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The use of evolutionary operations to assess the intervention effect on the behaviour of dairy cows

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ABSTRACT

The aim of the study was to use evolutionary operations (EVOP) to evaluate changes in the behaviour of dairy cows depending on the strategy according to which they were grouped after calving. The experiment was carried out on a Danish farm keeping about 200 Holstein cows. The farm had two separate areas for lactating cows: a small area with 54 waterbeds and a larger area with 133 beds with mattresses. During the experiment both areas were filled with cows. Cows after calving were introduced to either the small area (group) or the large area (group). After 14 days, the cows from the small group were transferred to the large group. The impact of different cow grouping strategies on their lying time, considered a welfare indicator, was examined. During the 210-day experiment, 195,703 observations were collected. The behavioural data were analysed using a linear mixed-effect regression model fitted by the maximum likelihood method. Days in milk, parity number, and lying time of herd mates were found to significantly affect the lying time of individual cows, while the strategy of cow grouping after calving had no effect on lying time.

KEY WORDS: evolutionary operation, dairy cows, cow grouping strategy, lying time

INTRODUCTION

The main goal of livestock farm management is to achieve satisfactory productivity and profitability, which are undoubtedly linked to the level of animal welfare. One of the indicators of animal welfare is behaviour, which in modern livestock facilities can be observed and monitored

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online (Müller and Schrader, 2003; O'Driscoll et al., 2008). Detection of abnormalities in the physical activity of cows, including locomotion and rumination time, enables early detection of metabolic disorders, lameness, or mastitis, thus potentially reducing cow mortality and involuntary culling. In addition, observation of cows' behaviour is used to detect oestrus and identify problems in the establishment of a social hierarchy after the animals are moved from one group to another (Cook and Nordlund, 2004; Song et al., 2008; Barman et al., 2017).

The daily time budget of cows typically consists of 3-5 h of feeding, 12-14 h of resting (lying), 2-3 h of social interactions, 7-10 h of rumination, and 0,5 h of drinking. This leaves 2,5-3,5 h left for management activities, such as milking or moving outside the pen (Grant and Albright, 2000). If one of the elements of the daily routine takes more time, the time left for other activities is reduced, potentially affecting cows' well-being and productivity. Krawczel and Grant (2009) reported that a 1 h increase in resting time results in a 1,7 kg gain in milk production, while Grant (2001) found that each additional hour of resting time translated into 0,9 to 1,5 kg more milk per cow daily.

One of the common practices in dairy herd management that may substantially influence behavioural parameters such as lying time is grouping and regrouping of animals (Grant and Albright, 2001; Cook and Nordlund, 2004; Torres-Cardona et al., 2014). Cows are grouped mainly due to their different nutritional requirements, resulting from varied milk yield and physiological status. Regrouping of animals is stressful and forces them to adjust to the new environment. After every change that disturbs the social hierarchy in the herd, it takes time for cows to establish a new order (Chebel et al., 2016). It has been observed that a hierarchy is more easily established in smaller groups of cows of a similar age, lactation stage and physiological status, exhibiting similar patterns of behaviour, than in a herd consisting of more varied individuals. During that time, social interactions between cows affect their activity, including lying time, feed intake, and rumination. Activity increases in regrouped cows because they are exposed to new herd mates, environment and treatment (von Keyserlingk et al., 2008; Torres-Cardona et al., 2014).

