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Effects of cubicle characteristics on animal welfare indicators in dairy cattle

D. Gieseke[1a†], C. Lambertz[2] and M. Gauly[2]

[1]Department of Animal Sciences, Georg-August-University of Göttingen, Albrecht-Thaer-Weg 3, Göttingen 37075, Germany; [2]Faculty of Science and Technology, Free University of Bolzano, Universitätsplatz 5, Bolzano 39100, Italy

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Cubicle characteristics such as cubicle dimensions or management factors such as cow-to-cubicle ratio could affect health and behaviour of dairy cows. The objective of this study was to estimate effects of cubicle characteristics on animal welfare indicators in dairy cattle. A total of 64 loose housing farms in Germany were assessed once during the winter housing period by one experienced assessor. Nearly 15% of the dairy cows had access to pasture during summer months for <6 h/day, whereas 85% were zero-grazing farms. Selected animal welfare indicators (duration of the lying down process, collisions of cows with cubicles, cows lying outside cubicles, cow cleanliness, integument alterations, lameness and subclinical mastitis incidence) of the Welfare Quality® protocol and cubicle characteristics such as cow-to-cubicle ratio and cubicle dimensions were recorded. Data were statistically analysed using a multiple linear regression approach. Pasture access and cubicle type were considered as potential influencing factors. Wider cubicles positively affected the proportion of dairy cows with dirty flanks (−18.5% per 10 cm increase) but increased the number of cows with severe integument alterations (+8.9% per 10 cm increase). Larger lying areas reduced the percentage of cows with dirty udders (−2.9% per 10 cm^2 increase). Longer distances from neck rail to curb were associated with higher prevalence of cows with dirty flanks (+3.1% per 10 cm increase) and subclinical mastitis incidence (+1.2% per 10 cm increase). With increasing neck rail height, the duration of the lying down process (−0.1 s per 10% increase), the percentages of cows with dirty legs (−8.4% per 10 cm increase), dirty udders (−7.0% per 10 cm increase) and severe lameness (−3.0% per 10 cm increase) decreased. Compared with rubber mat-equipped cubicles, deep-bedded cubicles showed a reduction in the lying down duration (−0.8 s), percentages of cows with dirty legs (−34.2%), dirty udders (−30.5%) and lesions and swellings (−13.1%). Compared with farms that did not provide any summer grazing, pasture access was associated with an increase of cows with severe lameness (+5.6%). Contrastingly, the number of cows with subclinical mastitis incidence was lower when cows had access to pasture in summer (−5.4%). Findings of the present study indicate several associations between cubicle characteristics and animal welfare in dairy cattle. Bedding type was found as the most influencing factor in terms of health and behaviour. Results of this study are valuable for farmers to identify the optimal cubicle design and improve the animal welfare level.

Keywords: dairy cows, housing system, cubicle design, Welfare Quality® protocol, well-being

Implications

The observed associations between cubicle characteristics (e.g. cow-to-cubicle ratio, cubicle dimensions) and related animal welfare indicators (e.g. lying down duration, cow cleanliness and lameness) can help farmers to optimize the lying areas of their dairy cows. Based on the most relevant animal welfare problems in the herds, cubicle characteristics can be modified by the farmers and resting comfort of the cows effectively improved. For example, deep-bedded cubicles were favourable regarding lying down duration, cow cleanliness and integument alterations compared to rubber mat-equipped cubicles and can be recommended to obtain higher animal welfare levels in dairy cattle farms.

Introduction

Currently, the majority of dairy cows in Germany are kept in loose housing systems (73%) with or without access to pasture. The majority of these farms have cubicle barns

[a]Present address: Faculty of Organic Agricultural Sciences, University of Kassel, Nordbahnhofstraße 1a, Witzenhausen 37213, Germany.

