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Effects of space allowance on the behaviour and cleanliness of finishing bulls kept in pens with fully slatted rubber coated flooring

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Abstract

To assess whether and how much indicators of animal welfare are influenced when space allowance is increased we studied the behaviour of finishing bulls in pens of 2.5, 3.0, 3.5 and 4.0 m^2/animal with rubber coated slatted floors.

A total of 56 finishing bulls were kept in eight groups which were observed in two consecutive batches of four groups each. Space allowance was varied in a randomised-block design and changed every 4 weeks when the bulls weighed about 360, 405, 450 and 500 kg. After 3 weeks of adaptation to the new space allowance, the bulls' behaviour was recorded using video for 48 h. At the end of the fourth week, the bulls were scored for dirtiness. Data were evaluated using generalised mixed-effects models.

With increasing space allowance, bulls had more lying bouts per day (by a factor of 1.056 m^{-2}, $P = 0.012$), lay for longer periods on their sides or on their belly with at least one fore and one hind leg stretched out (by a factor of 1.458 m^{-2}, $P < 0.001$) and changed their lying posture more often (plus 5.26 changes m^{-2}, $P < 0.001$). Moreover, they avoided the area in the centre of the pen while lying (OR = 0.354, $P < 0.001$), kept greater distances from other lying bulls (by a factor of 1.28 m^{-2}, $P < 0.001$) and stepped less frequently on a lying animal (OR = 0.341, $P < 0.001$). When more space was provided, the likeliness of an animal becoming dirtier was reduced. There was no significant effect of space allowance on the rate of mounting. It is concluded that increasing space allowance up to the investigated 4 m^2 has several beneficial and no negative effects on indicators of the welfare of finishing bulls kept on fully slatted rubber coated floors.

Keywords: Cattle; Finishing bulls; Rubber coated slatted floors; Space allowance; Behaviour; Cleanliness

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1. Introduction

Finishing bulls are often kept in pens with fully slatted concrete floors. Compared to housing systems with a straw bedded lying area, this is advantageous with regard to labour input and production costs. From an animal welfare point of view, however, slatted concrete floors are considered as restrictive. Several studies have shown that the time spent lying and the number of lying bouts per day are reduced in pens with fully slatted floors compared to housing systems with straw bedding (Andreae, 1979; Graf, 1987; Ruis-Heutinck et al., 2000; Hickey et al., 2002, 2003; Gygax et al., in press) indicating that bulls avoid frequent lying down and a long total lying duration on a hard surface. Moreover, slipperiness may be a problem with slatted concrete floors. Falling and slipping while lying down and standing up as well as abnormal lying-down and standing-up movements are less frequent in housing systems with a straw bedded lying area (Andreae, 1979; Ruis-Heutinck et al., 2000; Gygax et al., in press). Finally, hock lesions are more prevalent in bulls kept in pens with fully slatted concrete floors (Schulze Westerath et al., in press).

Recently, rubber coated slatted floors have been tested as an alternative floor quality in housing systems for finishing bulls (Ruis-Heutinck et al., 2000; Thio et al., 2005; Gygax et al., in press; Schulze Westerath et al., in press). The results of these studies show that finishing bulls lie down more frequently, slip less and have fewer hock lesions on such floors compared to concrete slatted floors. When compared to housing systems with a straw bedded lying area, however, other variables of lying behaviour such as the proportion of interrupted standing-up or lying-down movements and the number of displacements of lying animals per day as well as the incidence of hock lesions indicate that the animal welfare level is reduced in housing systems with rubber coated slatted floors (Gygax et al., in press; Schulze Westerath et al., in press).

In studies comparing pens for finishing bulls with a slatted floor and straw bedding, floor quality is often confounded with space allowance, as housing systems with a straw bedded lying area usually have an additional feeding area and are therefore characterised by a larger total floor area per animal than fully slatted pens. Thus, it cannot be excluded that some of the differences observed between these two housing systems are caused by differences in space allowance rather than floor quality. The aim of the present study was, therefore, to test whether and how much indicators of animal welfare are influenced when space allowance is varied in pens with rubber coated slatted floors. In an experiment, we analysed the effects of four space allowances (2.5, 3.0, 3.5 and 4.0 m^2) on the behaviour and cleanliness of finishing bulls.