Various management activities can be undertaken to achieve an optimal level of livestock welfare. However, due to considerable differences between farming conditions, the results of the same management procedures can vary from farm to farm. This problem can be overcome by conducting small management experiments and assessing their effects without substantial additional labour or costs involving the entire herd. Evolutionary Operations (EVOP) is a method that can be used to analyse the effect of small experimental changes in production factors and procedures in a specific herd. The experimental changes do not overly disturb ongoing production activity, so the experiments can take place during the normal production process. The results of the intervention are reported frequently and evaluated continuously, e.g. daily or weekly. This rapid process provides herd managers and advisors with the most up-to-date information, which can be used to increase production efficiency, while also protecting against financial losses in case of any negative effects. EVOP can be particularly useful in production systems in which a large amount of data can be obtained automatically every day, e.g. from dairy herds. Direct and immediate evaluation of the effect of the changes introduced can be considered an advantage over other, more traditional methods of herd management support (Østergaard et al., 2020). EVOP has been widely used for process optimization in the chemical and engineering industries (Box, 1957). However, thus far this method has rarely been applied in livestock farming. One of the first examples is a study by Andersen et al. (2016) on the effect of different management strategies (stocking density, number of straw allocations, and allocation of pigs to pens) on the diurnal rhythm of water intake in pigs. Also recently, Stygar et al. (2017) conducted two EVOP experiments on the possible variation in cow milk production resulting from changes in certain management practices. The first experiment concerned an increase in the amount of energy provided to dairy cows in a Partial Mixed Ration (PMR) and a simultaneous decrease in concentrate supply in an Automatic Milking System (AMS). The second experiment tested the effect of increased energy concentration in a Total Mixed Ration (TMR) on reduced feeding time. A description of the applicability of various EVOP interventions to support management in commercial Danish dairy herds was also given in a recent paper by Østergaard et al. (2020).

To the authors' best knowledge, the EVOP concept has not been used to analyse data on cattle behaviour. Therefore, in the present study this method was used to assess the possible effect of two grouping strategies on the lying time of fresh cows in their second lactation and older. It was hypothesized that lying time differs between cows with fewer herd mates in a small group and those that need to associate with a larger group at the beginning of lactation and afterwards.

MATERIAL AND METHODS

Data from a commercial Danish dairy herd was used in the study. The herd consisted of approximately 200 Danish Holstein cows. The average energy-corrected milk production per cow-year was 12,500 kg. All cows were milked three times a day at 8-hour intervals in a 2 x 12 DeLaval milking parlour. Cows were fed a PMR diet consisting of grass and maize silage, with additional concentrate provided to the cows in the milking parlour according to their milk yield. The amount of concentrate in the milking parlour was gradually increased over the first 5 weeks (from 1 kg in week 1 to 5 kg in week 5).

Dry cows were housed in groups of 6 in a space with an area of about 44 square metres. They calved in this area and were moved (after minimum 0 and maximum 5 days) to a loose housing system with a slatted floor. The farm had two separate areas for lactating cows – a large area and a small area. The large area contained 133 beds, between 1,15 m and 1,25 m in width and 2,00 m in length. Each bed was covered with a mattress. Most mattresses (119) were < 5 cm thick, and the rest (14 mattresses) were 10 cm thick. The small area contained 54 beds, 1,20 m wide and 2,10 m long (from the neck rail to the back of the bed). Each bed was covered with a mattress filled with 50 litres of water. The small area was primarily used by first-lactation cows, which stayed there until approximately 150 days in milk (DIM). This area was also used for cows in need of some additional care. There was one feeding space (width 0,70 m) per cow in both areas. During the experiment, both areas, large and small, were filled with cows. The experiment was designed so that cows after calving (in second or higher lactation) stayed in the calving area from 0 to 5 days. Afterwards they were moved to either the small group (small area) or the large group (large area). Assignment to groups for each cow was determined by the expected calving dates. Cows that were moved to the small group stayed there for 14 days and were then transferred to the large group. Cow lying time was recorded with an accelerometer (IceTag3D, IceRobotics, Scotland) attached to one of the cow's legs on the day it left the calving area.

Observations were made over 210 days, from 11 February 2016 until 7 September 2016. Data was collected at 15-minute intervals. The following information was available for each cow: cow number, calving date, parity number, treatment group, date of accelerometer installation, observation date (year, month, day and minutes during the day), standing time (minutes and seconds during a 15 min interval), lying time (minutes and seconds during a 15 min interval), and date moved to a particular group (if cows were not moved, the value was set to NA). During the experiment 195,703 observations were collected. For each cow, lying data was aggregated to daily level, and 2,072 observations of daily lying time were obtained. As accelerometers were switched on and off during the day, the initial and final days of observations had to be removed (since the aggregated values did not cover a whole 24 h period). Moreover, observations for cows with daily lying time ≥ 1000 min and ≤ 300 min were deleted from the data set as outliers. To properly account for the variability among cows, days with fewer than 5 cows observed were not taken into account. The final data set contained 1,586 daily observations for 45 cows. An example of a plot for aggregated data of two selected cows is presented in fig. 1.