[†] E-mail: daniel.gieseke@uni-kassel.de

(87%), in which the animals can rest in individual cubicles (Destatis, 2018). Restrictive cubicle separations have positive effects on the cleanliness of lying surfaces and dairy cows, respectively. Cows are not able to stand with all four feet in cubicles when neck rails are positioned low and consequently do not defecate on the lying surface (Abade *et al.*, 2015). For example, lower distances (130 cm) between neck rails and rear curb reduced the dirtiness of cows compared to higher distances (190 cm) (Bernardi *et al.*, 2009). However, restrictive cubicle separations might also have detrimental effects on behaviour and health of dairy cattle. Inadequate cubicle dimensions might disturb standing up and lying down movements in the cubicles. These lead to painful collisions with cubicle partitions and integument alterations on prominent parts of the body such as spinal column or hip bones (Potterton *et al.*, 2011; Brenninkmeyer *et al.*, 2013). Cubicles with inadequate cubicle dimensions are uncomfortable for the cows and might lead to increasing standing durations (Chapinal *et al.*, 2013). Due to prolonged contact with manure in the walking alleys, animals are at higher risk of claw diseases and lameness (Cook and Nordlund, 2009). Aspects of housing and management such as cubicle type or pasture access could also have strong effects on animal welfare in dairy cattle. Deep-bedded cubicles have positive effects on locomotion (Husfeldt and Endres, 2012) and integument alterations (Brenninkmeyer *et al.*, 2013). Pasture access during the summer period is beneficial regarding integument alterations (Haskell *et al.*, 2006) and lameness (Wagner *et al.*, 2018; Armbrecht *et al.*, 2019). Most studies examined the effects of different cubicle characteristics on single animal welfare indicators (e.g. lameness, hock lesions or cleanliness). However, effects of cubicle design or management decisions might differ between welfare indicators and should consequently be evaluated using a multidimensional approach. Therefore, the objective of this study was to examine the various relationships between cubicle characteristics and related animal welfare indicators. The results could help farmers to optimize cubicle design and consequently improve animal welfare in their herds.

Material and methods

Study design

A total of 64 conventional dairy farms located in northern Germany were visited once during the winter housing season from 2014 to 2016 by one experienced animal scientist. The animal welfare level was assessed using the Welfare Quality® protocol **(WQP)** for dairy cattle (Welfare Quality, 2012). This is a standardized indicator system for on-farm animal welfare assessment, which focuses mainly on animal-based measures from the fields of feeding, housing, health and behaviour. The assessor was trained intensively by a member of the Welfare Quality® Network. The official training course consisted of theoretical exercises with photo and video material and practical applications on several dairy cattle farms. Data collection of this study was conducted by one assessor, so that a consistent application of the WQP can be assumed.

Farm selection

Farm recruitment was organized with the support of different agricultural stakeholders (e.g. chamber of agriculture, milk-recording associations and research facilities). The dairy farms were selected on a voluntary basis according to the prevalent housing conditions, because comparability between the farms should be guaranteed. Therefore, all lactating dairy cows were kept in cubicle barns. The cubicles were either deep bedded (72%) or equipped with rubber mats (28%). Farms with both types of cubicles were not considered. Nearly 15% of the dairy cows had access to pasture during summer months (<6 h/day), whereas 85% were zero-grazing farms. The dominant breed was Holstein-Friesian. Further information on farm characteristics and performance data is presented in Table 1.

Welfare indicators

The animal welfare level of the dairy farms was generally assessed following the instructions of the WQP. Minor modifications and assessment methods are described in Supplementary Table S1. At the beginning of the farm visit, indicators of lying comfort (duration of the lying down process, collisions of cows with cubicles and cows lying outside cubicles) were recorded using continuous behaviour sampling. The clinical scoring of individual dairy cows was carried out in the same sample of animals (cow cleanliness, integument alterations and lameness). Depending on the herd size, a sample of 32 to 102 cows were assessed at each farm visit (Welfare Quality, 2012). Finally, milk-recording data (milk somatic cell count (**SCC**)) of the last 3 months before farm visit were gathered during a farmer interview.

Cubicle characteristics

In addition to the indicators of the WQP, potentially associated cubicle characteristics such as cow-to-cubicle ratio and cubicle dimensions were recorded. The data collection was executed based on the methods described in von Keyserlingk *et al.* (2012). Cow-to-cubicle ratios of the different lactating groups were averaged and multiplied by 100 (>100% = overstocking; <100% = understocking). Cubicle dimensions including bed length from curb to brisket locator (cubicle length), distance between two adjacent cubicle partitions (cubicle width), distance between neck rail and lying surface (neck rail height), distance between neck rail and curb (neck rail to curb), distance between divider and lying surface (divider height) and lying surface dimensions (cubicle length × cubicle width) were recorded exemplary on at least two representative cubicles. Deep-bedding cubicles contained long straw, horse manure or sawdust, whereas rubber mat-equipped cubicles were interspersed with chopped straw and chalk. Further information on cubicle design parameters is presented in Table 1.