2. Material and methods

2.1. Animals, housing and treatments

A total of 56 finishing bulls, mainly cross breeds of Simmental, Red Holstein, Brown Swiss, Limousin, Hinterwald and Aubrac, were used in the experiment. They were acquired in two batches of 28 animals at an age of about 6 months and housed at the Agroscope Reckenholz-Tänikon Research Station ART (Tänikon). They were habituated to each other for about 4 weeks in either two pens with straw bedding on a sloping floor (batch 1) or in one deep-litter straw pen (batch 2), all with concrete feeding areas. At an average weight of 339 kg (batch 1: 342 kg, batch 2: 338 kg), the bulls in each batch were assigned to four groups of seven animals and introduced into the experimental pens with fully slatted rubber coated floors (slat gap width 3.5 cm; brand name LOSPA, Gummiwerk Kraiburg Elastik GmbH, Tittmoning, Germany). The groups were matched for weight and breed as well as possible with the aim of obtaining groups of similar average initial weight, similar weight variability and similar variability in breed composition. Thus they reflected groups that are found commonly in on-farm situations. Data collection periods for the two batches started in May and October 2004, respectively, and lasted 16 weeks each.

Space allowances of 2.5, 3.0, 3.5 and 4.0 m^2/bull were tested. In an initial phase of 2 weeks directly after grouping, all the groups were kept on the same space allowance of 3.25 m^2 per animal to adapt to the new housing conditions and floor quality. Afterwards, space allowance was changed for each batch in a crossed design every 4 weeks (at approximately 360 kg: set-up of initial experimental space allowance; at approximately 405, 450 and 500 kg: changes to the space allowance; at about 543 kg: final observation after the fourth experimental space allowance). Each experimental group thus experienced each space allowance once for a period of 4 weeks and each of the four space allowances was assigned to one group at any one time. The sequence of space allowances tested in each group was randomised, but changes of pen size from the smallest to the biggest space allowance or vice versa were avoided. Though the design was fully balanced, we decided to include both space allowance and point in time, i.e. age of the bulls, in the statistical analyses. This was done to ensure that the influence of the space allowance was estimated corrected for temporal effects and because we expected different effects of the space allowances at different times due to the increasing size and weight of the bulls.

Two experimental pens were installed on each side of a feed alley within an insulated building illuminated by natural daylight. To optimise climate, all the windows and the door were kept open and a ventilator was switched on during hot periods. Changes of space allowances were made by means of movable rails separating adjacent pens, resulting in changes of pen width (varying from 3.5 to 5.6 m) while pen depth (5 m) was kept constant. By varying space allowance in this way, the groups remained in the same pen over the whole experimental period. After each change of pen size, the bulls had 3 weeks to get used to the new space allowance before data were collected in the fourth week. The experimental period ended when the bulls reached an average live weight of 543 kg (batch 1: 549 kg, batch 2: 535 kg). Due to injuries unrelated to the experimental treatments, one animal in batch 1 and one animal in batch 2 needed to be taken from their group for the last (4.0 m^2) and the two final space allowances (4.0, 3.0 m^2), respectively. The size of the pens was adjusted in a way that the space allowance per bull remained the same as before the removal of the animals.

Feed (79% maize silage, 21% hay and 2 kg pellets/(animal day)) and water were available ad libitum. The bulls were fed once a day, between 8:30 and 9:30 in the morning and feed was pushed to the feed rack once or twice later on in the day. Manger space was not split into separate feeding places and was kept constant at 3 m per group over the whole experimental period.

2.2. Behavioural observations and dirtiness scoring

The behaviour of the bulls was observed over 48 h for each space allowance using video recordings. During the night, a dim light was switched on above each pen to allow continuous recording. Similar-looking bulls in the same pen were marked (patterns dyed on their coat) to allow individual recognition. Behaviour was recorded using the ETHO software (Windows Version 4.1.0, R. Weber, Agroscope Reckenholz-Tänikon Research Station ART).

Standing-up and lying-down movements were recorded continuously for each animal, and the total lying duration as well as the number of lying bouts per animal per 24 h were calculated. In addition, each change in lying posture was recorded continuously, differentiating between (a) lying on the side with all legs stretched out, (b) lying on the belly with at least one fore and one hind leg stretched out, (c) lying on the belly with one or (d) two fore legs but no hind legs and with (e) one or (f) two hind legs but no fore legs stretched out (angle between hind leg and trunk axis greater than 45°) and (g) lying with none of the legs stretched out. We report the duration of an outstretched lying posture combining lying postures a and b. It was also recorded continuously whenever a bull lay in the central area of the pen. To do so, the total floor area was fictitiously split into nine even-sized rectangles and it was decided whether the front part of the bulls (at least the shoulders and head) were inside the fictitious rectangle positioned in the centre of the pen. Furthermore, we collected data on all occurrences of stepping on a lying bull and mounting.

