



Can we detect patterns in behavioral time series of cows using cluster analysis?

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ABSTRACT

Time series analysis can facilitate the detection of complex behavioral patterns and potentially provide new opportunities to assess animal welfare. The aim was to investigate whether dairy cows exhibit daily, individual patterns in activity and in area use in the barn. We predicted that behavioral patterns will be more consistent (1) within than between cows, (2) when area categorization is more specific and, thus, allows the detection of individual preferences for areas, and (3) during the night. We conducted the study at an experimental farm with 20 lactating Brown Swiss and Swiss Fleckvieh cows. The animals were housed in cubicles, and they received feed and were milked twice daily. Activity was recorded with IceTag pedometers (IceRobotics Ltd.), and area use with the SMARTBOW sensor system (Zoetis). Data were collected for 55 consecutive days and analyzed at 1-min intervals. To investigate the behavioral time series, we performed a hierarchical clustering analysis. A clustering process calculated distances between days, which were compared within and between cows based on *t*-tests and analyses of variance. Dendrograms of activity and area use showed that days of individual cows could not be grouped more closely together than those of different cows. A slightly better grouping was achieved with a more specific area categorization, but not during a specific time period. However, the average distances between days were always smaller within (mean \pm SD; activity: 95.62 ± 76.88 , lying areas: 0.14 ± 0.03 , functional areas: 0.12 ± 0.01) than between cows (activity: 109.62 ± 75.33 , lying areas: 0.16 ± 0.02 , functional areas 0.13 ± 0.01). Considering that the time series of individual cows were slightly but always more similar compared with those between cows, and that more consistent patterns were found when the area categorization was more specific, it can be concluded that the cows exhibited weak in-

dividual preferences in area use and also weak daily individual patterns in activity and area use. Because the visual exploratory and empirical approaches used in this study do not account for variability, they do not seem to be suitable for the detection of patterns in animals that display greater plasticity in their temporal structure of activity. Thus, although determining the temporal structure of activity and area use bears the potential to assess the behavior and, in turn, for example, the physiological state and health status of cows, it does not seem to be achievable with a cluster analysis. Therefore, time series methods that account for temporal fluctuations in behavior should be further explored.

Key words: functional areas, location, activity, area use, cow behavior

INTRODUCTION

Assessing behavior is an important tool in the field of animal science. Consequently, discovering new variables and approaches for analysis is a key aim to be pursued. For a long time, behavioral responses were largely quantified based on their intensity, frequency, or duration. For example, the daily duration of brush use was shown to be shorter for cows with metritis compared with control cows (Mandel et al., 2017). Further, the frequency of visits to electronic feeders and feed consumption served as indicators for tail-biting outbreaks in pigs (Wallenbeck and Keeling, 2013). Finally, average locomotor activity was shown to be higher in non-lame than in moderately lame cows (Weigele et al., 2018). In contrast, behavioral patterns of greater complexity such as the directional, sequential, and temporal structure of behavior have been mostly neglected. However, research interests gradually shift toward the analysis of more complex patterns of behavior. For instance, Kalueff and Tuohimaa (2004) reported that the grooming microstructure of mice varied between distress and comfort grooming. In chickens, María et al. (2004) showed that the complexity of locomotor sequences decreased during distress, whereas the complexity of

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behaviors such as perching, foraging, and resting increased under enriched conditions. Moreover, a recent work by Rufener and colleagues (2018) investigated behavioral time series in laying hens, revealing that the hens displayed very consistent daily, individual-specific movement and location patterns. The findings are very intriguing as they imply that, first, the hens are able to maintain a relatively stable behavioral rhythm under husbandry conditions; second, that they follow an individual rather than a flock rhythm; and third, their rhythm could be reflected by the use of areas in the barn.

Because a well-defined rhythm is considered to be characteristic of a healthy organism (Berger et al., 2003), and stressors are known to disrupt the rhythm (Harper et al., 1996; Berger et al., 2003, 2011; Veissier et al., 2017; Nunes Marsiglio Sarout et al., 2018), an individual signature in the temporal patterns of behavior could potentially provide a new opportunity to assess an animal's state. Therefore, it would be interesting to verify whether such patterns could also be found in other animals. Particularly, simultaneously inspecting activity and location patterns could deliver a holistic picture of the temporal coordination of behavior. Although it can be assumed that visiting different areas and consequently being in proximity to functional features can be associated with certain behaviors and, thus, with overall activity, it is not clear whether such an association exists or how strong it is.

For the investigation of behavioral time series, continuous data are required. Precision livestock farming technologies facilitate the continuous collection of behavioral and physiological data on the individual level, and can therefore provide support in animal monitoring, and, in turn, in the detection of physiological states and health issues (Lee and Seo, 2021). For cows, a range of commercial animal-borne sensors are available (Umstätter and Stachowicz, 2020; Lee and Seo, 2021); thus, they represent a great study species for the exploration of behavioral time series. In contrast to laying hens, though, cows experience estrus, parturition, different lactation states, and more infrequent procedures such as insemination and claw trimming. All these internal and external events might disrupt the temporal order of behavior in cows and result in irregular activity and area-use patterns. However, cows also undergo daily routine management procedures, such as milking and feeding, which do entrain the onset of specific behaviors and thus might act as pre-defined zeitgebers. However, it is not known whether these reoccurring artificial cues might nonetheless disrupt the temporal patterns or, on the contrary, even impose a rhythm on the cows. Therefore, it is also conceivable that the consistency of patterns in cows might vary depending on the time

of day. Finally, more choice in areas might also affect the regularity of patterns. If several areas containing the same functional features are available, the animals can choose preferred sites and potentially exhibit more individually distinct patterns.

