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Cubicle design and dairy cow rising and lying down behaviours in free-stalls with insufficient lunge space

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ABSTRACT

Cubicle partitions divide the resting area of free-stalls into individual lying places for cows, thereby facilitating the maintenance of good hygiene and reducing competition by separating animals. The forward lunge space in lying cubicles is often insufficient for a natural head lunge movement during rising. Cubicles with open frame partitions and a flexible neck strap aim to alleviate this welfare issue. The open partition frame facilitates lateral space sharing (using space of neighbouring cubicles for the head lunge movement) and the flexible neck strap is presumably less painful upon collision. In an observational study, we investigated the lying behaviour of free-stall housed dairy cows in this 'permissive' cubicle type with open frame partitions and a flexible neck strap positioned relatively high above the lying surface compared to 'restrictive' cubicles with partitions with more bar work in the lateral lunge space and a lower-positioned rigid neck rail. The study was conducted on commercial Swiss dairy farms with exclusively wall-facing lying cubicles of either the permissive (four farms) or restrictive (six farms) type. The forward lunge space on these farms ranged from 55 to 70 cm, which we considered insufficient for adult cows to lunge their heads forward. On each farm, 18–20 lactating dairy cows were selected. In total, 188 animals were used in the statistical analysis. Over 1.5 days, rising and lying down movements were videotaped, and the prevalence of atypical behaviours during these movements was recorded. In addition, we determined the daily lying duration, the lying frequency, and the mean lying bout duration using accelerometers mounted on the left hind leg. The data was analysed in relation to the cubicle type (permissive or restrictive). In the permissive cubicle type, staggered head lunge movements during rising and displays of hesitance before lying down were less prevalent. The lying frequency was higher, and daily lying duration was longer in the permissive cubicle type, although these estimates should be interpreted with caution due to the short data collection period. The results of this study suggest that the permissive cubicle with open partitions and a high-positioned flexible neck strap may improve conditions for dairy cows to rise and lie down. A permissive cubicle design may therefore improve cow welfare in free-stalls with insufficient forward lunge space, where increasing lunge space is not feasible.

Implications

Cubicle housing often does not provide sufficient space for dairy cows to easily rise and lie down. We investigated rising and lying down behaviour in two cubicle types with insufficient forward lunge space ($\leq$ 70 cm): permissive cubicles with open-frame partitions and flexible neck straps, and restrictive cubicles with more bar work and rigid neck rails. Cows in permissive cubicles had less difficulty rising, hesitated less before lying down, and had higher lying frequencies and longer daily lying durations. These results suggest that permissive cubicle designs may help to alleviate the negative effects of insufficient forward lunge space on cattle welfare.

Introduction

In free-stall housing systems for dairy cows, the resting area is divided into individual lying places by cubicle partitions. Together with a transverse neck rail, these partitions guide cows into the lying cubicle and ensure that they lie down near the end of the cubicle with their rears towards the walking alley. This promotes defecation and urination in the walking alley and increases the hygiene of the lying area (Abade et al., 2015). Additionally, cubicle

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partitions help prevent undesirable behaviours, such as diagonal lying and turning around, while allowing cows to lie closer together than they would in open environments by providing a physical barrier between lying cows (van Eerdenburg and Ruud, 2021).

However, cubicle partitions and the neck rail can restrict the movement of cows during rising and lying down. This is particularly problematic because cows rise to the standing position and lie down according to innate, species-specific movement patterns with limited ability to adapt these movements to their environment (Lidfors, 1989; Österman and Redbo, 2001). During rising, a cow normally thrusts her head forward, the so-called head lunge movement, and uses it as a counterweight to generate the momentum needed to stand up (Lidfors, 1989). On pasture, cows use 1.20 m to 1.40 m of forward space for this movement (measured from the front of the carpal joints; CIGR, 2014). In free-stalls, the available forward space is determined by the size of the head space plus lunging space, hereafter together referred to as 'lunge space' and defined as the distance from the cow side of the brisket board to the wall in wall-facing cubicles or to an opposing cow in head-to-head cubicles. On commercial dairy farms, cows rarely have the > 1 m of lunge space required for a natural, forward-directed head lunge movement (Lardy et al., 2021).

If sufficient lunge space is not available, cows may direct their heads to the side when rising (Lidfors, 1989). Whether cows can fluidly lunge sideways into the neighbouring cubicle is largely determined by the design of the cubicle partitions (Bewley et al., 2017). Early cubicle partition designs focused primarily on stability and durability. These partitions typically contained bar work in the lateral lunge space and were combined with a rigid neck rail for structural support (Carlsson, 1999). Such partitions are still popular in the European Alpine region because of their long lifespan and low maintenance requirements, and because they can be conveniently wall-mounted in free-stalls with limited forward space, such as those converted from tie stalls. Later designs aimed to improve the lying comfort and movement space of cows, but often still contained bar work in the lateral lunge space (Veissier et al., 2004). Obstructions in the lateral lunge space impede lunging to the side, as cows must carefully aim their heads through the bar work if at all possible (Siebenhaar et al., 2012). In addition, the neck rail can hinder rising movements when placed too low (St John et al., 2021). Difficulties with rising can cause atypical behaviours, such as multiple head lunges, horse-like rising, and aborted rising attempts (Zambelis et al., 2019; Dirksen et al., 2020). Inadequate cubicle design is also associated with hesitation to lie down, which is reflected in a prolonged inspection phase and atypical behaviours such as repeated stepping (Lidfors, 1989; Haley et al., 2000; Dirksen et al., 2020). Cows unable to rise and lie down without excessive effort may mentally associate lying with pain, discomfort, and a lack of control (Lovarelli et al., 2020) and consequently lie down less frequently. In several studies, unfavourable lying conditions (reviewed in Tucker et al., 2021) and the incidence of abnormal rising behaviours (Zambelis et al., 2019) have been associated with a decreased lying frequency.

To address these issues, manufacturers of dairy housing installations have designed more permissive lying cubicles with open partitions and a flexible neck strap. The open frame partition with virtually no bar work in the lateral lunge space allows cows to use the space in neighbouring cubicles when lunging the head (Bewley et al., 2017). The flexible neck strap is presumably less painful than a rigid neck rail upon collision. Although sideways head lunging is still considered an atypical behaviour (Dirksen et al., 2020), facilitating sideways lunging might alleviate welfare issues in free-stalls where insufficient forward lunge space restricts natural rising. Experimental studies by Gwynn et al. (1991) and Ruud and Bøe (2011) suggest that cows prefer more permissive cubicle partitions (flexible and with fewer obstructions in the lateral lunge space). O'Connell et al. (1992) and Carlsson (1999) also found that cows prefer more open cubicle partitions when experimentally comparing differently shaped metal partitions. In another experimental study, Siebenhaar et al. (2012) reported that cows had more difficulty head lunging and showed increased hesitance before lying down with cubicle partitions with bar work in the lateral lunge space compared to more open partitions. To our knowledge, the effect of cubicle partition shape on dairy cow behaviour has not been investigated under real production conditions. Furthermore, the effect of flexible neck straps on dairy cow behaviour has not been previously researched.

In an observational study on commercial dairy farms, we investigated associations between lying cubicle design—more permissive versus more restrictive—and dairy cow lying behaviour under real production conditions in free-stalls with insufficient forward space. We compared the prevalence of atypical rising and lying down movements and the general lying behaviour (lying duration, lying frequency, and mean lying bout duration) of cows on farms with open partitions and a flexible neck strap (permissive cubicle type) with that of cows on farms with partitions that obstruct lateral head lunge movements and a rigid neck rail (restrictive cubicle type). We hypothesised that cows would have less difficulty rising and would show fewer signs of hesitance before lying down in the permissive cubicle type. Additionally, we expected cows to lie down more frequently in the permissive cubicle type because they would presumably be more comfortable rising and lying down.

Material and methods

Study design

Between November 2022 and March 2023, we examined the lying behaviour of free-stall housed dairy cows in two different types of lying cubicle designs on 10 commercial dairy farms in Switzerland. Farms with the permissive cubicle type (n = 4) had open partitions that facilitated lateral space sharing with the neighbouring cubicles and a flexible neck strap. Farms with the restrictive cubicle type (n = 6) had partitions that obstructed sideways movements through the partition frame and thus impeded lateral space sharing, and were fitted with a rigid neck rail (details in section Lying Cubicle Design).

We visited commercial dairy farms that already had one of the two cubicle types installed. Thus, the farm was the experimental unit and the cow was the observational unit. The type of cubicle design could not be randomised across farms. Therefore, our study was observational and can show potential associations between cow lying behaviour and cubicle design, which may suggest but not prove causality. To limit confounding factors, we only included farms with lying cubicles that adhered to the following search criteria: exclusively wall-facing, bed length 185–200 cm, lunge space $\leq$ 70 cm, and deep bedded with a lime-straw mixture. The number of farms we included in our study was mainly limited by these search criteria, and by the willingness of farmers to participate.

Housing and animals

The farms participated voluntarily and were contacted with the help of dairy housing equipment dealerships (details on study farms in Supplementary Table S1 at https://doi.org/10.5281/zenodo.10639101). All farms had free-stalls with exclusively wall-facing deep-bedded lying cubicles ($\geq$ 1 cubicle per cow) with a 20–30 cm high curb and brisket boards to retain the bedding material in the cubicles. All lying cubicles were sufficiently bedded with a lime-straw mixture so that both boards did not exceed the bedding surface by more than 10 cm, as required by Swiss legislation (FSVO, 2008b; Article 3). The lime-straw mixture provided a compact mattress so that the lying surfaces had sufficient compressibility to adequately conform to the shape of the cow when she was lying down. Farms maintained their cubicles 2 or 3 times per day (i.e., removing faeces and levelling of bedding material). Bed length and lunge space were similar across farms (max. 15 cm difference for both dimensions). The lunge space was between 60 and 70 cm on the farms with the permissive cubicle type, and between 55 and 70 cm on the farms with the restrictive cubicle type. These dimensions meet the minimum requirements of the Swiss legislation (FSVO, 2008b; Article 16), but are considered insufficient for adult cows for forward lunging (Dirksen et al., 2020). Within each farm, cubicle dimensions were consistent. The maximum difference in cubicle length between different rows on the same farm was < 5 cm.

The herds consisted of 25–50 (mean ± SD = 33 ± 7.2) adult dairy cows of the breeds Brown Swiss and Holstein (Red Holstein and Holstein-Friesian). On each farm, we randomly selected 18–20 lactating cows. Cows that we saw limping or were reported by the farmer to have locomotion problems were not included. All farms practised non-seasonal calving. In total, we collected data from 198 dairy cows (75 Brown Swiss and 123 Holstein). Their wither height ranged from 134 to 160 cm (mean ± SD = 149 ± 5.9 cm; Supplementary Table S1 at https://doi.org/10.5281/zenodo.10639101). During the data collection period, the cows had no pasture access, but they could access an outdoor exercise yard.

Lying cubicle design

The farms with the permissive cubicle type all had the CNS Surselva20 cubicle partition (Fig. 1; DeLaval AG, Switzerland). This partition was fixed to the floor at a single point, contained virtually no bar work in the lateral lunge space and had a chamfered back. The Surselva partition was always fitted with a flexible neck strap positioned at a mean height of 130 cm, which is higher than the Swiss recommendations (Zähner, 2009). The farms with the restrictive cubicle type had either the Thurgi partition (Fig. 1; DeLaval AG, Switzerland) or the Liegeboxenbügel Wandständig (Fig. 1; Krieger AG, Switzerland). The shape of these two partitions was similar, as they were both cantilevered to the wall and contained bar work in the lateral lunge space. Both restrictive partition models were always fitted with a steel neck rail positioned at a mean height of 110 cm, which is at the lower end of the Swiss recommendations (Zähner, 2009).

Data collection

We recorded tri-axial acceleration at a sampling frequency of 5 Hz using accelerometers with a working range of ± 15 g (MSR 145, MSR Electronics GmbH, Switzerland). These accelerometers were attached to the left hind leg of the cows on the outward-facing side of the metatarsus using a piece of foam and self-adhesive bandage. Attachment and removal were performed when the cows were fixed in a self-locking feed yoke during the morning feeding. The cows were given 1 day of habituation to get used to the accelerometers and to relieve the potential stress of attaching them (Fig. 2). The accelerometers recorded for 39 h, after which the internal memory was full. Concurrent to the acceleration data collection, continuous video recordings of the lying area were made. Depending on the layout of each barn, we installed one or two video cameras (Bascom 4XB40K, Bascom, Vianen, the Netherlands) at a height of 3–5 m. With a few exceptions, all lying cubicles were in view.

Data processing and statistical analyses

Data processing

Data processing and statistical analyses were conducted in R (version 4.2.0; R Core Team, 2023). Rising and lying down movements were labelled for behaviours used in the evaluation of dairy cow housing conditions as proposed by Zambelis et al. (2019) and Dirksen et al. (2020; Table 1). These behaviours are atypical (i.e., not the norm) for dairy cows under spatially unrestricted conditions, but not all of them are necessarily harmful to the animal. For efficient labelling, the rising and lying down events in the videos were located based on the accelerometer data using the triact R package (version 0.3.0; Simmler and Brouwers, 2024). This drastically reduced the amount of video material to be analysed and allowed the individual cows to be identified reliably without physically marking them. If two cows rose or lied down from/on the same lying side at exactly the same time, the next posture transition event of one of the cows was examined to identify the individuals. The triact R package uses rule-based algorithms to distinguish between standing and lying postures and to determine the lying side based on which axis of the leg-mounted accelerometer gravity loads (see Simmler and Brouwers, 2024 for details). To locate the posture transitions, we followed the triact workflow using default settings, apart from specifying minimum_duration_lying = 0 when calling the add_lying method to ensure that we did not miss any posture transitions (rising or lying down). The few false positive posture transitions introduced as a result of deviating from using the default settings were manually discarded during the video analysis.

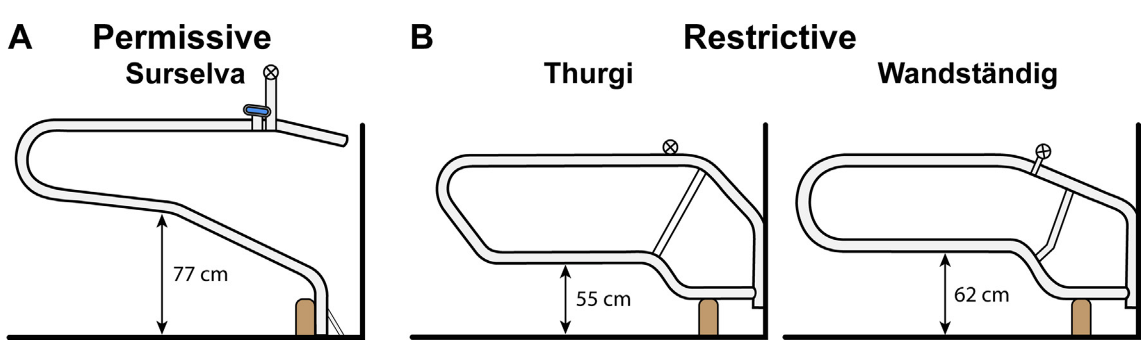

Fig. 1. Cattle lying cubicle types examined in the study. (A) The permissive cubicle type featured open partitions with a chamfered back designed to facilitate lateral space sharing with the neighbouring cubicle (partition model Surselva). It also included a flexible neck strap and was fitted with a transverse waved bar positioned well above the wither height of the cows for structural support. (B) The restrictive cubicle type had partitions with bar work in the lateral lunge space (partition models Thurgi and Wändstandig) and a metal neck rail. Brown boxes indicate brisket boards.

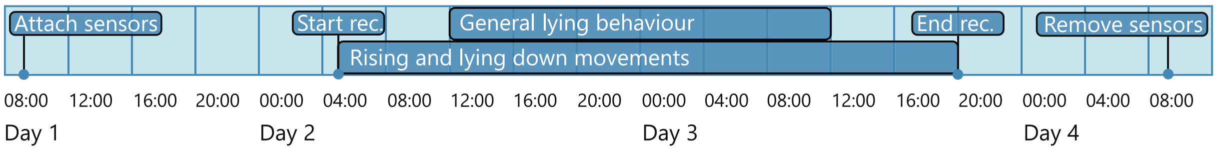

Fig. 2. Timeline of data collection on farms and time windows used for data analyses. Accelerometers recorded for 39 h until the internal memory was full. Rising and lying down movements were analysed during the whole recording period until ≥ 5 rising events and ≥ 5 lying down events per cow were assessed. A time window of 24 h was used to analyse general lying behaviour. Abbreviations: rec. = recording.

Table 1
Ethogram of atypical behaviours in cattle during rising and lying down movements (adapted from Zambelis et al., 2019; Dirksen et al., 2020). Source: from Zambelis et al., 2019; Dirksen et al., 2020

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 examined only 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 our own experience, we considered this to be very rare.

The identified posture transitions in the videos were labelled for atypical behaviours by one experienced observer (S.P.B.). It was not possible to blind the observer for cubicle type. Video material was analysed until ≥ 5 rising events and ≥ 5 lying down events per cow were assessed. Cows with either < 5 rising events recorded clearly on video or < 5 lying down events recorded clearly on video were not considered in the statistical analysis (10 of 198 cows, leaving 188 cows for statistical analysis). If the presence/absence of an individual atypical behaviour could not be determined (e.g., because another cow was standing partly in front of the focal cow), it was recorded as a missing value (Supplementary Table S2 at https://doi.org/10.5281/zenodo.10639101). To determine intra-observer reliability, the observer labelled 20 randomly selected rising events and 20 randomly selected lying down events a second time 2 months after completing the video analysis (Cohen's Kappa κ = 0.94).

We also used the triact R package to determine common measures for lying behaviour over 24 h (see the time window in Fig. 2). For each individual cow, we determined the daily lying duration, the lying frequency, and the mean lying bout duration. We followed the triact workflow using default settings for all parameters affecting the underlying algorithms.

Statistical analyses

We investigated the associations between cubicle type on atypical rising and lying down behaviours and on measures of general lying behaviour using (generalised) linear mixed effects models from the R package lme4 (Bates et al., 2015). The model formulas in lme4 syntax were:

$$response \sim 0 + cubicleType + (1|farm/cow) + (1|breed)$$

As fixed effects, we included the categorical variable cubicle type (permissive or restrictive). The random effects included a random intercept for cow nested in farm to account for multiple observations per cow and for the potential effects of farm affiliation. Furthermore, a random intercept for the breed was added to account for the potential effects of the breed. For models with measures of general lying behaviour as the response, the random effects were simplified to a random intercept for farm and breed, as here we had only a single observation per cow.

The generalised linear mixed effects models (**GLMM**s) with atypical behaviours as the response were fitted with a binomial response (yes/no) and logit link using the glmer function. The linear mixed effects models (**LMM**s) with measures of general lying behaviour as the response were fitted with the lmer function. We checked underlying model assumptions using the R package DHARMa (Hartig, 2022; model diagnostics in Supplementary Figures S1–S3 at https://doi.org/10.5281/zenodo.10639101). We calculated contrasts between the permissive and restrictive cubicle type from the population-level fitted values (based only on the fixed effect estimates) obtained with the predict.MerMod function (parameters re.form = ~0, type = "response"). We determined 95% quantile confidence intervals (95% CIs) for fixed effects and contrasts through parametric bootstrapping as implemented in the bootMer function (10^4 bootstraps). This is considered to provide a more reliable indication of statistical significance than the *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 (typically 0). However, we refrain from a discussion based on hard significance cut-offs and also consider the observed effect sizes with respect to biological relevance in our conclusions.

Results

Atypical behaviours during posture transitions

We analysed the prevalence of atypical behaviours on 10 farms (experimental unit) in 188 cows (observational unit) by labelling a total of 1337 rising events and 1310 lying down events (Table 2). The observed durations of these events, including the inspection

Table 2
Number of farms, cows, rising events, and lying down events per cubicle type analysed for atypical behaviours.

	Cubicle type		
	Restrictive	Permissive	Total
Number of farms[1]	6	4	10
Number of cows[2]	113	75	188
Rising events	783	554	1 337
Lying down events	801	509	1 310

[1] Farm was the experimental unit.
[2] Cow was the observational unit.

phase, are given in Supplementary Figure S4 at https://doi.org/10.5281/zenodo.10639101. In the restrictive cubicle type, 3 (0.4%) rising events were horse-like, and 4 (0.5%) rising events were interrupted (Supplementary Table S2 at https://doi.org/10.5281/zenodo.10639101). In the permissive cubicle type, horse-like rising was never observed, and 1 (0.2%) rising event was interrupted. Dog-sitting was not observed in either cubicle type. In the restrictive cubicle type, 4 (0.5%) lying down events were interrupted. In the permissive cubicle type, 1 (0.2%) lying down event was interrupted. We did not further analyse these rare atypical behaviours statistically.

Fig. 3 shows the GLMM estimated probabilities of atypical behaviours during rising movements (staggered head lunge, sideways head lunge, and crawling backwards) in the restrictive and permissive cubicle type (random effect variance components in Supplemental Table S3 at https://doi.org/10.5281/zenodo.10639101). The GLMM estimated probabilities of staggered head lunging were 0.48 and 0.17 in the restrictive and permissive cubicle type, respectively. The GLMM estimated probabilities of sideways head lunging were 1.00 in both cubicle types. The GLMM estimated probabilities of crawling backwards were 0.02 and 0.01 in the restrictive and permissive cubicle type, respectively. Fig. 4 shows the estimated contrasts between the cubicle types for atypical rising behaviours. The estimated probability of staggered head lunging was 0.31 higher in the restrictive cubicle type (95% CI: 0.11–0.49). The estimated probability of crawling backwards was 0.01 higher in the restrictive cubicle type, however with weak statistical support (95% CI: 0.00–0.02). As we consider this effect size too small to be biologically relevant, we will not discuss it further. We did not find statistical support for an association between cubicle type and the probability of sideways head lunging.

Fig. 5 shows the GLMM estimated probabilities of atypical behaviours prior to lying down movements (extensive inspection, repeated stepping, and pawing) in the restrictive and permissive cubicle type (random effect variance components in Supplemental Table S4 at https://doi.org/10.5281/zenodo.10639101). The GLMM estimated probabilities of extensive inspection were 0.35 and 0.21 in the restrictive and permissive cubicle type, respectively. The GLMM estimated probabilities of repeated stepping were 0.39 and 0.20 in the restrictive and permissive cubicle type, respectively. The GLMM estimated probabilities of pawing were 0.02 and 0.04 in the restrictive and permissive cubicle type, respectively. Fig. 6 shows the estimated contrasts between the cubicle types for atypical behaviours prior to lying down. The estimated probability of extensive inspection was 0.14 higher in the restrictive cubicle type, although with weak statistical support (95% CI: -0.03–0.32). The estimated probability of repeated stepping was 0.19 higher in the restrictive cubicle type, although with weak statistical support (95% CI: 0.00–0.38). We did not find statistical support for an association between cubicle type and the probability of pawing.

General lying behaviour

Fig. 7 shows the LMM estimates of daily lying duration, lying frequency, and mean lying bout duration with the restrictive and permissive cubicle type (random effect variance components in Supplemental Table S5 at https://doi.org/10.5281/zenodo.10639101). LMM estimates for daily lying duration were 10.6 and 12.5 h/day with the restrictive and permissive cubicle type, respectively. LMM estimates for lying frequency were 7.3 and 8.9 bouts/day with the restrictive and permissive cubicle type, respectively. LMM estimates for daily lying duration were 95 and 87 min per bout with the restrictive and permissive cubicle type, respec-

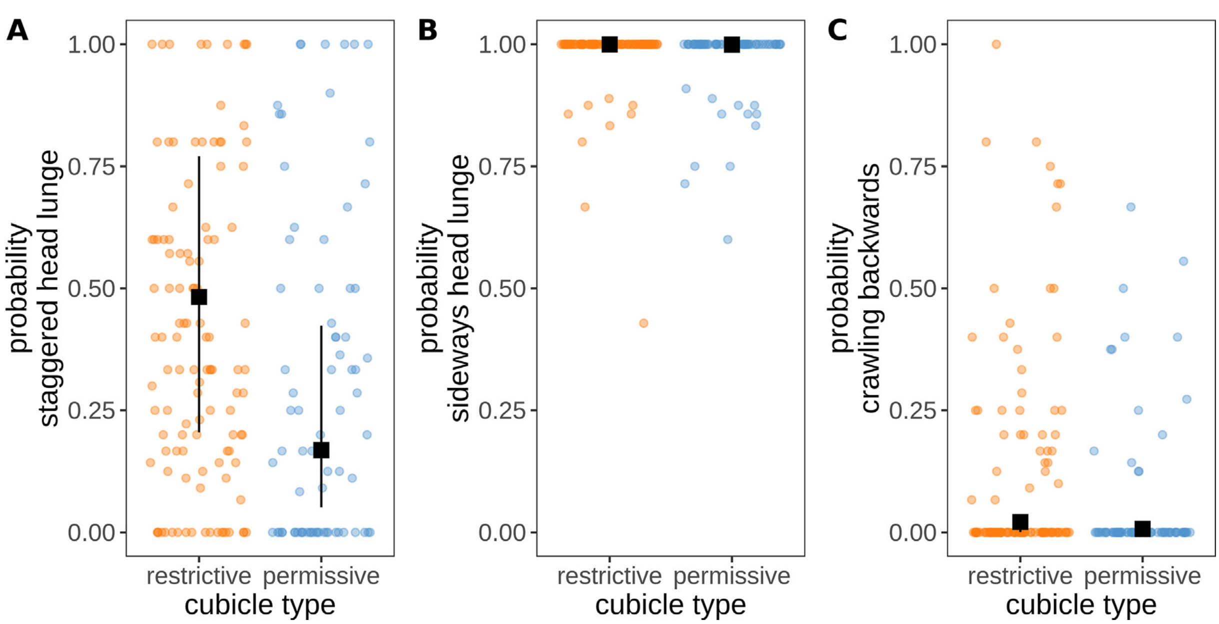

Fig. 3. GLMM estimated probabilities (squares) with 95% CI (error bars) for atypical behaviours during rising (population level, considering only fixed effects): (A) staggered head lunge, (B) sideways head lunge, and (C) crawling backwards on the carpal joints. Coloured points represent observed proportions for individual cows (please note that model estimates are based on non-aggregated observations taking into account potential cow, farm, and breed effects). Abbreviations: GLMM = generalised linear mixed effects model; CI = quantile confidence intervals.

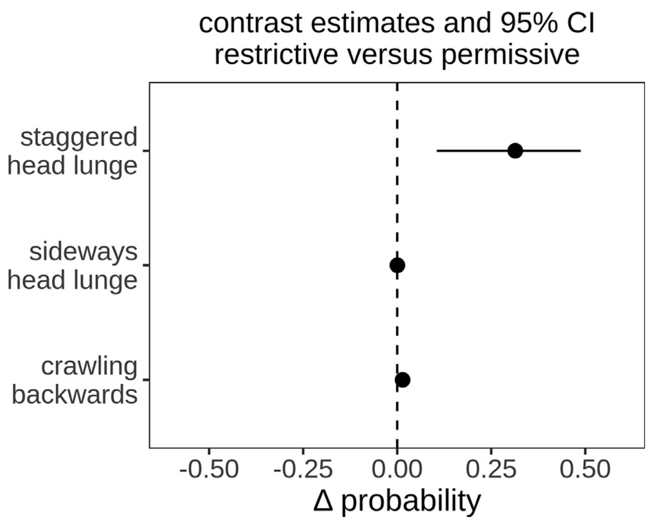

Fig. 4. GLMM estimated contrasts (points) with 95% CI (error bars) between the restrictive cubicle type (reference) and permissive cubicle type for the probability that a cow performs atypical behaviours during rising: staggered head lunge, sideways head lunge, and crawling backwards. A statistically significant difference at the 0.05 level is indicated when the 95% CI does not include 0. Abbreviations: GLMM = generalised linear mixed effects model; CI = quantile confidence intervals.

tively. Fig. 8 shows the estimated contrasts between the cubicle types for measures of general lying behaviour. The estimated daily lying duration was 1.9 h/day lower with the restrictive cubicle type (95% CI: -3.4 to -0.5 h/day). The estimated lying frequency was 1.6 bouts per day lower with the restrictive cubicle type, although with weak statistical support (95% CI: -3.1 to -0.2 bouts/day). We did not find statistical support for an association between cubicle type and the mean lying bout duration.

Discussion

In general, all lying cubicles in this study met the minimum Swiss animal welfare requirements, which should allow cows to rise and lie down according to their species-specific movement patterns (i.e., no horse-like rising and dog-sitting; FSVO, 2008a; Article 8). In addition, cows almost never interrupted rising or lying down movements with either cubicle type. These results are in line with Dirksen et al. (2020) and Brouwers et al. (2023), who found that horse-like rising, dog-sitting, and interrupted posture transitions were rare in lying cubicles with dimensions similar to our study.

The cows in our study performed nearly exclusively sideways head lunges when rising in both cubicle types. Thus, our results provide evidence that lunge spaces of ≤ 70 cm are not sufficient for cows of 140–160 cm wither height to perform the natural forward head lunge when rising. In contrast, Dirksen et al. (2020) estimated the probability of sideways head lunging to be around 0.50 for cubicles with small lunge spaces, without separating wall-facing and head-to-head cubicles in the analysis. However, from Fig. 1F in Dirksen et al. (2020), it appears that cows in wall-facing cubicles predominantly performed sideways head lunges, as in our study. It is interesting to note that cows in the restrictive cubicle type with partitions with bar work in the lateral lunge space were able to lunge their heads sideways. They were generally not observed to lunge upwards or to resort to horse-like rising, as has been reported for cubicles with a very small lunge space and partitions that severely restrict lateral space sharing (reviewed in Lidfors, 1989).

The probability of staggered head lunging was around 0.30 lower in the permissive cubicle type. This observed difference may be related to the reduced need for cows to aim their head between bar work with the open partitions. Other plausible explanations could be the difference between the flexible neck strap and the rigid neck rail, as cows anticipating a collision with a rigid neck rail may be more hesitant when lunging their heads. However, the probability of crawling backwards was close to zero in both cubicle types. This may suggest that the neck rails in this study were generally installed at sufficient heights for cows to rise without collisions. However, due to the small lunge spaces, it is likely that the cows were lying close to the rear curb without their backs under the neck rail, thereby mitigating the influence of the neck rail on rising behaviour. Our findings are in line with Siebenhaar et al.

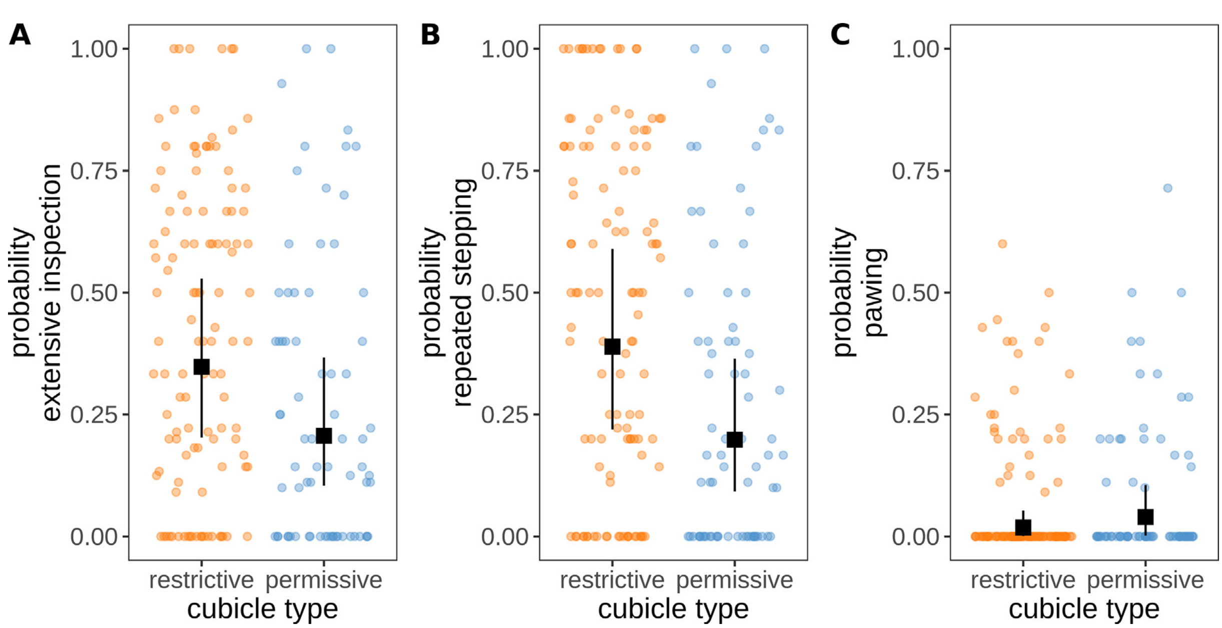

Fig. 5. GLMM estimated probabilities (squares) with 95% CI (error bars) for atypical behaviours before lying down (population level, considering only fixed effects): (A) extensive inspection of the lying area, (B) repeated stepping with the front legs, and (C) pawing the bedding material. Coloured points represent observed proportions for individual cows (please note that model estimates are based on non-aggregated observations taking into account potential cow, farm, and breed effects). Abbreviations: GLMM = generalised linear mixed effects model; CI = quantile confidence intervals.

(2012), who also reported a decrease in staggered head lunge movements when comparing cubicle partitions with bar work in the lateral lunge space to more open partitions. Thus, open partitions appear to be associated with more fluid sideways head lunges, which may explain the observed preferences of dairy cows for cubicle partitions with less bar work in the lateral lunge space by O'Connell et al. (1992) and Carlsson (1999). Altogether, this might suggest that facilitating lateral space sharing can alleviate difficulties with head lunging in cubicles that do not allow for forward lunging. However, it is important to note that sideways head lunging is a behavioural adaptation to insufficient forward space and is not common on pasture (Brouwers et al., 2022). Furthermore, sideways head lunging may be uncomfortable for cows due to the strain on the neck muscles (Dirksen et al., 2020), and even in the permissive cubicle type, staggered head lunging was around twice as common as observed on pasture (Brouwers et al., 2022).

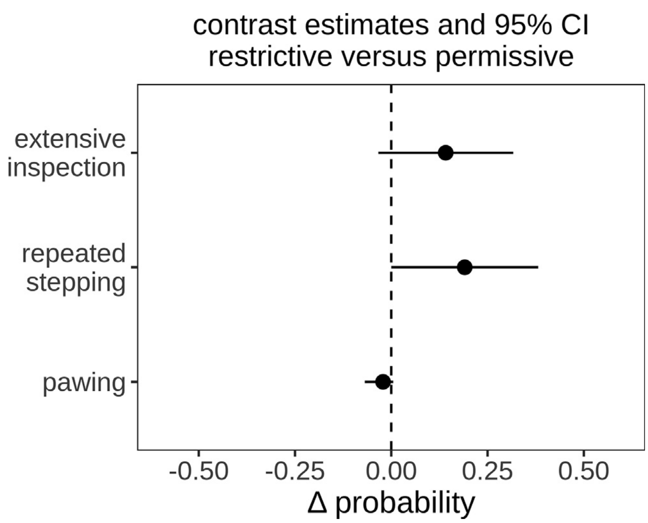

Fig. 6. GLMM estimated contrasts (points) with 95% CI (error bars) between the restrictive cubicle type (reference) and permissive cubicle type for the probability that a cow performs atypical behaviours before lying down: extensive inspection, repeated stepping, and pawing. A statistically significant difference at the 0.05 level is indicated when the 95% CI does not include 0. Abbreviations: GLMM = generalised linear mixed effects model; CI = quantile confidence intervals.

In addition to the lower prevalence of staggered head lunges, cows in the permissive cubicle type also performed fewer behaviours indicative of hesitance prior to lying down (extensive inspection and repeated stepping). This is in line with Wilson et al. (2022) who observed a shorter duration of the inspection phase before lying down in experimental lying cubicles with minimal partitions and no neck rail. Inspection of the lying area is a natural behaviour and is performed on pasture (Lidfors, 1989). However, extensive inspection (i.e., repeated head pendulum movements) has been associated with suboptimal housing conditions, such as insufficient bedding material (Müller et al., 1989) and tethering (Haley et al., 2000). Our findings are partially in line with Siebenhaar et al. (2012), who observed a higher frequency of repeated stepping with the front legs with obstructed partitions compared to open partitions, but found no difference in the prevalence of extensive inspection of the lying area. The greater hesitancy to lie down that we observed in restrictive cubicles may have been induced by previous negative (painful) experiences during rising or lying down, such as the inability to perform a fluid head lunge or collisions with the flank against the partition when lying down. However, the hesitance to lie down may also be related to the differences between flexible neck straps and rigid neck rails. For example, it may have been more uncomfortable for the cows to stand fully inside restrictive cubicles because the lower-positioned and rigid neck rail pressed more against their necks in this position.

Although not systematically recorded, we observed multiple instances of cows becoming trapped in or under partitions of the restrictive cubicle type when attempting to rise. This usually occurred because the cows required multiple head lunges and shifted forward with each lunging attempt, getting their heads stuck in the bar work of the partition. Such events have serious welfare consequences as animals lose control over their environment and can suffer traumatic injuries.

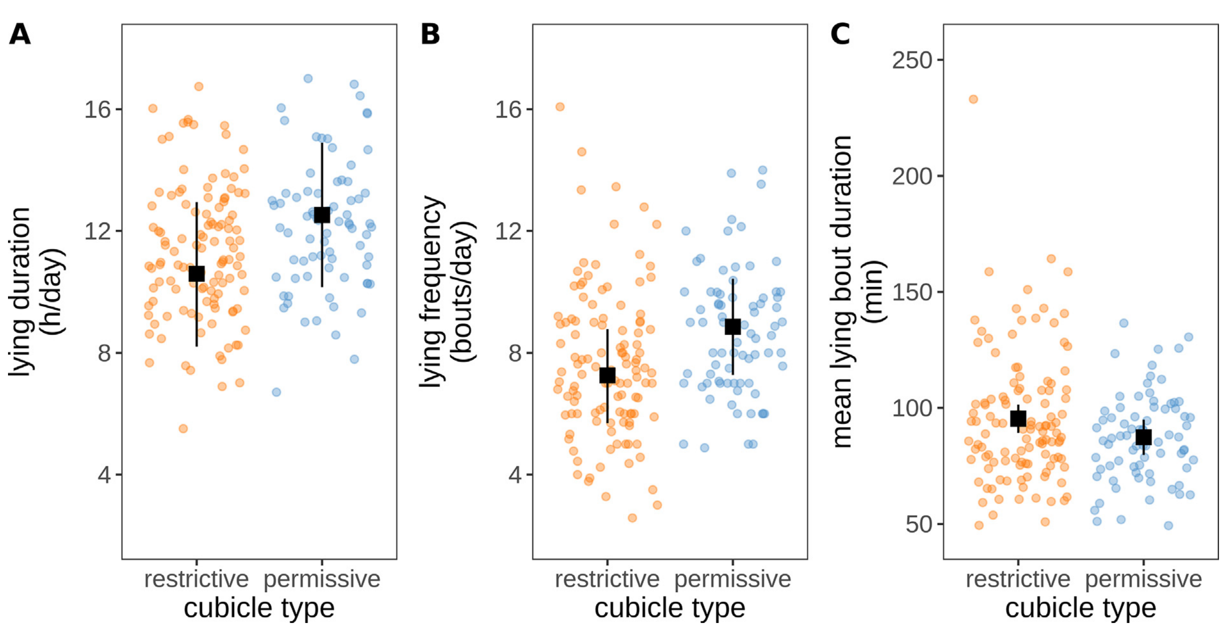

Fig. 7. LMM estimates (squares) with 95% CI (error bars) for measures of general lying behaviour (population level, considering only fixed effects): (A) daily lying duration, (B) lying frequency, and (C) mean lying bout duration. Points represent observations for individual cows (please note that model estimates take into account potential farm and breed effects). Abbreviations: LMM = linear mixed effects model; CI = quantile confidence intervals.