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Table 1 *Characteristics (farm data, performance data and cubicle design) and results of selected indicators of the Welfare Quality® protocol of dairy cattle of 64 dairy farms classified by pasture access (zero-grazing* v. *pasture access <6 h) and type of cubicle (rubber mats* v. *deep bedded), respectively*

Farm parameters/welfare indicators	Pasture access		Type of cubicle		Total ($n=64$)
	Pasture access ($n=9$)	Zero-grazing ($n=55$)	Deep bedded ($n=46$)	Rubber mats ($n=18$)	
Farm data[a]					
Herd size cows (n)	127 (61 to 465)	415 (47 to 1609)	376 (48 to 1609)	370 (47 to 1555)	374 (47 to 1609)
Pasture access (h)	4 (2 to 5)	0 (0 to 0)	0 (0 to 5)	1 (0 to 5)	1 (0 to 5)
Pasture access (days)	180 (150 to 210)	0 (0 to 0)	12 (0 to 180)	42 (0 to 210)	20 (0 to 210)
Deep-bedded cubicles (%)	55.6 ($n=5$)	74.6 ($n=41$)	100.0 ($n=46$)	0.0 ($n=0$)	71.9 ($n=46$)
Rubber mat cubicles (%)	44.4 ($n=4$)	25.4 ($n=14$)	0.0 ($n=0$)	100.0 ($n=18$)	28.1 ($n=18$)
Performance data[b]					
Milk yield (kg)	8913 (658)	10 014 (946)	10 088 (863)	9274 (1061)	9859 (985)
Fat content (%)	4.0 (0.2)	4.0 (0.2)	4.0 (0.2)	4.1 (0.2)	4.0 (0.2)
Protein content (%)	3.4 (0.1)	3.4 (0.1)	3.4 (0.1)	3.4 (0.1)	3.4 (0.1)
Cubicle design[b]					
Cow-to-cubicle ratio (%)	110.3 (18.2)	97.9 (13.1)	100.4 (13.4)	97.6 (17.1)	99.6 (14.4)
Cubicle length (cm)	183.6 (8.2)	190.9 (14.2)	190.6 (15.2)	188.1 (8.9)	189.9 (13.7)
Cubicle width (cm)	111.9 (3.7)	111.8 (3.4)	111.9 (3.6)	111.6 (3.1)	111.8 (3.4)
Length × width (m^2)	2.1 (0.1)	2.1 (0.2)	2.1 (0.2)	2.1 (0.1)	2.1 (0.2)
Neck rail to curb (cm)	200.2 (15.2)	200.4 (11.0)	199.2 (9.4)	203.4 (15.7)	200.4 (11.6)
Neck rail height (cm)	113.3 (7.1)	118.0 (8.8)	118.1 (8.5)	115.4 (9.0)	117.3 (8.7)
Divider height (cm)	58.2 (7.7)	57.1 (11.9)	57.2 (12.2)	57.2 (8.8)	57.2 (11.3)
Welfare indicators[b]					
Duration of the lying down process (s)	5.9 (0.6)	5.9 (0.8)	5.7 (0.6)	6.6 (0.7)	5.9 (0.7)
Collisions with cubicles (%)	11.1 (9.8)	19.0 (16.4)	17.0 (14.5)	20.0 (19.1)	17.9 (15.8)
Cows lying outside cubicles (%)	3.2 (4.6)	3.5 (5.7)	3.6 (5.9)	2.9 (4.5)	3.4 (5.5)
Cows with dirty legs (%)	66.5 (28.4)	53.2 (28.1)	44.8 (23.9)	81.3 (21.1)	55.1 (28.3)
Cows with dirty flanks (%)	65.4 (29.0)	68.9 (20.5)	67.2 (19.5)	71.7 (26.8)	68.4 (21.7)
Cows with dirty udders (%)	55.1 (27.3)	43.2 (24.2)	35.4 (18.3)	69.2 (22.6)	44.9 (24.8)
Cows with lesions/swellings (%)	29.0 (19.5)	27.1 (13.9)	23.8 (13.5)	36.5 (13.8)	27.3 (14.6)
Cows with severe lameness (%)	18.3 (11.4)	15.3 (10.1)	14.6 (10.1)	18.6 (10.2)	15.7 (10.2)
Cows with mastitis incidence (%)	15.5 (7.5)	21.0 (7.5)	20.0 (8.4)	20.7 (5.5)	20.2 (7.7)

[a]Median (minimal – maximal).
[b]Mean (SD).

Statistical analysis

The hypothesized effects of different cubicle characteristics on related animal welfare indicators were analysed using a multiple linear regression approach. Observed values of the selected animal welfare indicators were used as outcome variables. Cubicle characteristics such as cow-to-cubicle ratio, cubicle length, cubicle width, length × width, neck rail height, neck rail to curb and divider height were considered as explanatory variables. Pasture access (<6 h/day) and type of cubicle (deep-bedded *v.* rubber mat) were also included as explanatory variables in all multiple linear regression models, because they were potential confounding effects. The selection process consisted of three consecutive steps. First, collinearity analysis between each of the candidate explanatory variables was performed. Second, potential risk factors were screened for associations between outcome and explanatory variables using a univariate linear regression analysis. Variables with a *P*-value below 0.20 were carried over for subsequent statistical analysis. Third, multivariate linear regression analysis was executed to select explanatory variables to be included in the final model (Proc REG, SAS 9.4). The following multivariate linear regression model was used:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_m x_{mi} + \varepsilon_i$$