A scan sampling method (once every hour) was used to record the distance between each lying animal and its nearest lying neighbour (from neck to neck). From this data, an average value for each of the bulls was calculated for each of the space allowances.

Dirtiness scoring of the bulls was carried out at the end of the 2 weeks of the initial phase of the experiment and, thereafter, every 4 weeks after video recordings, just before changing the space allowance. Bulls were scored in their home pen in a mobile weighing box. Dirtiness of the animals was scored for eight body zones (area around tail, upper and lower hind legs, belly, sternum, shoulders, upper and lower front legs) using the method described by Faye and Barnouin (1985), differentiating between five levels of intensity (scores from 0 to 2 in steps of 0.5). For the statistical analysis, sum scores over all zones were calculated and differences (improvements and deteriorations) per individual bull between these scores at the beginning and the end of an experimental condition with a given space allowance were analysed.

2.3. Statistical analyses

All our data was collected at the level of the individual bulls. In principle, 56 bulls were observed on four different space allowances (224 potential observations), but three measurements were missing due to the two bulls that needed to be taken from their group towards the end of the data collection period ($n = 221$).

It was expected that some of the nine response variables could measure the same underlying mechanism and should thus not be evaluated independently. Therefore, we conducted a correlation analysis in which we correlated our response variables using a Kendall correlation. Surprisingly, no pair of variables was highly correlated (τ maximally up to 0.3). This may have been due to the hierarchical structure of the data, i.e. data points were more closely correlated within the individuals than overall, though with only four measurements per individual it was not possible to quantify this effect. In addition, we attempted to reduce the number of variables using principal component analysis (Venables and Ripley, 2002). It was not possible to reduce the response variables to a few principal components which would reflect a high proportion of the variability in the data. In addition, the principal components were not easily interpretable.

2.3.1. Continuous response variables

The variables were used as continuous responses in linear mixed-effects models (Pinheiro and Bates, 2000) where statistical assumptions were met. With all variables (except the number of changes in lying posture), a logarithm transformation needed to be taken to satisfy the assumptions (Table 1). The basic model was of the form:

$$Y_{ijkl} = \alpha + b_i + b_{ij} + b_{ijk} + \beta_1 X^{(1)}_{ijkl} + \beta_2 X^{(2)}_{ijkl} + \beta_3 X^{(1)}_{ijkl} X^{(2)}_{ijkl} + \varepsilon_{ijkl}, \text{ or}$$

$$\log(Y_{ijkl}) = \alpha + b_i + b_{ij} + b_{ijk} + \beta_1 X^{(1)}_{ijkl} + \beta_2 X^{(2)}_{ijkl} + \beta_3 X^{(1)}_{ijkl} X^{(2)}_{ijkl} + \varepsilon_{ijkl}, \text{ i.e.}$$

$$Y_{ijkl} = e^{\alpha} e^{b_i} e^{b_{ij}} e^{b_{ijk}} e^{\beta_1 X^{(1)}_{ijkl}} e^{\beta_2 X^{(2)}_{ijkl}} e^{\beta_3 X^{(1)}_{ijkl} X^{(2)}_{ijkl}} e^{\varepsilon_{ijkl}}$$

with $X^{(1)}$, the space allowance (2.5, 3.0, 3.5, 4.0 m^2/bull), $X^{(2)}$, the points in time (of the observations, i.e. experimental period and age class of the bulls: 1, 2, 3, 4), $X^{(1)}X^{(2)}$, their interaction, and b_i, b_{ij} and b_{ijk} the nested random effects of batch, group and individual.

If the interaction was non-significant, it was omitted from the model, but the two main effects were retained even if they were not significant to keep the models more comparable. We then tested whether this reduced model was significantly improved, if we included space allowance and points in time as ordered factors (i.e. additionally including the variables to the power of 2 and 3) and their interaction. If this was not the case, we concluded that the pattern observed was so close to linear that we could treat space allowance and points in time as continuous variables. In other words, the deviations between the data and the model fits visible in Fig. 1 must be considered random. This procedure led to the simplest possible descriptions of the change in the response variables depending on space allowance and point in time. Because we conducted multiple tests and we viewed the inclusion of an interaction or a polynomial extension as a severe complication of a model, we included such extensions only if they improved the model at a level of $P < 0.01$.

Random effects of the intercept of bulls nested in housing group nested in batch were included to reflect the experimental design and to accommodate correlations in the data within animals, housing groups and batches. Model assumptions required that the random effects and the error term were iid (independently identically distributed) following a normal distribution with a variance specific to each term. These assumptions were checked using diagnostic plots. Normality of the residuals and random effects were checked using quantile–quantile plots of the residuals and random effects, respectively. Residuals were plotted against fitted values and explanatory variables (space allowance, points in time) to check for homoscedasticity. The plots against the explanatory variables were used at the same time as a further check whether residuals showed some consistent deviation from the assumed linear relationship between the response and the explanatory variables.

