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Determination of static space requirements for finishing bulls based on image analysis

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Abstract

*In Europe, conventional housing systems for finishing bulls (*Bos taurus*) tend to consist of group pens with a high stocking density. Up until now there have been no regulations in place defining bulls' space requirements, even although insufficient space allowance is considered to impair animal welfare. Our study aimed to measure the surface area that finishing bulls occupy in standing and lying positions. We observed 46 bulls on a German fattening farm. The animals from one pen were assigned to one of three weight classes (W1: < 450 kg; W2: 450–649 kg; W3: ≥ 650 kg), and two pens of each weight class were examined. For image recordings, a camera trap was installed above the pens. To analyse the covered surface, the recorded images (n = 242) were edited. Furthermore, the observed lying postures were differentiated in terms of lying position and stretched-out legs. On average, the areas covered by the bulls increased with class of bodyweight. A finishing bull covered up to 1.21 m² in a standing position and up to 1.57 m² in a lying position, the most space being needed in an outstretched position. The calculated values provide information only about the surface a finishing bull covered in different positions in the pen. In practice, additional dynamic and social space must be taken into account for recommendations on space requirements, in order to ensure adequate inter-individual distances, social interaction and characteristic behaviours to improve animal welfare.*

Keywords: *animal welfare, finishing bulls, lying position, space requirement, standing position, static space*

Introduction

Housing on concrete slatted flooring with high stocking densities is the most common method of keeping bulls (*Bos taurus*) for fattening in Europe (Wechsler 2011). However, these housing systems have major drawbacks in terms of animal welfare (Park *et al* 2020).

One important factor is the impact of hard flooring on animals' physical health. Several studies have shown hard surfaces to be the cause of increased occurrence of claw and leg lesions (Schulze Westerrath *et al* 2007; Graunke *et al* 2011; Magrin *et al* 2019) and abnormal lying behaviour (Gygax *et al* 2007a; Graunke *et al* 2011). The additional limitations regarding space might exacerbate these negative effects since insufficient space on a hard, uncomfortable floor has been shown to increase the risk of bulls stepping onto a lying pen-mate (Schrader *et al* 2001). Such housing conditions cause animals to be dirtier, thereby exposing them to increased levels of discomfort and infection (Bosilevac *et al* 2005; Gygax *et al* 2007b; Zerbe *et al* 2008), not to mention stress (Gupta *et al* 2007).

Irrespective of the type of surface, lying behaviour is fundamentally important to animal behaviour because limitations in lying space can seriously impact various parameters such as health and the ability to fulfil various physical and social needs. Since bulls are forced to spend increased time standing, pens that fail to also provide sufficient lying space create an increased risk of lameness (Fjeldaas *et al* 2007; Gygax *et al* 2007a; Graunke *et al* 2011). Furthermore, bulls have a tendency for abnormal standing-up and lying-down movements (Gygax *et al* 2007a). Reduced space allowance was shown to curtail daily lying times (Ruis-Heutinck *et al* 2000), and natural behaviour impaired by restricted lying synchronisation (Schrader 2007). A review of intensive beef production found overall lying behaviour to be negatively affected by decreased space allowance (Wechsler 2011) while a study looking into the welfare and meat quality of beef cattle found space restriction to increase conflicts between the bulls, leading to more fights and mounting activities (Gottardo *et al* 2003). Accordingly, Tessitore *et al* (2010) reported decreased negative interactions such as displacement or head-butts when space allowance was increased.

As regards the housing of finishing bulls in terms of minimum space allowance and suitable floor quality,

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Table 1 Number of evaluated images of lying and standing animals in each bodyweight class. The numbers in the round brackets indicate the count of animals from which these images originated.