with Y_i = observed value of animal welfare indicators, β_0 = interception term, $\beta_1 \ldots \beta_m$ = regression coefficients for the m explanatory variables and ε_i = model error term. The multivariate regression models were fitted using backward selection procedure. Variables with $P > 0.20$ were removed from the model. Explanatory variables with *P*-values between 0.05 and 0.20 remained in the model, if they contributed to the adjusted R^2 value. Assumptions of normal distribution and homoscedasticity of the residuals were examined visually.

Results

Observed values of the animal welfare indicators are shown in Table 1. On average, dairy cows needed 5.9 s for lying down

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Table 2 *Results of the multiple linear regression analysis regarding the effect of different housing parameters on selected indicators of lying comfort, cow cleanliness and animal health in dairy cattle*

Welfare indicators/housing parameters	Estimate	SE	*P*-value	R^2
Duration of the lying down process				
Intercept	7.23	1.34	<0.001	0.307
Cow-to-cubicle ratio	−0.01	0.01	0.126	
Neck rail height	−0.01	0.01	0.156	
Rubber mat cubicle (*v.* deep bedded)	0.83	0.17	<0.001	
Collisions with cubicles				
Intercept	39.12	13.57	0.006	0.026
Cow-to-cubicle ratio	−0.22	0.13	0.114	
Cows lying outside cubicles				
Intercept	9.05	3.68	0.017	0.021
Divider height	−0.10	0.06	0.135	
Cows with dirty legs				
Intercept	109.97	40.21	0.008	0.386
Neck rail height	−0.84	0.33	0.012	
Rubber mat cubicle (*v.* deep bedded)	34.17	6.23	<0.001	
Cows with dirty flanks				
Intercept	242.10	107.22	0.028	0.108
Cow-to-cubicle ratio	−0.29	0.19	0.127	
Cubicle width	−1.85	0.77	0.019	
Neck rail to curb	0.31	0.29	0.181	
Cows with dirty udders				
Intercept	149.80	46.09	0.002	0.448
Length × width	−0.29	0.14	0.036	
Neck rail height	−0.70	0.27	0.013	
Rubber mat cubicle (*v.* deep bedded)	30.52	5.19	<0.001	
Cows with lesions/swellings				
Intercept	−89.39	55.23	0.111	0.174
Cubicle width	0.89	0.49	0.073	
Rubber mat cubicle (*v.* deep bedded)	13.05	3.70	0.001	
Cows with severe lameness				
Intercept	48.50	26.67	0.074	0.144
Cow-to-cubicle ratio	−0.24	0.09	0.007	
Cubicle length	0.13	0.09	0.136	
Neck rail height	−0.30	0.14	0.040	
Access to pasture (*v.* zero-grazing)	5.59	3.70	0.135	
Cows with subclinical mastitis incidence				
Intercept	−2.84	16.39	0.863	0.063
Neck rail to curb	0.12	0.08	0.153	
Access to pasture (*v.* zero-grazing)	−5.37	2.67	0.049	

SE = standard error; $P < 0.20$; R^2 = coefficient of determination.

and 17.9% collisions with cubicle partitions were recorded. The mean percentage of cows lying outside cubicles was 3.4%. The number of dirty animals differed between the examined body regions. Mean percentages of cows with dirty legs (55.1%) and flanks (68.4%) were higher compared to the proportion of cows with dirty udders (44.9%). Severe integument alterations such as lesions or swellings were recorded in 27.3% of the assessed cows, whereas 15.7% of the cows were classified as severely lame. On average, 20.2% of the cows showed signs of subclinical mastitis (>400 000 cells/ml).

Effect of cubicle characteristics on lying comfort

The results of the statistical analysis are presented in Table 2. The final multivariate regression model for the indicator 'duration of the lying down process' explained 30.7% of the variance ($P < 0.001$). Shorter lying down movements were observed in farms with higher cow-to-cubicle ratios (−0.1 s per 10% increase) and higher neck rails (−0.1 s per 10 cm increase). Furthermore, cubicles equipped with rubber mats (+0.8 s *v.* deep-bedded cubicles) were associated with longer durations of lying down movements. The final model for the indicator 'collisions with cubicles' explained 2.6% of the variance ($P = 0.114$). Lower percentages of collisions with cubicles were associated with higher cow-to-cubicle ratios (−2.2% per 10% increase). The final model for the indicator 'cows lying outside cubicles' explained 2.1% of the variance ($P = 0.135$). Lower percentages of cows lying outside cubicles were found in farms

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with higher distances between divider and lying surface (−1.0% per 10 cm increase).

