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Sows turned unhindered at less than their own body length - implications for farrowing pen design

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Periparturient and lactating sows need to turn around when expressing important nest-building and piglet-gathering behaviors. To determine the minimum pen width required to allow unhindered turning, 26 Danish crossbred sows were selected in late gestation to represent younger (parity 2-4) and mature (parity 5-6) ages. A test pen measured 2.6m on one side, with the other side being adjustable in intervals of 0.2m (1.2–2.2m). Each sow was encouraged to make three food-motivated turns at each of the 6 pen widths according to a randomized design. Direct observations of the time taken to complete a turn and a subjective score of turning difficulty (range 1-6) were supplemented by automated analysis of video recordings, measuring the maximum curvature of the body during a turn and the proximity to the pen walls at the time of maximum curvature. Turns took longer to complete when pen width was 1.2m and 1.4m. Inability to complete some turns occurred at 1.2m and more turns were scored as hindered when pen width was ≤1.6m. Older, larger sows were more frequently hindered. Body curvature during a turn was greater when pen width was 1.2m, while distance from pen walls at maximum curvature only increased in pen widths of ≥1.8m. In conclusion, the trial indicated that a minimum width of 1.6m should be provided to allow unhindered turning for the full grown late pregnant sows. This should be factored into a suitable overall farrowing pen design for loose sows to avoid negative impacts on sow and piglet welfare.

KEYWORDS

loose housing, turning behavior, pen and sow dimensions, lactating sows, pigs, end the cage age

1 Introduction

If sows cannot freely turn around, the freedom to express normal behavior is reduced which is detrimental to their welfare (Baxter et al., 2011). Therefore when designing pens for loose sows, it is important for the function of the pens and for the welfare of the sows that the sows can turn around unhindered, with hindered being defined as creating difficulties in turning resulting in delay or obstruction. Sows turning around unhindered may make some contact with a pen wall or pen components, but without having to squeeze. In addition to facilitating highly motivated nest-building behavior (Algers and Uvnäs-Moberg, 2007), unhindered turning is expected to be beneficial for piglet survival as turning around is an important part of piglet gathering behavior prior to lying down (Burri et al., 2009; Melišová et al., 2011).

Baxter et al. (2011) pointed out that it would require detailed experiments to determine sufficient area for sows to turn unhindered and thus be able to recommend design criteria for farrowing pens. Some studies assessing sows' turning behavior have focused on reducing the risk of turning in gestation stalls (Curtis et al., 1989; Robertson et al., 1972). Others have focused on space used by sows when turning or dimensions of space in relation to the sows' own body dimensions. Bøe et al. (2011) recorded whether pregnant sows turned 180 degrees to obtain food within three minutes after individually entering a pen. In their experiment, all 30 sows turned around when the pen width was 1.2m, six sows turned at 0.9m, one sow turned at 0.8m and no sows turned at 0.7m. Additionally, they placed 20 sows individually in a pen that started at 2.4m wide, before being reduced to 100%, 90%, 80%, 70%, 60% and 50% of the sow's length, respectively. Almost 200 successful turns were observed during 24 hours when the pen was 2.4m, but less than 36 successful turns when the pen was 60% of the sow's length, and fewer than two turns when the pen was 50% of the sow's length. All sows turned several times a day, when the pen was 60% of the sow's length, but less than half of the sows turned within 24 hours when the pen was reduced to 50% of the sow's length. More recently Leonard et al. (2021) used a computer-vision system to measure the static and dynamic space usage of 61 modern commercial sows in late gestation (sow body weight averaged 228kg, with the 95th percentile sows averaging 267kg). Free choice dynamic space usage by sows of average body weight was 1.15 m and they surmised that it was likely that most sows would be able to turn around with minimal restriction if the stall width were based solely on free choice space usage. To accommodate the largest sows estimated at 350kg, Baxter et al. (2011) used previous experiments and calculations based on the expectations of sow weight and dimensions. They recommended a width of at least 1.53m and an area of at least 3.17m^2 to turn unhindered.

Based on these previous findings, it is reasonable to assume that the sow's physical dimensions impact the area used when they turn around. Information on the actual dimensions required to achieve this with minimal hindrance is lacking for sows of modern genotype, especially in late pregnancy and thus with a heavily gravid uterus, and is necessary to give recommendations for dimensions of pens for loose housing of farrowing and lactating sows. Therefore, our research objective was to determine how easily late-pregnant hyperprolific sows of different parities and physical dimensions can turn around in pens of different widths. To do this we investigated how sows in late gestation turned around in pens measuring 2.6m in one dimension (pen length), i.e. considerably more than a sow's body length, and varying in the other pen dimension (pen width) from 1.2m to 2.2m (tested according to a random design), and assessed when the pen dimension did not cause hindrance.

