x Time slot	25	178.84	< 0.001	***

*Table 2. Output of the generalized linear mixed-effects models for the total number of the electric pulses emitted by the collars. The models evaluate the effects of Period (P1 to P6), time slot (00:00–04:00, 04:00–08:00, 08:00–12:00, 12:00–16:00, 16:00–20:00, and 20:00–24:00), and their two-way interaction. Degrees of freedom (DF) and Chi-square values (Chisq) are reported. Significance (Signif.) e levels are indicated as * P < 0.05, ** P < 0.01, and *** P < 0.001.*

Response variable	Effect	SSq	Df	F value	p-value
Hair Cortisol Content (pc/mg)	Group	0.57	1	0.61	0.44
	Calving	0.057	1	0.30	0.59
	Gestation Day	0.0053	1	0.03	0.86

Response variable	Effect	SSq	Df	F value	p-value
	Residuals	3.61	19		

*Table 3. Output of the linear model for the Hair cortisol content. The model evaluates the effects of Group (CSG and SG), Calving (yes/no), and the Gestation Day. Degrees of freedom (Df), Sum of square Chi-square values (SSq), and F value are reported. Significance (Signif.) levels are indicated as * P < 0.05, ** P < 0.01, and *** P < 0.001.*

Figure 1. Schematic view of the experimental design. Pink lines represent the physical border of Pasture 1, while black lines represent the physical border of Pasture 2 assigned to Continuous Stocking Grazing (CSG) and Strip Grazing (SG) group, respectively. Blu lines indicate the virtual borders designed for each grazing period (P1 to P5).

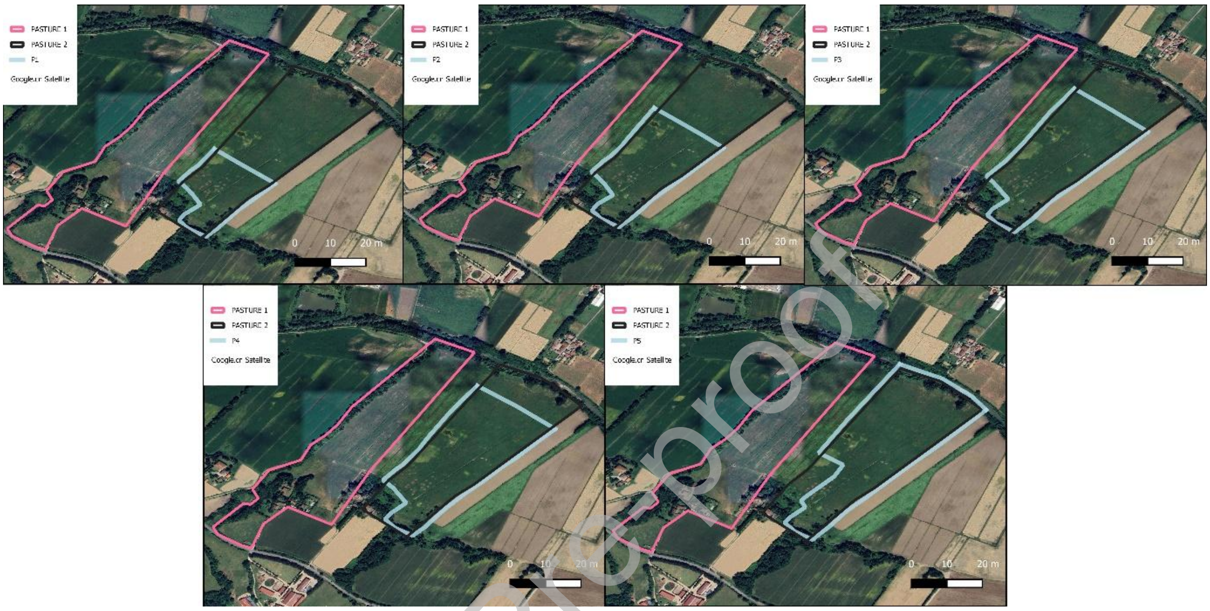


Figure 2. Correlation matrix of the studied variables for both groups (e.g., Continuous Stocking Grazing (CSG) and Strip Grazing (SG) group) (a) and for the SG group alone (b). Circle color indicates the direction of the correlation (blue = positive, red = negative), whereas circle size is proportional to the magnitude of the correlation coefficient. Larger circles and values correspond to stronger correlations. EP = electric pulses, AW = audio warnings.