For the response variables lying in an outstretched body posture and distance between lying bulls, we found three and one outliers, respectively, which were omitted from the model presented in Section 2 though they hardly changed parameter estimates or P values. The outliers in lying in an outstretched body posture were very low values from three individuals in different groups, one at a space allowance of 2.5 m^2 and two at a space allowance of 3.5 m^2. The outlier in the distances was an exceptionally high value at 3.5 m^2 space allowance.

2.3.2. Dichotomised response variables

The distribution of the residuals for three variables (lying in the central area of the pen, stepping on lying bulls, changes in the dirtiness score, Table 1) deviated markedly from the expected normal distribution. We decided to dichotomise these variables and thus model the probability of a bull lying down in the central area of the pen, the probability of a bull stepping on lying bulls and the probability of a deterioration in the dirtiness score (generalised linear mixed-effects model; McCulloch and Searle, 2001; Venables and Ripley, 2002). We chose the quasi-binomial distribution because it estimates a dispersion parameter and can thus account for over-dispersion in the data. We checked that the response variables contained a minimum number of positive (and negative) outcome values 10 times the number of degrees of freedom used by the explanatory variables in all three models as recommended by Hosmer and Lemeshow (2000, chapter 8). We were well within this range except for the deterioration of the dirtiness score where we just reached this limit due to the many polynomial extensions of the explanatory variables (Table 1). These logistic models were of the form:

$$P[Y_{ijkl} = 1] = \frac{1}{1 + e^{-\eta}}, \quad \eta = \alpha + b_i + b_{ij} + b_{ijk} + \beta_1 X^{(1)}_{ijkl} + \beta_2 X^{(2)}_{ijkl} + \beta_3 X^{(1)}_{ijkl} X^{(2)}_{ijkl} + \ldots$$

with the same structure in the linear part as was used in the models with a continuous response (see above).

For the generalised mixed-effects models no likelihood-ratio tests should be conducted but rather one should use approximations based on the parameter estimates and their standard error (Pinheiro, personal communication; Ripley, personal communication). This is why we could not use a model-comparison test to decide whether polynomial extensions were necessary in these variables. We thus set up the model as depicted in the formula above and additionally included both variables (space allowance and point in time) to the power of 2 and 3 and all two-way interactions (i.e. we included the variables space allowance and points in time as ordered factors and also considered their interaction). We started out from this model and reduced terms in a step-wise backward manner until only significant terms, the two main effects, or terms still used in interactions remained in the model (the necessary extensions all happened to have $P < 0.01$, Table 1).

For the models based on the binomial distribution, residuals were plotted against the fitted values including a smoother to see that there were no consistent deviations in the residuals from an average value of zero. We also checked whether the random effects were normally distributed based on quantile–quantile plots. In addition to checking the statistical assumptions of the models regarding error distribution, we

Table 1
Response variables, definitions, units of measurement, transformations, modelling approach, statistical results and biological relevance