The objective of this study was to examine whether dairy cows display consistent, daily, and individually distinct patterns in area use and activity under husbandry conditions, using visual exploratory and empirical approaches. We hypothesize that more consistent daily patterns can be found (1) within than between cows, (2) during the night compared with a 24-h period or during the day, and (3) when area categorization is more specific and thus allows the detection of individual preferences.

METHODS

This study was licensed by the Cantonal Veterinary Office (Frauenfeld, Thurgau, Switzerland, TG02/2020).

Animals and Housing

The study was conducted on a herd of dairy cows ($n = 20$) at the Swiss center of excellence for agricultural research (Agroscope, Ettenhausen, Switzerland). The cows were kept in a naturally ventilated freestall housing system with a space allowance of 11.65 m² per cow. The lying area consisted of 3 rows of deep-bedded cubicles with a lime-straw mixture. Fresh bedding material was added daily, and every 3 mo the bedding material was replaced completely. The cubicles were 1.25 m in width and varied in length, depending on whether they were head-to-head (2.60 m) or wall-facing (2.80 m). The cubicle-to-cow ratio was 1:1. A feed fence with headlocks, a feeding space per cows of 78 cm, and a feeding-place-to-cow ratio of 1:1 characterized the feeding area. Twice per day, the cows were fed with a TMR, and they received concentrates via an automatic concentrate feeder at least twice per day. During feeding, the cows could move freely and change feeding places. However, in the morning, the cows were confined in the feed line for a short period of up to 20 min to prohibit the cows from returning to the milking parlor until the milking was over. The alleys were composed of the aisles between the feeding fence and the cubicles (Figure 1), which had rubber mats and automatic stationary manure scrapers. In addition, 2 drinking troughs, a concentrate feeder, and a grooming brush were provided in the alleys. The cows were milked twice per day and experienced other ordinary management procedures such as insemination. The herd consisted of Brown Swiss ($n = 13$) and Swiss Fleckvieh ($n = 7$) cows. All animals were lactating and between

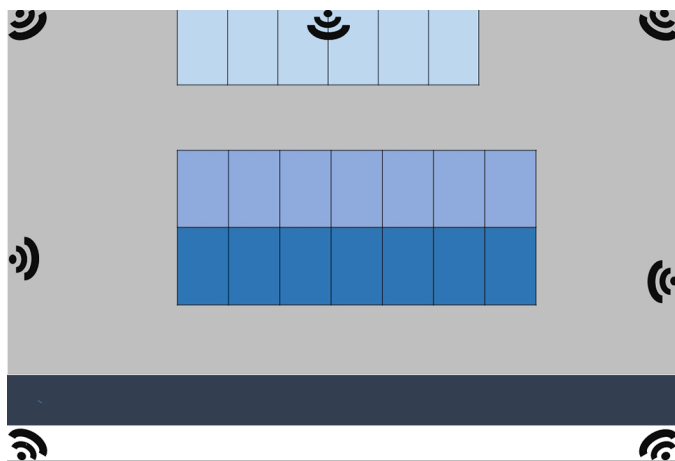


Figure 1. Interior arrangements of the barn. The alleys are depicted in gray, the feeding area in dark grey, and the 3 lying areas in light blue, blue, and dark blue. The signal waves represent the locations of the SMARTBOW antennas (Zoetis).

64 and 187 DIM (mean \pm SD: 121.00 \pm 41.75 d) at the beginning of data collection. A total of 8 cows were in the first lactation, 4 in the second, 2 in the third, 4 in the fourth, and 2 in the fifth lactation. Further, 10 cows were in gestation, and 3 cows were inseminated after exhibiting signs of estrus. All cows were daily observed for signs of sickness or discomfort, as part of the ordinary management routine.

Data Recording

Data were obtained from all cows in the herd, and the single animal was the experimental unit. Area use was recorded via SMARTBOW (Zoetis), a system with a tracking function composed of ear-tag sensors and wall-mounted receivers. The locations of the wall-mounted receivers in the barn are depicted in Figure 1. Via SMARTBOW, the position of the cows was acquired with a nonconstant sampling rate ranging between 4 to 30 s. In particular, the system was matched with the map of the facility structures, which comprised 3 lying areas, 1 feeding area, and alleys (Figure 1). Thus, it was possible to track which of the compartments the cows were located in real time. Activity was recorded using IceTag pedometers (IceRobotics Ltd.) that were attached to 1 of the hind legs of the cows. The pedometers recorded the lying and standing time, the number of lying bouts and steps, and the motion index at a resolution of 1 min. The motion index is based on the acceleration values of the 3-dimensional leg movements, and thus includes all activities such as lying, standing, and walking. Consequently, the motion index provides a more holistic picture about cow's activity and was therefore considered as the only vari-