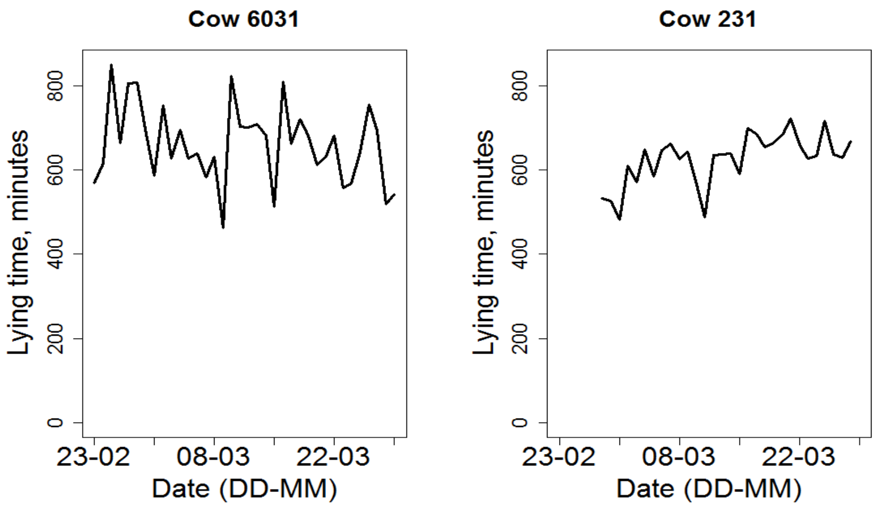

Fig. 1. Aggregated lying time (in minutes) of two selected cows from the herd, where DD is day, MM is month

In the final data set, the observations were taken over a period of 156 days, from 23 February 2016 until 27 July 2016. The cows were classified according to parity: parity 2 (24 cows with 849 observations) and parity ≥ 3 (21 cows with 737 observations). The data for each cow was supplemented with an additional continuous variable, the mean lying time of all cows on a given day. Moreover, the number of DIM was calculated for each cow based on the calving date and observation date.

The observations of the cows were assigned to four groups (A1, A2, B1 and B2). The group design is graphically presented in fig. 2.

Group A1 included the observations conducted for the first 14 DIM in cows allocated to the small group after calving (from day 0 to max day 5 after calving); group A2 consisted of observations conducted for max 44 days in cows moved to the large group after spending 14 DIM in the small group; group B1 comprised observations conducted for first the 14 DIM in cows allocated to the large group after calving (from day 0 to max day 5 after calving); and group B2 consisted of observations conducted from >14 DIM for max 50 days in cows allocated to the large group after calving.

A1 - small group Number of cows = 20 Number of observations = 258 Observation period: first 14 DIM	**A2 - large group** Number of cows = 20 Number of observations = 519 Observation period: >14 DIM for max 44 days
B1 - large group Number of cows = 25 Number of observations = 288 Observation period: first 14 DIM	**B2 - large group** Number of cows = 25 Number of observations = 687 Observation period: >14 DIM for max 50 days

*DIM - days in milk

Fig. 2. Group design in the experiment

Table 1

Linear mixed-effects regression models

Model number	Model equation[1]	Model comparison[2]		
		AIC	R^2M	R^2C
1	$Y_{it} = b_0 + b_1DIM + A_i + \varepsilon_{it}$	18638	0,06	0,52
2	$Y_{it} = b_0 + b_1DIM + b_2Parity + A_i + \varepsilon_{it}$	18640	0,12	0,52
3	$Y_{it} = b_0 + b_1DIM + b_2Parity + b_3DailyMean + A_i + \varepsilon_{it}$	18450	0,18	0,57
4	$Y_{it} = b_0 + b_1DIM + b_2Parity + b_4Grouping + A_i + \varepsilon_{it}$	18654	0,14	0,52
5	$Y_{it} = b_0 + b_1DIM + b_2Parity + b_3DailyMean + b_4Grouping + A_i + \varepsilon_{it}$	18460	0,20	0,58
6	$Y_{it} = b_0 + b_1DIM + b_2Parity + b_3DailyMean + b_4Grouping + A_i + d_t + \varepsilon_{it}$	18467	0,20	0,58