Traits used as response variables (including their definition)	U	T	Space allow (m^2)	Summary statistics			Statistical model fixed effects					Biological relevance		Statistical model random effects		
				Mean	CI	*N*	Effect	*b* ± S.E.	d.f.	*F*, *t*	*P*	Change per unit	CI	gg	ii	Error
Lying behaviour																
Lying duration	min	log	2.5	806.20	789.89; 822.85	221	Space	0.008 ± 0.006	1,163	1.77	0.18	F: 1.008	0.996; 1.020	0.032	0.040	0.049
Total duration spent lying per 24 h			3.0	813.98	799.81; 828.41		Time	0.003 ± 0.003	1,163	0.96	0.33	F: 1.003	0.997; 1.009			
			3.5	798.47	783.09; 814.14		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	823.28	809.15; 837.67											
Lying bouts	#	log	2.5	12.58	11.67; 13.55	221	Space	0.054 ± 0.022	1,163	6.38	0.012	F: 1.056	1.010; 1.103	0.051	0.180	0.186
Number of lying instances that were interrupted by standing per 24 h			3.0	12.90	11.92; 13.96		Time	−0.100 ± 0.011	1,163	78.76	<0.001	F: 0.905	0.885; 0.925			
			3.5	14.01	12.96; 15.15		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	13.41	12.42; 14.48											
Lying in outstretched body posture	min	log	2.5	25.60	20.35; 32.20	221	Space	0.377 ± 0.060	1,160	39.70	<0.001	F: 1.458	1.295; 1.642	0.181	0.456	0.495
Duration of lying on the side with all legs stretched out or lying on the belly with at least one fore and one hind leg stretched out per 24 h			3.0	33.00	26.92; 40.45	(−3)	Time	−0.065 ± 0.030	1,160	4.60	0.034	F: 0.937	0.883; 0.995			
			3.5	38.51	29.65; 50.02		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	45.57	38.69; 53.68											
Changes between lying postures	#	–	2.5	34.35	26.94; 41.76	221	Space	5.260 ± 0.995	1,163	27.99	<0.001	A: +5.260	3.296; 7.225	2.092	6.898	8.240
Number of changes between seven different lying postures per 24 h			3.0	42.50	34.59; 50.40		Time	−0.106 ± 0.498	1,163	0.05	0.83	A: −0.106	−1.090; 0.878			
			3.5	52.43	43.01; 61.85		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	53.01	45.52; 60.51											
Lying at centre of pen	min	>0	2.5	0.79	0.67; 0.90	221	Space	−1.039 ± 0.254	163	−4.10	<0.001	OR: 0.354	0.215; 0.582	0.119	1.274	0.875
Duration of lying in the central area of the pen per 24 h			3.0	0.58	0.45; 0.72		Time	0.210 ± 0.126	163	1.67	0.10	OR: 1.234	0.964; 1.579			
			3.5	0.52	0.38; 0.65		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	0.48	0.34; 0.62											
Distance between lying bulls	cm	log	2.5	113.45	108.74; 118.36	221	Space	0.247 ± 0.019	1,162	167.41	<0.001	F: 1.280	1.233; 1.33	0.032	0.071	0.158
Average distance to the nearest lying bull (based on hourly scan samples)			3.0	120.15	115.11; 125.41	(−1)	Time	−0.012 ± 0.010	1,162	1.65	0.20	F: 0.988	0.969; 1.007			
			3.5	147.67	139.95; 155.81		*s:t*	*r*	*r*	*r*	*r*	*r*	*r*			
			4.0	160.61	152.03; 169.68											
Interactive behaviour																
Stepping on lying bull	#	>0	2.5	0.77	0.65; 0.88	221	Space	−1.076 ± 0.271	163	−3.98	<0.001	OR: 0.341	0.201; 0.580	0.00006	0.0004	0.982
Number of times a bull stepped on another lying bull per 24 h			3.0	0.67	0.54; 0.80		Time	−0.545 ± 0.135	163	−4.02	<0.001	OR: 0.580	0.444; 0.756			
			3.5	0.39	0.26; 0.52		*s:t*	r	r	r	r	r	r			
			4.0	0.48	0.34; 0.62											

Mounting	#	log	2.5	1.96	1.49; 2.59	221	Space	−0.120 ± 0.089	1,163	1.62	0.20	F: 0.887	0.744; 1.059	0.394	0.587	0.741
Number of times a bull mounted			3.0	1.82	1.35; 2.45		Time	−0.231 ± 0.045	1,163	26.66	<0.001	F: 0.793	0.726; 0.867			
another bull per 24 h			3.5	1.82	1.37; 2.40		*s*:*t*	r	r	r	r	r	r			
			4.0	1.65	1.27; 2.16											
Other																
Change in cleanliness	score	det	2.5	See Fig. 1i		221	Space	2.770 ± 4.699	157	0.59	0.55	see		0.0002	$7 \cdot 10^{-10}$	1.016
Total change in the cleanliness			3.0				Space^2	−3.331 ± 1.296	157	−2.57	0.011	Fig. 1i				
score from the time point			3.5				Time	−60.647 ± 16.719	157	3.63	<0.001					
before to the time point			4.0				Time^2	26.119 ± 7.397	157	3.53	<0.001					
after a specific space							Time^3	−3.378 ± 0.978	157	3.45	<0.001					
allowance							s^2:t	4.391 ± 1.529	157	2.87	0.005					
							s^2:t^2	−1.982 ± 0.693	157	−2.86	0.005					
							s^2:t^3	0.265 ± 0.093	157	2.84	0.005					

