Animal 19 (2025) 101507

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

The effect of neck strap positioning relative to dairy cow body size on rising, lying down, and defecation behaviour in lying cubicles

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ARTICLE INFO

Article history:
Received 31 October 2024
Revised 28 March 2025
Accepted 28 March 2025
Available online 3 April 2025

Keywords:
Animal welfare
Cattle
Free stall
Livestock housing
Stall equipment

ABSTRACT

In cubicle housing systems for dairy cows, neck rails/straps/chains are used to limit bedding soiling by faeces and urine. Flexible neck straps are an alternative to rigid neck rails, which are associated with animal welfare issues such as painful collisions, injuries, and atypical behaviours. However, no literature exists on the positioning of flexible neck straps in relation to their effectiveness in limiting soiling of the bedding material and their effect on cow behaviour. In a research barn with 40 cows, we experimentally investigated how neck strap positioning relative to cow body size affects rising and lying down behaviours, general lying behaviour, and defecation behaviour in lying cubicles. To expand the range of body-relative positioning beyond that resulting from the herd's variation in body size, we varied the neck strap height (105, 120, and 135 cm) and its distance from the curb (155 and 170 cm) in two experiments. The resulting ratios of neck strap height to withers height (**NSH** ratio) ranged from 0.65 to 0.96, and the ratios of neck strap distance from the curb to diagonal body length (**NSD** ratio) ranged from 0.85 to 1.11. With the exception of sideways head lunging, atypical rising and lying down behaviours were rare throughout the study. A higher (less restrictive) NSH ratio was associated with a reduced probability of crawling backwards on the carpal joints during rising. We found no statistical support for an effect of neck strap positioning relative to cow body size on the probabilities of other atypical rising and lying down behaviours, or daily lying time and frequency. For defecations within a 120 s time window around rising events while in the lying cubicle, a higher (less restrictive) NSH ratio was associated with a higher probability of faeces landing in the cubicle. This probability also increased with a higher (less restrictive) NSD ratio. Overall, our results indicate that the positioning of flexible neck straps relative to cow body size, as tested in this study, does not considerably affect dairy cow behaviour, suggesting that flexible straps can accommodate cows of different sizes. The effectiveness of positioning cows in the lying cubicle in such a way that limits soiling of the bedding around rising events increased with a lower (more restrictive) NSH ratio. Thus, flexible neck straps can be a viable alternative to rigid neck rails by limiting soiling of lying cubicles around rising events without considerably impeding dairy cow movements during rising and lying down.

Implications

In cubicle housing systems for dairy cows, flexible neck straps are considered a welfare-friendly alternative to rigid neck rails, which are associated with collisions, injuries, and atypical behaviours. Our study suggests that flexible neck straps can accommodate cows of various sizes without considerably affecting their rising or lying down behaviours. Cubicle soiling around rising decreased with lower relative neck strap positioning. Dairy farmers could benefit from using flexible neck straps as an alternative to neck rails, potentially reducing injury risks and improving the welfare of dairy cows in cubicle housing systems, while managing hygiene through appropriate strap positioning.

Introduction

Cubicle housing systems should allow dairy cows to lie down and rest comfortably on a clean and dry lying surface. Therefore, the design and configuration of lying cubicles should limit soiling

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https://doi.org/10.1016/j.animal.2025.101507
1751-7311/

of the bedding material while minimising the hindrance of other behaviours. Typically, a rigid neck rail or flexible neck strap or chain is placed across the cubicle partitions in the front half of the cubicle to encourage cows to stand in the lying cubicle with their hind legs close to the rear curb so that faeces and urine fall into the walking alley and do not soil the bedding material (van Eerdenburg and Ruud, 2021). Together with the brisket board, the neck rail/strap should also guide cows to lie down near the end of the lying cubicle to limit bedding soiling by lying cows and to ensure that cows have sufficient space to lunge their heads when rising. The effectiveness of the neck rail/strap/chain depends on both the height above the lying surface and the distance from the curb at which it is installed (Cook and Nordlund, 2005). To prevent cows from standing and lying too far forward in the lying cubicle, the neck rail/strap/chain should be placed below the cows' wither height (Veissier et al., 2004). However, the space required for a cow to rise and lie down is proportional to her body size. Therefore, neck rails/straps/chains should be positioned relative to cow body size (CIGR, 2014; EFSA, 2023).

For rigid neck rails, the influence of their positioning on lying cubicle hygiene and dairy cow welfare has been extensively studied. Restrictive neck rail positioning can cause cows to collide with the rail when rising, resulting in abrasions, bruises, and even fractures (Cermak, 1988; Veissier et al., 2004). It can also increase the prevalence of lameness and hoof disease by forcing cows to stand in the walking alley, which contains manure (Bernardi et al., 2009; Gieseke et al., 2020). Conversely, overly permissive neck rail positioning or the complete absence of neck rails is associated with a reduction in both lying cubicle and animal cleanliness (Robles et al., 2021; Tucker et al., 2005; Wilson et al., 2022). Therefore, overly permissive neck rail positioning increases the need for cubicle maintenance and may increase the risk of udder infections (Breen et al., 2009). However, positioning the neck rail so that all cows can stand with four hooves in the cubicle and are not hindered in their natural movements, while limiting soiling of the bedding, is virtually impossible due to the natural variation in cow body size in commercial herds (de Boyer des Roches et al., 2019; Rushen, 2017).

Flexible neck straps are considered as an alternative to neck rails because they may reduce the animal welfare problems associated with rigid neck rails. Collisions with a flexible strap are presumably less painful and chances of injury are lower compared to rigid neck rails. However, there is no scientific literature on the positioning of flexible neck straps in relation to their effectiveness in limiting soiling of the bedding material and their effect on cow behaviour. Therefore, the aims of the current study were to investigate the effects of neck strap positioning (height above the lying surface and horizontal distance from the curb) relative to cow body size on rising and lying down behaviours, general lying behaviour (total lying time, lying frequency, and mean lying bout duration), and defecation behaviour around rising events in lying cubicles. We hypothesised that restrictive neck strap positioning relative to cow body size does not markedly impede rising and lying down behaviours or affect general lying behaviour, but does effectively limit defecation inside lying cubicles around rising events.

Material and methods

Housing

The study took place in October and November 2023 in a research barn of Agroscope (Aadorf TG, Switzerland). The barn consisted of two identical (mirrored), spatially separated pens. Each pen contained two rows of seven head-to-head lying cubicles and one row of six wall-facing lying cubicles, resulting in a total of 20 cubicles per pen. Throughout the study, the stocking density in both pens was 100% (i.e., a cow:cubicle ratio of 1:1). All lying cubicles were deep-bedded with a lime-straw mixture with a bedding depth of approximately 15 cm. Faeces were removed and the bedding was levelled (adding bedding if necessary) three times a day: before morning milking, after fresh feed was provided, and before afternoon milking. The individual lying cubicles measured 125 cm in width and were separated by partitions of the Liberty model (Fig. 1; Krieger AG, Switzerland). The cubicles had a brisket board located 195 cm from the inside of the rear curb with a height of 5–10 cm above the bedding, depending on the bedding level. Wall-facing lying cubicles had a lunge space of 80 cm. In head-to-head cubicles, the space between opposite brisket boards was 105 cm and opposing rows were separated by a front rail positioned in the centre of the lunge space at a height of 100 cm above the brisket board. All lying cubicles were fitted with a flexible neck strap (Fig. 1A; Krieger AG, Switzerland) made of nylon lashing strap material, angled at approximately 45° and tightened with a