To identify the minimum width needed for sows to turn unhindered and the width at which further increase did not influence the sows' ability to turn around, the following expectations were identified and hypothesis tested:

- A wider pen was expected to reduce the sows' body *curvature* when turning around. It was hypothesized at some pen width between 1.2m and 2.2m, the curvature would not decrease further.
- A narrower pen was expected to decrease the *distance* from the body of the sow to the pen wall. It was hypothesized at some pen width between 1.2m and 2.2m, the distance could not decrease further.

2 Method

The experiment was carried out in a commercial herd in Denmark over a period of 4 weeks, where each week 4–8 sows closest to farrowing were selected from the gestation unit. All sows experienced their normal husbandry routines, including feeding (at 06.30 and 14.00 CET), before the experiment commenced. All experimental procedures in the herd were carried out by two trained SEGES Innovation staff, experienced in trial work including pig behavioral observations. The sows were weighed (Bjerringbro Vægte, capacity 500kg; interval 1kg) and their dimensions measured with a folding ruler (height at shoulder, length from nose to tailhead and shoulder width). All sows were marked using a marker pen (Bovivet Marker) with a line along the spine from the hip to the shoulder, and lines perpendicular to this dorsal line at the shoulder and hip [Figure 1 (left)].

A total of 26 Danish crossbred sows in late gestation were included; 11 sows that were parity two to four (SP2t4) and 15 sows that were parity five or older (SP5+). Although young sows represent the main population in most herds, they were not included in the trial, as pens must be designed for the biggest sows on farm represented in the trial by the SP5+ sows. However, younger sows (parity 2-4) were included to determine whether distances needed to turn were generic or related to sow dimensions.

To give different pen widths, a test pen was set up measuring 2.6m in length to ensure it was greater than the body length of full-grown sows (Nielsen et al., 2018). The pen width was adjustable in intervals of 0.2m (1.2m – 2.2m). As pens differed in width, they are referred to hereafter as W1.2; W1.4; W1.6, W1.8; W2.0 and W2.2. The adjustable dimensions were chosen to range from widths previously reported as causing turning difficulty (Bøe et al., 2011) (<70% of the length of the sow (W1.2)) to a point where additional distance was not expected to have any impact on the sow's turning behavior (W2.2). To provide least interference with the sows

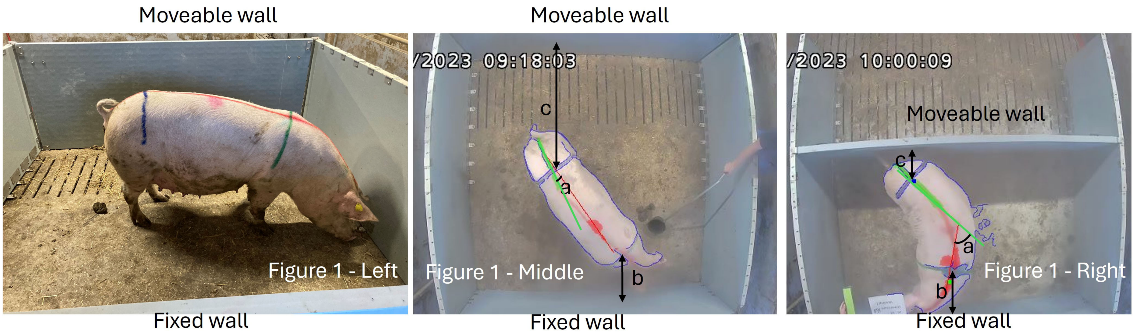

FIGURE 1
Left: Example of sow in pen marked with red line along the spine, blue line perpendicular to this at the hip and green line perpendicular to this at the shoulder. Middle and Right: Examples of sow marking with angle **(a)** to determine curvature and measured distances (in pixels) from shoulder **(b)** and from hip **(c)** to nearest pen wall. The moveable pen wall was adjustable for the pen dimensions to vary between 1.2m to 2.2m during the test (and 2.6m while the sow was habituated to the test pen).

turning behavior, the pen had a simple, smooth sided design without any additional features. A video camera was placed over the test pen to make it possible to record the sows' turning behavior.