U: units of measurement; durations (min) and counts (#) as per 24 h. T: transformation of the data for the statistical analysis, some variables were dichotomised according to whether behaviour occurred (>0) or according to whether cleanliness deteriorated (det) and evaluated using the binomial distribution. Summary statistics: mean and 95% confidence interval (CI) per space allowance based on the data of the individual bulls. Calculations were made with the same transformations as used in the statistical model and values as presented were then back-transformed to the original scale. *N*: number of observations (in parenthesis number of outliers that were omitted in the statistical analysis, see Section 2). Fixed effects: *b* ± S.E. = estimated parameter and its standard error, i.e. slope of the linear part of the model due to space allowance (space), point in time (time) and their interaction (*s*:*t*); for the variable cleanliness, some of these terms needed to be squared and cubed. d.f., *F*, *t*, *P*: degrees of freedom, *F*-values for the continuous response variables, *t*-values for the dichotomised response variables and *P*-values; *r* = reduced in a step-wise backwards approach due to non-significance (see also Section 2). Biological relevance: change per unit of the explanatory variable (space allowance: 1 m^2, point-in-time: 4 weeks) given as an additive amount (A), factor (F) or odds ratio (OR); CI: 95% confidence interval of the same values. Random effects: estimated standard deviation of the group to group variability (gg), individual to individual variability (ii) and error term (on the scale of the transformed variable). No estimate for batch to batch variability is given because this estimate was only based on two batches.

checked goodness-of-fit. We followed the recommendation by Agresti (2002) by calculating an expected number of individuals that scored a positive outcome for all combinations of space allowance and points in time based on the model predictions. This expected number was then compared to the observed number using a χ^2-test statistic. We found a good level of fit in all three models (all $P > 0.5$).

3. Results

The overall lying duration slightly increased with increasing space allowance and over time, but this effect was small and not statistically detectable (Table 1, Fig. 1a). The number of lying bouts increased by 5.6% with each additional square meter of space allowance and decreased by 9.5% from one point in time to the next (Table 1, Fig. 1b). Bulls also spent an additional 45.8% of time in an outstretched body posture with each additional square meter of space allowance and 6.3% less time in this posture from one point in time to the next (Table 1, Fig. 1c).

The number of changes between lying postures increased by 5.26 with each square meter of additional space allowance but did not show any changes with time (Table 1, Fig. 1d). The probability of a bull lying down in the centre of a pen decreased with increasing space allowance (OR: 0.354) and tended to increase with time (OR: 1.234; Table 1, Fig. 1e).

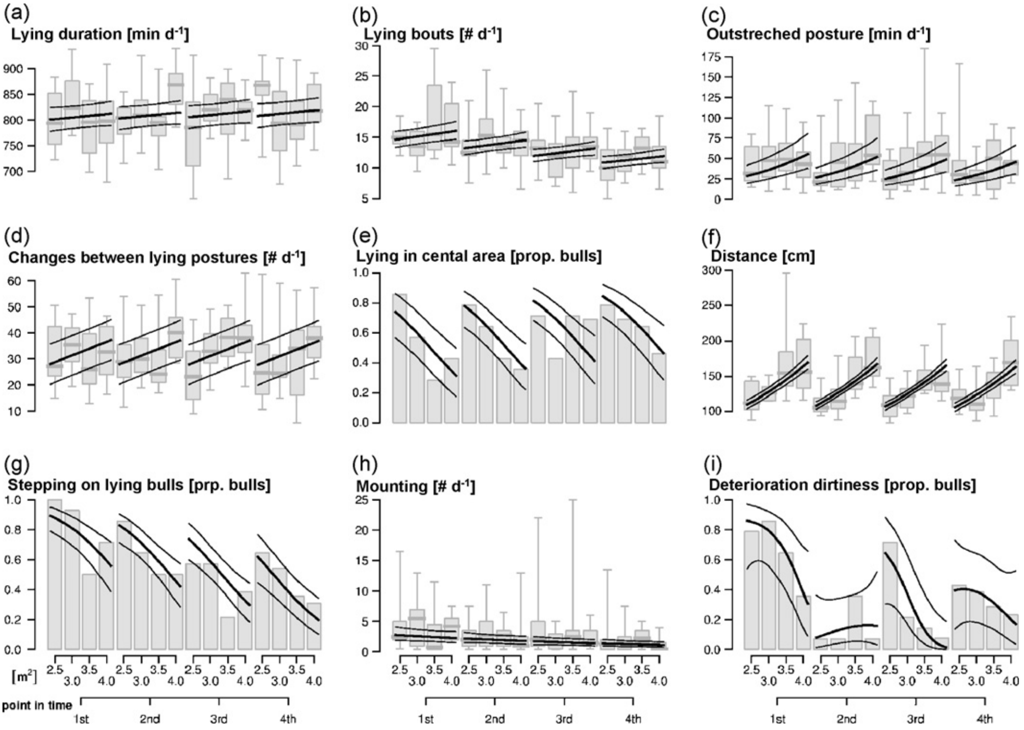

Fig. 1. Influence of space allowances of 2.5, 3.0, 3.5 and 4.0 m^2 per bull and points in time (1st–4th) on the lying duration (a), the number of lying bouts (b), the duration of lying in an outstretched body posture (c), the number of changes between lying postures (d), the proportion of bulls that lay down in the central area of the pen (e), the mean distance to the nearest lying bull (f), the proportion of bulls stepping on lying animals (g), the number of times a bull mounted another (h), and the proportion of bulls for which the dirtiness score deteriorated (i). Model fits (thick line) are given including their 95% confidence intervals (thin lines) and the raw data is given as box- or bar-plots (for continuous and dichotomised variables, respectively).