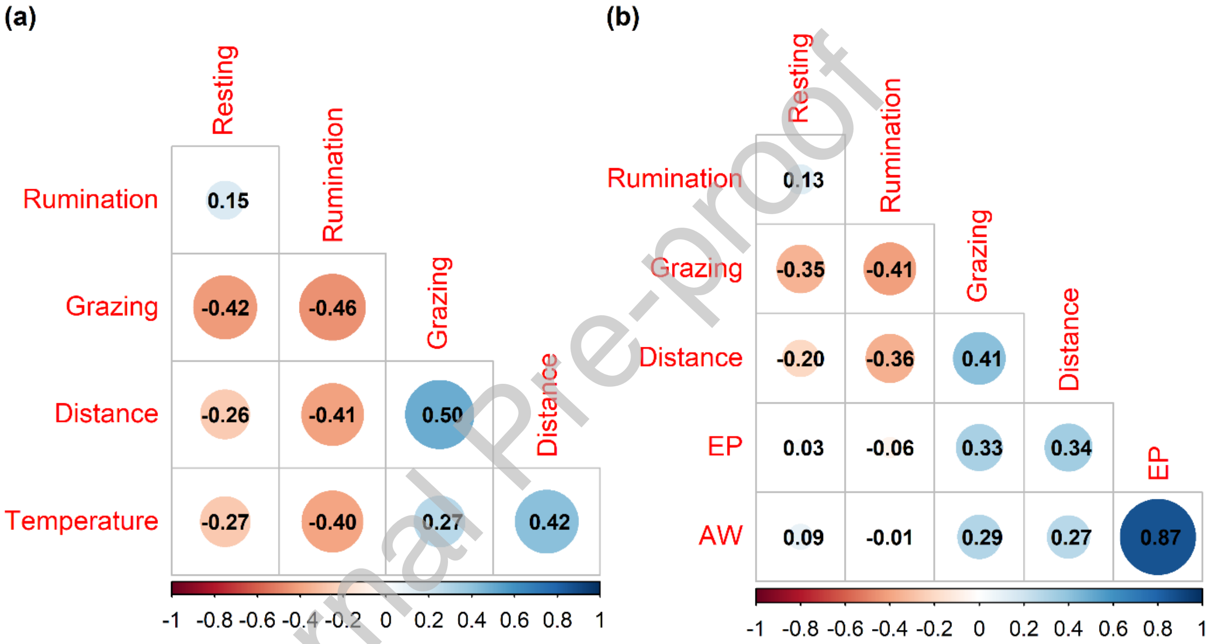


Figure 3. Time spent grazing expressed in min/4h, for Continuous Stocking Grazing (CSG) and Strip Grazing (SG) groups (CSG= blue boxplot, SG= pink boxplot) within each grazing Period and time slots. Box plots represent the median (central line), interquartile range (box), and whiskers extending to 1.5×IQR. Grey dots indicates the outliers. Labels show the significance of the estimated marginal means contrasts among groups: *P < 0.05, ** P < 0.01, and *** P < 0.001.