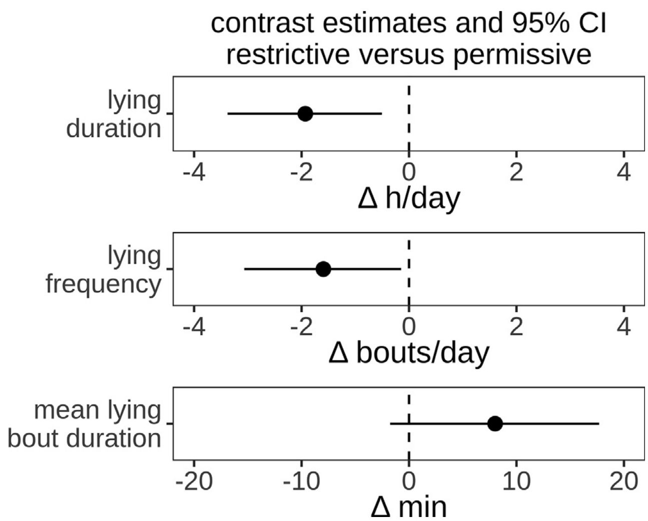

Fig. 8. LMM estimated contrasts (points) with 95% CI (error bars) between the restrictive cubicle type (reference) and permissive cubicle type for daily lying duration, lying frequency, and mean lying bout duration of cows. A statistically significant difference at the 0.05 level is indicated when the 95% CI does not include 0. Abbreviations: LMM = linear mixed effects model; CI = quantile confidence intervals.

Daily lying duration, lying frequency and mean lying bout duration were generally within typical ranges for dairy cows (reviewed in Tucker et al., 2021). However, lying frequency was higher with the permissive cubicle type compared to the restrictive cubicle type. The higher probability of staggered head lunging in the restrictive cubicle type was thus associated with a lower lying frequency, a relationship also previously reported by Zambelis et al. (2019). A decreased lying frequency is generally linked to unfavourable lying conditions (Rushen et al., 2007; Bouffard et al., 2017). Thus, our results might suggest that the difference in lying frequency between permissive and restrictive cubicle types is related to the willingness of cows to transition between standing and lying in cubicles with a small lunge space.

In addition to the increased lying frequency, daily lying duration was also higher with the permissive cubicle type. The difference of nearly 2 h per day is biologically relevant as cows lie between 8 and 13 h per day on average (Tucker et al., 2021). The relationship between changes in lying duration and lying comfort is not entirely clear (Tucker et al., 2021). Nevertheless, our observations might suggest that cows were more comfortable when lying in permissive cubicles. This may be due to the absence of bar work in the lateral lunge space and/or because of the chamfered back of the open partition (Fig. 1). The chamfered back allows for more space sharing with the hips and gives cows more freedom to adopt different lying positions. However, our estimates of general lying behaviour are based on only 1 day of accelerometer data per cow. Ito et al. (2009) found that 3 days of recording provided excellent estimates of farm-level means calculated from 5 days of recording (R^2 = 0.94 and 0.95 for daily lying duration and lying frequency, respectively), while using only 1 day provided less reliable estimates (R^2 = 0.74 and 0.77 for daily lying duration and lying frequency, respectively). This may suggest that using 3 days of recordings instead of 1 day would have reduced the uncertainty in the estimates in our study. We used 1 day of recordings because of the limited storage capacity of our accelerometers and because we wanted to record at 5 Hz to further develop the detection models proposed in Brouwers et al. (2023).

We studied the lying behaviour of cows in two different types of cubicle design under real production conditions on commercial farms. The type of cubicle design could therefore not be randomised (see section on study design). Thus, the study is observational and comes with the challenge of being susceptible to confounding factors. Through the selection of the study farms, we aimed to limit confounding by factors known to influence rising behaviour (lunge space size, wall-facing versus head-to-head cubicle orientation; Dirksen et al., 2020). However, it is likely that our response variables, particularly measures of general lying behaviour, are influenced by factors not accounted for in our study. Due to the observational nature of this study, any observed associations between cubicle type and our response variables can only suggest, not confirm, causation. Consequently, randomised experiments are necessary to verify the hypotheses derived from our observations.

Conclusion

A permissive lying cubicle design with open partitions and a flexible neck strap positioned relatively high above the lying surface was associated with a reduced prevalence of staggered head lunge movements during rising, less signs of hesitance before lying down, and increased lying frequency and daily lying duration. The estimates of general lying behaviour (lying frequency and duration) should be interpreted with caution due to the short data collection period (1.5 days). Despite this limitation, our findings might suggest that this permissive cubicle design can improve conditions for dairy cows to rise and lie down in free-stalls with a small lunge space ($\leq$ 70 cm in this study). However, wherever possible, the first priority should be to increase the lunge space to allow for natural rising behaviour (forward lunging), and cubicles that require sideways head lunging are a compromise at best. If it is not possible to increase forward lunge space, permissive cubicle design with open cubicle partitions and a flexible neck strap may help improve dairy cow welfare in free-stalls with insufficient lunge space.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101314.

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.10639101).

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.

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References

Abade, C.C., Fregonesi, J.A., von Keyserlingk, M.A.G., Weary, D.M., 2015. Dairy cow preference and usage of an alternative freestall design. Journal of Dairy Science 98, 960–965. https://doi.org/10.3168/jds.2014-8527.

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67, 1–48. https://doi.org/10.18637/jss.v067.i01.

Bewley, J.M., Robertson, L.M., Eckelkamp, E.A., 2017. A 100-Year Review: Lactating dairy cattle housing management. Journal of Dairy Science 100, 10418–10431. https://doi.org/10.3168/jds.2017-13251.

Bouffard, V., de Passillé, A.M., Rushen, J., Vasseur, E., Nash, C.G.R., Haley, D.B., Pellerin, D., 2017. Effect of following recommendations for tiestall configuration on neck and leg lesions, lameness, cleanliness, and lying time in dairy cows. Journal of Dairy Science 100, 2935–2943. https://doi.org/10.3168/jds.2016-11842.

Brouwers, S.P., Scriba, M.F., Savary, P., 2022. Assessment of lying down and standing up movements of dairy cows on pasture and in free-stall cubicles. KTBL Bauschriften 524, 54–56. https://doi.org/10.13140/RG.2.2.33207.39847.

Brouwers, S.P., Simmler, M., Savary, P., Scriba, M.F., 2023. Towards a novel method for detecting atypical lying down and standing up behaviors in dairy cows using accelerometers and machine learning. Smart Agricultural Technology 4, 100199. https://doi.org/10.1016/j.atech.2023.100199.

Carlsson, H., 1999. Cubicles for dairy cows in loose housing. Master Thesis. Swedish University of Agricultural Sciences, Uppsala, Sweden.

CIGR, 2014. The design of dairy cow and replacement Heifer housing. Report of the CIGR Section II working Group No. 14, Cattle Housing. International Commission of Agricultural and Biosystems Engineering, Gainesville, FL, USA.

Dirksen, N., Gygax, L., Traulsen, I., Wechsler, B., Burla, J.-B., 2020. Body size in relation to cubicle dimensions affects lying behavior and joint lesions in dairy cows. Journal of Dairy Science 103, 9407–9417. https://doi.org/10.3168/jds.2019-16464.

FSVO, 2008a. Animal Protection Ordinance (455.1). Federal Food Safety and Veterinary Office FSVO, Bern, Switzerland. Status as at Mar. 1, 2018. https://www.fedlex.admin.ch/eli/cc/2008/416/de.

FSVO, 2008b. Ordinance of the FSVO on the housing of farm and domestic animals (455.110.1). Federal Food Safety and Veterinary Office FSVO, Bern, Switzerland. Status as at Mar. 1, 2018. https://www.fedlex.admin.ch/eli/cc/2008/610/de.

Gwynn, P.E.J., Wilkinson, R., Thomas, T.P., 1991. Modifying timber cow cubicle divisions to improve cow acceptability. Applied Animal Behaviour Science 28, 311–319. https://doi.org/10.1016/0168-1591(91)90163-R.

Haley, D.B., Rushen, J., de Passillé, A.M., 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. https://doi.org/10.4141/A99-084.

Hartig, F., 2022. DHARMa: Residual diagnostics for hierarchical (multi-level/mixed) regression models. (Version 0.4.6). https://florianhartig.github.io/DHARMa/. Accessed on 14 March 2024.

Ito, K., Weary, D.M., von Keyserlingk, M.A.G., 2009. Lying behavior: assessing within-and between-herd variation in free-stall-housed dairy cows. Journal of Dairy Science 92, 4412–4420. https://doi.org/10.3168/jds.2009-2235.

Lardy, R., de Boyer des Roches, A., Capdeville, J., Bastien, R., Mounier, L., Veissier, I., 2021. Refinement of international recommendations for cubicles, based on the identification of associations between cubicle characteristics and dairy cow welfare measures. Journal of Dairy Science 104, 2164–2184. https://doi.org/10.3168/jds.2019-17972.

Lidfors, L., 1989. The use of getting up and lying down movements in the evaluation of cattle environments. Veterinary Research Communications 13, 307–324. https://doi.org/10.1007/BF00420838.

Lovarelli, D., Tamburini, A., Mattachini, G., Zucali, M., Riva, E., Provolo, G., Guarino, M., 2020. Relating lying behavior with climate, body condition score, and milk production in dairy cows. Frontiers in Veterinary Science 7, 880. https://doi.org/10.3389/fvets.2020.565415.

Müller, C., Ladewig, J., Thielscher, H.H., Smidt, D., 1989. Behavior and heart rate of heifers housed in tether stanchions without straw. Physiology and Behavior 46, 751–754. https://doi.org/10.1016/0031-9384(89)90362-4.

O'Connell, J.M., Giller, P.S., Meaney, W.J., 1992. Factors affecting cubicle utilisation by dairy cattle using stall frame and bedding manipulation experiments. Applied Animal Behaviour Science 35, 11–21. https://doi.org/10.1016/0168-1591(92)90012-Z.

Österman, S., Redbo, I., 2001. Effects of milking frequency on lying down and getting up behaviour in dairy cows. Applied Animal Behaviour Science 70, 167–176. https://doi.org/10.1016/S0168-1591(00)00159-3.

R Core Team, 2023. R: A language and environment for statistical computing. (Version 4.2.3). R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rushen, J., Haley, D., de Passillé, A.M., 2007. Effect of softer flooring in tie stalls on resting behavior and leg injuries of lactating cows. Journal of Dairy Science 90, 3647–3651. https://doi.org/10.3168/jds.2006-463.

Ruud, L.E., Bøe, K.E., 2011. Flexible and fixed partitions in freestalls—Effects on lying behavior and cow preference. Journal of Dairy Science 94, 4856–4862. https://doi.org/10.3168/jds.2010-3824.

Siebenhaar, M., Gygax, L., Wechsler, B., 2012. Assessment of a novel cubicle partition in respect to animal welfare. Landtechnik 67, 212–215. https://doi.org/10.15150/lt.2012.299.

Simmler, M., Brouwers, S.P., 2024. *triact* package for R: analyzing the lying behavior of cows from accelerometer data. PeerJ 12, e17036. https://doi.org/10.7717/peerj.17036.

St John, J., Rushen, J., Adam, S., Vasseur, E., 2021. Making tiestalls more comfortable: I. Adjusting tie-rail height and forward position to improve dairy cows' ability to rise and lie down. Journal of Dairy Science 104, 3304–3315. https://doi.org/10.3168/jds.2019-17665.

Tucker, C.B., Jensen, M.B., de Passillé, A.M., Hänninen, L., Rushen, J., 2021. Invited review: Lying time and the welfare of dairy cows. Journal of Dairy Science 104, 20–46. https://doi.org/10.3168/jds.2019-18074.

van Eerdenburg, F.J.C.M., Ruud, L.E., 2021. Design of free stalls for dairy herds: A review. Ruminants 1, 1–22. https://doi.org/10.3390/ruminants1010001.

Veissier, I., Capdeville, J., Delval, E., 2004. Cubicle housing systems for cattle: Comfort of dairy cows depends on cubicle adjustment. Journal of Animal Science 82, 3321–3337. https://doi.org/10.2527/2004.82113321x.

Wilson, A.M., Wright, T.C., Cant, J.P., Osborne, V.R., 2022. Development of a novel stall design for dairy cattle: Part II. the effect of minimal stall partitioning on lying behavior, rumination, stall cleanliness, and preference. Animal 16, 100428. https://doi.org/10.1016/j.animal.2021.100428.

Zähner, M., 2009. Rindvieh - Liegeboxenabmessungen für Milchvieh. ART-Baumerkblatt Nr. 01.06. Agroscope, Tänikon, Switzerland.

Zambelis, A., Gagnon-Barbin, M., St John, J., Vasseur, E., 2019. Development of scoring systems for abnormal rising and lying down by dairy cattle, and their relationship with other welfare outcome measures. Applied Animal Behaviour Science 220, 104858. https://doi.org/10.1016/j.applanim.2019.104858.