Effect of cubicle characteristics on cleanliness

The final multivariate regression model for the indicator 'cows with dirty legs' explained 38.6% of the variance ($P < 0.001$). Lower prevalence of cows with dirty legs was detected in farms with higher neck rails (−8.4% per 10 cm increase). Contrastingly, higher prevalence of cows with dirty legs was associated with rubber mat-equipped cubicles (+34.2% *v.* deep-bedded cubicles). The final model for the indicator 'cows with dirty flanks' explained 10.8% of the variance ($P = 0.021$). Lower prevalence of cows with dirty flanks was found in farms with higher cow-to-cubicle ratios (−2.9% per 10% increase) and wider cubicles (−18.5% per 10 cm increase). Contrastingly, higher prevalence of cows with dirty flanks was associated with higher distances from neck rail to curb (+3.1% per 10 cm increase). The final model for the indicator 'cows with dirty udders' explained 44.8% of the variance ($P < 0.001$). Higher prevalence of cows with dirty udders was observed in farms providing cubicles equipped with rubber mats (+30.5% *v.* deep-bedded cubicles). Contrastingly, lower prevalence of cows with dirty udders was associated with larger lying areas (−2.9% per 10 cm^2 increase) and higher neck rails (−7.0% per 10 cm increase).

Effect of cubicle characteristics on animal health

The final multivariate regression model for the indicator 'integument alterations' explained 17.4% of the variance ($P = 0.001$). Higher prevalence of cows with severe integument alterations was found in farms providing cubicles equipped with rubber mats (+13.1% *v.* deep-bedded cubicles). Furthermore, higher numbers of cows with lesions and swellings were associated with wider cubicles (+8.9% per 10 cm increase). The final model for the indicator 'severe lameness' explained 14.4% of the variance ($P = 0.010$). Higher prevalence of severely lame cows was found in farms with longer cubicles (+1.3% per 10 cm increase) and providing access to pasture (+5.6% *v.* zero-grazing). Contrastingly, a lower prevalence rate of severely lame cows was associated with higher cow-to-cubicle ratios (−2.4% per 10% increase) and higher neck rails (−3.0% per 10 cm increase). The final model for the indicator 'subclinical mastitis incidence' explained 6.3% of the variance ($P = 0.053$). More cows with subclinical mastitis were found in farms with higher distances between neck rail and curb (+1.2% per 10 cm increase), whereas fewer cows were observed in farms providing access to pasture (−5.4% *v.* zero-grazing).

Discussion

The average time needed to lie down (5.9 s) was in accordance with values found in France with 5.9 s (de Boyer des Roches *et al.*, 2014) and Germany with 5.7 s (Wagner *et al.*, 2018). Slightly lower lying down durations were measured with 5.2 s in the United Kingdom (Heath *et al.*, 2014). The number of cows colliding with cubicle partitions (17.9%) was similar to the median of 14.3% in France (de Boyer des Roches *et al.*, 2014) and the mean of 20.6% in Germany during barn season (Armbrecht *et al.*, 2019). Higher values were found with 26.5% in the United Kingdom (Heath *et al.*, 2014) and 32.3% in the Netherlands (de Vries *et al.*, 2013), which might be explained by methodological challenges. Collisions with cubicle partitions were assessed during a relatively small number of lying down movements, so that high variability between farms could be expected. The percentage of cows lying outside cubicles (3.4%) was similar to 2.3% observed by Heath *et al.* (2014). Slightly higher values were found in Belgium with 5.1% (de Graaf *et al.*, 2017). Farms had a large number of cows with dirty flanks (68.4%) and dirty udders (44.9%), which was in accordance with previous studies. However, percentages of cows with dirty legs (55.1%) were considerably lower compared with 80% to 90% in the literature (Heath *et al.*, 2014; de Graaf *et al.*, 2017; Wagner *et al.*, 2018). Conceivably, farms of the present study had cleaner walking alleys, which might be explained by higher cleaning frequencies (deVries *et al.*, 2012; de Graaf *et al.*, 2017). The observed percentages of cows with severe integument alterations (27.3%) comply with the mean prevalence of 21.4% in Belgium (de Graaf *et al.*, 2017). Contrastingly, higher percentages of lesions and swellings were investigated in France with 39.2% (Coignard *et al.*, 2013) and in the Netherlands with 35.3% (de Vries *et al.*, 2013). The prevalence of severely lame cows (15.7%) was higher compared to other examinations. Coignard *et al.* (2013) found only 2.9% (0.0% to 34.6%) severely lame cows, whereas de Vries *et al.* (2013) detected 5.0% (0.0% to 65.9%). Presumably, lameness prevalence was influenced by the study design. Straw barns were excluded from this study, which are known as beneficial for preventing claw disorders or lameness (Haskell *et al.*, 2006). Percentages of cows with high milk SCCs (20.2%) were in accordance with other studies. Coignard *et al.* (2013) observed on average 20.6% of the dairy cows with a SCC above 400 000 cells (2.0% to 46.6%). The subclinical mastitis incidence rates were somewhat lower with 15.5% in the United Kingdom (Heath *et al.*, 2014). This might be explained by a higher amount of pasture access, which is beneficial for udder health (Arnott *et al.*, 2017).