able for the analysis of activity. The cows were used to wearing both sensors, and thus a habituation period was not required. Validating the 2 sensor systems was beyond the scope of the study and redundant, as both have been previously scientifically validated (SMARTBOW: Rose-Meierhöfer et al., 2015; Will et al., 2017; and Wolfger et al., 2017; IceTags: Nielsen et al., 2018; Högberg et al., 2020). For SMARTBOW, Wolfger et al. (2017) measured a position error of a minimum of 1.2 m. Such localization errors result from signal interferences between the ear tags and receivers caused by, for example, metal elements of the barn. Therefore, some inaccuracies might have occurred in our data of area use, particularly in the cases when a cow was standing at the border of 2 areas. However, we had more than twice as many receivers per area size than Wolfger et al. (2017), and thus, in our case, the error might have been smaller.

Data collection took place between June and August 2020. During this time the thermal conditions were fairly constant across days, as a mean temperature of 19.42°C \pm 3.94°C (SD), a relative humidity of 85.30 \pm 19.61%, and a wind speed of 0.63 \pm 0.50 m/s were measured. Data were recorded over a period of 55 consecutive days. However, due to technical issues, the SMARTBOW system broke down for 4 d, resulting in 2 time periods of approximately 2 and 4 wk. In addition, failures occurred in both systems for individual cows, and 2 cows with clinical signs of mastitis and lameness had to be excluded. Consequently, to have similar data sets for area use and activity, only days and cows were taken into account, which provided data from both sensors, leaving 51 time series from 14 cows for analysis.

Data Analysis

As a first step, the data from SMARTBOW were aggregated to values per minute, which resulted in 1,440 data points per day for each data set. A resolution of 1 min was chosen because cows rarely change areas within seconds, and averaging the data to 1 h or a longer sampling period would lead to a great information loss, particularly for area use. In addition, because we aimed to analyze both variables in a similar manner, the 1-min interval was also used for activity.

For the analysis of area use, 2 variations of area categorization were considered. First, the 3 functional areas—feeding, lying, and alleys—were used (“use of functional areas”), and in this case, the data of the 3 lying areas were taken as 1 lying area. Second, the 3 lying areas were analyzed individually (“use of lying areas”). The latter categorization allowed investigation of whether a more detailed area categorization led to the detection of individual preferences and, as a result,

to more consistent daily individually distinct patterns. Further, to test whether more consistent daily, individually distinct patterns could be found at a specific time of day, the data were divided into 3 time periods as follows: 24 h (“full day”), 10 h between the morning and the evening milking (“light”), and 10 h between the evening and the morning milking (“dark”). In addition, to estimate the proportion of activity performed by the cows during day and night, we calculated the diurnality index according to Hoogenboom et al. (1984). The respective formula required a classification of the 24 h into a day and night period. Thus, in a rough alignment with the natural light/dark cycle during June and August in the northern and eastern hemisphere, the hours between 0050 and 2200 h were assigned as day, and the hours between 2200 and 0050 h as night period. The values of the diurnality index range between -1 and $+1$. A value of -1 represents activity performed strictly during the night, a value of zero represents equal activity during the night and day, and a value of $+1$ indicates activity only during the day.

Statistical Analysis

All statistical analyses were conducted using R studio (version 4.0.5; R Core Team, 2021). To examine whether the cows exhibited individual daily patterns in “area use” and “activity,” hierarchical cluster analyses (stats, hclust package; R Core Team, 2021) were performed. Hierarchical cluster analysis is an explanatory technique used to classify data into a nested sequence of homogeneous groups based on similar properties within data. Because the analysis of time series was the objective, dissimilarity measures enabling a time warp were considered. The sequence comparison in a time warp is nonlinear, and thus enables the identification of sequences that are similar, but out of phase (Senin, 2008). Although there is no sample size requirement for conducting a cluster analysis, we followed the suggestion by Formann (1984) that the minimal sample size should not include fewer than $2k$ cases (k = number of variables), or preferably $5 \times 2k$.

For area use, the dissimilarities between all pair combinations in the time series were estimated via Time Warp Edit Distance (TraMineR package; Studer and Ritschard, 2016), which is an appropriate dissimilarity measure for categorical variables that lack an ordinal scale. Mean was used as the linkage method, and a stiffness of 1 was used to extend the window size range in the Time Warp Edit Distance algorithm. Further, to determine the dissimilarities between the categorical time series, substitution costs for the alignment of each data pair were required (Studer and Ritschard, 2014).

All substitution costs equaled 1, whereas no substitution equaled 0.