BWC	Average age (months)	Pen	Animals in pen (n)	Images lying (n)	Images standing (n)	Total
W1	10	A	8	14 (6)	11 (7)	25
		B	8	29 (7)	15 (8)	44
W2	14	A	8	57 (8)	27 (8)	84
		B	7	25 (5)	15 (7)	40
W3	18	A	8	21 (6)	7 (6)	28
		B	7	11 (3)	10 (6)	21
		Total	**46**	**157 (35)**	**85 (42)**	**242**

BWC: Bodyweight class (W1: < 450 kg; W2: 450–649 kg; W3: ≥ 650 kg);

recommendations are in place both from the Council of Europe (European Council 1998) and the Scientific Committee on Animal Health and Animal Welfare (SCAHAW) (2001) assigned by the European Commission, which are based on production experiments or common practice. However, these recommendations are yet to be included in European legislation. In Lower Saxony, Germany, the Guideline for the Housing of Fattening Cattle (LAVES 2018) demands, for the first time, that the lying area should be large enough to enable all animals to lie down simultaneously and on an appropriate surface affording sufficient space. Intensive consultations between veterinary authorities, agriculture and animal welfare representatives lead the minimum space requirement for animals weighing at least 650 kg to be set at 3.5 m² total area per animal, including 2.5 m² of lying area per animal. However, no legislation or EU standards dealing with space allowance in housing systems for finishing bulls are in place. In the US, the North American Meat Institute (NAMI) published 'Recommended Animal Handling Guidelines and Audit Guide' with minimum space allowances for livestock during transport and standards for holding pen stocking capacity at slaughter facilities (Grandin & NAMI 2019). Here, however, no legal requirements are in place either.

Additionally, to our knowledge, no scientific data are available that exactly measure the static space in regard to a finishing bull's minimum space requirement both in a standing and lying position relative to its physical dimensions. A review of the spatial requirements of different farm animals included an allometric method designed to calculate the space required for individuals both standing and lying (Petherick 2007). Previous studies had also used biometric data on animals' physical dimensions to define space requirements in pens and on transportation vehicles. A colour-contrast planimetric method determined the surface area covered by poultry (Spindler *et al* 2016; Giersberg *et al* 2017), rabbits (Giersberg *et al* 2015) and pigs (Arndt *et al* 2019) while calculations from direct measurements of the animal and from digital images were used in an Italian study estimating the space occupied by finishing and heavy pigs (Pastorelli *et al* 2006). However, such animal-specific measurements are yet to be carried out on fattening bulls.

Public concern for the housing condition of pigs and poultry tends not to be matched when it comes to finishing beef cattle (Wechsler 2011). So, this study sought to draw more attention to the welfare of finishing bulls by assessing the absolute minimum surface area covered by a lying or standing animal. Image analysis was used to investigate the static space requirement of bulls during their fattening, measuring the covered surface.

The aim being to improve bulls' housing conditions via provision of recommendations regarding space allowance.

Materials and methods

Study animals and housing

This study was conducted on 46 finishing bulls (Simmental and German Holstein breeds) on a commercial fattening farm in Lower Saxony, Germany which housed 250 bulls in total. The Simmental bulls (n = 44) were purchased at eight weeks of age from a variety of farms and fattened on-farm until slaughtering (22 months). The German Holstein bulls (n = 2) were born on the farm as it kept ten dairy cows. The animals were housed in groups of seven to eight (3.5–4.0 m² per bull) in fully slatted pens (28.3 m²) with rubber mats (Gummiwerk Kraiburg, Waldkraiburg, Germany) covering the slats at the rear of the pen (16.5 m²). Once or twice daily bulls were fed and water was made available *ad libitum*. For investigation, bulls from one pen were assigned to one of the three groups depending on their estimated bodyweight (W1: < 450 kg; W2: 450–649 kg; W3: ≥ 650 kg) in accordance with customary fattening phases in Lower Saxony, Germany (Herzog *et al* 2019), and two pens of each weight class were examined. The average age (in months) of the animals at the time of observation in each pen is shown in Table 1. Individual animals in the pen were identified by the colour and patterns of their fur.

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Image recordings

For image recordings, a camera trap (SnapShot Mini 5.0 MP Model UV 555, Dörr GmbH, Neu-Ulm, Germany) was installed above each pen (n = 6 pens) focusing primarily on the part of the lying area at the rear of the compartment covered in rubber mats. Cameras took a picture every 10 min, 24 h per day, over seven days and, overall, 1,008 pictures of each pen were taken. A structurally identical pen not containing any animals had the same camera in place and a 2 m² wooden frame (2 × 1 m; length × width) placed on the ground. This frame was also recorded for the two examined body positions (lying and standing) for each weight class. The height of the standard frame was set to the levels (height from the ground) shown in Table 2 representing the back height of the bulls and used as a reference value. Thus, the area covered by the animals and the reference surface from the standard frame both represented the same distance from the camera.

After data acquisition, each image's usability was assessed. Only those images in which the entire animal was represented in a standing or lying position were used for further processing. Overall, 242 images were evaluated which did not originate from all animals in the pen (Table 1).

The observed lying positions were differentiated according to Gygax *et al* (2007b) as shown in Figure 1(a)–(f).

Image analysis

To analyse the surface covered by bulls of differing weights, the images were edited using the ImageJ programme (Version 1.51q, NIH, Bethesda, Rockville, MD, USA). First, the areas of the standard frames were measured, counting the covered pixels and equated to 2 m². Then, the images from the bulls were edited using the freehand selection tool marking the outline of the animals. Again, the area was measured, and its content was calculated in relation to the 2 m² of the respective standard frames. In order to standardise the measurement method, each photograph was edited three times, and the mean value of the area calculated. These means were used for further analysis.

Statistical analysis

Statistical analyses were performed using the SAS programme (Statistical Analysis Software 9.4, SAS Institute Inc, Cary, NC, USA). To estimate inter-observer agreement, ten randomly selected images from each bodyweight class (five lying and five standing bulls) were examined by two researchers (NV and SLR). Intra-observer reliability was calculated by comparing the agreement between 30 pictures evaluated thrice by one observer. Finally, to calculate intra- and inter-observer agreement, Krippendorff's α (KALPHA) (Hayes & Krippendorff 2007) as the statistical measure of reliability was used with the 'macro' developed by Hayes (2020). The results were valued using the classification proposed by Landis and Koch (1977) (< 0.00 = poor; 0.00–0.20 = slight; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.8 = substantial; 0.81–1.00 = almost perfect). Covered surface measurements in a standing and lying position (all postures) were analysed on a descriptive basis.

Table 2 Adjusted height of the standard frame for each bodyweight class for lying and standing position.

BWC	Lying	Standing
W1	50 cm	120 cm
W2	80 cm	140 cm
W3	90 cm	150 cm

BWC: Bodyweight class (W1: < 450 kg; W2: 450–649 kg; W3: ≥ 650 kg).

Results

The calculation of intra- and inter-observer agreement for the measurements of the covered surface resulted in a Krippendorff's reliability of α = 0.99.

The overall covered surface increased with increasing bodyweight, and the animals required more static space in a lying position than in a standing one. A finishing bull in a standing position covered, on average, 0.73 m² in W1, 0.97 m² in W2 and 1.09 m² in bodyweight class W3. In a lying position the animals required, on average, 1.12 m² (W1), 1.25 m² (W2) and 1.39 m² (W3) static space (Table 3).

In analysing the covered surface measurements within the different lying positions, the largest space was required for an outstretched body posture (Figure 1[a]) in all bodyweight classes. In this lying posture, the finishing bulls covered up to 1.39 m² in bodyweight class W1, 1.54 m² in W2 and up to 1.57 m² in W3. The least space was needed when the bulls were lying on their belly with none of their legs stretched out (Figure 1[f]) (W1 = 0.79 m², W2 = 1.05 m², W3 = 1.18 m²) (Table 4). The distribution of the static space required in the different lying positions within the three weight classes is shown in Figure 2.

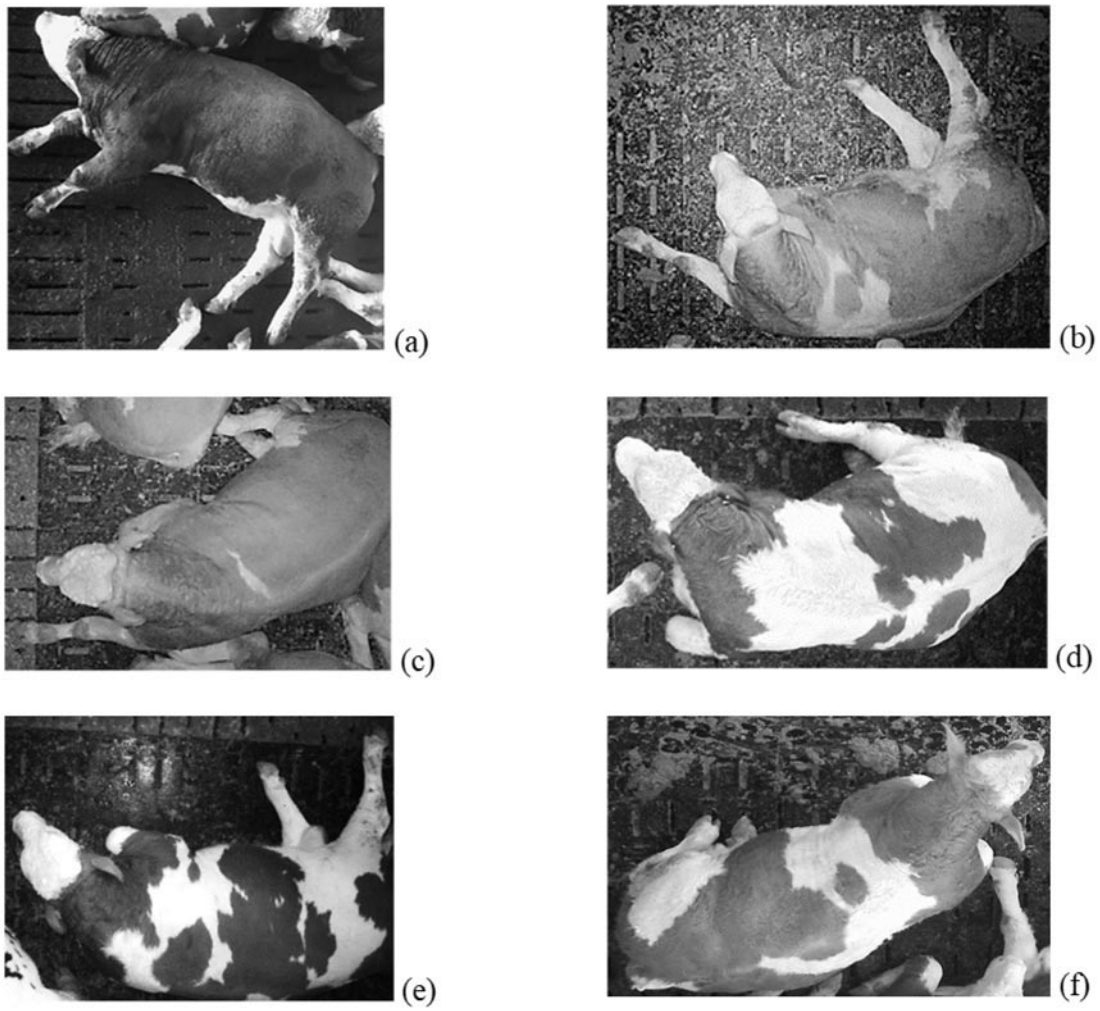
Discussion

This study aimed to measure the minimum floor space covered by finishing bulls depending on their supposed bodyweight and body positions. Several studies have dealt with the problem of housing fattening cattle under intensive farming conditions and, thus, the space requirements of finishing bulls (Gottardo *et al* 2003). Specific information on the static space is demanded and, as a result, information is needed on the space requirements of each finishing bull (in m²) to ensure a standing or lying position.

The suitability of our chosen study method was deemed acceptable due to the agreement between the two observers (inter-rater reliability) as well as the intra-observer reliability revealing near perfect agreement (both α = 0.99) according to the classification values proposed by Landis and Koch (1977). The image processing method with the programme, ImageJ was also used by Rodrigues dos Santos *et al* (2017) to evaluate biometric data in equines, obtained by the traditional method of body measurement. Moreover, Campbell *et al* (2016) used ImageJ to measure animals' body space as they sought to calculate the percentage of litter floor space occupied by laying hens.

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Figure 1



Examples of different lying positions showing (a) lying on the side with both hind legs and at least one foreleg stretched out, (b) lying on the belly with at least one foreleg and one hind leg stretched out, (c) lying on the belly with one foreleg but no hind leg stretched out, (d) lying on the belly with one hind leg but no foreleg stretched out, (e) lying on the belly with two hind legs but no foreleg stretched out and (f) lying on the belly with none of the legs stretched out.

Only one-quarter of the 1,008 images taken were evaluated, since these were the only ones showing the animals in full. While these pictures showing the middle of the pen benefited from showing lying animals that were somewhat isolated and not obscured by a pen-mate lying next to them, not every bull per pen was represented for each standing and each lying position as bulls generally avoid lying in the centre of the pen (Siegwart *et al* 2005; Gygax *et al* 2007b). This was most evident in bodyweight class W3, where only six out of eight and three out of seven animals in a lying position could be evaluated. Hence, we have to keep in mind also that the different lying postures were not imaged with the same frequency. For example, lying posture (c) in class W1 and W3 could be evaluated only once; values given therefore represent one animal solely. Thus, the present study can thus make no reliable conclusions on differences of the covered surface for the various lying positions in between bodyweight classes, even if its an interesting aspect. But for such conclusions the number of evaluated images should be considerably larger and the animals and groups imaged should be more uniform.

As expected, the measured covered surface increased with increasing class of bodyweight. However, since the study animals were weighed neither before nor during the fattening period, their live-weights — and, by association, their bodyweight classes — were based only upon the farmer's estimation. Furthermore, the different heights of the standard frame — and, thus, the represented back heights of the bulls — were not measured exactly but were also an estimation. That said, the standing height corresponds approximately with information on breed characteristics of Simmentals (Porter *et al* 2016) and the lying height was closely correlated with the dimensions of the partitions between cubicles in dairy cattle housings (Veissier *et al* 2004).

In practice, finishing bulls are kept in one single pen in small groups that remain stable throughout the entire

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Table 3 Results of image analyses with covered surface measurements in a standing and lying position (all postures).

BWC	Position	N	Mean (± SD) (m²)	Minimum (m²)	Maximum (m²)
W1	Standing	27	0.73 (± 0.09)	0.87	0.58
	Lying	43	1.12 (± 0.14)	1.39	0.79
W2	Standing	42	0.97 (± 0.06)	1.12	0.83
	Lying	82	1.25 (± 0.11)	1.54	1.05
W3	Standing	17	1.09 (± 0.07)	1.21	0.98
	Lying	33	1.39 (± 0.11)	1.57	1.18

BWC: Bodyweight class (W1: < 450 kg; W2: 450–649 kg; W3: ≥ 650 kg);

Table 4 Values (m²) for the different lying positions within the three bodyweight classes.

	W1				W2				W3			
LP	N	Min	Max	Mean (± SD)	N	Min	Max	Mean (± SD)	N	Min	Max	Mean (± SD)
a	7	1.25	1.39	1.30 (± 0.07)	31	1.10	1.54	1.33 (± 0.10)	6	1.36	1.57	1.48 (± 0.09)
b	7	0.95	1.32	1.18 (± 0.11)	9	1.17	1.35	1.25 (± 0.05)	3	1.38	1.47	1.44 (± 0.05)
c	1	1.19	1.19	1.19	3	1.06	1.30	1.17 (± 0.12)	1	1.20	1.20	1.20
d	2	0.89	1.02	0.96 (± 0.09)	7	1.06	1.24	1.15 (± 0.07)	7	1.25	1.51	1.37 (± 0.09)
e	13	0.93	1.26	1.07 (± 0.11)	12	1.12	1.42	1.24 (± 0.09)	7	1.31	1.54	1.42 (± 0.08)
f	13	0.79	1.19	1.06 (± 0.11)	20	1.05	1.26	1.16 (± 0.06)	9	1.18	1.53	1.32 (± 0.12)

LP: Lying posture, W1: < 450 kg, W2: 450–649 kg, W3: ≥ 650 kg;

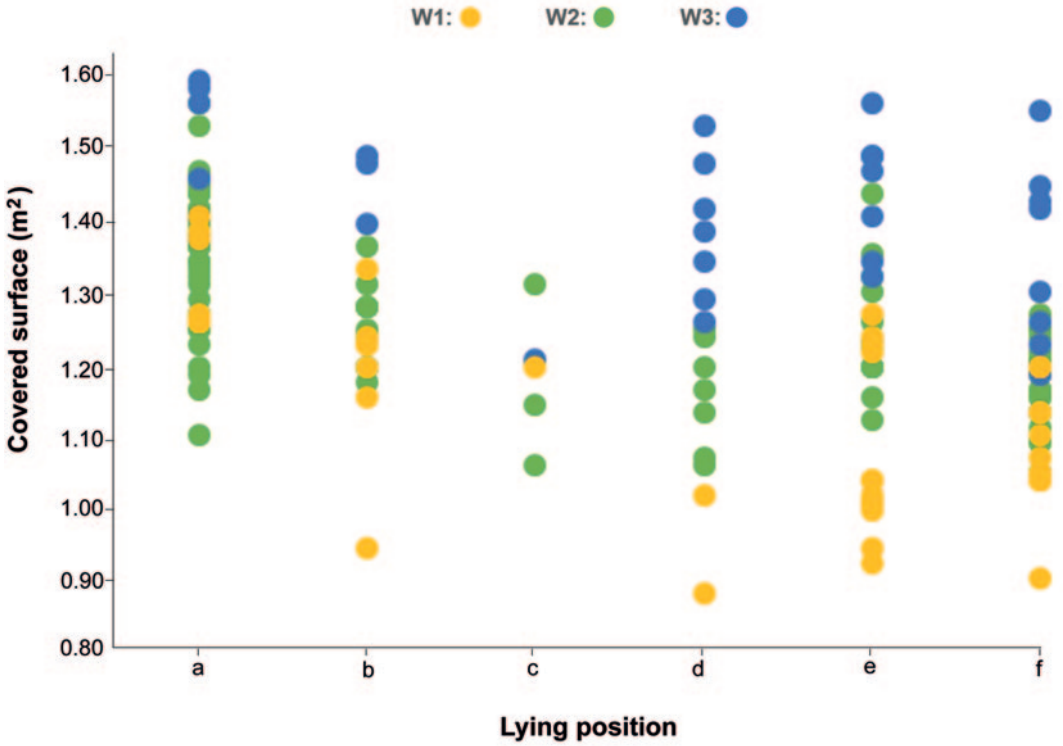
fattening period. This would imply more space for animals at the start and in the middle of the fattening period (< 650 kg) with space limitations becoming more pronounced during the final period of fattening (≥ 650 kg) (Herzog *et al* 2019). For 500 kg animals in the final fattening period, the Scientific Committee on Animal Health and Animal Welfare recommend a minimum space allowance of 3.0 m² for each bull plus 0.5 m² for each additional 100 kg of bodyweight (SCAHAW 2001). There are general requirements for new buildings and conversions set out in the 'Animal Welfare Guidelines for Animal Husbandry of Fattening Bulls and Suckler Cows in Lower Saxony (Germany)' whereby a bull in the final period of fattening (≥ 650 kg) should have at least 2.5 m² (per animal) of the total space in the pen set aside as a soft and deformable lying area (Herzog *et al* 2019). Considering the static space requirement calculated in this study, a bull would cover approximately 56% (1.39 m² of 2.5 m²) of this lying area which, according to the guideline, should be available to a finishing bull in the final fattening period. Thus, the animal would have an additional 1.11 m² on the lying surface to maintain, for example, inter-individual distances and species-characteristic movements, such as head lunges. Depending on the animal's lying posture, this space may even reduce in size since a finishing bull lying in an outstretched position (Figure 1[a]) would cover 1.57 m², leaving only 0.93 m² additional surface area.

Since cattle are naturally gregarious animals, they generally show synchronised behaviour and tend to eat and lie at the same time, if they have the space and opportunity to do so (Phillips 2002; Winckler 2009; Schneider *et al* 2020). Not only sufficient space should be provided for the bulls to rest comfortably, but also to access resources asynchronously, ie animals should have the space for a usable path to feed while all the other animals in the pen keep on lying. In the present study, finishing bulls were housed in pens (28.3 m²) with a rubber-coated area of 16.5 m². If we were to consider such a pen housing eight fattening bulls, weighing at least 650 kg and, therefore, requiring an average space of 1.39 m² each in a lying position, together the animals would take up 11.1 m². If all eight bulls in a pen chose to lie in an outstretched position, thereby covering 1.57 m² each, the collective required space would be around 12.6 m², leaving 3.9 m² available. Thus, in a purely mathematical sense, the lying area would be sufficient for lying simultaneously and there would even be additional free space available on the rubber-coated area. But, again, we must bear in mind, that bulls have preferred lying areas so even though the lying area provides sufficient space for all animals to lie down simultaneously, there may be intense competition for specific areas linked to important resources (Gygax *et al* 2007b).