The average distance between a lying bull and its nearest lying neighbour increased by 28.0% with each additional square meter of space allowance and did not change over time (Table 1, Fig. 1f). Furthermore, the probability of a bull stepping on a lying bull decreased with increasing space allowance (OR: 0.341) and with time (OR: 0.580; Table 1, Fig. 1g).

The frequency of mounting decreased by 11.3% with each additional square meter of space allowance but this did not reach statistical significance. The number of mountings decreased by 20.7% from one point in time to the next, though (Table 1, Fig. 1h).

The probability of bulls getting dirtier showed a more complex pattern, dependent on space allowance and time (Table 1, Fig. 1i). This pattern can be summarised by stating that the probability of becoming dirtier decreased to different degrees with increasing space allowance at all points in time except at the second observation, where this probability seemed to be independent of the space allowance.

The individual to individual variability estimated by the random effects was mostly in a similar range as the estimated variability of the error term, whereas the group to group variability was clearly smaller in most of the variables (Table 1). There were two exceptions to this pattern. Firstly, both group to group variability and individual to individual variability was very small in comparison to the error in the model of the probability of a bull stepping on a lying bull and, secondly, for the probability of a deterioration in the dirtiness score, a very small individual to individual variability was observed (Table 1).

4. Discussion

The bulls used an increase in space allowance in the context of lying. They showed more lying bouts, lay longer in outstretched positions, altered their lying posture more often, increased the distance to other lying bulls and avoided lying in the centre of the pen and stepping on lying bulls. Moreover, there were some effects over time possibly reflecting ontogenetic changes in the bulls. With increasing age they showed fewer lying bouts, had a lower probability of stepping on a lying bull and mounted other bulls less often.

A direct comparison of these results with those from earlier studies investigating the influence of space allowance on the behaviour of beef cattle kept in fully slatted systems is complicated by the fact that in some of those studies different ranges, levels and number of levels (often two) of space allowances were compared, bulls were compared at higher weights, were kept in smaller groups and the samples were often small.

Some previous studies did find some improvement in the lying behaviour on larger space allowances (time spent lying: Kirchner, 1987; Ruis-Heutinck et al., 2000) whereas other studies did not find such effects (time spent lying: Andreae et al., 1980; Graf, 1984; Wierenga, 1987; Hickey et al., 2003; number of lying bouts: Graf, 1984; Kirchner, 1987; Ruis-Heutinck et al., 2000; lying with outstretched legs: Graf, 1984). Compared to our study, these previous experiments all included smaller minimal space allowances, suggesting that some differences in behaviour may only become visible if comparisons are made among a wider range of space allowances. With regard to mounting behaviour, we did not observe a significant influence of space allowance, which is in accordance with the results of other studies (Andreae et al., 1980; Graf, 1984; Kirchner, 1987; Wierenga, 1987). Thus, there seems to be no detrimental effect of increasing space allowance regarding an increased occurrence of sexual behaviour in finishing bulls.

It is commonly assumed (e.g. Andreae et al., 1980), that slatted floors become dirtier and animal hygiene a problem with larger space allowances. Contrary to this, we found that animal cleanliness actually changed more often for the better with larger space allowance, which is in accordance with the findings of Hickey et al. (2003). Stocking density thus remained high enough to ensure the self-cleaning effect of a slatted floor. In our study, the probability of a deterioration of the dirtiness score was also influenced by time, with a clearly different pattern in the second time period than in the others. Possibly this was due to the fact that a large proportion of bulls became dirtier from the start of the study until the end of the first period. If there is an asymptote for dirtiness in the housing system investigated here, only a small proportion of bulls could become even dirtier during period 2, which could explain the low and constant probabilities observed there.

Our groups were not fully balanced in respect to cattle breeds but represented groups that are typical on Swiss farms. However, even if there were slight differences between different breeds, these were reflected in the individual to individual and group to group variability which may, in parts, be attributed to the different breeds and breed composition, respectively. Most random effects for the individuals were clearly larger than those for groups, indicating that breed may have had a somewhat larger influence than breed composition assuming that the random effect of the individuals was indeed an effect caused by breed (rather than by other individual traits).