[1] Y_{it} - lying time (in minutes) of cow i on day t; b_0 – fixed effect of intercept; b_1DIM – fixed effect of DIM (days in milk), $b_2Parity$ – fixed effect of parity (2 levels: parity 2 and parity ≥ 3); $b_3DailyMean$ – fixed effect of mean daily lying time (describing lying time of all cows in the herd), $b_4Grouping$ – fixed effect of grouping (4 levels: A1, A2, B1, B2), A_i – random effect of cow i, d_t – random effect of day t, ε_{it} – random error. [2] AIC - Akaike information criterion; R^2M - marginal coefficient of determination, representing the variance explained by fixed effects, R^2C - conditional coefficient of determination, representing the variance explained by both fixed and random effects.

The collected data were analysed using linear mixed-effects regression models (tab. 1) fitted by the maximum likelihood method (ML). The models were compared using the Akaike information criterion (AIC). The proportion of variance in lying time explained by the models was expressed by the marginal and conditional coefficients of determination (R^2M and R^2C, respectively), defined by Nakagawa and Schielzeth (2013). Marginal and conditional R^2 coefficients, representing the variance explained by fixed factors (R^2M) and both fixed and random factors (R^2C), were calculated using the MuMIn package (Bartoń, 2016). Since records on lying consisted of repeated measurements on the same cow, and data on lying was collected at equally spaced calendar times, the effect of the individual cow was assumed to be an autoregressive process of order 1. While testing the differences between parities, second parity was adopted as the reference.

The main aim of the EVOP experiment described above was to test whether there were any differences in lying time between groups A1 and B1 and between groups A2 and B2. The initial order of factors in the *grouping* variable was set so that group A1 (assumed as the reference) was compared with groups A2, B1 and B2. To test the differences between groups A2 and B2, the final model was refitted with a different order of factors, so that group A2 (assumed as the reference) was compared with groups A1, B1 and B2.

Data were plotted and analysed in R statistics software (R Core Team, 2014). Model control was performed using graphical and numerical summaries as recommended by Pinheiro and Bates (2000).

RESULTS AND DISCUSSION

Among the six models tested in the present study, models 1-3 included various effects, apart from the effect of grouping (tab. 1). The effect of grouping was added to models 4-6. Based on the AIC criterion, it can be seen that among the models with this effect, model 5 was better fitted than model 4 and did not differ significantly from model 6, which additionally included the random effect of a given day. Therefore, as a compromise between accuracy and simplicity, model 5 was selected as the most appropriate. The results indicate that both fixed and random effects in this model explained almost 60% of the variability in cow lying time.

In model 5, the effects of DIM, parity and mean daily lying time were found to be significant (tab. 2). With the increase in DIM, lying time was shortened by 1,2 minutes per day ($P < 0,01$). Significantly shorter lying time in cows in the early weeks of lactation than in later weeks was also reported by Blackie et al. (2006). Their analysis of the first 12 weeks of lactation revealed that cows at 6 weeks after calving spend 1.5 h less time lying than cows at 12 weeks. In the present study, older cows (parity ≥ 3) were also shown to spend more time lying ($P = 0,03$) than second-lactation cows, by approximately 53 minutes. Interestingly, in the present study the behaviour of other cows in the herd (described by the fixed effect of mean daily lying time) significantly ($P < 0,01$) affected the lying time of a given cow. Thus, if a cow's herd mates spent more time lying, the lying time of that cow was longer as well. This could be explained by the social nature of cattle, which exhibit similar behaviour in the same environmental conditions.