For area use, 6 cluster analyses, including the 2 variations of “area use” (3 functional and 3 lying areas) combined with the 3 time periods (“light,” “dark,” and “full day”), were conducted. The time series analysis of activity data were carried out accordingly. However, as “activity” presents as a continuous variable with an abundant natural scale, Dynamic Time Warping (dtwclust package; Sardá-Espinosa, 2019) was used as a distance measure. A window size of 90 min was chosen to account for the changes in the light/dark period (about 1 h) that occurred during the experiment and for the potential temporal variability in management procedures. Further, L2 was applied as the norm, and Ward D was the linkage method (stats, hclust package; R Core Team, 2021). Further, to assess whether more similar patterns can be found between cows of the same breed and age, we visualized the clustering process by coloring the dendrograms in 3 different ways. In the main dendrogram, the days of individual cows are marked in different colors, whereas in the other 2, the days of cows of the 2 breeds and the days of cows of different ages were indicated by different colors. In a subsequent step, the distances between days, which were generated via the clustering process, were extracted from the dissimilarity matrix and compared within and between cows by running *t*-tests (stats package, R Core Team, 2021). Further, to determine whether different patterns could be found during the different time periods (“full day,” “light,” and “dark”), 3-way ANOVA (stats package; R Core Team, 2021) were conducted.

However, time series data are usually defined by large sample sizes; in turn, large sample sizes increase the risk of finding significant differences, even though the effect might be negligible, or even absent (Sullivan and Feinn, 2012). Thus, in addition to the *P*-values, the effect size was estimated by applying Cohen’s *d* (effsize package; Torchiano, 2016) for the *t*-test and Cohen’s *f* (parameters package; Lüdtke et al., 2020) for the ANOVA. Before running the *t*-test and ANOVA, residuals of the data were plotted and visually inspected for normal distribution.

In addition, pre-analyses were conducted beforehand to determine what periods can be included into and which days might have to be excluded from analysis. As aforementioned, due to the breakdown of the SMART-BOW system for several days, we had 2 periods consisting of consecutive days; thus, we analyzed each period separately once and we analyzed the periods together once. Because we found no obvious differences in the clustering, we used the approach where the 2 periods were considered as 1. Accordingly, we checked for the

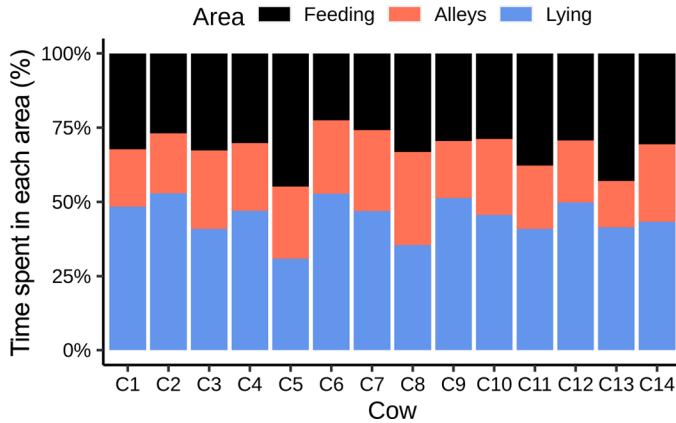


Figure 2. Stacked barplot showing the percentage of time cows spent on average in each of the 3 functional areas.

effect of estrus on the cluster patterns, but found no apparent effect, which is probably due to the low number of cows that exhibited signs of estrus and the short estrus period in comparison to the experimental period. Therefore, because the estrus periods of the 3 cows did not affect the results, we kept the days in the analysis.

RESULTS

The cows spent most of their time in the lying area, followed by the activity and feeding areas (Figure 2). However, the time spent on average in the respective functional areas was fairly similar overall. The daily duration ranged from 214.3 to 431.6 ± 56.5 min (mean \pm SD) for the feeding area, 418.6 to 716.0 ± 84.8 min for the lying area, and 313.5 to 625.0 ± 84.0 min for the alleys. For the use of lying areas, greater variation was found between individuals. Nonetheless, all cows were using all 3 lying areas, but to different extents (Figure 3). The daily duration ranged from 163.0 to 491.2 ± 119.7 min for lying area 1, 326.2 to 935.2 ± 153.1 min for lying area 2, and 286.7 to 843.7 ± 158.2 min for lying area 3. We also found a wide variation in the intensity of daily activity between individuals, ranging from 2,223.3 to $6,082.4 \pm 907.9$ (Figure 4). Finally, the mean diurnality index varied from 0.34 to 0.61 ± 0.08 between cows.

The generated dendrograms (“use of functional areas,” Figure 5; “use of lying areas,” Figure 6; and “activity,” Figure 7) revealed that the days (24-h period) of individual cows could not be grouped more closely together than those of different cows. Further, neither a clear grouping of days of individuals of the same breed (“use of functional areas,” Supplemental Figure S1; “use of lying areas,” Supplemental Figure S2; and “activity,” Supplemental Figure S3; <http://doi.org/10.6084/>

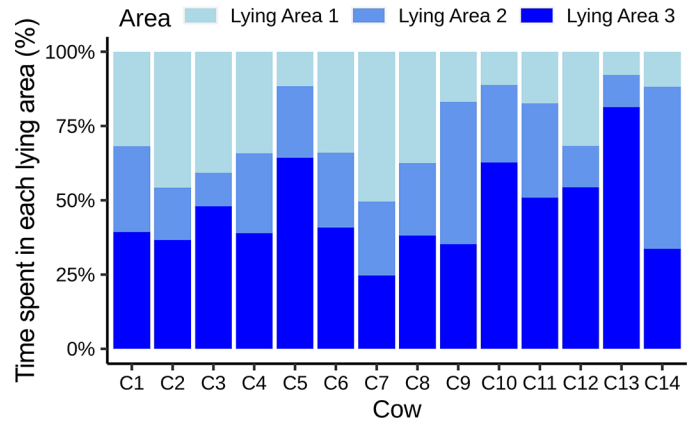


Figure 3. Stacked barplot showing the percentage of time cows spent on average in each of the 3 lying areas. The different lying areas are indicated by different shades of blue.

[m9.figshare.21195598](http://doi.org/10.6084/m9.figshare.21195598); Stachowicz et al., 2022) nor of individuals of the same age (“use of functional areas,” Supplemental Figure S4; “use of lying areas,” Supplemental Figure S5; and “activity,” Supplemental Figure S6; <http://doi.org/10.6084/m9.figshare.21195598>; Stachowicz et al., 2022) was achieved. The best grouping of days for individual cows was obtained for area use when 3 lying areas were individually considered, and the worst was achieved when 3 functional areas were considered, which was indicated by how dense the same colors were grouped together. However, the extracted distance metrics between days were smaller within cows compared with between cows for all 3 analyses (“use of functional areas”: $T_{(17,164)} = 55.76$, $P = 0$; “use of lying areas”: $T_{(17,029)} = 80.16$, $P = 0$; and “activity”: $T_{(194)} = -52.66$, $P < 0.001$). The Cohen’s d indicated a medium difference of 0.50 (CI = 0.48 to 0.52) when the functional areas were used (Figure 8A), a medium difference of 0.74 (CI = 0.72 to 0.75) when 3 lying areas

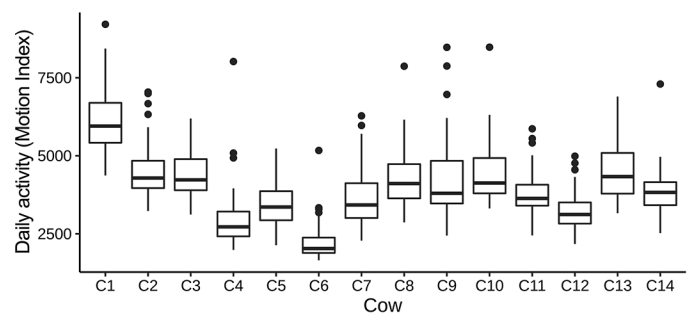


Figure 4. Boxplot showing the average daily activity of all cows. The midline represents the median, boxes indicate the upper and lower quartile ranges, whiskers show the absolute ranges, and dots represent outliers.

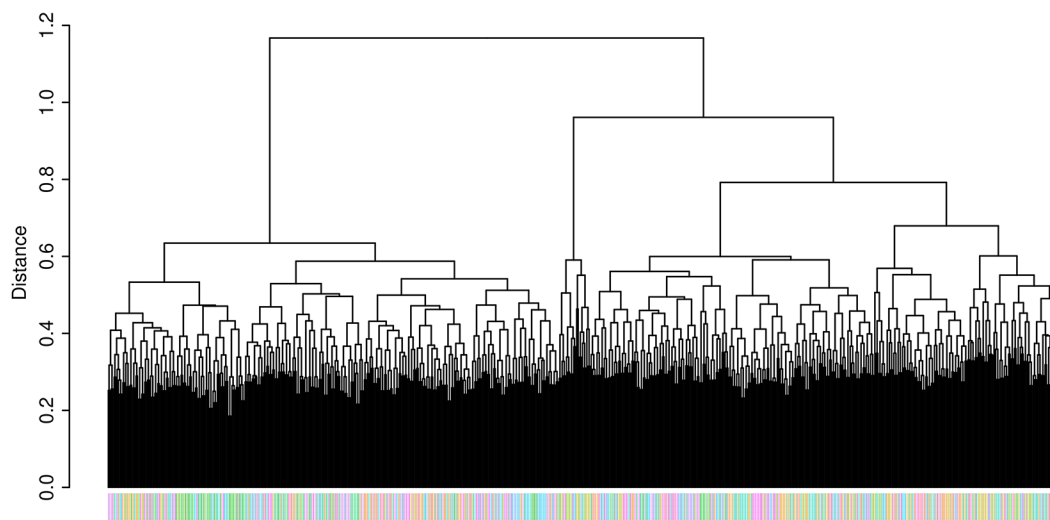


Figure 5. Dendrogram of the clustering process of the “use of functional areas” based on 51 daily time series of 14 cows. The days of different cows are presented in different colors and shades of colors.

were considered (Figure 8B), and a small difference of -0.19 (CI = -0.20 to -0.16) for activity (Figure 8C).

Further, dividing the days into periods did not lead to an overtly better grouping of days for individuals compared with different cows in the dendrograms. However, the 3-way ANOVA indicated a difference in the extracted distances between the 3 periods for all analyses (“use of functional areas”: $F_{(2)} = 522.8$, $P < 0.001$; “use of lying areas”: $F_{(2)} = 7,005$, $P < 0.001$; “activity”: $F_{(2)} = 24,329$, $P < 0.001$). In contrast, the Cohen’s f confirmed only a small difference of 0.24 (CI = 0.19 to 0.25 , Figure 9A) for “use of functional areas,” a negligible difference of 0.08 (CI = 0.08 to 0.08 , Figure 9B) for “use of lying areas,” and a small difference of 0.15 (CI = 0.14 to 0.16 , Figure 9C) for “activity.”

