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Flexible front barrier instead of a rigid neck rail to control the use of cubicles of cows – a pilot study

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In a cubicle barn, cubicles serve as a resting spot and as such the quality influences the well-being of the cows. To control the usage of cubicles, a rigid metal pipe neck rail attached to the cubicle separation rails is commonly used. The aim of the present pilot study was to investigate the influence of utilising a fire hose as a flexible front barrier (instead of a rigid neck rail) on the quantity and quality of standing and lying behaviour of cows, as well as the effect on the deformability of the litter mattress in the front foot area of the deep box. Neither design proved to have an influence on the lying time. However, the claw-damaging, bipedal standing in the cubicle with the hind legs situated outside of the cubicle (perching) was reduced and replaced by standing with all four feet inside the cubicle. Additionally, the number of standing events without lying down was reduced and with that the total number of standing events in the cubicle. The litter mattresses of the deep boxes were found to be significantly more deformable in the front area with a flexible front barrier. The results indicated that a flexible front barrier increased the quality of cubicle usage.

Key words
Lying behaviour, standing behaviour, neck rail, front barrier

The free stall barn with cubicles represents the most highly structured housing system for dairy cows. The cubicles used in this barn system must satisfy dairy cow requirements according to two species-specific behavioural characteristics: dairy cows are “distance animals” and they eliminate diffusely. Cubicles require a minimum size. Nevertheless, they should remain clean, as lying areas contaminated by faeces are a risk for infectious udder diseases (Bernardi et al. 2009). Additionally, polluted lying areas increase pollutant gas emissions (Mader et al. 2017), as well as increasing cleaning and bedding costs. The design of cubicles in a cubicle housing barn should therefore permit unimpeded lying down, resting and getting up (Hoy et al. 2006, Galindo and Broom 2000) and offer a comfortable and clean lying area (von Keyserlingk et al. 2011).

The neck rail is the most important control element for positioning cows in cubicles (Dahlhoff et al. 2009). Its height and the distance from the cubicle rear end influences cubicle usage (Fregonesi et al. 2009). Limiting the distance between the neck rail and the rear end of the cubicle reduces manure deposition on the lying surface (Tucker et al. 2005). At the same time, the time of perching increased and replaced standing in the cubicle with all four feet (Fregonesi et al. 2009). If the neck rail position is too low, collisions between cow and neck rail may occur in the process of rising. If a smooth and rapid movement sequence, in which the momentum of the swinging head overcomes inertia with a leverage effect easing hindquarter movement, is prevented due to the animals’ behavioural adaption,

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an increase in pressure peaks with only a slight reduction in pressure maxima may develop (Boxberger 1982). In order to buffer the effect of such pressure peaks on the carpal joints, the deformability of the cubicle litter mattress is important. Hereinafter, the neck rail will be referred to as front barrier and differentiated between a rigid front barrier (the conventional metal pipe) and a flexible front barrier (e.g. a fire hose). Thus, the conflict that the term's description refers to the structural design is circumvented.

As an alternative to changing the height and distance of the front barrier, Benz et al. (2017) suggested a flexible front barrier design positioned approximately 90 cm above the lying surface. To prepare for lying down, cows perform swinging movements with their head tilted downwards inspecting the lying surface in order to then rapidly lie down after the ground control (Hörning et al. 2001, Hörning, 2003). In this process, the head is underneath the front barrier. A rigid front barrier stops cows at the neck that enter the cubicle with an upright head position and the intention of standing, whereas a flexible front barrier at a lower level controls the position of the cows at their brisket. For this reason, the control mechanism of a flexible and a rigid front barrier differs for cows with the intention of standing (neck versus brisket), although the positioning is comparable. When the cow rises, the flexible front barrier is deformed upwards, thereby fulfilling the controlling function of a rigid front barrier. At the same time, the flexible rail enables the cow to stand with all four legs in the cubicle, as the cow is able to hold her head above the front barrier and is not forced to adopt a perching stance.