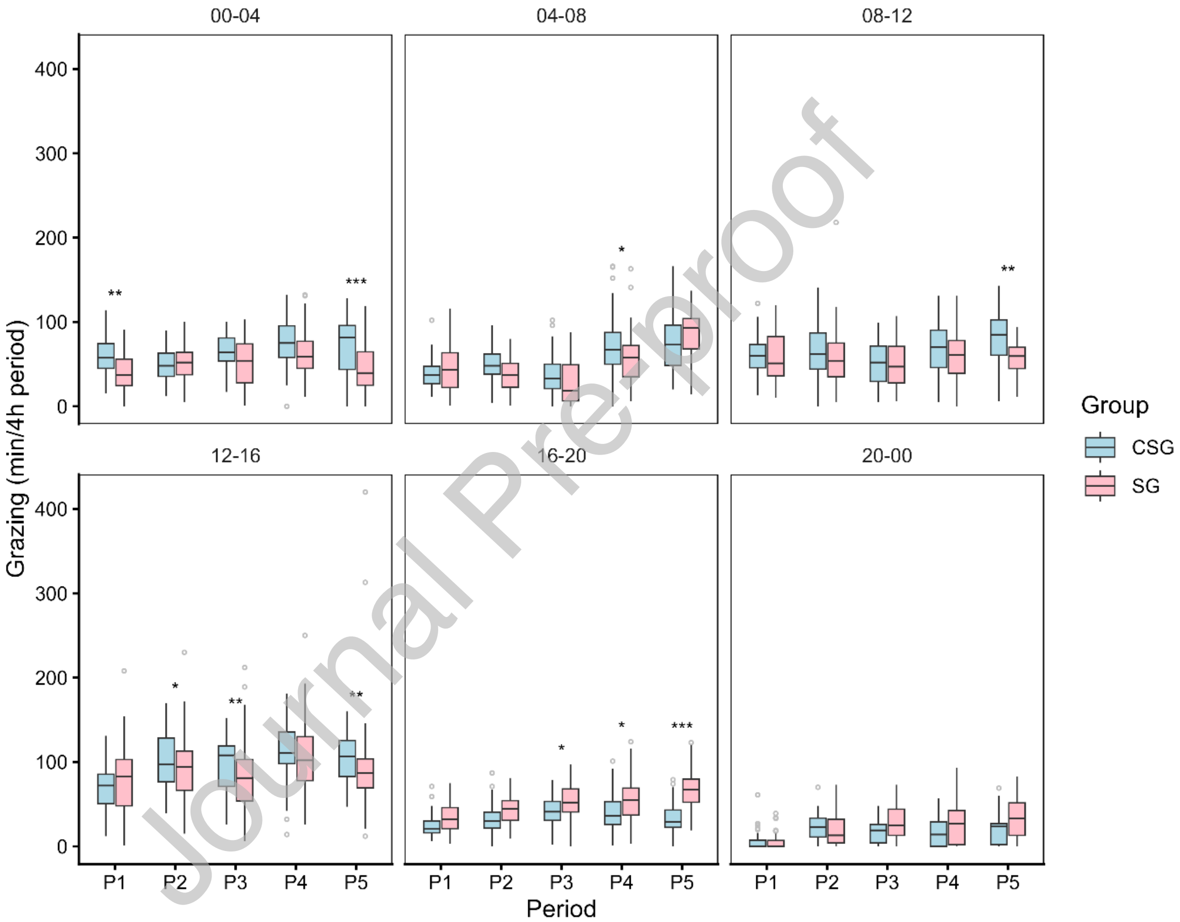


Figure 4. Time spent ruminating expressed in min/4h, for Continuous Stocking Grazing (CSG) and Strip Grazing (SG) groups (CSG = blue boxplot, SG= pink boxplot) within each grazing Period and time slots. Box plots represent the median (central line), interquartile range (box), and whiskers extending to 1.5×IQR. Grey dots indicates the outliers. Labels show the significance of the estimated marginal means contrasts among groups: *P < 0.05, ** P < 0.01, and *** P < 0.001.