If bulls lay down in random locations one could expect to observe an increase in the distance between lying animals along with increasing space allowance due to the fact that this distance is inherently related to space allowance. In the present study, the changes in the bulls' lying behaviour were much more structured, however. They selectively avoided lying down in the centre of the pen with increasing space allowance, thus showing that they carefully chose where to lie. When bulls were larger, they even seemed to be restricted in their preferences for lying places, as seen in an increase in the probability of older bulls lying in the central area of the pen and a shorter time that older bulls spent in an outstretched posture. Similarly, with several other variables in which we observed a significant effect of space allowance (number of lying bouts, changes between lying postures, change in cleanliness), there is no reason to assume that these are inherently related to space allowance, simply because there is more room. Space was never so restricted that bulls could not have chosen their number of lying bouts or made changes between lying postures. Cleanliness is not directly dependent on space, either. Even the increase in distance between lying animals cannot necessarily be considered as random. Bulls chose to lie farther apart and at the edges of the pen if more space was available. It is very likely that these patterns were caused by their social circumstances. In other species, for example, pigs, one would expect individuals to lie close together even with some extra space (Hillmann et al., 2004). Thus, lying farther apart may well be a meaningful sign of avoidance in a social species. Thus, overall, it seems very unlikely and simplistic if the observed changes were considered to be direct effects of the increased space allowance.

Comparing concrete slats, rubber coated concrete slats and pens with a straw bedded lying area, Mayer et al. (2005) found that rubber coating improved the situation for the bulls, but the rubber coated system was still deficient regarding, for example, the number of lying bouts, the number of short standing bouts, the proportion of interrupted lying-down and standing-up events and the number of displacements of lying bulls in comparison with the straw bedding system. Because the pens with rubber coated slats were smaller than those with straw bedding, it was thought that an increased space allowance on the rubber coated slats might improve the situation. There was no detectable dependence of these variables on space allowance in the current study (data not shown). This suggests that an unstructured housing system, even with rubber coated slats, differs from a housing system in variables relevant for animal welfare that are not fully compensated by increasing space in pens with rubber coated slats.

If we accept the reduced softness of the lying area and lack of structuring in the pen with fully slatted rubber coated floors in comparison to a system with straw bedding, we need to address the difficult question of minimum space allowance with regard to animal welfare. Taking the results of our study investigating a range of space allowances from 2.5 to 4 m^2, all changes which we found must be judged in a positive way: bulls lay longer, had more lying bouts, lay longer in an outstretched 'relaxed' posture, changed their lying posture more often, increased the distance to their lying neighbours, avoided the central area of the pen, avoided stepping on lying bulls, mounted less often and were less likely to become dirtier. Moreover, some of the observed changes were considerable. Lying in an outstretched posture and distance between lying bulls increased by 45.8% and 28% and lying at the centre of the pen and stepping on lying bulls decreased by odds ratios of 0.345 and 0.341 m^{-2} of additional space, respectively. In our opinion, such large relative differences need to be considered as biologically meaningful for the bulls, whereas the absolute values of these variables (Table 1, Fig. 1) may not be that important in judging the relevance for the bulls. A behaviour that is shown but rarely can still be fundamental to the animals and a restriction therein can significantly affect their welfare. Thus, changes in behaviour in relation to space allowance seem to be more suitable to assess the bulls' needs. As most of the observed changes were either close to linear (changes between lying postures, probability of lying in the central area of the pen and stepping on lying bulls) or exponentially increasing (lying duration, number of lying bouts, lying in an outstretched posture, distance between lying animals), we need to conclude that it is beneficial to the bulls if space allowance on rubber coated slatted floors is increased to at least 4 m^2. If the exponential shapes were taken as an indication of how to extrapolate to the effect of space allowances higher than 4 m^2 on the welfare of the bulls, space allowance would need to be even further increased.

The Scientific Committee on Animal Health and Animal Welfare (2001) concluded that 'the minimum space allowance [for beef cattle] should be 3 m^2 for an animal expected to reach 500 kg plus or minus 0.5 m^2 for each 100 kg difference expected between 400 and 800 kg'. Similarly, Hickey et al. (2003) recommended a minimum of 3 m^2/bull at over 500 kg. Based on our observations of bulls between 360 and 540 kg, we conclude that increasing space allowance up to the investigated 4 m^2 had several beneficial and no negative effects on indicators of the welfare of finishing bulls kept on fully slatted rubber coated floors.

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