The present study will therefore examine a flexible front barrier's effect on cubicle usage, i.e. the length of time spent lying down and standing with all four feet in the cubicle. Impairments of the movement sequence when a cow stands up could possibly influence the formation and deformability of the litter bed in the front area of the cubicle. The quality of the litter bed was thus also measured.

Animals, material and method

The pilot study was conducted as a before-and-after comparison. The trial farm kept 120 Fleckvieh cows in a three-rowed cubicle housing barn built in 2009, with oppositely arranged straw-littered deep boxes (125 cm wide, 260 cm long) and solid concrete walkways with manure removing scrapers. The cows were milked daily in a separate milking building at 5:30 am and 5:30 pm. The deep boxes were also littered on a daily basis with straw stored in the headspace (which was replenished weekly) so that a constant supply of litter can be assumed. The average milk yield of the cows on the farm was 8614 kg in 2016. The feeding was based on grass and maize silage. Feeding took place at milking times. The front of the cubicle lying surface was limited by a 25 cm high vertical brisket board. In this investigation, the before situation (hereinafter referred to as "rigid front barrier") was recorded in a separated area with 47 cubicles and 47 lactating cows over six days between 16.5.2017 and 22.5.2017. The after situation (hereinafter referred to as "flexible front barrier") was recorded in the same area over six days between 29.6.2017 and 4.7.2017. There were 47 cows present in the area with flexible front barriers as well, although some cows that had previously been at the end of their lactation were removed from the group, while freshly calved cows were added. The removal of the rigid front barrier and the installation of the flexible front barrier took place on 25.5.2017. This resulted in an acclimatisation period of four weeks for the cows to get used to the flexible front barrier. The outside temperatures were between 14 and 22°C in the first evaluation period and between 19 and 24°C in the second period.

Retrofitting the front barriers

In the present study, the rigid front barrier was replaced by a flexible one, with the maximum height of the flexible front barrier corresponding to the height of the rigid neck rail. The distance to the rear edge of the cubicle of both front barrier designs was constantly at 180 cm. The initially available rigid front barriers mounted at a height of 115 cm were replaced by a flexible front barrier in the form of a size C synthetic fibre-coated fire hose and fixed with the existing clamps. The hose was protected by a metal plate fitted against the edges of the pipe clamps. Due to its flexibility, the fire hose sagged across the width of the cubicle with a height of approximately 85 cm in the middle of the cubicle. When rising, the flexible front barrier roughly reached the position of the original rigid front barrier.

Data collection

Data were collected on (i) dairy cow behavioural activity (pedometer data), (ii) cubicle usage (cubicle use data) and (iii) the deformability of the deep box (deformability data). These will be described separately below.

Collection of behavioural activity

To investigate dairy cow behavioural activities, hereinafter referred to as lying, walking and standing behaviour, 20 cows (lactation day 54 to 195 at the beginning of the preliminary recording) were randomly selected and fitted with pedometers on each left hind foot. Six of the pedometers malfunctioned during data collection, one cow had to be removed due to injury so that the total data of 13 cows with their respective pedometers were used for evaluation ($n = 13$). Moreover, the daily values of the lying and walking times of two consecutive days during the rigid front barrier period were excluded from the analysis for one cow because this cow was in heat. The pedometers collected signals continuously at ten measurements per second. The times were added up system-internally to return hourly standing, lying and walking times. Subsequently, these were used to calculate the daily lying time in the afternoon (12:00 pm to 5:00 pm), the daily total values per cow as well as the mean time spent lying per hour. Furthermore, the pedometers collected the number of lying down events per day. For data collection, RumiWatch® Pedometers (Firmware 02.23) validated by Alsaaod et al. (2015) were used (Itin + Hoch GmbH, Liestal, Switzerland).

Collection of cubicle usage

The cubicles were photographed at a total of ten out of twelve (two front barriers were defective) oppositely arranged cubicles in the middle of the barn adjacent to one of the crossways once a minute in the time between 12:00 pm and 5:00 pm. This evaluation period was chosen because within this section the standing and lying behaviour of the cows change from the midday main resting period to the typical restlessness before milking. To collect data, an infrared wildlife camera (Snapshot Limited 5.0 from Dörr GmbH, New Ulm) was installed at a height of four metres above the double-rowed cubicles and serial photographs were taken at one-minute intervals. Thus, 1800 photographs were available per evaluation period (six days of five hours each and 60 photos per hour). Usage for each cubicle was collected under the categories “not occupied”, “lying cow”, “cow standing with two feet in the cubicle” and “cow standing with four feet in the cubicle”. From this, events per cubicle were derived, whereby an event lasts from the change of a usage category (beginning) to a new change of usage (end). The time of an event was then defined as the mean time between the beginning and the end. In addition, the average standing, lying and unoccupied times as well as the number of standing and lying events were determined. Furthermore, the number of "cubicle being entered" (cubicle entry event) and the number of rising events were determined.

Collection of deformability data

The deformability of the litter mattress was measured with a mobile pneumatic measuring device developed at the University of Hohenheim, Institute of Agricultural Engineering. The device features a pneumatic cylinder and a hemispherical test calotte with a diameter of 5 cm and simulates a carpal joint's pressure load of a 700 kg cow at a load of 3150 N (Kieffer 1999). In each evaluation period, the depth of penetration was measured in all cubicles (n = 47) in the central front area below the front barrier in the mornings before adding new litter. The 47 measurements with rigid front barrier were collected on the first day of the evaluation period and another 47 measurements with the flexible front barrier were collected on the last day of the evaluation period. The measured values varied between 0.6 cm and 5.5 cm. Thus, they were within the measuring range of the device (0 – 6 cm).

Data analysis

The pedometer data on activity behaviour (lying, walking and standing time per cow and day, the number of lying events per cow and day as well as the calculated average lying time per lying event) represented data from a paired sample, as the same animals were recorded in both periods. Due to the design of the study, the treatment factor time, the period of measurements, and the day in lactation of cows are confounded. According to Maselyne et al. (2017), the daily lying time increases with increasing lactation day. Thus, the daily recorded lying time with the flexible front barrier was corrected with the formula given in Maselyne et al. (2017) depending on lactation day t:

$$y_{t-44} = y_t + 44 \cdot 0.0279 + 2.79 \cdot \left(e^{-0.0387(t-44)} - e^{-0.0387t}\right) + 12.5 \cdot [ln(t + 182 - 44) - ln(t + 182)] \quad \text{(Eq. 1)}$$

where y_{t-44} is the corrected daily lying time in hours and y_t is the observed daily lying period in hours. Note that the observed data y_{t-44} are on average 25 minutes shorter than y_t. A linear mixed model with a fixed treatment effect (rigid and flexible front barrier) and random day and cow effect was fitted to adjusted y_{t-44} data. A first order autoregressive error variance-covariance structure was assumed to account for correlated daily lying times of the cows from consecutive days. The model can be described as follows:

$$y_{ijl} = \mu + \tau_i + d_{ij} + c_l + e_{ijl} \quad \text{(Eq. 2)}$$

where τ_i is the i-th treatment effect, d_{ij} the effect of the j-th day, c_l the effect of the l-th cow and e_{ijl} is the error of observation y_{ijl}. Model (2) was also fitted for the daily walking time and the average length of lying events. Note that the data for daily walking time was logarithmically transformed. For presentation purposes only, estimated means of walking time were back-transformed. The back-transformed value estimates the median of the original scale. The standard errors were back-transformed using the delta method. An analysis of the daily standing time was omitted. Daily standing time can be calculated as difference between day length, and the sum of lying time and walking time. Thus, it also dependant on lactation stage. The hourly values were only descriptively evaluated. A Poisson distribution was assumed in contrast to the normal distribution for the number of lying events. Accordingly, a generalised linear mixed model was fitted to this data, where the expected value from model (2) was equivalent to the linear predictor. The logarithm was selected as link function. Additionally, the power of the study was determined using the approach of Stroup (2002).

On the cubicle usage data, the following model was fitted for the traits time of standing and time of lying events:

$$y_{ijkl} = \mu + \beta t_{ijkl} + \tau_i + \beta_i t_{ijkl} + d_{ij} + b_k + (bd)_{ijk} + e_{ijkl} \quad \text{(Eq. 3)}$$

whereby τ_i is the *i*-te treatment effect, β and β_i are the slope, or treatment-specific slopes, t_{ijkl} is the time of the event, and d_{ij} and b_k are the *j*-te day effect and the *k*-te cubicle effect. $(bd)_{ijk}$ is the day-specific cubicle effect. Day and cubicle effects are assumed as random. e_{ijkl} is the error of the observation y_{ijkl}. Data were logarithmically transformed for time per event traits. Calculated means were back-transformed for presentation purpose only. Again, back-transformed values represent the median of the original scale. Standard errors were back-transformed using the Delta method. For the traits number of standing, lying, rising and cubicle-entering events, a Poisson distribution was assumed. Therefore, a generalised linear mixed model was fitted to these data, where the linear predictor is equivalent to the expected value of model (3). The logarithm was chosen as link function. For the probability of standing with two or four feet in the cubicle, an analogous generalised linear mixed model was fitted assuming a binomial distribution with a logit link. For this trait, probabilities were calculated using the inverse link function for presentation purpose only. Probabilities were calculated for a variety of time points. Additionally, the absolute number of all the standing, lying, rising events and cubicle-entering events were given.

For all analysis, residuals were graphically checked for homogeneous variance and normal distribution (only in the case of traits for which no generalised linear model had been fitted for). Non-significant slope estimates (α = 0.05) were removed from the model. Afterwards, treatment means were estimated. The litter penetration depths of the pressure measurements were analysed using a paired t-test, where the pairs results from measuring cubicles twice. All evaluations were carried out within the SAS statistical software.

Results

Analysis of the activity data (lying, walking, standing times)

Based on the pedometer data from 13 cows, the average daily lying time with flexible front barrier was 15 minutes longer after its correction than with rigid front barrier (Table 1). A significance could not be proven. The lengths of lying events respective to the number of lying events did not change significantly within the study. The cows each laid down 11.6 times daily. The daily walking times did not differ significantly either.

Table 1: The influence of the front barrier design (rigid at a height of 115 cm, flexible at a height 85 cm) on selected behavioural parameters with 13 dairy cows in a before-and-after comparison, mixed linear model or generalised linear mixed model for the number of standing events.

Parameter	Unit	Rigid front barrier	Flexible front barrier	S.E.D.[2)]	p-value
Lying time per day and cow (corrected[1)])	min/24 h	742.8	756.5	15.1	p = 0.359
Length of lying events	min/event	66.4	69.7	1.9	p = 0.086
Walking time per day and cow	min/24 h	36.7	38.1	2.7/2.8[3)]	p = 0.115
Number of lying events	/day	11.6	11.6	0.03	p = 0.897

[1)] Corrected according to equation (1) (Maselyne et al. 2017).
[2)] Standard error of treatment differences.
[3)] Standard error of the median.

In both evaluation periods, a biphasic course of standing times, presumably influenced by feeding and milking times, was found (Figure 1). In the period between 12:00 pm and 6:00 pm, the average standing time per hour increased continuously and reached the daily maximum at 6:00 pm with approximately 50 minutes per hour in both evaluation periods.

Figure 1: Average standing times per cow and hour over the course of the day (hourly average values from six recording days, n = 13)

Analysis of the cubicle usage

From the data on cubicle usage, the duration of standing and lying events, the number of standing, lying, rising and cubicle entry events as well as the probability of standing with two or four feet during the observation period from 12:00 pm to 5:00 pm were derived. The number of cubicle entry events, i.e. the sum of standing events with subsequent observed lying and the standing events without subsequent lying, deviated significantly from a 1:1 ratio (162 for rigid front barrier and 102 for flexible front barrier, $p < 0.001$). No significant difference was found in the number of lying events (158 for rigid front barrier and 151 for flexible front barrier, $p = 0.733$). This means that, with a rigid front barrier, cows entered and left the cubicle more frequently without using it for lying down.

Per ten cubicles and observation minute between 12:00 pm and 5:00 pm, an average of 0.18 ± 0.014 standing events per minute took place when using a rigid front barrier, whereas with a flexible front barrier the number of standing events was significantly lower ($p < 0.001$) with 0.14 ± 0.012 standing events per minute. No time dependency of the standing events could be proven. Over the six days, there were a total of 193 standing events with rigid front barrier and 152 with flexible front barrier. There were no differences in the mean standing time per standing event ($p = 0.567$) with a median of 4.67 ± 0.27 with rigid front barrier and 4.88 ± 0.30 minutes per standing event with flexible front barrier. There were significant differences in standing quality: With the rigid front barrier, the probability of standing with four feet in the cubicle to the total standing time was significantly lower at 7 to 11% than in the period of flexible front barrier with 41 to 52%. The probability of cows standing in the cubicle with all four feet decreased significantly over time in both front barrier designs (Figure 2).

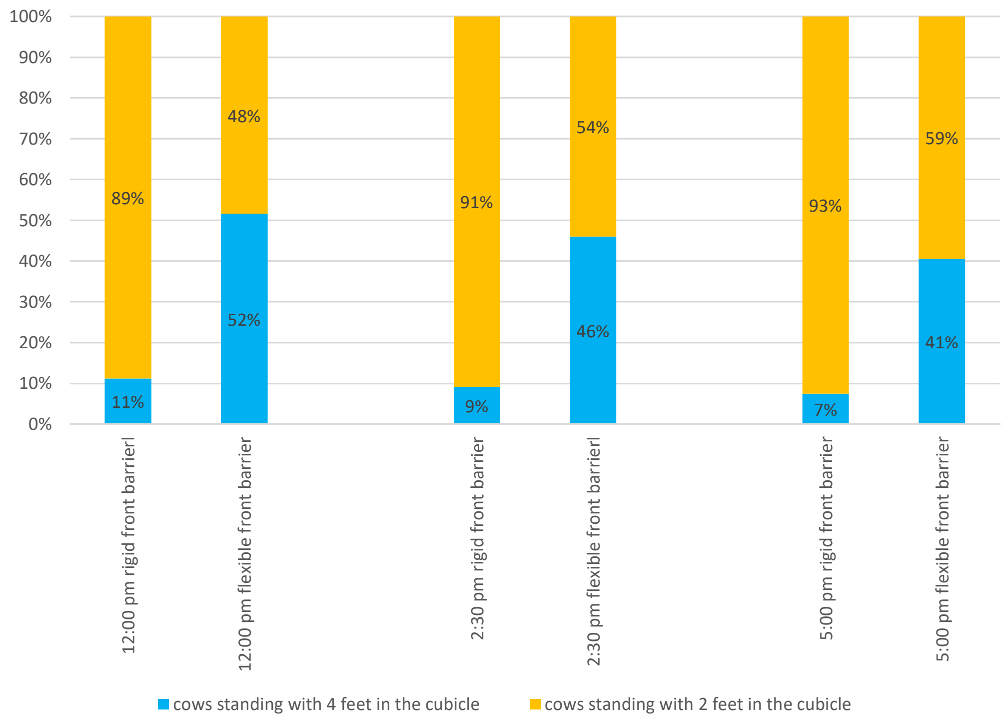

Figure 2: Estimated probability of standing with two or four feet in the cubicle over total time (values estimated from observations of six recording days in both evaluation periods of rigid and flexible front barriers in ten cubicles at 12:00 pm, 2:30 pm and 5:00 pm)

The length of lying events of the cows between 12:00 pm and 5:00 pm were comparable for both front barrier designs (p = 0.486). However, over the course of the afternoon, the length of the lying events decreased continuously (from about 70 minutes at 12:00 pm to 25 minutes at 5:00 pm, Figure 3).

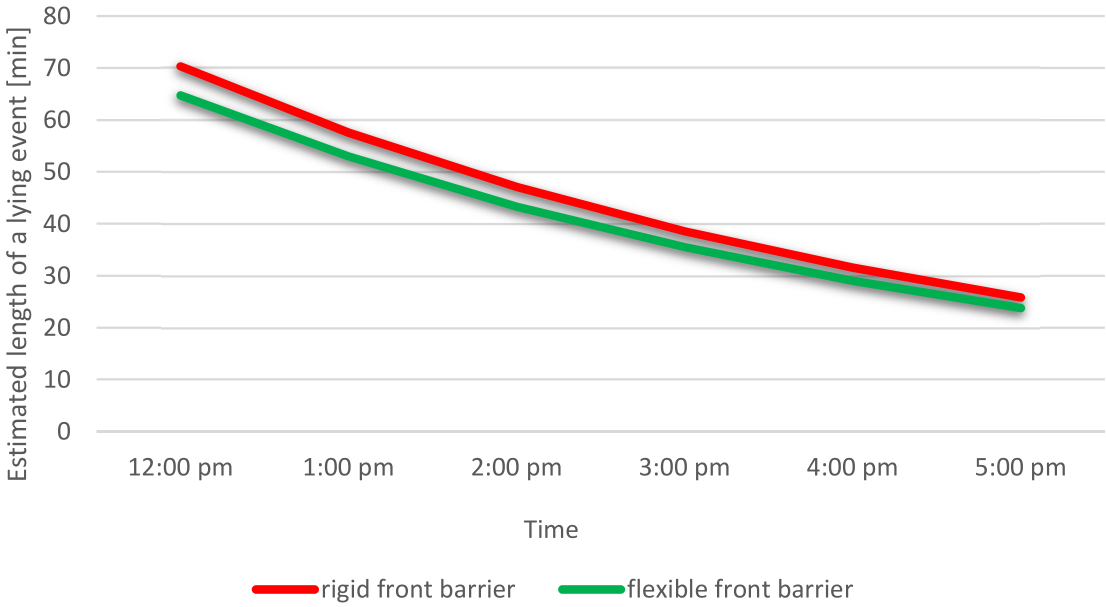

Figure 3: Changes in the estimated average length of lying events with rigid and flexible front barrier, observed in ten cubicles over six days each in the period from 12:00 pm to 5:00 pm.

Deformability of the lying surface

The deformability of 47 cubicles showed significant differences between the front barriers (Figure 4). With rigid front barrier, an average deformation of 2.2 cm was measured, with flexible front barrier the average value increased to 3.6 cm (n = 47, p < 0.001).

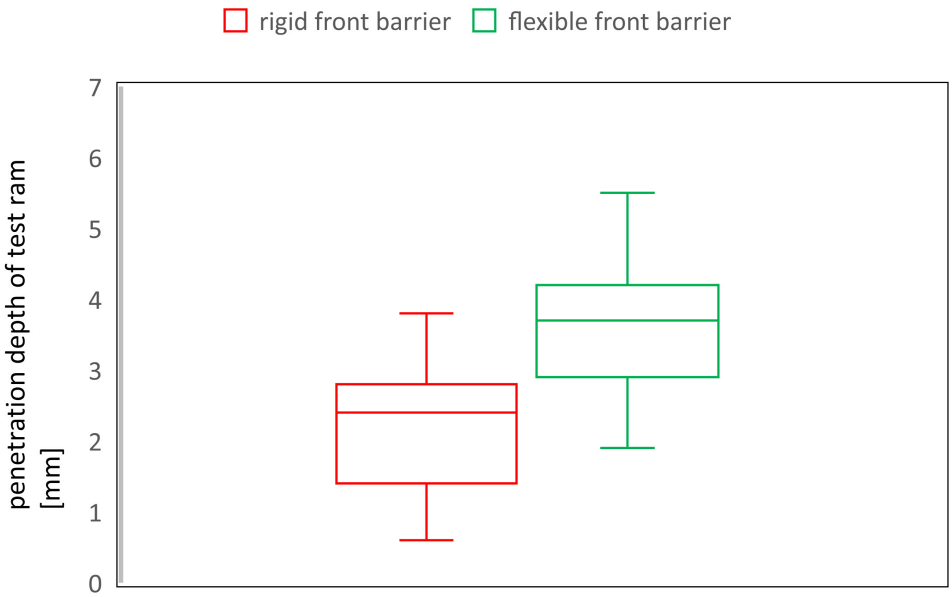

Figure 4: Deformation of the lying surface with rigid and with flexible front barrier, measured in 47 cubicles. The boxplots show the median and the quartile, the asterisks show the significance for p <0.001.

Discussion

In the current experiment, a rigid metal pipe front barrier at a height of 115 cm was replaced by a flexible front barrier at a height of 85 cm. This was not only a change in the front barrier's material and height, but also its mode of operation. When rising and lying down, the flexible front barrier reached approximately the position of the original rigid front barrier so that the positioning of a lying cow is expected to be similar in either case. In contrast, the flexible design's controlling mechanism of a standing cow deviates fundamentally from that of a rigid front barrier. The flexible front barrier carried out the function of positioning a standing cow in the cubicle by brisket contact and not by neck contact.

The present experiment was conducted as a before-and-after comparison, whereby the treatment, time period and lactation stage effects cannot be statistically separated from one another. In order to be able to identify treatment effects nevertheless, the evaluation periods have to be comparable and the lactation stage effect eliminable. To achieve comparable evaluation periods, similar conditions with respect to outside temperatures were considered within the present study. With temperatures of up to 24°C, it can be assumed that no heat stress was experienced by the cows that could have influenced their lying behaviour (Geischeder et al. 2016). Additionally, there were no changes in feed ration, feeding routine or milking times.

Discussion of the activity data

The results showed that the lying behaviour of the examined cows in both front barrier designs corresponded with the guideline values with at least 720 – 780 minutes per day (NFACC 2009, Charlton et al. 2014). Benz et al. (2020) measured average daily walking times of 44 minutes on 159 farms with a total of 1414 animals. The comparatively short walking times on the farm in this experiment (around 37 minutes daily partly explain the resulting quantity of standing, but not its quality. The daily courses of standing times each showed a biphasic course, with its rhythm primarily determined by photoperiod, feeding routine and milking times (Tilger 2005). In order to eliminate the effects of lactation stage in the characteristics recorded with pedometer, the function from Maselyne et al. (2017) was used. After a correction of the pedometer data, the total lying time for both evaluation periods did not differ significantly from one another, which corresponds to the results of other studies (Tucker et al. 2004, Bernadi et al. 2009, Fregonesi et al. 2009, Abade et al. 2015). It should be noted, however, that this result is based on the data of 13 pedometers, which, depending on the number of recording days, could prove a real difference of 30 to 45 minutes with about 80% probability. For cubicle usage data, it was assumed that the mean lactation day was the same for both evaluation periods due to newly joining animals. For the interpretation of the results, it was therefore postulated that the test periods were comparable and that the differences of the lactation stage in the pedometer data were correctable using the formula of Maselyne et al. (2017).

Discussion of the cubicle usage data

The study showed that, depending on type of front barrier, there were no differences in the number of lying events in the time between 12:00 pm to 5:00 pm; however, the number of cubicle entry events (162 with rigid front barrier and 102 with flexible front barrier) and the number of standing events differed significantly. Although the standing time per event was shorter with a rigid front barrier, the difference was not significant. If one assumed that cubicles are entered with the intention of lying as well as standing, it could be assumed that both variants of cubicles are entered with the intention of lying with the same frequency. The additional cubicle entry events with a rigid front barrier would then be considered to be events with standing intention, in which the cubicle is visited as a place of retreat for standing. The more frequent but shorter visits to cubicles with fixed front barriers could be explained by a premature termination of the standing event in the cubicle and a new attempt to stand in another cubicle. Further research should look into this aspect more deeply, as premature termination of a standing event in a cubicle could possibly lead to increased social stress and in any case moving from one cubicle to another exposes the claw to manure.

The use of flexible front barriers resulted in a shift from the undesired standing with two feet in the cubicle (perching) to cows standing with all four feet in the cubicle. Increased standing with four feet inside the cubicle generally suggests improved claw health (Somers et al. 2003, Bernardi et al. 2009, Galindo and Broom 2000). Perching increases mechanical stress on the rear claws and is considered claw-damaging, as there is often increased contamination directly behind the cubicle (Figure 5). The duration of perching was nearly halved after the installation of flexible front barriers, while the claw-friendlier standing in the cubicle was more than tripled. In subsequent investigations, it should therefore be investigated whether these orders of magnitude are also reflected when the entire day is taken into account. Moreover, long-term observations on the development of claw health should be carried out. It would also be interesting to explore whether other influencing factors besides the front barrier, such as the dimensions of the head space, limit the use of the cubicle for standing.

Figure 5: An example of perching on a working dairy farm: Claws standing in a manure covered area behind the cubicle (© B. Benz)

Uninfluenced by the kind of front barrier, the length of lying events decreased from noon to evening, which might be explained by the fact that high-yielding cows may find lying on an increasingly full udder uncomfortable. If further studies were carried out on farms with automated feeding and milking, this question could be examined. The knowledge about the optimum for the respective time budget and the temporal distribution of the behavioural activities lying, walking and standing is still incomplete. However, it can be assumed that nowadays standing is a logical consequence in the daily budget of feeding instead of foraging, which is confirmed by numerous studies (Benz et al. 2020, Oberschätzl-Kopp 2017, Tilger 2005).

Discussion of possible interactions between cubicle usage and the deformability of the straw mattress

In the present study, in addition to animal behaviour parameters, the deformability of the straw mattress in the deep box was investigated. The assumption was that adverse effects of a rigid front barrier could possibly change the sequence of the cow's rising process. A flexibly designed front barrier could support the unimpeded rising of the cow, which requires a smooth, rapid movement sequence in order to fully exploit inertia and leverage during head swings (Boxberger 1982). As cows are presumably heavier nowadays, the forces on the carpal joints are likely to be even higher than in the cited studies. Unimpeded rising should put less strain on the straw mattress in the front area of the cubicle. Within the present study, a higher deformability of the straw litter mattress could be proven with flexible front barrier. Additionally, the relative height of the brisket board directly depends on the thickness of the litter mattress. A brisket board that is too high can restrict the lying position (Pelzer et al. 2007), reduce lying times (Tucker et al. 2006) and hinder the rising process (Boxberger 1982). The study presented here showed a correlation between the type of front barrier and litter mattress quality in the front area of the cubicle deep box for the first time. Due to the high relevance of such a possible correlation for practical farming and the methodological limitations of the pilot study presented here, it would be desirable to verify this approach in further studies. In addition, the relative height of the brisket board to the lying surface and its effect on the cow's natural lying positions with extended front legs should also be investigated.

Conclusions

The results of the pilot study presented here showed that a lower-positioned flexible front barrier has potential to increase the use of the cubicle by facilitating lying as well as complete standing with four feet in the cubicle. These findings are of great interest in commercial farming because retrofitting a flexible front barrier is practical and, besides encouraging improvements in cubicle use, leads to expectations of long-term positive developments in claw health.

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