Finally, in the time series plots of the combined data of “activity” and “use of functional areas” for individual cows, an overt daily pattern across days was also not

detectable (Figure 10 for 1 cow, and Supplemental Figures S7–S19 for the other 13 cows; <http://doi.org/10.6084/m9.figshare.21195598>; Stachowicz et al., 2022). The plots do show, however, that activity was closely related to the use of functional areas, as the lowest activity was predominantly seen in the lying area, whereas the highest activity was exhibited in the alleys.

DISCUSSION

In the present study, daily time series of cow behavior were investigated for an individual signature. Although the extracted distances, generated by the cluster analysis, showed that the days of individual cows were more similar than those of different cows, overt consistent daily individually distinct patterns were not revealed, neither in activity nor in the use of the areas in the barn.

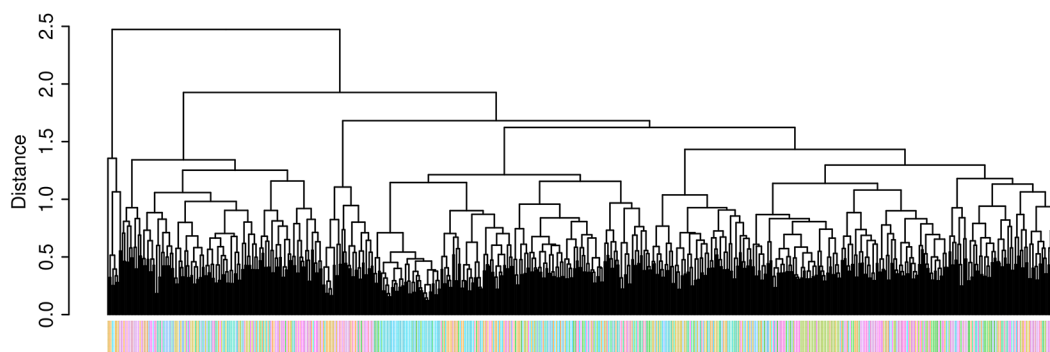


Figure 6. Dendrogram of the clustering process of the “use of lying areas” based on 51 daily time series of 14 cows. The days of different cows are presented in different colors and in different shades of colors.



Figure 7. Dendrogram of the clustering process of the “activity” based on 51 daily time series of 14 cows. The days of different cows are presented in different colors and in different shades of colors.

A visual inspection of the created dendrograms showed that the days of individual cows could not be grouped more closely together than those of different cows. In view of these results, it can be assumed that the time series of activity and area use were not individually distinct, or at least not enough to facilitate a clear grouping, which was in contrast to our predictions. Because a herd of cows usually consists of individuals of different age classes and different lactation states and, thus, more heterogeneous than a commercial hen flock, we expected to find more pronounced individual differences in the temporal structure of activity and area use. However, marking the individuals of different ages in different colors in the dendrograms revealed that the activity and area use patterns did not differ between cows of different ages. Similar results were obtained when the days of individuals were colored according to breed, indicating that both breeds used in this study had similar activity and area use patterns. One explanation for the low individual signature in the time series could be synchronized behavior. Behavioral syn-

chrony is prevalent among group-living animals, both wild and domesticated (Duranton and Gaunet, 2016). In husbandry, artificial cues such as feeding (Miller and Wood-Gush, 1991) and milking times (Wagner-Storch and Palmer, 2003), or the lighting regimen (Alvino et al., 2009), are conceived to entrain synchronization. The higher the degree of synchrony, the fewer distinctive individual patterns will be found among group members. In the present work, a possible hint that the cows might indeed have synchronized their behavior was provided by the similar amount of time all cows spent in the respective functional areas. However, given that a flock of hens are also known to synchronize their behavior and are subjected to management cues (Alvino et al., 2009), yet constant daily individually distinct patterns are still found (Rufener et al., 2018), it could be argued these factors do not necessarily erase individuality completely.

With regard to the time series plots of individual cows, it seems that the absence of clear individual patterns in the dendrograms resulted from a lack of consis-

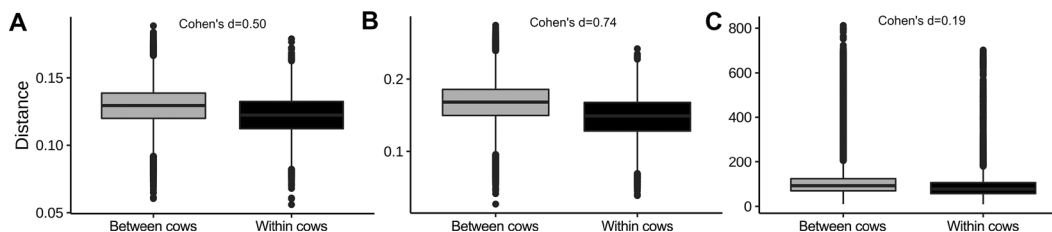


Figure 8. Boxplots showing the extracted distances between days for individual and different cows. The Cohen's d indicates a medium difference between individual and different cows for (A) “use of functional areas” and (B) “use of lying areas,” and a small difference for (C) “activity.” Note that the values of the distance metrics are not comparable among the different boxplots. The midline represents the median, boxes indicate the upper and lower quartile ranges, whiskers show the absolute ranges, and dots represent outliers.

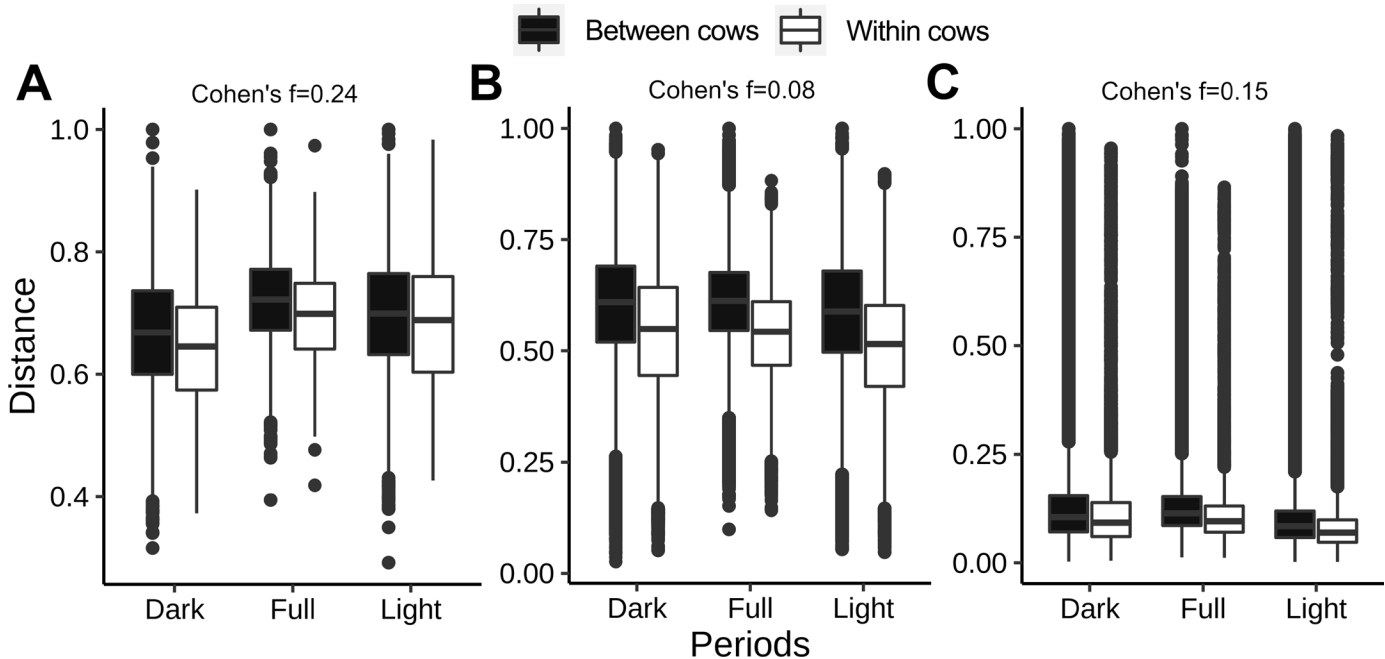


Figure 9. Boxplots depicting the distances between days for individual and distinct cows during different periods. The Cohen's f indicates a small difference between the 3 periods "dark," "full day," and "light" for (A) "use of functional areas," a negligible difference for (B) "use of lying areas," and a small difference for (C) "activity." Note that the values of the distance metrics are not comparable among the different boxplots. The midline represents the median, boxes indicate the upper and lower quartile ranges, whiskers show the absolute ranges, and dots represent outliers.

tency in daily activity and area use, rather than from behavioral synchrony. However, the distances between days showed that the daily time series of individual cows were slightly but always more similar than those of different cows. Hence, a more plausible explanation is that such temporal individually distinct patterns in activity and area use exist in cows, but that these patterns are characterized by greater plasticity. Although, in hens, the exact time of visits to single areas also varied slightly across days, an overall daily pattern was visible (Rufener et al., 2018). The greater variation found in the temporal structure of activity and area use in individual cows might be caused by social interactions (Syme et al., 1975; Miller and Wood-Gush, 1991), a changing internal state such as estrus (Roelofs et al., 2010), gestation, or lactation (Kok et al., 2017), or by management procedures (DeVries and von Keyserlingk, 2005; Belle et al., 2012). However, in light of the results of the 3 time periods, the assumption that management procedures might have disrupted the daily routine of cows cannot be confirmed. In fact, no difference, or only a small or negligible difference, was found between the periods, and the difference among the respective periods was not consistent across all analyses ("activity," "use of functional areas," and "use of lying areas"), although all cows exhibited a higher proportion of ac-

tivity during the day than during the night. The lack of a clear difference between the 3 periods indicated that the management procedures neither disrupted the daily routine of the cows nor facilitated the cows to allocate their activities around the fixed time-frames in a homogeneous rhythm. The last and probably main factor responsible for the greater temporal variability in the cows' behavior might be the natural activity patterns of cows. Cows exhibit multimodal activity patterns, which are characterized by several activity periods per day (Refinetti et al., 2016). In addition, although cows are a diurnal species, they can perform some degree of activity during the night (Sheahan et al., 2013), which was also mirrored in the data of the present study. Finally, it has been demonstrated that the onset of activity was quite variable in cows compared to sheep (for example, Refinetti et al., 2016). All these factors provide room for fluctuations and can lead to greater variability in the temporal structure of behavior compared with animals that are strictly diurnal, or that exhibit uni- or bimodal activity patterns. Consequently, the greater the variability, the more difficult it should be to detect patterns with a cluster analysis, considering that a cluster analysis does not account for temporal fluctuations (noise), which is in contrast to common methods for estimating rhythmic behavior. There is no indica-