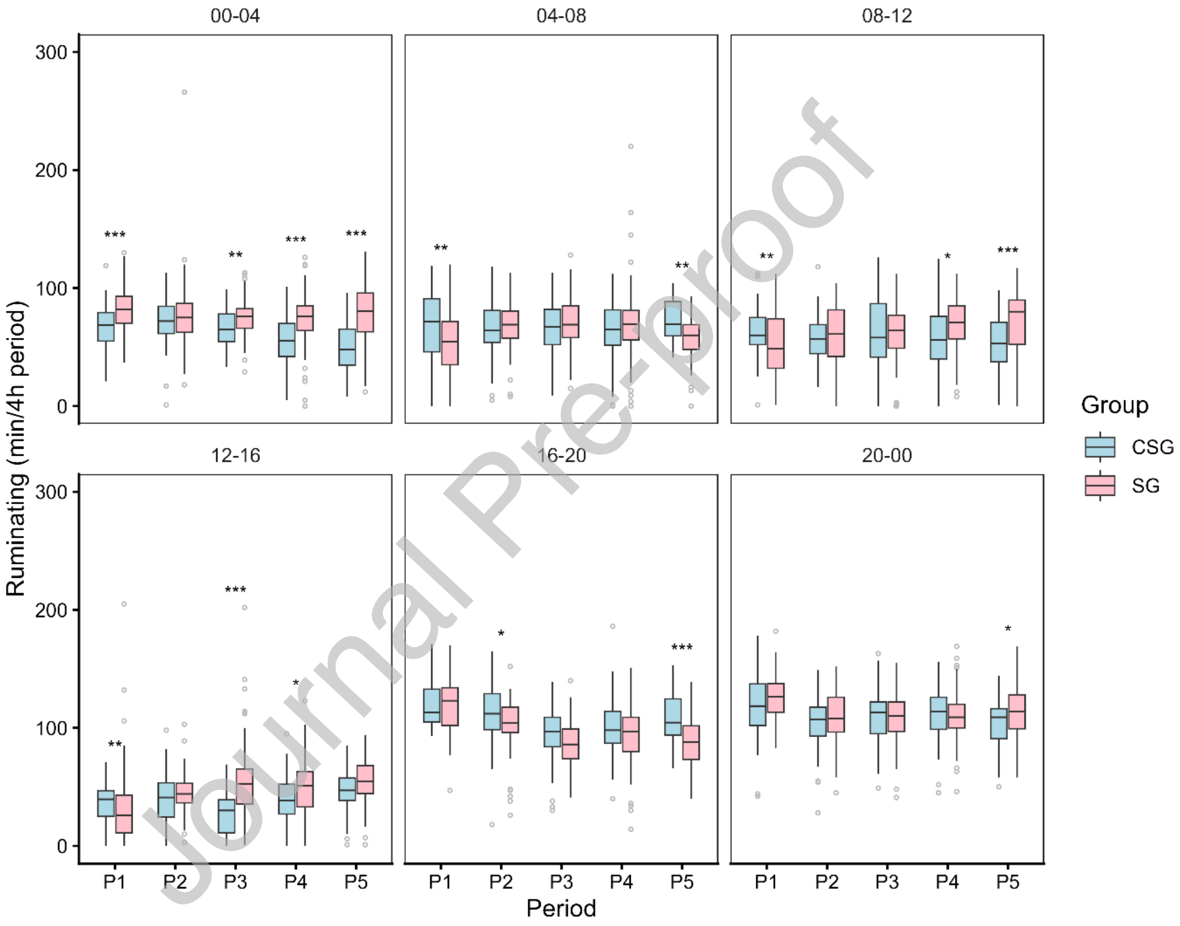


Figure 5. Time spent resting expressed in min/4h, for Continuous Stocking Grazing (CSG) and Strip Grazing (SG) groups (CSG = blue boxplot, SG= pink boxplot) within each grazing Period and time slots. Box plots represent the median (central line), interquartile range (box), and whiskers extending to 1.5×IQR. Grey dots indicates the outliers. Labels show the significance of the estimated marginal means contrasts among groups: *P < 0.05, ** P < 0.01, and *** P < 0.001.