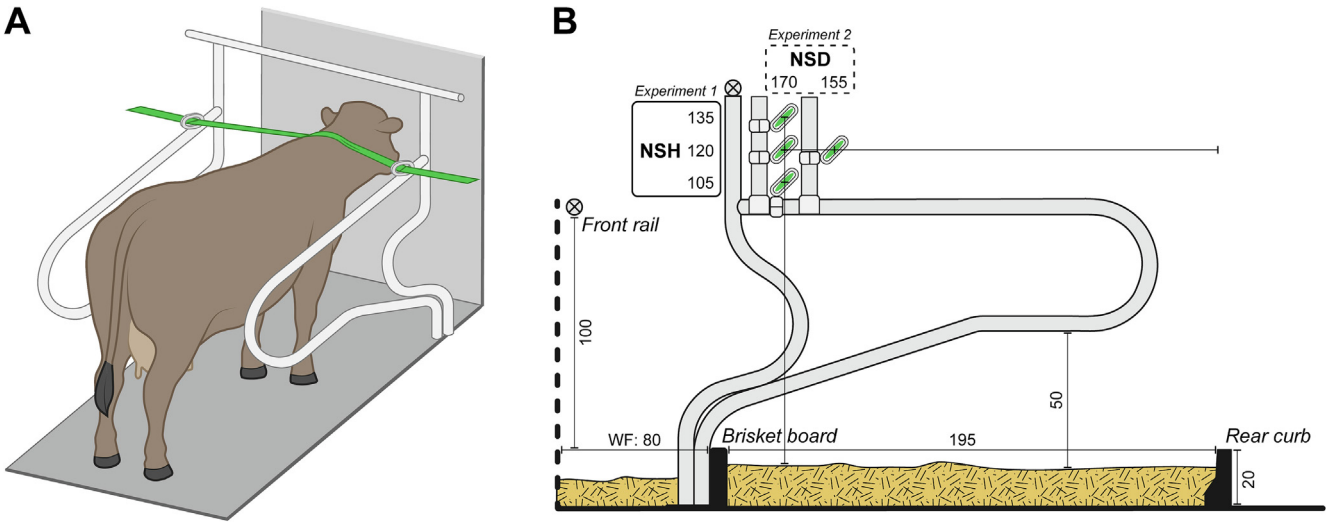

Fig. 1. (A) Illustration of a dairy cow standing in a lying cubicle fitted with a flexible neck strap across the partitions. The flexibility of the neck strap allows the cow to stand with all four hooves in the cubicle, but discourages her from walking forward by pushing against her neck. (B) Lying cubicle dimensions (cm), and neck strap positions (cm) investigated in Experiment 1 (solid square) and Experiment 2 (dashed square). Both wall-facing and head-to-head cubicles were used in the study. Abbreviations: NSH = neck strap height; NSD = neck strap distance from the curb; WF = wall-facing cubicles.

cogwheel tensioner fixed to the end gate of each lying cubicle row. In the period prior to the experiments, the neck straps were positioned at a height of 105 cm above the bedding and 155 cm from the rear curb in all lying cubicles, and the front rails were positioned at a height of 80 cm above the brisket board in the head-to-head cubicles. At the start of the study, all neck straps were replaced with new ones.

The alleys were covered with rubber mats and cleaned 12 times a day by automatic scrapers. Cows were fed *ad libitum* a total mixed ration consisting of grass silage, maize silage, and minerals. Fresh feed was provided daily at 0800 h, and the feed was automatically pushed up 18 times per day. Additionally, concentrate was offered at an automated feeding station according to the animal-individual allowance. The cows were locked in the headlock feeder for approximately 1 h after fresh feed was provided. The cows did not have access to pasture or the outdoor exercise yard during the study. Water was freely available from two self-filling troughs per pen. The cows were milked twice daily at 0500 and 1600 h. The research barn was managed alternately by two staff members.

Animals

In each of the two pens, the dairy herd consisted of 20 primiparous and multiparous lactating cows of the Brown Swiss and Swiss Fleckvieh breeds (n = 40). The cows remained in their respective pens throughout the entire study, including between the two experiments. The herds were balanced as best as possible with respect to breed, age, parity, days in milk, wither height, and diagonal body length (Table 1, body dimensions measured as described in CIGR, 2014). Prior to the experiment, the cows were housed either in the barn where the experiment took place or in a nearby barn (Ettenhausen TG, Switzerland) with similar lying cubicle dimensions, partitions, and neck straps. The herds were established 1 week before the start of the experiment.

Study design

We investigated the effects of neck strap positioning relative to cow body size on dairy cow behaviour by conducting two experiments in direct succession. A digital hanging suspension scale was used to control the tension of the neck strap. The neck straps were tightened to the point where it took a pulling force of 147 N (15 kg on the scale) to stretch the neck strap 10–12 cm upwards. This was measured again on day 3 of each experiment week and the neck straps were re-tightened on three occasions as they stretched more than 12 cm.

Experiment 1: neck strap height relative to cow wither height

We investigated the effects of neck strap height (**NSH**) relative to cow wither height (NSH ratio; Eq. (1) on dairy cow behaviour in lying cubicles, namely atypical rising and lying down behaviours, general lying behaviour, and defecation behaviour around rising events. NSH was defined as the vertical distance from the bedding surface to the midpoint of the neck strap, considering the strap's 45° angle. To increase the range of variation in NSH ratio beyond that resulting from the herd's variation in wither height (Table 1), we adjusted the NSH in the two pens to 105, 120, and 135 cm (Fig. 1B) for 1 week each, in the order shown in Table 2. The resulting NSH ratios ranged from 0.65 to 0.96. To change the NSH, we installed a short metal pipe on each lying cubicle partition (Fig. 1B). We slightly compressed the bedding to form a flat surface when measuring NSH. In Experiment 1, the neck strap was always positioned at 170 cm from the curb (measured from directly above the inner edge of the rear curb).

$$NSH\ ratio\ = \frac{NSH\ (cm)}{wither\ height\ (cm)} \quad (1)$$

Experiment 2: neck strap distance from the curb relative to cow diagonal body length

We investigated the effects of neck strap distance from the curb (**NSD**) relative to cow diagonal body length (NSD ratio, Eq. (2) on dairy cow behaviour in lying cubicles, namely atypical rising and lying down behaviours, general lying behaviour, and defecation behaviour around rising events. NSD was defined as the horizontal distance from directly above the inner edge of the rear curb to the midpoint of the neck strap, considering the strap's 45° angle. To increase the range of variation in NSD ratio beyond that resulting from the herd's variation in diagonal body length (Table 1), we adjusted the NSD in the two pens to 155 and 170 cm (Fig. 1B) for 1 week each, in the order shown in Table 2. The resulting NSD ratios ranged from 0.85 to 1.11. To change the NSD, the short metal pipe was moved backwards or forwards relative to the curb. In Experiment 2, the NSH was fixed at 120 cm.

$$NSD\ ratio\ = \frac{NSD\ (cm)}{diagonal\ body\ length\ (cm)} \quad (2)$$

Neck strap height (Experiment 1) and neck strap distance from the curb (Experiment 2) were applied at pen level according to balanced (incomplete) block designs (Table 2). However, due to variation in cow size, the NSH ratio and NSD ratio varied among individual cows, rendering the cow the experimental unit. The cow was also the observational unit throughout the study, as all data were collected at the individual cow level.

Data collection

On day 2 of each experiment week, triaxial accelerometers (MSR 145; MSR Electronics, Switzerland) recording at 1 Hz were attached to the outward-facing side of the left metatarsus of each animal using a piece of foam and self-adhesive bandage when the cows were fixed in the headlock feeder during feeding. Accelerometer recording started at 1200 h on experiment day 3 and ended at 0800 h on day 1 of the following experiment week, after which the accelerometers were removed, read out, and recharged. Two cameras (Bascom 4XB40K, Bascom, Vianen, The Netherlands) were installed in each pen at a height of approximately 4 m so that all lying cubicles and walking alleys were in view. Continuous video recordings were made. The cameras had built-in IR lights for night-time recording.

Table 1
Characteristics of the dairy cows in the study population (all values represent mean ± SD).

Item	Pen A	Pen B
Breeds	12 Brown Swiss, 8 Swiss Fleckvieh	12 Brown Swiss, 8 Swiss Fleckvieh
Age (years)[1]	4.3 ± 1.43	4.7 ± 1.80
Parity[1]	2.3 ± 1.22	2.8 ± 1.62
Days in milk[1]	51 ± 38.4	54 ± 42.0
Wither height (cm)	149 ± 5.8	151 ± 4.9
Diagonal body length (cm)	171 ± 7.3	168 ± 5.8

[1] At start of Experiment 1.

Table 2
Overview of neck strap positions in dairy cow lying cubicles in Experiment 1 and Experiment 2.

	Experiment 1			Experiment 2	
Pen	Week 1	Week 2	Week 3	Week 4	Week 5
Pen A	105 cm	135 cm	120 cm	155 cm	170 cm
Pen B	120 cm	105 cm	135 cm	170 cm	155 cm

Data processing and analysis

Atypical rising and lying down behaviours

Data processing and statistical analyses were conducted in R (version 4.2.3; R Core Team, 2023). For days 4–7 of each experiment week, timestamps of rising and lying down events were obtained from the accelerometer data using the extract_liedown and extract_standup functions of the triact R package (version 0.3.0; Simmler and Brouwers, 2024) with default parameter settings. This R package uses a simple rule-based algorithm to distinguish between standing and lying postures, based on the axis of the leg-mounted accelerometer on which the reaction force of gravity loads. The extracted timestamps were then used to locate the corresponding events in the video footage. From these events, we randomly selected three clearly observable rising and three lying down events between 0500 and 2000 h per cow per day for assessment of atypical behaviours using an ethogram based on Brouwers et al. (2023; Table 3). Events were considered clearly observable if lighting conditions were good and the focal cow was not obstructed by other cows. In a few cases (3% of cow-days), only two or one clearly observable event(s) were available. Cows were sometimes tethered to the lying cubicle for a few hours if they needed veterinary treatment or if they were close to oestrus (i.e., if they were mounting other cows). Rising and lying down events of tethered cows were not considered; instead, the next closest event of that cow, if available, was selected for analysis. Throughout the study, the atypical rising and lying down behaviours were analysed by two trained observers (SPB and AFES). Both observers analysed 2 days per experiment week per pen. The observers could not be blinded to the position of the neck strap. To determine inter-observer reliability, the observers assessed the same set of 50 randomly selected rising events and 50 randomly selected lying down events (Cohen's Kappa $\kappa = 0.88$).

General lying behaviour

General lying behaviour was analysed using the accelerometer data and the triact R package. For each cow, daily lying time, lying frequency, and mean lying bout duration were determined from days 4 to 7 of each experiment week. Due to the change from Central European Summer Time to Central European Time, the milking and feeding times on days 6 and 7 of experiment week 2 were shifted by +1h with respect to our observation period. In order to account for this and other potential differences between weeks, the statistical analysis includes week as a random effect (see Statistical analysis).

Defecation behaviour

We studied defecation behaviour around the same rising events used to study atypical behaviours (selection as described above). We assessed defecations in lying cubicles within an operationally defined 120 s time window around the selected rising events (centred around the end of the rising events; Table 4), thus analysing defecation behaviour shortly before and shortly after rising events. When a cow exited the cubicle within 60 s after rising and defecated in the walking alley, this was not recorded.

Statistical analysis

We used (generalised) linear mixed effects models (**GLMMs**/**LMMs**) from the R packages lme4 (Bates et al., 2015). Fixed effects and odds ratios were obtained from population-level estimates obtained using the predict.MerMod function with the parameter re.form = ~0. Corresponding 95% bootstrap quantile confidence intervals/bands (**95% CI**) were obtained by parametric bootstrapping using the bootMer function (10^4 bootstraps). This is considered to provide a more reliable indication of statistical significance than *P*-values based on Wald statistics (Bates et al., 2015). A significant difference from the null hypothesis at the 0.05 level is indicated when the 95% CI does not include the null value (0 for fixed effects, 1 for odds ratios). For all models, we checked the underlying model assumptions using the DHARMa R package (Hartig, 2022).

Atypical rising and lying down behaviours and general lying behaviour

We investigated the effects of NSH ratio and NSD ratio on atypical rising and lying down behaviours and general lying behaviour using (G)LMMs with formulae in lme4 syntax as follows:

$$\text{response} \sim 1 + \text{ratio} + (1|\text{pen/cow}) + (1|\text{week})$$

Fixed effects included a general intercept and a slope for NSH ratio or NSD ratio, respectively (1 + ratio). Random effects included a random intercept for cow nested within pen (1|pen/cow) to account for multiple observations of the same cow and the potential effects of pen affiliation. Furthermore, a random intercept for week was included (1|week). The GLMMs with atypical behaviours as the response were fitted with a binominal response (yes/no) and a logit link using the glmer function. We used the GLMM estimates to calculate odds ratios for a 0.1 increase in NSH ratio or NSD ratio. For a cow with a wither height of 150 cm, a 0.1 increase in NSH ratio corresponds to a 15 cm higher neck strap. The LMMs with measures of general lying behaviours as the response were fitted with the lmer function.

Table 3
Ethogram of atypical behaviours in cattle during rising and lying down movements. Source: Brouwers et al., 2023

Atypical behaviour	Definition
Rising	
Horse-like rising (yes/no)	Cow first raises the forequarters and then the hindquarters.
Interruption (yes/no)	Hindquarters are lifted from the ground, but the rising movement is then terminated by lowering the hindquarters (to the same or other side of the body).
Staggered head lunge (yes/no)	Staggered, interrupted, or repeated motion of the head during the head lunge movement.
Sideways head lunge (yes/no)	Head lunge movement is directed sideways by bending the head and neck to the side.
Crawling backwards (yes/no)	When resting on carpal joints, cow moves her front leg(s) backwards after propelling herself.
Lying down	
Dog-sitting (yes/no)	Cow first lowers the hindquarters and then the forequarters.
Interruption[1] (yes/no)	Carpal joints touch the ground, but the lying down movement is then terminated by raising from the carpal joints.
Extensive inspection (yes/no)	Head is lowered and swept sideways (while sniffing the bed surface) more than 2 times before the lying down movement.
Repeated stepping (yes/no)	Stepping in place with front legs more than 2 times before the lying down movement.
Pawing (yes/no)	Pawing the bedding material with a front leg just before the lying down movement.

[1] We used the triact R package to support the video analysis; thus, we only assessed actual lying down events with respect to interrupted events. Possible interrupted lying down events not shortly followed by a completed event were therefore not considered. However, based on Dirksen et al. (2020) and Brouwers et al. (2024), we considered this to be very rare in lying cubicles complying with Swiss legislation.

Table 4
Ethogram of defecation behaviour of dairy cows around rising events.

Behaviour	Definition
Defecation (yes/no)	Cow defecates within a 120 s time window centred around the end of the rising event while in the lying cubicle [1]
Posture (standing with four hooves in the cubicle/standing with only the front hooves in the cubicle/lying in the cubicle)	Posture of the cow at the start of the defecation
Location (cubicle/walking alley)	Location where the majority of the faeces lands

[1] End of rising event: cow is standing with all four hooves in contact with the floor, in a balanced position.

Defecation behaviour around rising events

We investigated the effect of NSH ratio and NSD ratio on the probability that faeces lands in the lying cubicle around rising events using GLMMs with the same structure as the models described in the preceding section. Furthermore, we analysed the data on defecation behaviour around rising events in more detail using Item Response Tree (**IRTree**) GLMMs (López-Sepulcre et al., 2015). The data were encoded as a binary response tree with six nodes (Fig. 2). Node 1 indicated whether the cow defecated within the 120 s time window while in the lying cubicle (1: yes; 0: no). If yes, Node 2 indicated whether the cow defecated while standing (1: yes; 0: no). If the cow defecated while standing, Node 3 indicated whether the cow was standing with all four hooves in the lying cubicle at the start of the defecation (1: yes; 0: no). If the cow was lying at the start of the defecation, Node 4 indicated whether faeces landed in the lying cubicle (1: yes; 0: no). If the cow was standing with all four hooves in the lying cubicle at the start of the defecation, Node 5 indicated whether faeces landed in the cubicle (1: yes; 0: no). Lastly, if the cow was standing with only the front hooves in the lying cubicle at the start of the defecation, Node 6 indicated whether faeces landed in the cubicle (1: yes; 0: no). Node 6 was ultimately not included in the IRTree model because all responses at this node were 0 (no). The IRTree model was estimated as a GLMM with a binominal response (yes/no) and a logit link function using the glmer function. The model formulae in lme4 syntax were as follows:

$$\text{response} \sim 0 + \text{node} + \text{node} : \text{ratio} + (0 + \text{node}|\text{pen}/\text{cow}) + (0 + \text{node}|\text{week}) + (1|\text{obs})$$

Fixed effects in this model included for each node an individual intercept (0 + node) and an individual slope for NSH ratio or NSD ratio (node:ratio). Random effects included a random intercept for each node for cow nested within pen (0 + node|pen/cow) to account for multiple observations of the same cow and the potential effects of pen affiliation. Furthermore, a random intercept for week (0 + node|week) was included for each node. Lastly, a random intercept for the observation (1|obs) was included to ensure that the binary responses at the six nodes belonging to the same rising event shared the same variance and were not treated as independent observations. For a detailed discussion of data encoding and model formulation for IRTree GLMMs, see López-Sepulcre et al. (2015).

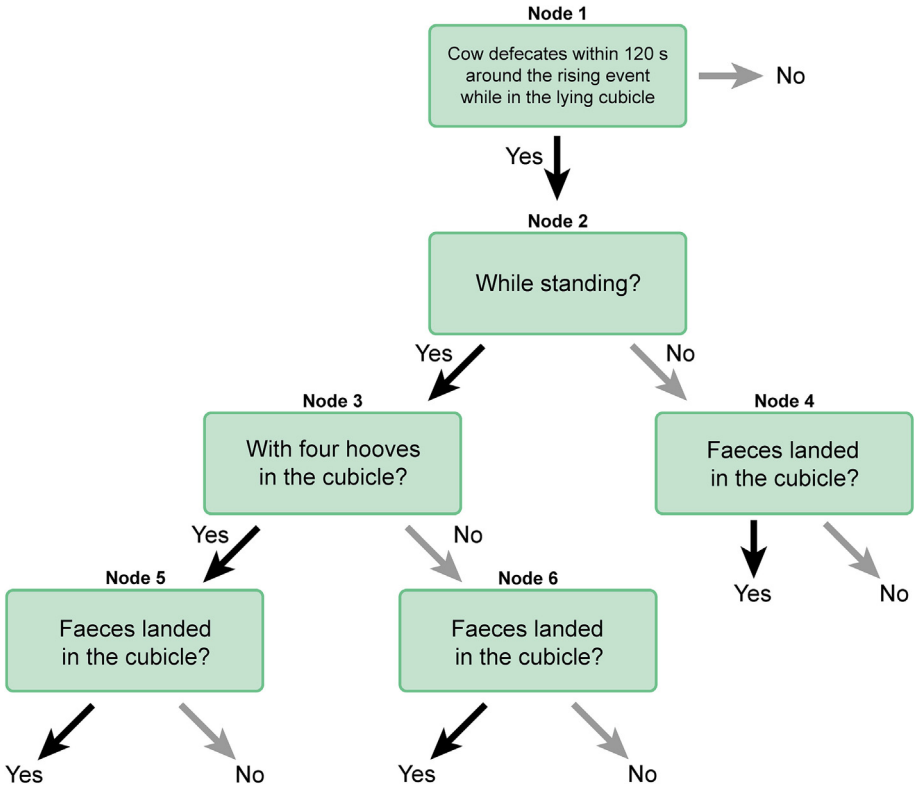

Fig. 2. Binary response tree for defecation behaviour of dairy cows around rising events. Black arrows represent outcomes coded as 1 in the binomial trial; grey arrows represent outcomes coded as a 0.

Results

Experiment 1: neck strap height relative to cow wither height

Atypical rising and lying down behaviours

In Experiment 1, we analysed 1 409 rising events (mean ± SD: 35 ± 2.0 per cow) and 1 405 lying down events (mean ± SD: 35 ± 1.9 per cow; Supplemental Table S1 at https://doi.org/10.5281/zenodo.15083338). None of the rising events were horse-like and 5 (0.4%) rising events were interrupted. Neither dog-sitting nor interrupted lying down events were observed. We did not statistically analyse these rare atypical behaviours further. The results of the GLMMs with the other atypical rising and lying down behaviours as responses are shown in Fig. 3 (random effect variance components in Supplemental Table S2 at https://doi.org/10.5281/zenodo.15083338). The odds that cows crawl backwards during rising decreased by a factor of 0.59 for a 0.1 increase in NSH ratio (95% CI: 0.43–0.79; Fig. 3B). The estimated probability of crawling backwards was never > 0.05 (Fig. 3A). We found no statistical support for an effect of NSH ratio on the odds that cows perform a staggered head lunge or a sideways head lunge during rising. We also found no statistical support for an effect of NSH ratio on the odds that cows perform extensive inspection, repeated stepping, or pawing prior to lying down.

General lying behaviour

In Experiment 1, cows were lying for 11.6 ± 2.02 h/day, divided into 11 ± 2.6 bouts with a mean duration of 66 ± 14.2 min (mean ± SD). The results of the LMMs with measures of general lying behaviour as responses are shown in Supplemental Fig. S1 at https://doi.org/10.5281/zenodo.15083338 (random effect variance components in Supplemental Table S3 at https://doi.org/10.5281/zenodo.15083338). We found no statistical support for an effect of NSH ratio on daily lying time, lying frequency, or mean lying bout duration (Supplemental Fig. S1D at https://doi.org/10.5281/zenodo.15083338).

Defecation behaviour around rising events

Of the 1 409 rising events analysed in Experiment 1, cows defecated 249 (17.7%) times and urinated 41 (2.9%) times within the 120 s time window around the rising event while in the lying cubicle (urinations not analysed further). The results of the GLMMs with faeces landing in the lying cubicle around rising events as responses are shown in Fig. 4 (random effect variance components in Supplemental Table S4 at https://doi.org/10.5281/zenodo.15083338). When considering all rising events, we found no statistical support for an effect of NSH ratio on the odds that faeces land in the lying cubicle (odds ratio: 1.39; 95% CI: 0.90–2.20; Fig. 4A). When considering only rising events involving a defecation while in the lying cubicle, the odds that faeces land in the cubicle increased by a factor of 2.16 for a 0.1 increase in NSH ratio (95% CI: 1.47–3.43; Fig. 4B). The results of the IRTree model are shown in Fig. 5 (random effect variance components in Supplemental Table S5 at https://doi.org/10.5281/zenodo.15083338). For defecations shortly after rising events while still in the lying cubicle, a 0.1 increase in NSH ratio increased the odds for cows to stand with all four hooves in the cubicle in the cubicle (Node 3) by a factor of 2.26 (95% CI: 1.16–5.98). For defecations of lying cows shortly before rising, a 0.1 increase in NSH ratio increased the odds for faeces to land in the lying cubicle (Node 4) by a factor of 2.54 (95% CI: 1.41–6.01). For defecations of cows standing with all four hooves in the lying cubicle shortly after rising, a 0.1 increase in NSH ratio increased the odds for faeces to land in the cubicle (Node 5) by a factor of 3.25 (95% CI: 1.21–26.37). We found no statistical support for an effect of NSH ratio on the odds that cows defecate around rising (Node 1) or the odds that cows are standing compared to lying when defecating around rising (Node 2).

Experiment 2: neck strap distance from the curb relative to cow diagonal body length

Atypical rising and lying down behaviours

In Experiment 2, we analysed 947 rising events (mean ± SD = 24 ± 1.1 per cow) and 954 lying down events (mean ± SD = 24 ± 0.7 per cow; Supplemental Table S1 at https://doi.org/10.5281/zenodo.15083338). None of the rising events was horse-like, and 1 (0.1%) rising event was interrupted. We also never observed dog-sitting or interrupted lying down events. We did not statistically analyse these rare atypical behaviours further. The results of the GLMMs with the other atypical rising and lying down behaviours as responses are shown in Fig. 6 (random effect variance components in Supplemental Table S6 at https://doi.org/

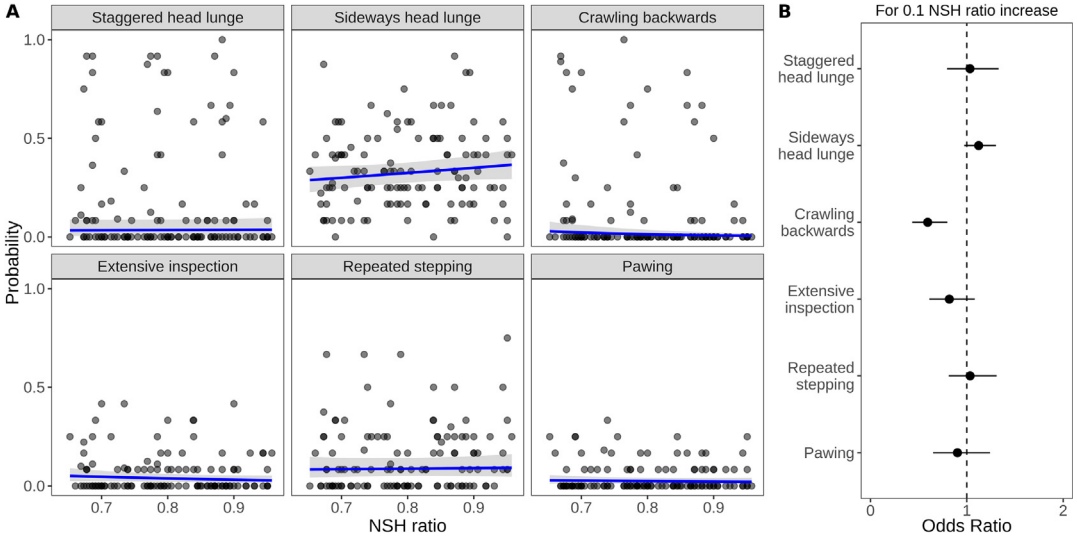

Fig. 3. (A) GLMM estimated probabilities (solid line) with 95% CI (shaded area) for atypical behaviours during rising and lying down in dependence of NSH ratio (population level, considering only fixed effects). Points represent observed proportions for individual cows (please note that model estimates are based on non-aggregated observations taking into account potential cow, pen, and week effects). (B) Odds ratios with 95% CI for a 0.1 increase in NSH ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: GLMM = generalised linear mixed effects model; 95% CI = 95% confidence interval; NSH = neck strap height.

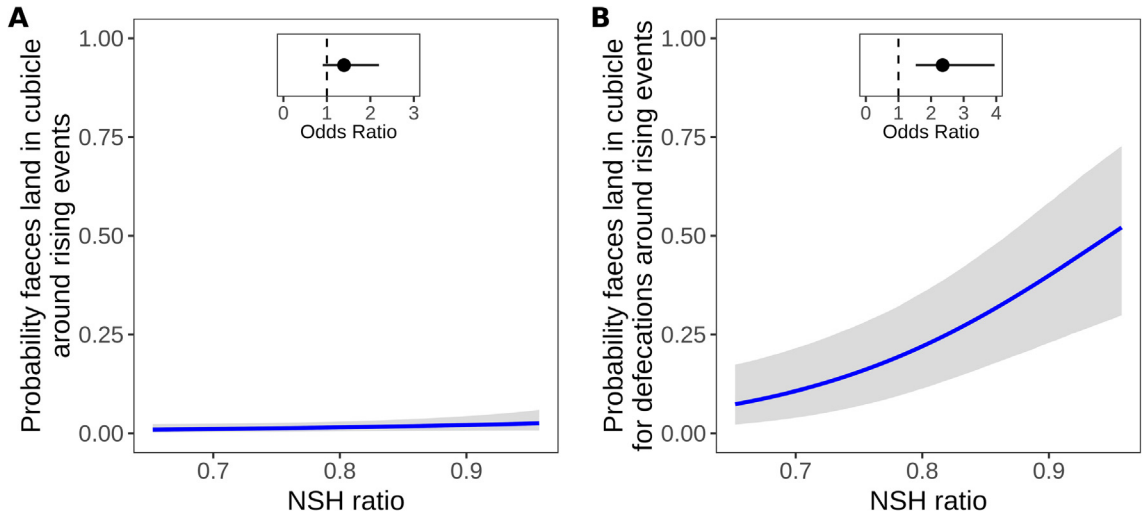

Fig. 4. GLMM estimated probabilities (solid line) with 95% CI (shaded area) of (A) faeces landing in the lying cubicle around rising events in dependence of NSH ratio, and of (B) faeces landing in the lying cubicle if a cow defecates around rising while in the cubicle in dependence of NSH ratio. Odds ratios with 95% CI are shown for a 0.1 increase in NSH ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: GLMM = generalised linear mixed effects model; 95% CI = 95% quantile confidence interval; NSH = neck strap height.

10.5281/zenodo.15083338). We found no statistical support for an effect of NSD ratio on the odds that cows perform a staggered head lunge, a sideways head lunge, or crawling backwards during rising (Fig. 6B). We also found no statistical support for an effect of NSD ratio on the odds that cows perform extensive inspection, repeated stepping, or pawing prior to lying down.

General lying behaviour

In Experiment 2, cows were lying for 12.2 ± 1.66 h/day, divided into 11 ± 2.3 bouts with a mean duration of 69 ± 13.9 min (mean ± SD). The results of the LMMs with measures of general lying behaviour as responses are shown in Supplemental Fig. S2 at https://doi.org/10.5281/zenodo.15083338 (random effect variance components in Supplemental Table S7 at https://doi.org/10.5281/zenodo.15083338). We found no statistical support for an effect of NSD ratio on daily lying time, lying frequency, or mean lying bout duration (Supplemental Fig. S2D at https://doi.org/10.5281/zenodo.15083338).

Defecation around rising events

Of the 947 rising events analysed in Experiment 2, cows defecated 197 (20.8%) times and urinated 32 (3.4%) times within the 120 s time window around the rising event while in the lying cubicle (urinations not analysed further). The results of the GLMMs with faeces landing in the lying cubicle around rising events as responses are shown in Fig. 7 (random effect variance components in Supplemental Table S8 at https://doi.org/10.5281/zenodo.15083338). For all rising events, the odds that faeces land in the lying cubicle increased by a factor of 2.18 for a 0.1 increase in NSD ratio, although with weak statistical support as the CI barely includes 1 (95% CI: 0.98–5.54; Fig. 7A). When considering only rising events involving a defecation while in the lying cubicle, the odds that faeces land in the cubicle increased by a factor of 2.44 for a 0.1 increase in NSD ratio (95% CI: 1.11–6.07; Fig. 7B). The results of the IRTree model are shown in Fig. 8 (random effect variance components in Supplemental Table S9 at https://doi.org/10.5281/zenodo.15083338). For defecations of lying cows shortly before rising, a 0.1 increase in NSD ratio increased the odds for faeces to land in the lying cubicle (Node 4) by 5.08 (95% CI: 2.24–18.61). We found no statistical support for an effect of NSD ratio on the other nodes of the IRTree.

Discussion

We investigated the effects of neck strap positioning relative to cow body size on atypical rising and lying down behaviours, general lying behaviour, and defecation behaviour around rising events. In both experiments, all but one of the investigated atypical rising and lying down behaviours were rare, and we generally found no statistical support for an effect of neck strap positioning relative to cow body size on their prevalence. This suggests that cows were typically able to rise without excessive difficulty and, prior to lying down, rarely displayed signs of hesitance defined as atypical in our ethogram. Our results indicate that positioning of flexible neck straps relative to cow body size, as investigated in this study, does not markedly affect the movements of dairy cows during rising and lying down. This may be because the flexibility of the neck strap does not cause an abrupt cessation of movement upon collision. However, it is important that the neck strap is properly tensioned to balance allowing unhindered animal movements with maintaining its functionality in keeping the lying surface clean. The only atypical behaviour frequently observed was sideways head lunging, with a mean probability of around 0.35, similar to the probability of 0.42 reported by Dirksen et al. (2020). However, no statistical support was found for an effect of neck strap positioning relative to cow body size on its prevalence. In wall-facing cubicles with a small lunge space, Brouwers et al. (2024) observed nearly exclusively sideways head lunging, supporting the suggestion of Veissier et al. (2004) that this atypical behaviour is more related to the available forward space in lying cubicles and less to the neck rail/chain/strap. Crawling backwards on the carpal joints was the only atypical behaviour affected by neck strap positioning, with a higher NSH ratio (neck strap height relative to cow wither height) decreasing the odds of this behaviour. This indicates that cows are less likely to crawl backward when rising when the neck strap is positioned less restrictive. Crawling backwards can cause skin abrasions and places excessive stress on the carpal joints due to the weight resting on them. Therefore, the design of lying cubicles should aim to minimise the occurrence of this behaviour. The estimated probability of crawling backwards was 0.05 at the most restrictive NSH ratio and decreased to even lower probabilities for higher NSH ratios, reaching near-zero probabilities at an NSH ratio >0.75. Similar

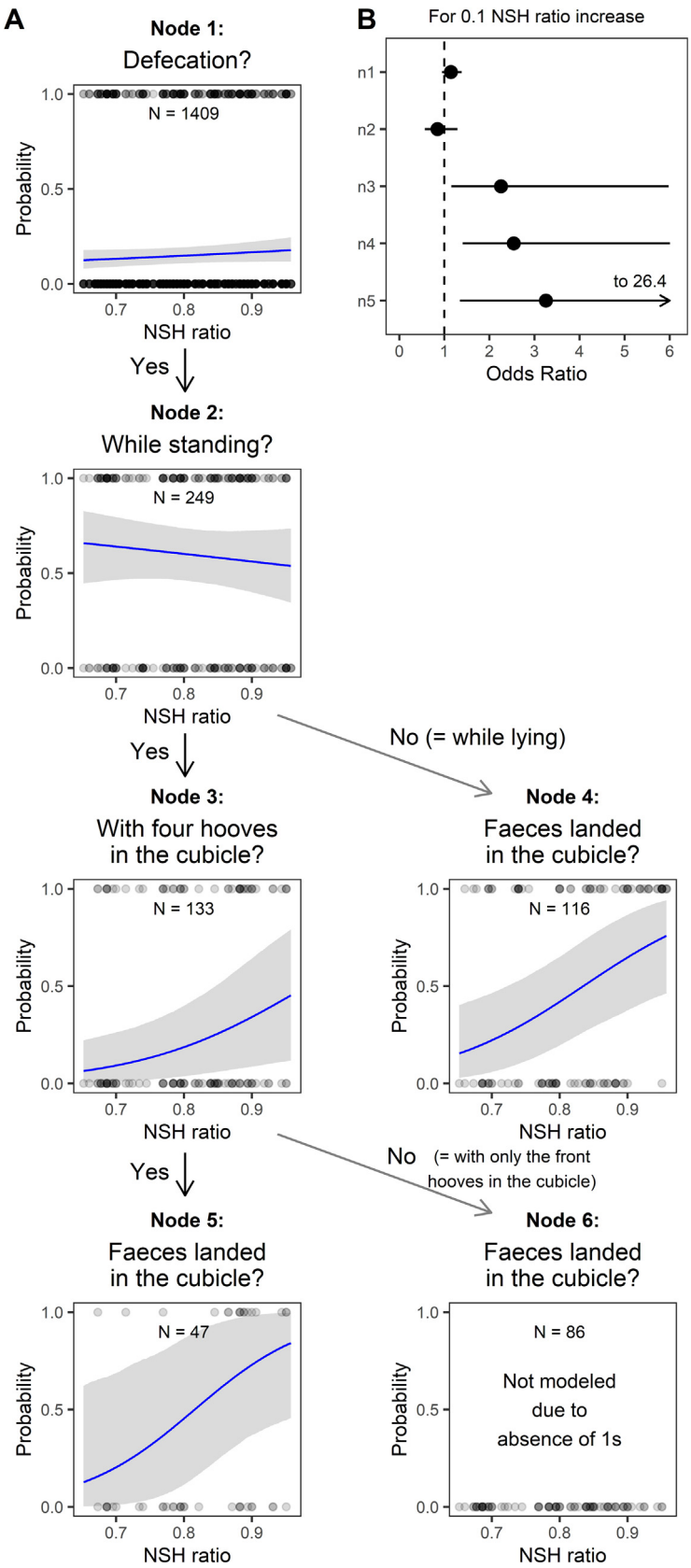

Fig. 5. (A) IRTree GLMM estimated probabilities (solid line) with 95% CI (shaded area) for the individual nodes of the IRTree in dependence of NSH ratio. Points represent individual observations. N represents the number of observations at each node. Node 6 was not modelled as faeces never landed in the lying cubicle if a cow defecated around rising while standing with only the front hooves in the cubicle. (B) Odds ratios with 95% CI for a 0.1 increase in NSH ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: IRTree = Item Response Tree; GLMM = generalised linear mixed effects model; 95% CI = 95% confidence interval; NSH = neck strap height.

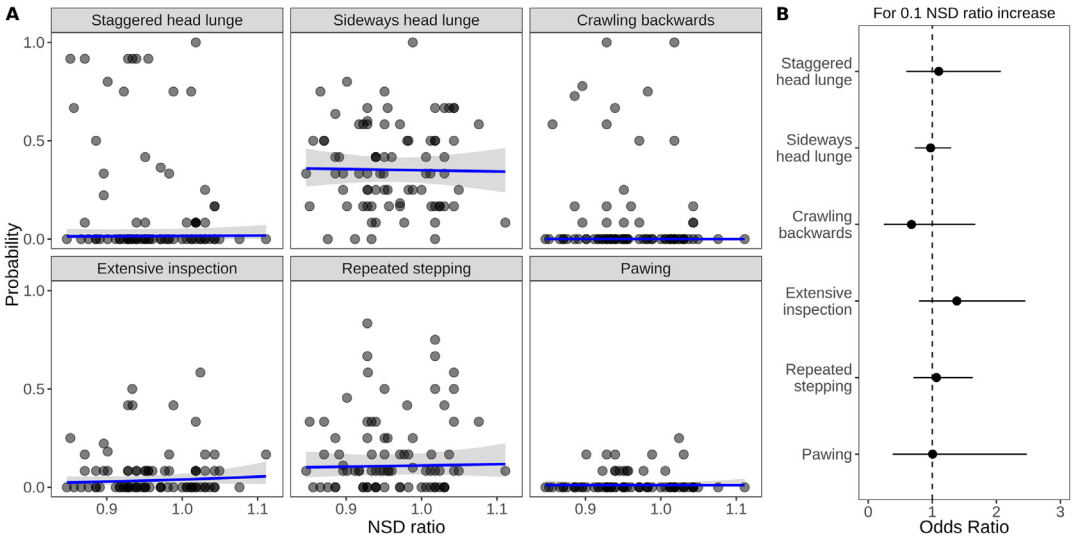

Fig. 6. (A) GLMM estimated probabilities (solid line) with 95% CI (shaded area) for atypical behaviours during rising and lying down in dependence of NSD ratio (population level, considering only fixed effects). Points represent observed proportions for individual cows (please note that model estimates are based on non-aggregated observations taking into account potential cow, pen, and week effects). (B) Odds ratios with 95% CI for a 0.1 increase in NSD ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: GLMM = generalised linear mixed effects model; 95% CI = 95% confidence interval; NSD = neck strap distance from the curb.

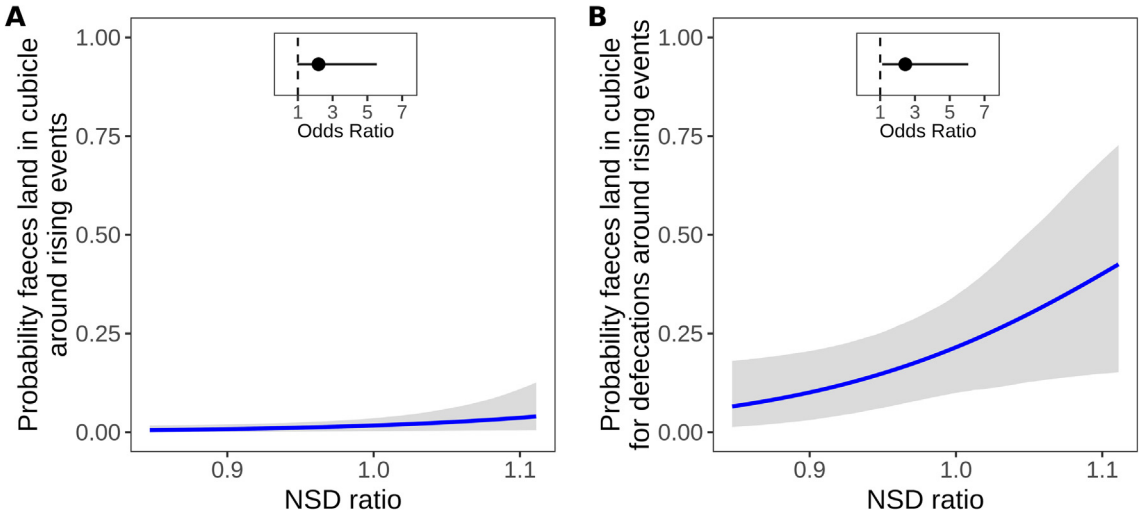

Fig. 7. GLMM estimated probability (solid line) with 95% CI (shaded area) of (A) faeces landing in the lying cubicle around rising events in dependence of NSD ratio, and of (B) faeces landing in the lying cubicle if a cow defecates around rising while in the cubicle in dependence of NSD ratio. Odds ratios with 95% CI are shown for a 0.1 increase in NSD ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: GLMM = generalised linear mixed effects model; 95% CI = 95% confidence interval; NSD = neck strap distance from the curb.

near-zero probabilities (<0.02) were reported by Brouwers et al. (2024) for commercial farms. Interestingly, crawling backwards was a highly individual behaviour with only 5 of the 40 cows accounting for almost 80% of the observed occurrences. All of these cows had above–average wither heights (ranging from 150 to 157 cm). Thus, our observations suggest that, despite the flexibility of the neck strap, some of the larger cows in our study did not have sufficient upward space to lift the front of their bodies or attempted to reduce contact with the neck strap and moved backwards in the lying cubicle while rising by crawling backwards on the carpal joints.

Regarding general lying behaviour, we found no statistical support for an effect of neck strap positioning relative to cow body size on lying frequency. As we also found no effects on atypical rising behaviours, this may indicate that neck strap positioning relative to cow body size, as included in the current study, did not affect the willingness of cows to transition between standing and lying. By contrast, Bernardi et al. (2009) found that restrictive neck rail positioning was associated with a reduced number of lying bouts, presumably because the neck rail interfered with rising and lying down. However, these authors investigated rigid neck rails, not flexible neck straps, and although the height of 118 cm was similar to that in this study, they tested them at 130 and 190 cm from the curb, which are more extreme compared to the positions in our study. Similar to lying frequency, we found no statistical support for an effect of neck strap positioning relative to cow body size on daily lying time or mean lying bout duration. This result is consistent with studies of neck rail placement that also reported no effect of neck rail position on lying time (Fregonesi et al., 2009; Tucker et al., 2005).

The average probability of a cow defecating shortly before or shortly after rising while still in the cubicle was 0.17 (Node 1 of the IRTree). This probability is consistent with the findings of Fregonesi et al. (2009), who also reported that defecation in lying

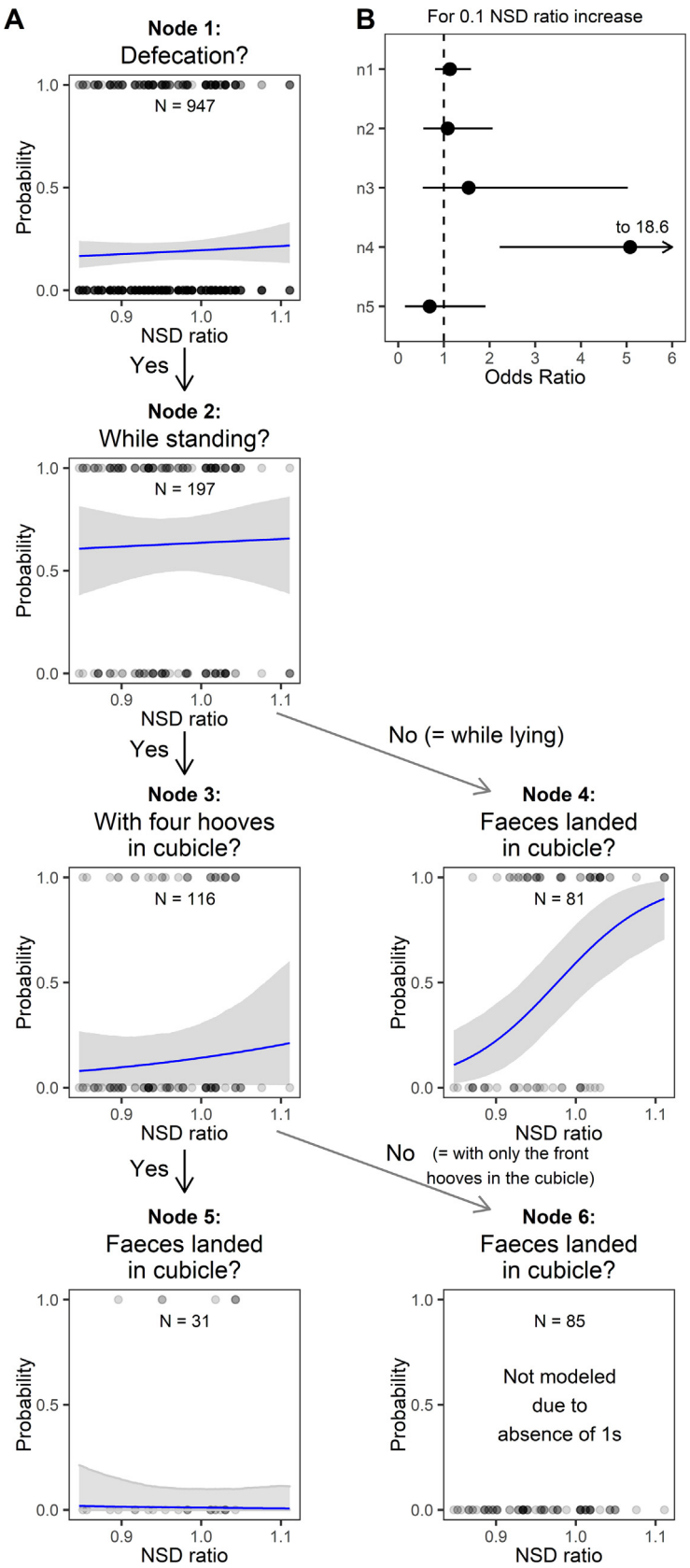

Fig. 8. (A) IRTree GLMM estimated probabilities (solid line) with 95% CI (shaded area) for the individual nodes of the IRTree in dependence of NSD ratio. Points represent individual observations. N represents the number of observations at each node. Node 6 was not modelled as faeces never landed in the lying cubicle if a cow defecated around rising while standing with only the front hooves in the cubicle. (B) Odds ratios with 95% CI for a 0.1 increase in NSD ratio. A significant effect at the 0.05 level is indicated when the 95% CI of the odds ratio does not include 1. Abbreviations: IRTree = Item Response Tree; GLMM = generalised linear mixed effects model; 95% CI = 95% confidence interval; NSD = neck strap distance from the curb.

cubicles was relatively rare and suggested that this may indicate that cows exited the cubicles quickly after rising, as cows defecate approximately 15 times per day (reviewed in Tonooka et al., 2022). If a cow defecated around rising while in the lying cubicle, the estimated probability of faeces landing in the cubicle was approximately 0.10 for an NSH ratio of 0.7. However, an increase of 0.1 in NSH ratio was associated with a more than twofold increase in the odds. Thus, the lowest (most restrictive) NSH ratio in our study of 0.7 was the most effective in positioning cows in the lying cubicle in such a way that limits soiling of the bedding and that higher neck strap positions may decrease cubicle cleanliness.

For defecations around rising events, the estimated probability that a cow was standing compared to lying at the start of the defecation (Node 2 of the IRTree) was around 0.60. Neck strap positioning relative to cow body size did not affect this probability. Cows on pasture do not tend to defecate while in a lying position (Whistance et al., 2011), suggesting that they rise to defecate when movement space is not restricted (i.e., in open environments). Our findings may indicate that cows that felt the need to defecate were able to rise before defecating in the majority of cases. In studies where defecation behaviour was continuously monitored, Tucker et al. (2005) and Fregonesi et al. (2009) found that 69% and 55%, respectively, of defecations from cows in lying cubicles with neck rails were from lying cows, which would correspond to 31% and 45% of defecations being from standing cows. However, as we only analysed defecations around successful rising events, these numbers cannot be compared directly to our results as it is possible that cows also defecated while lying without rising shortly afterwards.

For defecations shortly after rising, a higher NSH ratio was associated with a higher probability of cows standing with all four hooves in the lying cubicle compared to standing with only the front hooves in the cubicle (Node 3 of the IRTree). This is consistent with Tucker et al. (2005) who reported an increase in time spent standing with all four hooves in the lying cubicle with higher neck rail placement, presumably because cows find this more comfortable than standing partially in the cubicle. Moreover, Bernardi et al. (2009) linked the ability to stand fully in the lying cubicle to a reduced risk of lameness and hoof disease, highlighting its importance for cow health. For defecations of cows standing with all four hooves in the lying cubicle shortly after rising, the probability of faeces landing in the cubicle (Node 5 of the IRTree) was low for NSH ratios of around 0.7, but increased with higher NSH ratios. This indicates that an appropriately positioned neck strap can accommodate both smaller and larger cows. Smaller cows can stand fully in the lying cubicle without touching the strap, while larger cows can stand fully in the cubicle by slightly stretching the strap. Although smaller cows might stand further forward than desired, this behaviour is likely discouraged because pressing against the neck strap is presumed to be somewhat uncomfortable. For defecations of lying cows shortly before rising, the probability of faeces landing in the lying cubicle (Node 4 of the IRTree) was also positively associated with NSH ratio. This may indicate that cows were not only standing but also lying further forward in the lying cubicles. Cows may have positioned themselves further forward when lying down to ensure that they did not lie on the curb and that their bodies were fully supported by the bedded area (Fregonesi et al., 2009).

A higher NSD ratio (neck strap distance from the curb relative to cow diagonal body length) was also positively associated with the probability of faeces landing in the lying cubicle for defecations around rising events. However, we only found statistical support for this effect for defecations from lying cows (Node 4 of the IRTree) and not for standing cows (Probability of Node 3 multiplied by that of Node 5 of the IRTree). This suggests that the distance of the neck strap from the curb is important in guiding cows when lying down, thereby affecting lying cubicle hygiene. In contrast to our results regarding standing cows, Tucker et al. (2005) and Fregonesi et al. (2009) both reported that when standing cows defecated, more of the defecations landed in the lying cubicle when the neck rail was positioned further from the curb. It is plausible that we did not find statistical support for such an effect because of the difference between neck rails and neck straps, because of our smaller range of positions compared to the above-mentioned studies (130–195 cm in Fregonesi et al., 2009; 140–233 cm in Tucker et al., 2005), or because we are lacking the statistical power.

In preliminary experiments, we also investigated the neck strap at 195 cm from the curb (mean NSD radio of the herd: 1.15). However, with this NSD, cows were frequently observed stepping into the lunge space. Furthermore, even with the neck strap closer to the curb, cows were occasionally observed to step into the lunge space with one or both front legs after rising (not systematically recorded). This may indicate that the cows were motivated to step forward after rising, which is in line with their natural rising movement sequence (Lidfors, 1989) but typically discouraged by the neck rail. On two occasions (with NSH ratios of 0.84 and 0.95, respectively), a cow walked completely into the lunge space. In both cases, the cow was able to exit the lunge space again on her own without help from the farm staff. Stepping into the lunge space may be prevented by placing the front rail lower and closer to the brisket board to provide a better barrier to prevent cows from walking through (van Eerdenburg and Ruud, 2021). We placed the front rail at a height of 1 m to ensure that it did not interfere with the head lunge movement. However, the use of front straps made of flexible material, as done by Wilson et al. (2022), may be a more appropriate method of preventing cows from walking through the lying cubicle without considerably impeding head lunging.

In addition to the observed effects on cow behaviour and lying cubicle hygiene, the practical considerations of using flexible neck straps should also be addressed. Many cubicle partition designs rely on a rigid transverse rail, such as a neck rail, to provide structural stability to the cubicle. The use of flexible neck straps requires alternative designs, such as partitions with a (waved) bar positioned above the neck strap, which may require adjustments to the entire cubicle system. In addition, flexible neck straps may require more frequent maintenance than rigid neck rails, including periodic re-tightening to ensure consistent functionality and optimal tension.

Conclusion

Our study indicates that the positioning of flexible neck straps relative to cow body size, as tested in this study, does not considerably affect the rising and lying down behaviour of dairy cows. The flexibility of the neck strap appeared to accommodate cows of different sizes with only little impediment of movement. Lying cubicle soiling around rising events decreased with lower neck strap height relative to cow wither height and shorter neck strap distance from the curb relative to cow diagonal body length. We conclude that flexible neck straps can be a viable alternative to rigid neck rails by limiting the probability of defecation in lying cubicles around rising events without considerably impeding dairy cow movements during rising and lying down.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2025.101507) can be found at the foot of the online page, in the Appendix section.

Ethics approval

Ethical approval for the study was obtained from the Veterinary Office of the Canton Thurgau, Switzerland (TG03/2021, Approval No. 33448).

Data and model availability statement

The data that support the study findings are publicly available in the Zenodo repository (https://doi.org/10.5281/zenodo.15083338).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used DeepL Write in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Declaration of interest

None.

Acknowledgements

We sincerely thank the farm staff of the Swiss Future Farm for their support in the study. We are grateful to Urs Marolf and Christopher Geβenhardt for their help in attaching and removing the accelerometers. We also thank Eva Bouillon for her work in a pilot study upon which this study was designed.

Financial support statement

This publication emanated from research conducted with the financial support of the Federal Food Safety and Veterinary Office on behalf of the Swiss government (grant number: 2.21.01).

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