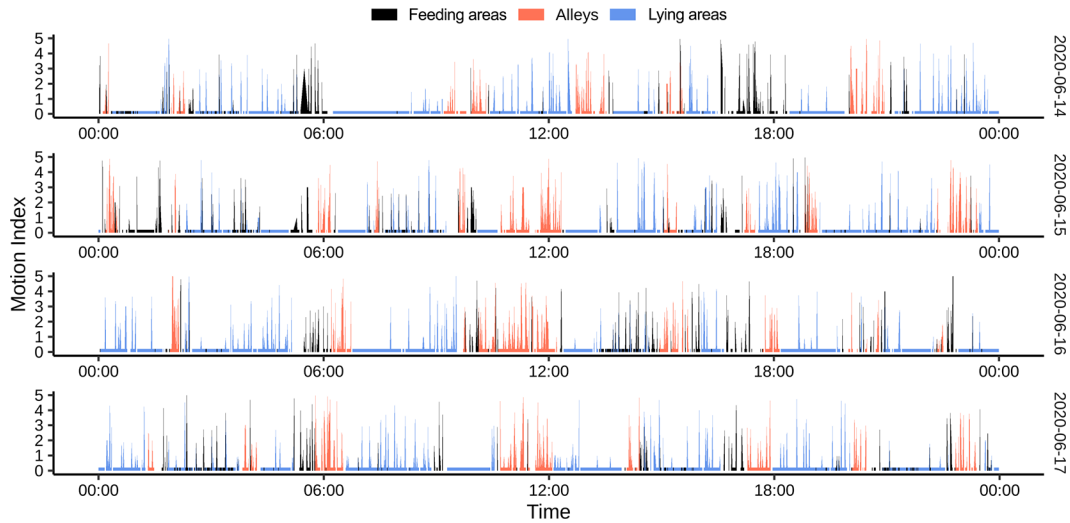


Figure 10. Time series data over 4 consecutive days for a single cow, showing the level of activity performed in the 3 functional areas: lying areas, feeding areas, and alleys.

tion that the lack of clear patterns was caused by the localization errors of the SMARTBOW system, because clear patterns were found neither in activity nor in the time series plots of area use.

Finally, an important differentiating factor between the study of hens and the present one was the number of areas provided. Not only could the hens choose between more areas than necessary to meet all their behavioral needs (Rufener et al., 2018), but they could also use some of the resources (e.g., feeding and drinking places) in several areas. Such conditions could facilitate the expression of preferences (Matthiopoulos, 2003) and, in turn, result in more individually distinct patterns. Support for the claim that choice can lead to more individual patterns can be found in our results of the use of lying areas. In fact, better clustering, and the largest difference in the distances between days of individual and different cows, was obtained when 3 lying areas were used instead of 3 functional areas. However, despite more choice, the clustering was still moderate. A possible reason might be that the 3 lying areas did not provide enough variation, as they were situated very closely together. That could also explain why all cows used all 3 lying areas. In addition, it was not possible to further distinguish which of the lying cubicles the cows were using in particular. This kind of additional information might also have led to more individually distinct patterns, despite the variability in the temporal structure of the cows' behavior. It has to be noted that our study contains a limitation; namely, that it was conducted on one group, with its herd-specific social structure and under housing and management conditions specific to the farm. However, because the time series data had to be obtained over

a prolonged period, and because 2 sensor systems were used for data acquisition, it was not feasible to consider more groups or farms, or both. Although the disregard of the within-day as well as the between-day variability in a cluster analysis is likely the main reason for not finding consistent individual patterns, to verify our results the same approach could be tested on different herds under different management and housing conditions and with more choice in areas. Another possibility is that the present data could be analyzed with other time series methods to facilitate a comparison with the results obtained by the cluster analysis.

CONCLUSIONS

We conclude that in dairy cows, no clear individual signature could be found in the daily time series of activity and area use based on the visual inspection of dendrograms and individual time series plots. However, because the extracted distances calculated by the cluster analysis were slightly, but always more, similar within than between individuals, it seemed that such patterns were still present, though less robust. The following 2 main factors might explain the greater variability: (1) the lack of choice in areas, and (2) the temporal variability in the cows' activity. Since the approaches applied in the present study consider all events and do not correct for variability, they do not seem to be suitable for the detection of individual patterns in behavioral time series of animals that naturally display greater plasticity in their temporal structure of activity compared with animals that exhibit uni- or bimodal activity patterns.

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