According to the available literature, resting is a strong need for cows, even stronger than feed intake. If a cow is deprived of feeding and lying, it will choose lying first when both become available (Munksgaard et al., 2005; Fregonesi et al., 2007). In a free-stall housing system, the daily lying time of a cow is approximately 12 h (Jensen et al., 2005; Mattachini et al., 2011). A deviation from the average lying time may suggest a change in physiological status (oestrus or approaching parturition) but also a decline in welfare, which in turn can negatively affect productivity (Grant, 2007; Maselyne et al., 2017).

Table 2

Summary of mixed-effect model parameters used to describe lying time of cows in model 5

Model parameters	Symbol	Value	SE[1]	P-value
	Fixed effects			
Intercept	b_0	108,8	46,9	0,02
DIM[2]	$b_1 DIM$	-1,2	0,3	< 0,01
Parity (≥ 3)	$b_2 Parity$	53,3	23,9	0,03
Mean daily lying time	$b_3 DailyMean$	0,9	0,1	< 0,01
Grouping	$b_4 Grouping$			
group A2	$b_4 A2$	-19,3	10,8	0,07
group B1	$b_4 B1$	-32,7	25,3	0,20
group B2	$b_4 B2$	-54,7	26,0	0,03
	Random effects			
Random effect of cow	σ_A	77	-	-
Random error	σ_ε	81	-	-

[1]SE – standard error, [2] DIM – days in milk

However, the main experimental factor in the EVOP was grouping of cows after calving, to assess the lying time of second-lactation and older cows kept in a small group for a predefined time period before joining a large group. In general, cows in group A1 (cows allocated to a small group after calving) were found to have the longest lying time. However, there was no significant difference (P = 0,20) between groups A1 and B1 (cows allocated to a standard large group after calving). Moreover, after the factors in the fixed effect of grouping were re-ordered, no significant difference (P = 0,08) was found between groups A2 and B2. Therefore, it was concluded that changing the standard strategy of grouping cows after calving (by allocating cows to the small group for about two weeks after calving instead of immediately to the large group) had no effect on their lying time. It should be noted that the lack of significant differences in lying time between groups A1 and B1 and between groups A2 and B2 was noted despite the different quality of mattresses between the small group (the small area) and the large group (the large area).

In an experiment by Schirmann et al. (2011), significant deviations from the baseline behaviour of multiparous non-lactating cows were observed only on the day of their regrouping and 1-2 days after. The changes included an approximately 9% decrease in dry matter intake, an increased number of displacements during feed delivery, decreased ruminating time, and an increased number of lying bouts. This was consistent with the results of Cook and Nordlund (2004), who found that social interactions between cows were very high for the first 48 hours after grouping and then decreased steadily and stabilized at the baseline level. Social interactions reduce lying time and indirectly affect productivity. Torres-Cardona et al. (2014) evaluated the effects of regrouping of dairy cows on their physical activity and milk production. They observed a 26% increase in physical activity in every parity group on the day of regrouping but, similarly to the results obtained by Cook and Nordlund (2004), the activity normalized 1-2 days after relocation. The drop in milk production on the day of regrouping was not significant and appeared mainly in primiparous and second-parity cows. An experiment by Grant and Albright (2001) also revealed a 2,5-5% decrease in milk production due to social disturbances associated with cow regrouping. Heifers separated from older cows had increased lying time and eating time by 8,8% and 11,4%, respectively. This could be due to the lack of older, more dominant cows, which affected the process of hierarchy establishment in the herd.

To conclude, the EVOP findings from the experiment presented in this study are consistent with general observations concerning the behavioural effects of cow grouping. Although the cows allocated to the small group for the first 14 days after calving had the longest lying time among the experimental groups, the differences in this trait between groups A1 and B1 and between groups A2 and B2 proved to be insignificant. This suggests that allocating cows to a small group after calving and then moving them to a larger group, instead of the standard practice of immediately placing them in a large group, does not noticeably influence their lying time and thus their welfare. Therefore, given the potential additional labour and costs entailed by this type of modification, it appears to be economically unjustified. However, it should be emphasized that one of the fundamental principles of EVOP is to conduct an experiment based on modification of a process taking place in a specific herd and to generalize the sample population to the target population. Because this approach greatly restricts external validity, the results of the present study should not be generalized outside the specific context described.

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