Effect of cubicle characteristics on lying comfort

Dairy farms with deep-bedded cubicles were characterized by shorter lying down durations compared to dairy farms equipped with rubber mats. Conceivably, high amounts of bedding material provide soft lying areas and make the lying down process more comfortable (Husfeldt and Endres, 2012). Similar results were found in the Netherlands (van Gastelen *et al.*, 2011). The authors recorded the duration from entering the cubicle with all four feet to the final lying down position. Cows needed more time for preparation and lying down on foam mattresses (140.2 s) compared with deep-bedded cubicles filled with sand (50.1 s) or horse manure (32.9 s),

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respectively (van Gastelen *et al.*, 2011). Contrastingly, no relationship between bedding type and lying down duration was observed in Switzerland (Wechsler *et al.*, 2000). When barns are over-stocked and less cubicles than cows are provided, competitions for the cubicles might occur (Fregonesi *et al.*, 2007). Conceivably, dairy cows lie down faster in order to avoid displacements by other herd members. However, in the present study average cow-to-cubicle ratio was nearly balanced (99.6%), so that no effect on the lying down duration could have been expected. The observed association might depend on an unidentified confounding effect. Farms with deep-bedded cubicles had higher cow-to-cubicle ratios (100.4%) compared to farms equipped with rubber mats (97.6%). Stall features such as neck rails can restrict the normal rising and lying down movements (von Keyserlingk *et al.*, 2012). Higher distances between neck rail and lying surface enable the cows to stand with all feet in the cubicles and potentially lie down faster due to less constraints (Tucker *et al.*, 2005). Furthermore, Bernardi *et al.* (2009) observed an increased number of lying bouts in cubicles with less restrictive neck rails, which was explained by undisturbed lying down and standing up movements. This training effect might have affected the lying down process, too. The indicator 'cows lying outside cubicles' describes not only cows lying completely outside the designated lying area but also cows lying with their hindquarter on the edge of cubicles (Welfare Quality, 2012). Therefore, cubicle dimensions such as cubicle length or cubicle width were expected to affect the results of this indicator. Cubicles with longer lying areas might prevent the legs of the cows from coming into contact with the protruding edge of the curb (Haskell *et al.*, 2006; Brenninkmeyer *et al.*, 2013). Wider cubicles might also be beneficial for the lying comfort, because the cows could lie down diagonally within the cubicles. Contact with cubicle restrictions such as the curb could therefore be avoided (Veissier *et al.*, 2004). However, only higher distances between cubicle divider and lying surface were associated with lower percentages of cows lying outside the lying area in the current study. Perhaps cows have problems in shifting their position in the cubicles, if the distance between divider and lying surface is too short (Brenninkmeyer *et al.*, 2013). More free space under the divider enables the cows to use adjacent cubicles with their rump or feet, which might result in lower percentages of cows lying outside cubicles (Veissier *et al.*, 2004).

Effect of cubicle characteristics on cleanliness

Deep-bedded cubicles were associated with lower percentages of soiled legs and udders compared to cubicles equipped with rubber mats. This may be explained with higher amounts of bedding material, which absorbs moisture from urine or faeces (Ruud *et al.*, 2011). Similarly, Plesch and Knierim (2012) observed 8.1% less cows with soiled teats in deep-bedded cubicles compared with rubber mats. Contrastingly, comparable cubicle hygiene scores were found for deep-bedded cubicles (2.49 ± 0.03) and rubber mats (2.53 ± 0.05) by Husfeldt and Endres (2012). Lying surfaces of deep-bedded cubicles are often restricted by curbs, in order to maintain the bedding material within the cubicles (Plesch and Knierim, 2012). Tails of the cows might be deposited less often in the soiled walking alleys, because the curbs confine the lying area. Consequently, cows are less often splashing manure with their tails from the alley floor on their bodies (deVries *et al.*, 2012). Cubicle width significantly affected the cleanliness of the cows' flanks. Wider cubicles were associated with lower percentages of cows with dirty upper legs. Similarly, Ruud *et al.* (2011) observed lower faecal contaminations in the stall surface of wider cubicles (>1.13 m) compared to narrower cubicles (<1.13 m) in Norwegian dairy cattle farms. Conceivably, dairy cows were forced to lie down with parts of their body in adjacent cubicles if the distance between two cubicles is too short (Veissier *et al.*, 2004). Cubicle surfaces and neighboured cows were therefore at a higher risk of being contaminated with soiled legs or tails (Ruud *et al.*, 2011). Contrastingly, wider stalls were described as a risk factor for cubicle cleanliness due to more frequent use by the cows (Tucker *et al.*, 2005).