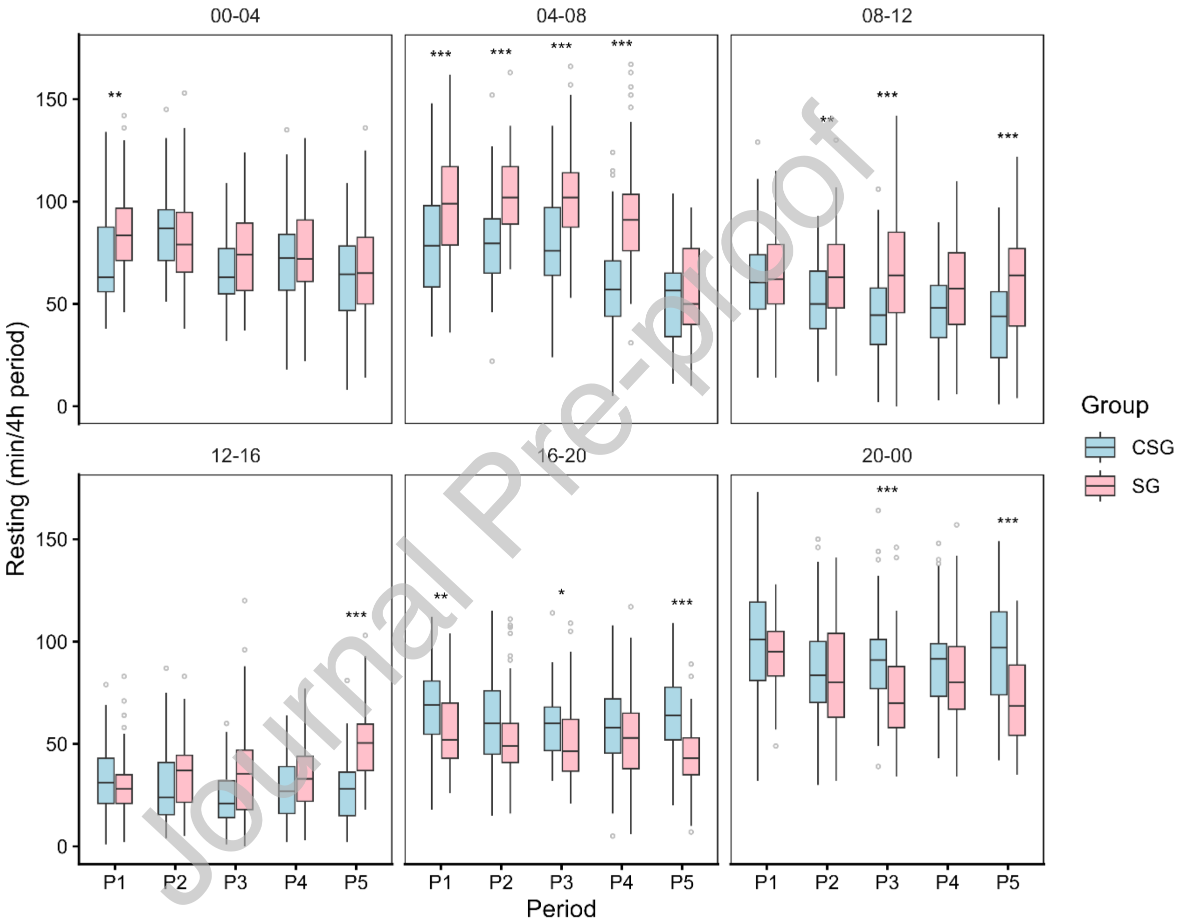
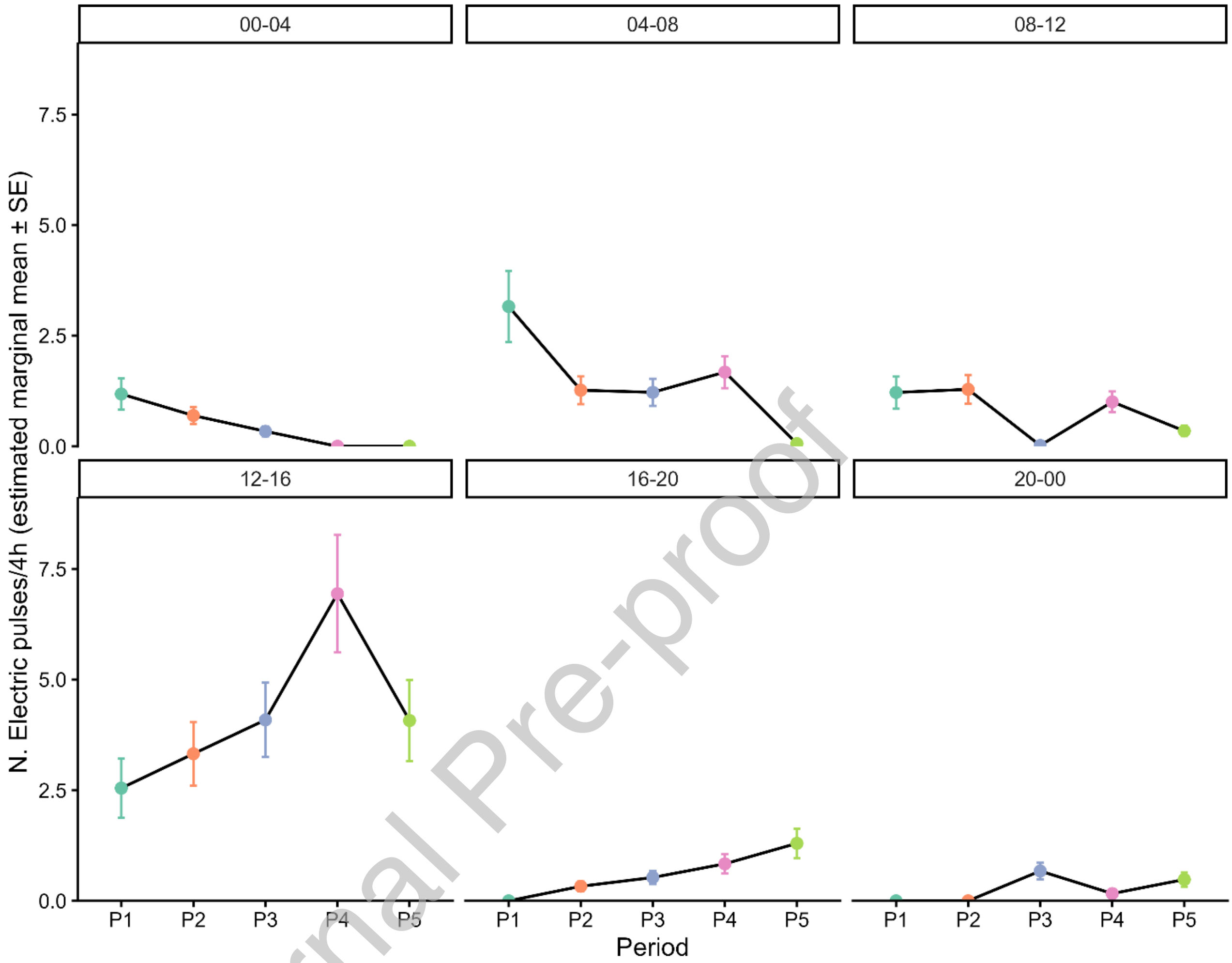


Figure 6. Model-estimated marginal means (± SE) of electric pulse emitted by the collars of the Strip Grazing group (SG) within experimental periods within each 4-h time block. Different coloured points represent adjusted means of each experimental periods (P1–P5), and error bars indicate standard errors.



Declaration of interests

☒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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: