*Animal* (2020), **14:5**, pp 1043–1051 © The Animal Consortium 2019
doi:10.1017/S1751731119002702

animal

# Effect of overlaying rubber on fully slatted concrete floors on hoof health and lying postures in finishing dairy-origin bulls offered two contrasting diets

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(Received 23 January 2019; Accepted 1 October 2019; First published online 29 October 2019)

*Fully slatted concrete floors are labour-efficient, cost-effective and thus common in beef cattle housing. However, the welfare of cattle accommodated on them has been questioned. The objective of this study was to evaluate the effect of floor and diet on hoof health and lying behaviours of housed dairy-origin bulls, from a mean age of 8 months to slaughter at 15.5 months old. Forty-eight bulls, which had a mean initial live weight of 212 (SD = 23.7) kg, were allocated to one of four treatments, which consisted of two floors and two diets arranged in a 2 × 2 factorial design. The floors evaluated were a fully slatted concrete floor and a fully slatted concrete floor overlaid with rubber, while the diets offered were either a high concentrate diet or a grass-silage-based diet supplemented with concentrates. The mean total duration of the study was 216 days. Floor had no significant effect on claw measurements measured on day 62 or 139. However, bulls accommodated on slats overlaid with rubber had a tendency to have a higher front toe length measured pre-slaughter than those accommodated on concrete slats (P = 0.063). Floor had no significant effect on the net growth of toes or heels during the duration of the study. The number of bruises (P < 0.01) and the bruising score (P < 0.05) were significantly higher on day 62 in bulls accommodated on fully slatted concrete floors than on concrete slats overlaid with rubber, but there was no significant effect of floor on these parameters on day 139 or at the measurement taken pre-slaughter. There was a tendency for bulls accommodated on concrete slats to have a higher probability of having sole bruising at the end of the experiment than those accommodated on slats overlaid with rubber (P = 0.052). Diet had no significant effect on toe length or heel height, number of bruises, or overall bruising score at any time point of the study. There was little evidence in the current study to suggest that bulls lying on fully slatted concrete floors could not express lying postures similar to those on concrete slats overlaid with rubber.*

**Keywords:** slats, floor type, beef cattle, sole bruises, lying positions

## Implications

The current study provides evidence that overlaying concrete slats with rubber provides a suitable alternative to fully slatted concrete floors for finishing dairy-origin bulls in terms of hoof health, particularly in regions where there is a lack of straw for bedding. Diet had minimal effect on hoof health in bulls.

## Introduction

Beef cattle in the UK and Ireland are mostly housed during the winter months to provide shelter from inclement weather conditions. Fully slatted concrete floors are used extensively in accommodation for finishing beef cattle, providing a labour-efficient slurry management system, without the need for a bedding substrate which is particularly pertinent in areas of low straw availability. However, concerns have been raised about the welfare of cattle accommodated on fully slatted concrete floors, particularly in terms of increased incidences of soles haemorrhages (Graunke *et al*., 2011; Thomsen *et al*., 2017) and joint swelling (Graunke *et al*., 2011) and the reduced ability to readily get up and down (Platz *et al*., 2007). Furthermore, Absmanner *et al*. (2009) reported that bulls accommodated on straw bedding had the shortest duration of lying down or standing up sequence and a lower number of lying down intentions were observed in bulls accommodated on straw or slats covered with rubber mats than on concrete slats. Absmanner *et al*. (2009) suggested that these behavioural changes observed in cattle

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on concrete slatted floors were due to the hardness of the floor, which Haley *et al.* (2001) reasoned made cattle more reluctant because of the discomfort they experienced. Lameness has potential to negatively affect the overall livestock productivity and thus farm profit margins (Huxley, 2013). Additionally, Lowe *et al.* (2001) showed that when offered a choice, beef cattle chose rubber-covered slats or solid floor covered with bedding over fully slatted concrete floors to both lie and stand on. Thus, overlaying concrete slats with rubber have been suggested as a potential practical solution to these concerns, particularly in areas where straw is limited and therefore expensive. Recently, Murphy *et al.* (2018) reported that accommodating bulls on rubber-covered slats reduced the odds of having bruised soles compared to those accommodated on concrete slats. Associations between lying behaviour and lameness have been reported in dairy cows (Solano *et al.*, 2016). Furthermore, lying postures in cattle may give an indication of comfort, and Relic *et al.* (2012) suggested that cows with injuries to a knee often lie with a leg in extension because swelling limits their ability to bend it. Cook *et al.* (2004) suggested that parturition, diet-induced subacute ruminal acidosis (**SARA**), and floor type may be potential triggers for the onset of laminitis in dairy cows. However, floor type has been shown to have a larger impact than diet on development of horn lesions of dairy cattle around calving (Webster, 2001; Knott *et al.*, 2007). Much less research has been carried out on the effect of diet and floor type on lameness in finishing bulls where their production cycle is much shorter than that of a dairy cow (Newcomer and Chamorro, 2016).

## Material and methods

### *Animals and treatments*

This experiment was carried out at the Agri-Food and Biosciences Institute (**AFBI**), Hillsborough, Co. Down, Northern Ireland, from October 2016 to June 2017. Forty-eight dairy-origin bulls (28 purebred Holsteins, 18 Holstein crosses, bred from Holstein cross Swedish Red cross Jersey cows and 2 Limousin cross Holstein) were housed on 11 October 2016 (day = 0 of the study) with a mean initial live weight of 212 (SD = 23.7) kg and an average age of 243 (SD = 26.7) days. Further details of the animals and diets used in this study have previously been reported by Lowe *et al.* (2019). Bulls were blocked according to live weight into 12 blocks, each of four animals. Cattle within each block were randomly assigned to one of four treatments, and treatments were balanced as far as possible for breed, whereby all four treatments contained seven pure Holsteins. Treatments 2 and 4 also contained five Holstein crosses, while the two remaining treatments contained four Holstein crosses and one Limousin × Holstein bull each. Four animals were accommodated per pen, and thus there were three pens of animals per treatment. The four treatments consisted of two floors and two diets, arranged in a 2 × 2 factorial design. The two floors were a fully slatted concrete floor and fully slatted concrete floor overlaid with rubber (Comfort Slat Mat; Irish Custom Extruders Ltd, Dublin, Ireland). The concrete slats used in the current study were in good condition with no obvious defects and had been *in situ* for approximately 30 years prior to the commencement of the study. Bulls were offered either an intensive high concentrate diet or a less-intensive grass-silage-based diet supplemented with a lower input of the same concentrates. Initially, all bulls were offered *ad libitum* medium quality grass silage supplemented with 2.0 kg concentrates/head/day. Concentrate was a finely ground commercial beef blend containing 20% maize and 20% rolled barley. This was stepped up by 1 kg per week for bulls offered the intensive high concentrate diet, until *ad libitum* levels of concentrate feeding were achieved. At this stage, chopped barley straw was offered *ad libitum* to these bulls as the forage component of their diet. Chemical composition of the feeds offered is presented in Table 1. Bulls offered the less intensive diet had their concentrate more gradually increased by 0.5 kg per week until they reached 6 kg/head per day, at which point it was capped at this level for the remainder of the experiment. The mean total duration of the experimental period was 216 days. One bull from treatment 1 had to be removed from the study on day 173 due to sore knees, on recommendation from the veterinary surgeon.

**Table 1** *Composition of feeds offered to cattle (g/kg unless otherwise stated)*

| | Grass silage | Concentrate | Straw |
|---|---|---|---|
| DM (g/kg) | 386.4 | 864.2 | 851.4 |
| pH | 4.3 | | |
| Composition of DM (g/kg unless otherwise stated) | | | |
| CP | 154 | 177 | 42 |
| Ash | 100.9 | 65.7 | 46.3 |
| Acid-detergent fibre | 291.8 | 154.1 | 478.1 |
| Neutral-detergent fibre | 503.1 | 326.5 | 843.9 |
| Gross energy (MJ/kg DM) | 19.6 | 18.4 | 18.9 |
| Metabolisable energy (MJ/kg DM) | 11.3 | | |

### *Experimental pens*

The dimensions of the experimental pens were 3.4 × 2.7 m for both floors. The fully slatted concrete flooring had individual slats which were 12.5 cm wide with a 4 cm void between them, thus giving a drainage area of 24% of the total area. The rubber was clipped into position by commercial technicians directly over the concrete slat, using a plastic rigid fixing system at each side of the slats, whereby no adhesives or screws were required. The rubber attachment marginally increased the width of the slat to 13.5 cm, leaving a 3-cm void area and thus reducing the drainage area to 18%. The German Agricultural Society, Deutsche Landwirtshafts Gesellshaft (DLG) certification tests (DLG, Groß-Umstadt, Germany) of the Comfort Slat Mat used in the current study

**Table 2** *Ethogram for behavioural observations carried out on bulls on 5 days per week throughout the experiment*

| Posture | Description |
|---|---|
| Standing eating | Eating at the feed barrier or standing chewing the feed just eaten |
| Standing other eating | Standing on three or four limbs not eating but may be carrying out other behaviours |
| Lying | |
| Sternal recumbency | Lying on the sternum, with all four limbs under the body |
| Sternal with one front limb extended | Lying on the sternum with one front limb stretched out and both back limbs either under the body or parallel to the side of the body |
| Sternal with two front limbs extended | Lying on the sternum with two front limbs stretched out and both back limbs either under the body or parallel to the side of the body |
| Sternal with front limbs in, one or two back limbs out | Lying on the sternum with both front limbs under the body and one or two of the back limbs stretched out |
| Sternal with front limbs out, one or two back limbs out | Lying on the sternum with both front limbs and one or two of the back limbs stretched out |
| Lateral recumbency | Lying on side with four limbs stretched out |

reported a shore hardness of 85 and a thickness of 19.1 mm. The space allowance for bulls accommodated on both floors was 2.3 $m^2$/animal, which is in line with the recommendations of the Farm Quality Assurance Scheme for Northern Ireland based on an animal up to 600 kg (Livestock and Meat Commission, 2014).

*Behaviour*

Three group scans of each of the pens were carried out 5 days a week throughout the experiment, by a single trained assessor at 1100, 1300, and 1600 h, to note the number of animals in each pen which were either standing or lying, as outlined in Table 2. These times were chosen to avoid feeding time (concentrates were offered first at 0800 h, while the forage was subsequently offered at approximately 1000 h) and times for taking measurements, so the animals were exhibiting undisturbed behaviours. The assessor was familiar to the animals and care was taken to observe the animals in a calm and unobtrusive manner, with no one else present in the house. The order that the pens were observed was randomised. There were two access doors to the house, one at each end of the feed passage, and the door the assessor entered the house was alternated for each scanning session. On entering the feed passage, the assessor noted the positions of the animals in the first four pens, which housed animals in treatment 1 to 4 and then immediately moved onto the next set of four pens and then onto a final set of four pens. The order that the pens were observed in each set of four was randomised.

**Table 3** *Severity and extent scores for sole bruising on bulls' hooves*

| Score | Severity | Extent |
|---|---|---|
| 1 | Faint pink mark | Less than 5 mm |
| 2 | Red mark | Between 5 and 10 mm |
| 3 | Dark red haemorrhage | Greater or equal to 10 mm |

*Hoof trimming and lesion scoring*

All bulls had all hooves examined before the beginning of the study (day −5), twice during the study (days 62 and 139) and prior to slaughter (day 215) by a fully qualified hoof trimmer (Dutch Diploma and member of The National Association of Cattle Foot Trimmers). Net growth of the toe or heel was calculated by subtracting the pre-experiment measurement from the pre-slaughter measurement. Each bull was restrained in a specifically adapted crush for hoof trimming cattle, whereby one leg was lifted at a time and securely held to facilitate cleaning and inspection. The sole of the hoof was cleaned using an electric blade, and a hoof trimmer's knife was used to remove any dirt between the claws. This removal of dirt and the superficial horn layer exposed fresh horn to facilitate the identification of bruises. The number of bruises on each claw was noted, and each bruise was given a severity and extent score as outlined in Table 3. Alongside hoof trimming, the length of each toe and depth of each heel was measured (hairline to tip of toe/depth of heel) to determine overgrown/excessively worn claws. The presence of any sole ulcers or abscesses was also noted. Additionally, each hoof was also scored by the hoof trimmer for digital dermatitis (**DD**) based on the five-point M0 to M4 scale as described by Holzhauer *et al.* (2008).

*Locomotion scoring*

During the fortnightly weighing, each animal was locomotion scored by an experienced trained assessor from 1 to 5 based on the scoring system as described by Flower and Weary (2006), where a score of 1 was assigned where there was a smooth and fluid movement observed through to a score of 5 where the movement was severely restricted. A score of ≥3 was classified as clinically lame. Animals were locomotion scored after weighing, walking on their own down the passageway back to their pen, as it was important that animals are calm and walking slowly while being scored.

*Leg swelling scores*

While the bulls were restrained in a crush for weighing at the beginning of the experiment, at day 60 and prior to slaughter, the occurrence of any swelling at the carpal and the tarsal joints was recorded by an experienced trained assessor according to the method described by Schulze Westerath *et al.* (2007), where 0 = no swelling; 1 = light swelling; 2 = medium swelling; and 3 = severe swelling.

*Statistical analysis*
All analysis was carried out using Genstat release 18 statistical package (Payne *et al.*, 2015). Claw measurements and mean locomotion score were analysed using an ANOVA in a $2 \times 2$ factorial design with pen fitted as a blocking term in the ANOVA. At each measurement date, whether an animal had bruises or not and the number of bruises was calculated at front and hind hoof level and analysed using a generalised linear mixed model. Pen and animal within pen were fitted as random effects, and a factorial arrangement of floor, diet, and hoof was fitted as fixed effects. In addition, bruising measured on day −5 was fitted as an additional fixed effect. A binomial distribution with logit link function was assumed for the presence or absence of bruises and a Poisson distribution with logarithm link function for the number of bruises. In addition, the severity and extent of each bruise were multiplied together and totalled at the front or back hoof level for each date and analysed using a linear mixed model. Pen and animal within pen were fitted as random effects, and a factorial arrangement of floor, diet, and hoof were fitted as fixed effects. The number of cases of DD and leg swelling were numerically low and could not be statistically analysed. Additionally, no sole ulcers or abscesses were noted. For lying and standing behaviours, the mean proportion of animals carrying out that behaviour at any point in time was calculated for each pen for each month. The resultant variables described in Table 2 were analysed as a linear mixed model with repeated measures with pen as the subject factor and month as the time factor. A factorial arrangement of floor, diet, and month was fitted as fixed effects, and the correlation between time points was accounted for using an autoregressive model of order 1. For all analyses, a $P$-value $<0.05$ was considered significant.

## Results

No interactions were noted between floor and diet on any of the measurements in the current study, and thus main effects of floor and diet are presented in Tables 4–8.

*Toe length and heel height*
Mean toe lengths and heel heights are presented in Table 4. Floor had no significant effect on toe length or heel height at day −5, 62, or 139. However, bulls accommodated on slats overlaid with rubber had a tendency to have a higher front toe length measured pre-slaughter than those accommodated on concrete slats ($P = 0.063$). However, floor had no significant effect on the net growth of toes or heels during the duration of the study. While diet had no significant effect on toe length or heel height, there was a tendency for bulls offered the intensive diet to have an increased net growth of their hind heel ($P < 0.055$).

*Hoof bruising*
There was a tendency for bulls accommodated on concrete slats to have a higher probability of having bruising on the

**Table 4** *The main effects of floor and diet on mean claw measurements of bulls*

| Day | Claw measurement | Floor | | SEM | Diet | | SEM | *P*-value | |
|---|---|---|---|---|---|---|---|---|---|
| | | S | R | | H | L | | Floor | Diet |
| Pre-experiment[1] | Hind toe length | 50.2 | 50.0 | 0.58 | 50.2 | 50.0 | 0.58 | 0.806 | 0.806 |
| | Front toe length | 50.9 | 51.7 | 0.43 | 51.3 | 51.3 | 0.43 | 0.197 | 0.947 |
| | Hind heel height | 18.9 | 18.9 | 0.27 | 18.6 | 19.1 | 0.27 | 0.957 | 0.205 |
| | Front heel height | 21.2 | 21.1 | 0.36 | 21.0 | 21.3 | 0.36 | 0.859 | 0.596 |
| 62 | Hind toe length | 58.1 | 58.7 | 0.97 | 58.8 | 58.1 | 0.97 | 0.699 | 0.606 |
| | Front toe length | 59.2 | 60.7 | 0.72 | 60.0 | 59.9 | 0.72 | 0.179 | 0.905 |
| | Hind heel height | 22.1 | 21.4 | 0.38 | 21.7 | 21.7 | 0.38 | 0.221 | 0.955 |
| | Front heel height | 27.3 | 26.1 | 0.77 | 26.8 | 26.6 | 0.77 | 0.318 | 0.831 |
| 139 | Hind toe length | 67.6 | 69.5 | 1.09 | 67.9 | 69.2 | 1.09 | 0.252 | 0.425 |
| | Front toe length | 68.8 | 70.4 | 0.70 | 69.8 | 69.4 | 0.70 | 0.154 | 0.676 |
| | Hind heel height | 24.0 | 23.6 | 0.46 | 24.0 | 23.5 | 0.46 | 0.529 | 0.510 |
| | Front heel height | 28.8 | 27.3 | 0.75 | 28.2 | 28.0 | 0.75 | 0.194 | 0.849 |
| Pre-slaughter[2] | Hind toe length | 73.9 | 76.0 | 1.44 | 76.3 | 73.7 | 1.44 | 0.330 | 0.244 |
| | Front toe length | 73.5 | 76.5 | 0.98 | 75.6 | 74.4 | 0.98 | 0.063 | 0.397 |
| | Hind heel height | 27.2 | 27.2 | 0.61 | 27.8 | 26.6 | 0.61 | 0.988 | 0.193 |
| | Front heel height | 32.8 | 31.9 | 1.02 | 33.5 | 31.2 | 1.02 | 0.535 | 0.154 |
| Net growth[3] | Hind toe | 23.8 | 26.1 | 1.84 | 26.1 | 23.7 | 1.84 | 0.403 | 0.384 |
| | Front toe | 22.6 | 24.8 | 1.22 | 24.3 | 23.1 | 1.22 | 0.881 | 0.094 |
| | Hind heel | 8.2 | 8.3 | 0.62 | 9.1 | 7.4 | 0.62 | 0.777 | 0.055 |
| | Front heel | 11.6 | 10.8 | 1.23 | 12.5 | 9.9 | 1.23 | 0.643 | 0.182 |

S = fully slatted concrete floor; R = fully slatted concrete floor overlaid with rubber; H = intensive high concentrate diet; L = grass-silage-based diet supplemented with a lower input of concentrates.
[1]Measured at day −5.
[2]Mean pre-slaughter measurement at day 215.
[3]Net growth from day −5 to pre-slaughter measurement.

**Table 5** *Main effects of floor, diet, and hoof position on the probability (%) of bulls having bruising on soles of hooves (95% confidence intervals presented in brackets)*

| | Floor | | Diet | | *P*-value | |
|---|---|---|---|---|---|---|
| | S | R | H | L | Floor | Diet |
| Day 62 | 58 (37–76) | 23 (10–43) | 38 (20–59) | 40 (21–62) | 0.076 | 0.591 |
| Day 139 | 83 (61–94) | 56 (33–76) | 73 (50–88) | 69 (44–86) | 0.242 | 0.828 |
| Pre-slaughter | 68 (44–85) | 28 (12–52) | 30 (12–55) | 65 (42–83) | 0.052 | 0.089 |

S = fully slatted concrete floor; R = fully slatted concrete floor overlaid with rubber; H = intensive high concentrate diet; L = grass-silage-based diet supplemented with a lower input of concentrates.

**Table 6** *The main effects of floor and diet on the number of bruises on soles of bulls' hooves as predicted by the generalised linear mixed model together with 95% confidence intervals*

| | Floor | | Diet | | *P*-value | |
|---|---|---|---|---|---|---|
| | S | R | H | L | Floor | Diet |
| Day 62 | 1.30 (0.79–2.14) | 0.36 (0.18–0.69) | 0.56 (0.30–1.04) | 0.82 (0.47–1.44) | 0.003 | 0.391 |
| Day 139 | 2.41 (1.69–3.41) | 1.53 (1.04–2.24) | 1.82 (1.26–2.64) | 2.02 (1.40–2.90) | 0.269 | 0.991 |
| Pre-slaughter | 1.48 (0.88–2.50) | 0.47 (0.23–0.98) | 0.52 (0.25–1.09) | 1.34 (0.80–2.26) | 0.152 | 0.255 |

S = fully slatted concrete floor; R = fully slatted concrete floor overlaid with rubber; H = intensive high concentrate diet; L = grass-silage-based diet supplemented with a lower input of concentrates.

**Table 7** *The main effects of floor and diet on bulls' mean hoof bruising scores and locomotion scores*

| | Floor | | | Diet | | | *P*-value | |
|---|---|---|---|---|---|---|---|---|
| | S | R | SEM | H | L | SEM | Floor | Diet |
| Bruising score day 62 | 1.71 | 0.56 | 0.314 | 1.14 | 1.13 | 0.314 | 0.032 | 0.957 |
| Bruising score day 139 | 4.60 | 3.21 | 0.792 | 4.15 | 3.67 | 0.792 | 0.239 | 0.662 |
| Pre-slaughter bruising score | 2.36 | 1.63 | 0.684 | 2.03 | 1.97 | 0.683 | 0.469 | 0.940 |
| Locomotion score | 1.016 | 1.006 | 0.0056 | 1.017 | 1.005 | 0.0056 | 0.239 | 0.188 |

S = fully slatted concrete floor; R = fully slatted concrete floor overlaid with rubber; H = intensive high concentrate diet; L = grass-silage-based diet supplemented with a lower input of concentrates.

**Table 8** *The main effects of floor and diet on the percentage of bulls lying and standing*

| | Floor | | | Diet | | | *P*-value | |
|---|---|---|---|---|---|---|---|---|
| | S | R | SEM | H | L | SEM | Floor | Diet |
| Standing eating | 10.9 | 11.9 | 0.44 | 10.4 | 12.4 | 0.44 | 0.111 | 0.003 |
| Standing not eating | 24.3 | 25.9 | 0.79 | 25.1 | 25.1 | 0.79 | 0.145 | 0.903 |
| Lying, all limbs under body | 41.4 | 39.2 | 0.73 | 41.3 | 39.3 | 0.73 | 0.043 | 0.080 |
| Lying, 1 front leg out | 11.1 | 10.9 | 0.38 | 10.8 | 11.3 | 0.38 | 0.471 | 0.521 |
| Lying, 2 front legs out | 1.58 | 1.19 | 0.129 | 1.31 | 1.47 | 0.129 | 0.078 | 0.678 |
| Lying, front legs in, 1 or 2 back legs out | 7.09 | 7.20 | 0.334 | 7.21 | 7.08 | 0.334 | 0.549 | 0.974 |
| Lying on side | 1.10 | 1.21 | 0.115 | 1.24 | 1.07 | 0.115 | 0.415 | 0.357 |
| Front legs out, 1 or 2 back legs out | 2.56 | 2.41 | 0.188 | 2.66 | 2.32 | 0.188 | 0.535 | 0.155 |
| All standing | 35.2 | 37.9 | 0.94 | 35.5 | 37.5 | 0.94 | 0.048 | 0.178 |

S = fully slatted concrete floor; R = fully slatted concrete floor overlaid with rubber; H = intensive high concentrate diet; L = grass-silage-based diet supplemented with a lower input of concentrates.

soles of their hooves than those accommodated on slats overlaid with rubber prior to slaughter ($P = 0.052$) (Table 5). Diet had no significant effect on the probability of having sole bruising. Additionally, there was higher probability of having bruising on the soles of hind hooves than front hooves on days 62 (60% *v.* 21%, respectively; $P = 0.001$) and 139 (86% *v.* 50%, respectively; $P = 0.003$). At the pre-slaughter measurement, there was a significant interaction between diet and hoof position ($P = 0.041$) on the probability of having sole bruises, whereby there was a significantly lower probability of sole bruising in the front hooves of bulls offered the intensive diet (13%) than in the front hooves of bulls offered the less intensive diet (66%) or in the back hooves of bulls offered either diet (56% and 65% for bulls offered the intensive and less intensive diets, respectively).

Bulls accommodated on concrete slats had significantly higher number of sole bruises on day 62 than those accommodated on slats overlaid with rubber ($P = 0.003$), but there was no significant effect of floor on the number of bruises at day 139 or when measured pre-slaughter (Table 6). Diet had no effect on the number of sole bruises. Interestingly, a significantly higher number of bruises was noted on hind hooves than front hooves on day 62 (1.28 *v.* 0.36, respectively) and day 139 (3.26 *v.* 1.13, respectively) ($P < 0.001$). There was a significant interaction between the effect of floor and hoof position on the number of bruises on the sole at pre-slaughter ($P = 0.028$), where there was a significantly higher number of bruises in front hooves in bulls on concrete slats than slats overlaid with rubber (1.32 *v.* 0.20, respectively), but not in their hind hooves (1.66 *v.* 1.12, respectively).

Bulls accommodated on concrete slats had a significantly higher bruising score on day 62 of the study than those accommodated on slats overlaid with rubber ($P < 0.05$), but there was no significant effect of floor on bruising score at day 139 or when measured pre-slaughter (Table 7). Diet had no effect on bruising score at any time point during the study. Neither floor nor diet had a significant effect on locomotion score of the bulls.

### *Lying and standing behaviours*

The effect of floor and diet on the percentage of animals lying and standing is presented in Table 8. Floor had no significant effect on the percentage of animals which were standing eating or standing other than when eating. However, when the two standing behaviours were combined, a lower percentage of the bulls accommodated on concrete slats were standing than those accommodated on slats overlaid with rubber (35.2% *v.* 37.9%, respectively) ($P < 0.05$). Conversely, a higher percentage of bulls accommodated on the concrete slats were observed lying compared with those accommodated on rubber-covered slats. Floor had a significant effect on the percentage of bulls observed lying with all limbs under their body ($P < 0.05$), with 41.4% of animals on concrete slats observed lying in this position compared to 39.2% of those accommodated on slats overlaid with rubber. Floor had no significant effect on the percentage of animals lying in other body positions. A higher percentage of bulls offered the less intensive diet were observed standing eating than those offered the intensive diet ($P < 0.01$). Diet had no other significant effect on the percentage of animals observed carrying out any other standing or lying behaviours.

### *Leg swelling scores*

All animals were scored zero for leg swelling at the beginning of the experiment and at day 60. At pre-slaughter, a swelling score of 1 was observed in the lateral front leg of one bull accommodated on concrete slats and offered the intensive diet; a swelling score of 3 was noted in one animal in both dietary treatments accommodated on concrete slats, in both medial front legs. One animal accommodated on concrete slats and offered the less intensive diet also had a swelling score of 3 observed in the lateral back leg. Additionally, one bull accommodated on slats overlaid with rubber and offered the intensive diet had a score of 3 on the lateral back leg. All other animals scored zero for leg swelling at pre-slaughter.

## Discussion

### *Hoof health*

Brscic *et al.* (2015) suggested that hoof overgrowth observed post-mortem in bulls accommodated on slats overlaid with rubber in their study was due to the rubber floor being less abrasive than concrete slats; a theory also supported by others (Platz *et al.*, 2007; Telezhenko *et al.*, 2009; Murphy *et al.*, 2018). In the current study, there was little evidence of hoof overgrowth, with only a tendency for bulls accommodated on slats overlaid with rubber to have higher front toe length measured prior to slaughter than those accommodated on fully slatted concrete floors. However, the concrete slats used in the current study, although in good condition with no obvious defects, were *in situ* for approximately 30 years prior to the commencement of the study and so are likely to be smoother and less abrasive than newer slats.

Bergsten and Frank (1996a) highlighted the sudden change from being at pasture to being housed as a significant factor in the development of sole haemorrhages. Bulls in the current study were at pasture prior to the commencement of the study, and it would appear that the suggestion of Bergsten and Frank (1996b) that hoof lesions become visible 2 to 3 months after an abrupt change of floor was more pronounced when changing onto a fully slatted concrete floor than to slats overlaid with rubber. The effect of overlaying concrete slats with rubber on hoof health has not been consistent in the literature, with some authors reporting lower sole haemorrhaging in cattle accommodated on rubber-covered slats than concrete slats (Graunke *et al.*, 2011; Murphy *et al.*, 2018). Murphy *et al.* (2018) attributed this to the hard surface of the concrete slats increasing the pressure on the sole, as well as the abrasiveness of the concrete accelerating wear on the sole. However, in contrast, others have reported impaired hoof health when slatted floors were covered in rubber, such as Ahrens *et al.* (2011) in dairy cows, Keane *et al.* (2015) in bulls, and Earley *et al.* (2015 and 2017) in steers. Furthermore, Keane *et al.* (2017) reported no effect of floor on hoof lesions in heifers accommodated on either concrete slats or straw bedding. Telezhenko *et al.* (2008) categorised floors according to hardness, coefficient of friction, and degree of abrasiveness, with rubber mats classified as soft, with a high coefficient of friction, and a low abrasiveness compared with concrete floor, which was classified as hard, with a low coefficient of friction and either a high or low abrasiveness depending on the age of the floor. These authors concluded that abrasiveness had the greatest influence on the studied parameters of the claw which affected the weight distribution. The more abrasive floor increased the total contact area at the sole surface resulting in a lower contact pressure exerted on the claws but reduced the weight-bearing role of the strongest part of the claw capsule, the claw wall (Telezhenko *et al.*, 2008). Telezhenko *et al.* (2008) reasoned that the floor's abrasiveness affects claw horn growth and wear and claw conformation, which affects susceptibility to claw lesions. Although claw dimensions were not measured in their study, Keane *et al.* (2015) postulated that the greater number of hoof lesions in bulls accommodated on rubber could be explained by overgrown claws and it would appear that hoof grown and number of bruises may be inextricably linked. The abrasiveness of concrete slats is likely to be linked to the age of the slats, and different commercial rubber products have differing hardness and abrasiveness properties. Although floor type had no significant effect on the number of bruises and bruising score pre-slaughter in the current study, there was a non-significant tendency for bulls on rubber to have a lower probability of having sole bruising pre-slaughter compared with those on concrete slats. Bruising occurring in the final months of the study may not have been readily identified since only the superficial layer of horn was removed. If bulls had been claw trimmed pre-slaughter, it would have allowed any recently developed bruises in the deeper layer of the sole horn to be identified.

Previous studies in dairy cows have highlighted higher incidences of lameness in dairy cows offered a higher concentrate diet (Manson and Leaver, 1988 and 1989). In the present study, there was no effect of diet on hoof bruising. Randall *et al.* (2018) reviewed associations between dietary factors and claw horn disruption lesions and suggested that the univariable analysis used in early studies such as that of Manson and Leaver (1988) did not take account of other confounding factors such as stage of lactation and parity and should thus be interpreted with caution. Randall *et al.* (2018) concluded that there was not sufficient evidence to demonstrate that feeding high concentrate diets (or other SARA-inducing diets) caused the development of claw lesions. The greater effect of floor type than diet on sole bruising reported in the current study is in agreement with the conclusion of others (Bergsten and Frank, 1996a; Webster, 2001). Newcomer and Chamorro (2016) reported that foot lameness due to hind limb lesions was more than twice as common as front feet, which is in line with the findings of the current study where bruising was much more prevalent in the hind hooves than the front ones. It is interesting to note the interaction between floor and hoof position in the current study. Some studies have only examined hind hooves for lesions since they are more commonly observed here. In the current study, there was no significant effect of floor type on the number of bruises in the hind hooves pre-slaughter, in contrast to the lower number of bruises observed in the front hooves of bulls accommodated on slats overlaid with rubber compared with those accommodated on concrete slats.

*Lying and standing behaviours*

Associations between changes in lying and lameness have been reported in dairy cows (Solano *et al.*, 2016), and so time spent lying may be an important indicator of subclinical or clinical lameness. Haley *et al.* (2001) suggested that a lower time spent lying and an increase in time spent standing other than standing while eating were two measurements that were indicative of a lack of comfort in dairy cows. Thus, using the criteria of Haley *et al.* (2001), there was no evidence in the current study that bulls accommodated on concrete slatted floors experienced a lack of comfort compared with those accommodated on rubber-covered slats. Keane *et al.* (2017) reported a higher number of heifers lying at any one time on straw than on concrete slats. However, in a subsequent meta-analysis, Keane *et al.* (2018) concluded that using rubber-covered slats or straw instead of concrete mats had no effect on lying duration. This was based on a review with eight studies comparing concrete slats versus rubber-covered slats and three studies comparing concrete slats and straw and is in agreement with the conclusions of Wechsler (2011) who reviewed the effect of floor type on total lying time. The important effect of floor type on lying behaviour appears to be on the duration and number of lying bouts (Absmanner *et al.*, 2009), whereby animals accommodated on rubber-covered slatted floors have more lying bouts of shorter duration than those accommodated on concrete slats, in effect meaning they get up and down more often. Wechsler (2011) concluded that finishing cattle accommodated on fully slatted concrete slatted floors avoid frequent standing up and lying down on the hard floor and this was improved when the slats were overlaid with rubber.

*Leg lesions and lying positions*

It has been reported that lesions and swelling at the carpal joint are higher in cattle accommodated on concrete floors compared to rubber-covered slats (Schulze Westerath *et al.*, 2007). Schulze Westerath *et al.* (2007) reasoned that this was mainly influenced by the pressure on the ground and thus the hardness of the floor.

The only effect of floor type on lying positions in the current study was on the most commonly observed posture, lying in a sternal position with legs tucked in under the body. Absmanner *et al.* (2009) reported that the percentage of animals accommodated on fully slatted concrete floor lying with their hind(s) legs stretched out was higher than those accommodated in straw bedded pens, and these authors suggested that this was a strategy to get relief in carpal and tarsal joints. Since there was little evidence of leg swelling in the current study, it is not surprising that there were few effects of floor type on lying positions. Relic *et al.* (2012) suggested that cows with injuries to a knee often lie with a leg in extension because swelling limits their ability to bend it. Interestingly, no difference was noted in this study between the percentage of bulls accommodated on slatted concrete floors lying with leg(s) stretched out compared with those accommodated on rubber-covered slats, although the limitations of only having three scans per day are acknowledged. However, in contrast to the current study, Brscic *et al.* (2015) reported that Continental bulls accommodated on fully slatted concrete floors spent longer lying with their front limbs extended than those accommodated on rubber-covered slats. Bulls in the study reported by Brscic *et al.* (2015) were an average live weight of 712 kg at slaughter, considerably heavier than in the current study where the mean slaughter weight was 534 kg. Schulze Westerath *et al.* (2007) reported that lesion scores at the carpal joints on concrete slats increased with increasing live weight of bulls, so this could potentially explain the difference between the current study and that of Brscic *et al.* (2015). There were no differences in the percentage of bulls lying in other resting positions in the current study and thus no evidence that the hardness of the concrete floor prevented bulls from assuming different positions during lying. Similar results were reported by Haley *et al.* (2000) in dairy cattle who despite reporting a reduced lying time, difference in lying duration and frequency between cattle in tie stalls and loose housing, few differences were observed in lying postures between the two treatments other than the most common lying position of lying in a sternal position with legs tucked in under the body.

## Conclusions

It is concluded in the current study that bulls moving from pasture to fully slatted concrete floors had a bigger initial impact on their hoof health (as assessed by the number of bruises and bruising score) than moving from pasture to concrete slats overlaid with rubber. However, no effect of floor type on hoof bruising score or number of bruises was noted at day 139 of the study or prior to slaughter. There was, however, a non-significant tendency for cattle accommodated on rubber slats to have a lower probability of having sole bruising than those on concrete slats prior to slaughter. There was little evidence from the current study that accommodating finishing dairy-origin bulls up to 550 kg on fully slatted concrete floors altered their lying positions compared with accommodating on rubber-covered slatted floors. Hoof growth and number of bruises may be inextricably linked, and it is postulated that this is dependent on the abrasiveness of the floor. Interestingly, diet had no significant effect on claw measurements or hoof health in finishing dairy-origin bulls.

## Acknowledgements

The authors sincerely thank staff from the Sustainable Beef Unit at AFBI, Hillsborough. This research was funded by the Department of Agriculture, Environment and Rural Affairs in Northern Ireland. Preliminary results of this study have been published in abstract form (Lowe *et al.*, 2018), and the results of intake, performance, and cleanliness in this study have also been published (Lowe *et al.*, 2019).
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## Declaration of interest

None.

## Ethics statement

This study was conducted with the approval of the AFBI Hillsborough Ethical Review Committee, in accordance with the requirements of the UK Animals (Scientific Procedures) Act 1986.

## Software and data repository resources

None of the data were deposited in an official repository.

## References

Absmanner E, Rouha-Mulleder C, Scharl T, Leisch F and Troxler J 2009. Effects of different housing systems on the behaviour of beef bulls-An on-farm assessment on Austrian farms. Applied Animal Behaviour Science 118, 12–19.

Ahrens F, Platz S, Link C, Mahling M, Meyer HHD and Erhard MH 2011. Changes in hoof health and animal hygience in a dairy herd after covering concrete slatted floor with slatted rubber mats: a case study. Journal of Dairy Science 94, 2341–2350.

Bergsten C and Frank B 1996a. Sole haemorrhages in tied primiparous cows as an indicator of periparturient laminitis: effects of diet, flooring and season. Acta Veterinaria Scandinavica 37, 383–394.

Bergsten C and Frank B 1996b. Sole haemorrhages in tied heifers in early gestation as an indicator of laminitis: effects of diet and flooring. Acta Veterinaria Scandinavica 37, 375–381.

Brscic M, Ricci R, Prevedello P, Lonardi C, De Nardi R, Contiero B, Gottardo F and Cozzi, G 2015. Synthetic rubber surface as an alternative to concrete to improve welfare and performance of finishing beef cattle reared on fully slatted flooring. Animal 9, 1386–1392.

Cook NB, Nordlund KV and Oetzel GR 2004. Environmental influences on claw horn lesions associated with laminitis and subacute ruminal acidosis in dairy cows. Journal of Dairy Science 87, E36–E46.

Earley B, McDonnell B and O'Riordan EG 2015. Effect of floor type on the performance, physiological and behavioural responses of finishing beef steers. Acta Veterinaria Scandinavica 57, 1–11.

Earley B, McNamara JD, Jerrams SJ and O'Riordan EG 2017. Effect of concrete slats, three mat types and out-wintering pads on performance and welfare of finishing beef steers. Acta Veterinaria Scandinavica 59, 1–14.

Flower FC and Weary DM 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. Journal of Dairy Science 89, 139–146.

Graunke KL, Telezhenko E, Hessle A, Bergsten C and Loberg JM 2011. Does rubber flooring improve welfare and production in growing bulls in fully slatted floor pens? Animal Welfare 20, 173–183.

Haley DB, de Passille AM and Rushen J 2001. Assessing cow comfort: effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Applied Animal Behaviour Science 71, 105–117.

Haley DB, Rushen J and de Passille AM 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Canadian Journal of Animal Science 80, 257–263.

Holzhauer M, Bartels CJM, Dopfer D and van Schaik G 2008. Clinical course of digital dermatitis lesions in an endemically infected herd without preventive herd strategies. Veterinary Journal 177, 222–230.

Huxley JN 2013. Impact of lameness and claw lesions in cows on health and production. Livestock Science 156, 64–70.

Keane MP, McGee M, O'Riordan EG, Kelly AK and Earley B 2015. Effect of floor type on hoof lesions, dirt scores, immune response and production of beef bulls. Livestock Science 180, 220–225.

Keane MP, McGee M, O'Riordan EG, Kelly AK and Earley B 2017. Effect of space allowance and floor type on performance, welfare and physiological measurements of finishing beef heifers. Animal 11, 2285–2294.

Keane MP, McGee M, O'Riordan EG, Kelly AK and Earley B 2018. Performance and welfare of steers housed on concrete slatted floors at fixed and dynamic (allometric based) space allowances. Journal of Animal Science 96, 880–889.

Knott L, Tarlton JF, Craft H and Webster AJF 2007. Effects of housing, parturition and diet change on the biochemistry and biomechanics of the support structures of the hoof of dairy heifers. The Veterinary Journal 174, 277–287.

Livestock and Meat Commission for Northern Ireland 2014. The product standard and rules of the Northern Ireland beef and lamb quality assurance scheme. FQAS Product Standard and Rules. Retrieved on 4 September 2017 from https://www.lmcni.com.

Lowe DE, Lively FO and Gordon AW 2018. The effect of floor type and diet on the performance and locomotion scores of housed finishing dairy-origin bulls. Advances in Animal Biosciences 9, 125.

Lowe DE, Lively FO and Gordon AW 2019. The effect of diet and covering fully slatted concrete floors with rubber strips on the intake, performance and cleanliness of dairy-origin bulls. Animal 13, 2092–2100.

Lowe DE, Steen RWJ and Beattie VE 2001. Preferences of housed finishing beef cattle for different floor types. Animal Welfare 10, 395–404.

Manson FJ and Leaver JD 1988. The influence of concentrate amount on locomotion and clinical lameness in dairy-cattle. Animal Production 47, 185–190.

Manson FJ and Leaver JD 1989. The effect of concentrate – silage ratio and of hoof trimming on lameness in dairy-cattle. Animal Production 49, 15–22.

Murphy VS, Lowe DE, Lively FO and Gordon AW 2018. The impact of floor type on lameness and hoof health of dairy origin bulls. Animal 12, 2382–2390.

Newcomer BW and Chamorro MF 2016. Distribution of lameness lesions in beef cattle: a retrospective analysis of 745 cases. Canadian Veterinary Journal-Revue Veterinaire Canadienne 57, 401–406.

Payne RW, Harding SA, Murray DA, Soutar DM, Baird DB, Glaser AI, Channing IC, Welham SJ, Gilmour AR, Thompson R and Webster R 2015. The guide to GenStat Release 12, part 2: statistics. VSN International, Hemel Hempstead, UK.

Platz S, Ahrens F, Bahrs E, Nueske S and Erhard MH 2007. Association between floor type and behaviour, skin lesions, and claw dimensions in group-housed fattening bulls. Preventive Veterinary Medicine 80, 209–221.

Randall LV, Green, MJ and Huxley JN 2018. Use of statistical modelling to investigate the pathogenesis of claw horn disruption lesions in dairy cattle. The Veterinary Journal 238, 41–48.

Relic R, Hristov S, Joksimovic-Todorovic M, Davidovoc, V and Bojkovski J 2012. Behaviour of cattle as an indicator of their health and welfare. Retrieved on 28 August 2018 from https://www.researchgate.net/publication/259194837_Behavior_of_cattle_as_an_Indicator_of_their_health_and_welfare

Schulze Westerath H, Gygax L, Mayer C and Wechsler B 2007. Leg lesions and cleanliness of finishing bulls kept in housing systems with different lying area surfaces. Veterinary Journal 174, 77–85.

Solano L, Barkema HW, Pajor EA, Mason S, LeBlanc SJ, Nash CGR, Haley DB, Pellerin D, Rushen J, de Passille AM, Vasseur E and Orsel K 2016. Associations between lying behavior and lameness in Canadian Holstein-Friesian cows housed in freestall barns. Journal of Dairy Science 99, 2086–2101.

Telezhenko E, Bergsten C, Magnusson M and Nilsson C 2009. Effect of different flooring systems on claw conformation of dairy cows. Journal of Dairy Science 92, 2625–2633.

Telezhenko E, Bergsten C, Magnusson M, Ventorp M and Nilsson C 2008. Effect of different flooring systems on weight and pressure distribution on claws of dairy cows. Journal of Dairy Science 91, 1874–1884.

Thomsen PT, Hansen I, Martin HL and Kudah AB 2017. Sole haemorrhages in Danish bull calves: prevalence and risk factors. Veterinary Journal 224, 44–45.

Webster AJF 2001. Effects of housing and two forage diets on the development of claw horn lesions in dairy cows at first calving and in first lactation. The Veterinary Journal 162, 56–65.

Wechsler B 2011. Floor quality and space allowance in intensive beef production: a review. Animal Welfare 20, 497–503.