The percentage of cows with dirty udders was influenced by the provided lying area (length × width). Positive effects of larger lying areas on the cleanliness of dairy cows were unexpected, because these were usually associated with more frequent defecating when standing or lying diagonally in the cubicles (Lombard *et al.*, 2010; Ruud *et al.*, 2011). More comfortable cubicles might also lead to longer lying durations, which are associated with poor hygiene of flanks and udder. Shifting of the lying position may increase the risk of soiling, because faeces might be spread over the body (deVries *et al.*, 2012). The observed positive effect of the accessible lying area on udder cleanliness remained unclear. Conceivably, other housing or management factors such as height of bedding material or cleaning frequency are more important (Fulwider *et al.*, 2007; Ruud *et al.*, 2011). Longer distances between neck rail and the edge of the curb were associated with more frequent soiling on the flanks. Previous studies have proven that restrictive neck rail positions closer to the curb contribute to less contamination of the cubicles, because dairy cows were forced to step back while defecating (Tucker *et al.*, 2005; Fregonesi *et al.*, 2009; Lombard *et al.*, 2010). For example, lower distances (130 cm) between neck rails and vertical plane above the rear curb reduced the contamination score of dairy cows compared to higher distances (190 cm) in a Canadian study (Bernardi *et al.*, 2009). Similarly, more faecal contamination was found in alternative stalls without neck rails (4.2 ± 0.3 dirty squares/stall) compared to more restrictive cubicles (0.2 ± 0.3 dirty squares/stall) in Canadian dairy cattle farms (Abade *et al.*, 2015). Not only the diagonal position of the neck rail but also the distance between neck rail and lying surface might influence cow cleanliness (Fregonesi *et al.*, 2009). Longer distances between neck rail and lying surface reduced the number of cows with dirty legs and dirty udders in the present study. Conceivably, dairy cows avoided rising in cubicles with lower neck rail heights and defecated more often while lying in the cubicle (Bernardi *et al.*, 2009; Plesch and Knierim, 2012). Restricted neck rail positions might also lead to increased standing times in the walking alleys, which

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is a further risk factor for soiling (Nielsen *et al.*, 2011; deVries *et al.*, 2012). Contrastingly, Ruud *et al.* (2011) did not observe an association between neck rail height and cubicle cleanliness.

Effect of cubicle characteristics on animal health

Wider cubicles were associated with a higher prevalence of severe integument alterations in the current study. Cubicle partitions such as dividers should control the position of the cows in the cubicles. Inappropriate positioning of the cows might increase the risk of hitting the obstructions while lying down or standing up and therefore cause injuries (Veissier *et al.*, 2004; Haskell *et al.*, 2006; von Keyserlingk *et al.*, 2012). Wider stalls are also more comfortable for dairy cows, so that they usually spend more time lying down (Bernardi *et al.*, 2009; Abade *et al.*, 2015). Dairy cows are exposed to the lying surface for a longer period and potentially at a higher risk of developing hock lesions (Potterton *et al.*, 2011). However, Brenninkmeyer *et al.* (2013) did not find any relationship between cubicle width and hock injuries. In contrast to other studies, no further cubicle dimensions had an influence on the number of lesions and swellings. Lack of associations might have been caused by different assessment methods. Integument alterations of all body regions were assessed in this study (e.g. neck region, carpal joint and tarsal joint), whereas only hock lesions were considered in most of the other studies. The positive effect of deep-bedded cubicles could be explained with soft bedding material, which prevents abrasion on the joints (Haskell *et al.*, 2006; Brenninkmeyer *et al.*, 2013). Cows from farms with deep-bedded cubicles had 10- to 20-fold fewer hock lesions compared to cows of farms with cubicles equipped with mattresses in Switzerland (Wechsler *et al.*, 2000). Similar results were found by other authors (Lombard *et al.*, 2010; Potterton *et al.*, 2011; Husfeldt and Endres, 2012).