Furthermore, the lying area that is provided would appear insufficient to allow, for example, appropriate distances to be maintained. Ekesbo and Gunnarsson (2018) found adult

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Figure 2



Scatterplot showing the covered surface measured in the different lying positions within the three bodyweight classes (W1: < 450 kg, W2: 450–649 kg, W3: ≥ 650 kg). For positions (a)–(f), see Figure 1.

cattle on pasture to be keen to preserve inter-individual distance and would not rest very close to one another. Given a choice, cattle would appear to favour keeping 2–3 m apart when lying (Broom & Fraser 2007). Such a distance was not possible for the bulls in the present study, as there was an average of 3.54 m² for each of the eight W3-animals in the whole pen (28.3 m²), and 2.06 m² for each at the lying area with rubber-coated slats. The study of Gygax *et al* (2007b) showed that the distance to their nearest neighbour finishing bulls choose, increases exponentially with increasing space allowance in the pen. They recommend an area higher than 4.0 m² per animal to account for this welfare parameter. Presumably, the 2.5 m² lying area recommended in the 'Animal Welfare Guideline for Animal Husbandry of Fattening Bulls and Suckler Cows in Lower Saxony (Germany)' can be considered as far too little space, in regard to animal welfare.

Furthermore, cattle require space to perform their characteristic lying-down and getting-up movements, as their centre of gravity has to shift dynamically, although the actual extent of this space varies between studies. Faull *et al* (1996) reported 0.60 m, Schrader (2007) 0.70–1.0 m, and Boxberger (1982) noted 1.30–1.50 m was necessary for dairy cows to carry out their typical head lunge at rising. Ceballos *et al* (2004) used kinematic techniques to provide accurate measures of mature Holstein cows' space requirements when executing their lying-down movement. They found this large dairy breed to require up to 3.0 m of longitudinal space when lying down. Therefore, designing compartment partitions, even for beef cattle, needs to additionally take these displacement measures into account.

For housing finishing bulls, it is also crucial to factor in their social interactions as a natural behaviour when calculating additional space requirements, eg during fighting protagonists must have the opportunity to be able to escape from a rival (Petherick 2007). Further social interactions occur in groups of finishing bulls when animals enter puberty during the fattening period (Byrne *et al* 2018). Therefore, the aggressive behaviour of these adult males, which has evolved in relation to dominance formation and access to resources, also increases (Tennessen *et al* 1985). As previous studies have shown that increased space allowance leads to a decrease in conflicts and an increase in positive interactions, additional space should also be set aside for those social space requirements (Fisher *et al* 1997; Gottardo *et al* 2003; Tessitore *et al* 2010).

To summarise, our data would suggest the need for further studies to be carried out into the space requirements of finishing bulls to enable characteristic behaviours (lying-down/standing-up) to be carried out and for social interactions and maintenance of inter-individual distance. Finally, due to the fact, that cattle weight and body size have increased considerably during the last two decades (for steers and heifers, see Kline *et al* 2019 and for dairy cows, see Dirksen *et al* 2020), it is recommended that space requirements are reviewed regularly in the future.

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Animal welfare implications and conclusion

This study measured the static space required by finishing bulls of different weight classes during various standing and lying positions, in order to demonstrate and evaluate the actual available space in lying areas for each animal, on-farm. The results showed that a finishing bull covered up to 1.21 m² in a standing position and up to 1.57 m² when lying. However, additional dynamic and social space must also be taken into account to improve natural behaviour in respect to the lying behaviour of fattening bulls.

Moving forward, a crucial step would be to enact legislation standardising the housing conditions of fattening cattle. This must legislate a minimum space allowance per animal in the pen as well as a minimum lying area with good floor quality. This would be essential in helping improve the welfare of the intensive beef production systems that are in use.

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