Overstocking is usually associated with reduced lying time, because fewer cubicles than cows are available (Fregonesi *et al.*, 2007). Due to prolonged standing times in the soiled alleys, higher percentages of lame cows might be assumed (Winckler *et al.*, 2015). However, reduction in daily lying time (<12 h) becomes evident at cow-to-cubicle ratios exceeding 150% (Cook and Nordlund, 2009). Mean cow-to-cubicle ratio in the current study (99.6 ± 14.4%) is far away from this value and therefore, no negative effects on claw health could be expected. The observed positive effect of higher cow-to-cubicle ratios on lameness may have been caused by other housing and management factors. Lower cow-to-cubicle ratios were mostly found in older barns within the present study. Conceivably, dairy cattle farmers provided more cubicles than cows to compensate unfavourable housing conditions (e.g. space per cow).

Higher neck rails were related to lower numbers of severely lame cows. Less restrictive neck rail positions enable the cows to stand with all four feet in the cubicles (Lombard *et al.*, 2010). For example, Abade *et al.* (2015) reported that dairy cows spent more time standing with their entire body in alternative cubicles without neck rails (0.60 ± 0.06 h/day) compared to conventional cubicles with neck rails (0.05 ± 0.06 h/day). Similar results were found by Tucker *et al.* (2005). Longer standing times with all four feet within the cubicles were beneficial for claw health, because claws were less exposed to manure in the alleys and could dry off more frequently (Fregonesi *et al.*, 2009; Nielsen *et al.*, 2011). No association of neck rail height and lameness was observed in North American dairy cattle farms (Chapinal *et al.*, 2013).

The observed association between pasture access and severely lame cows was unexpected, because pasture access is usually known as beneficial for claw health and locomotion (Arnott *et al.*, 2017; Armbrecht *et al.*, 2019). For example, Haskell *et al.* (2006) found 15% lame cows in farms with pasture access, whereas 39% lame cows were found in zero-grazing farms. Similarly, recent studies by Armbrecht *et al.* (2019) and Wagner *et al.* (2018) described lower percentages of lame cows with increasing pasture access (>6 h/day). Dairy cows of the present study had only minor access to pasture (<6 h/day), which might have reduced the beneficial effect of pasture. Furthermore, the proportion of farms providing access to pasture ($n = 9$) was relatively small compared to zero-grazing farms ($n = 55$). Results should therefore be interpreted cautiously due to missing statistical evidence.

Higher percentages of dairy cows with a SCC above 400 000 cells/ml were associated with longer distances between neck rail and the edge of the curb. This might be caused by poorer dairy cow hygiene in less restrictive cubicles (deVries *et al.*, 2012). Udder infections provoked by environmental pathogens might be more likely in cubicles with less restricted neck rails, because the udder is at a higher risk to be contaminated with faeces and urine (Ruud *et al.*, 2011). For example, lower distances (130 cm) between neck rails and rear curb reduced the dirtiness of dairy cows compared to higher distances (190 cm) (Bernardi *et al.*, 2009). Similarly, Tucker *et al.* (2005) and Fregonesi *et al.* (2009) observed higher soiling in cubicles with less restrictive neck rail positions.

Pasture access seemed to have a beneficial effect on udder health, presumably due to increased lying time or lower exposure with environmental pathogens (Arnott *et al.*, 2017). Washburne *et al.* (2002) reported that zero-grazing cows (42.8%) showed higher percentages of at least one clinical mastitis than cows with access to pasture (24.2%). However, average somatic cell scores were not significantly different between the systems (3.1 ± 0.9 *v.* 3.1 ± 0.9). Similarly, Wagner *et al.* (2018) and Armbrecht *et al.* (2019) found no positive effect of different levels of pasturing on the number of cows with high SCCs. Again, the low proportion of farms providing access to pasture might have influenced the results. Further research is needed to investigate potential effects of pasture access on udder health.

Conclusions

Findings of the present study indicate several associations between cubicle characteristics and animal welfare indicators

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in loose-housed dairy cattle farms. Bedding type had the strongest effect on health and behaviour. Deep-bedded cubicles positively affected most of the examined indicators (e.g. lying down duration, cow cleanliness and integument alterations) and can be recommended to obtain higher animal welfare levels in dairy cattle farms. Farmers who are not able to implement this beneficial housing system due to structural or economic reasons could use the results of the multivariate regression approach to find optimal cubicle designs for their individual farm situation. According to the most relevant animal welfare problems in the herds, cubicle characteristics could be modified and housing conditions of the dairy cows effectively improved.

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D. Gieseke 0000-0002-8199-219X

Declaration of interest

The authors declare that they have no competing interests.

Ethics statement

The authors confirm that ethical policies of the journal have been adhered to. No ethical approval was required as non-invasive procedures were conducted in this study.

Software and data repository resources

None of the data were deposited in an official repository.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1751731120000609

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