The flooring in the test pen was 1.6m solid concrete and 0.6m slatted concrete. For pens W1.2, W1.4 and W1.6 the floor was solid and for pens W1.8, W2.0 and W2.2 the floor was partly solid. The floor was cleaned between sows and whenever a sow fouled on the floor. If the sows urinated on the floor, wood shavings were spread to absorb the fluid and afterwards removed. The pen sides were 1.1m high (i.e. taller than the largest sow – Nielsen et al., 2018) and solid. The test pen measured 2.6m x 2.6m when the sows first entered it. Sows were motivated to turn by a technician, who stood outside the test pen, holding a bowl containing piglet feed at the end of a stick. This was introduced into the pen in front of the sow and then moved to encourage the sow to follow and access the feed. When the sow had turned around once at the 2.6m x 2.6m dimension, the size of the test pen was adjusted sequentially according to the test protocol for that sow. Each of the six test dimensions were replicated three times for each sow, so in total aiming at 18 recorded turns per sow. The order of dimensions of the test pen was defined by a randomization prior to the start of the experiment. For each individual sow, the experiment was carried out over two consecutive days, with three test dimensions per day to minimize the decline in motivation with progressive rewarded tests.

A turn was defined as the sow having turned through a half circle. Additionally, the level of hindrance observed when the sow turned around was subjectively scored on a six point scale. A turn was registered as unhindered (score 1) if the sow did not touch the pen sides or if the sow touched one pen side but had abundant distance to the opposite pen side making it clear to the observers that the sow was not hindered by lack of space. If sows made contact with two opposite pen sides, the turn was classified as hindered to some degree (scores 2-4). If the sow showed interest in the feed and initiated curving to turn, but then returned to the starting position, it was scored 5. If the sow showed no interest in the feed and remained in the same position, it was scored 6. The following categories were used for scoring hindrance:

1 = easy and unhindered.

2 = easy, but not completely unhindered.

3 = slightly difficult; required significant bending of body.

4 = difficult; had to bend the body a great deal and move repeatedly to reposition while turning.

5 = attempted a turn but did not succeed due to lack of space (i.e. tried and failed).

6 = the sow would not attempt to turn at all (i.e. did not try).

For each test occasion, as a secondary registration, the time at which the sow initiated (h:min) and completed (h:min) a turn was recorded on-site by the observer.

A video camera (Panasonic 4MP Outdoor Dome Camera - WV-U2540LA) was placed centrally 2.5m above the pen. From the video recordings, Shutter Encoder (Shutter Encoder 18.7 Windows 64bits) was used as image capture software. The information on: sow profile, hind/fore quarter crosses and the dorsal line on the sows, were extracted from the images using Azure AI - Machine learning studio. We used the standard pretrained model with an addition of 256 annotated images.

For analysis the packages tidy verse [general data management (TIDYVERSE 2.0.0)], sf [spatial analysis (SF: 1.0-12)], jsonlite [from json-format to data frame (jsonlite 1.8.4)), imager [to see images and validate data (IMAGER: 0.42.19)], openxlsx [to open and save as excel-files (openxlsx 4.2.5.2)] in R (version R 4.1.2) were used. In total, 351 video recordings of turns were identified based on filename and on-site registration of time initiated and completed for the individual turns. For each of these videos, the following information was extracted:

- The maximum curvature of the body during a turn was measured by dividing the line along the spine into defined sections and then determining the angle [angle 'a' in Figure 1 (right)] between the sections. The maximum curvature was identified as greatest value of angle 'a' during the turn.

- The proximity to the moveable and the fixed wall during a turn was defined by measuring the minimum distance from the moveable wall to a cross-point on the sow's hip and the minimum distance from the fixed wall to a crosspoint on the sow's shoulder. The greater of these two distances was the distance for proximity used in the analysis.

In the automatic video analysis, distance was measured in pixels, where pixels can be converted to cm by dividing the measured distance by 1.3. This was measured by first continuously capturing the distance from the spray mark at the midline shoulder and at the midline hip to the nearest pen wall [distance 'b' and 'c' in Figure 1 (right)]. It was considered that the smaller of these ['c' in Figure 1 (right)] provided a base point for the turn, whilst the larger ['b' in Figure 1 (right)] indicated how much leeway the animal actually had when making the turn, and was used in the statistical analysis. Since this distance was from the midline point on the body, as the body edge could be less reliably determined in the image, a part of the distance included the body of the sow.

$$D_1 - \min\left(dist(Moveable\ wall, P_1), dist(Moveable\ wall, P_2)\right)$$

$$D_2 - \min\left(dist(Fixed\ wall, P_1), dist(Fixed\ wall, P_2)\right)$$

$$D = \max\left(D_1, D_2\right)$$

2.1 Statistical analysis

All analyses were undertaken using R (version R 4.1.2). Generalized linear mixed models (GLMM) analyzed a) time to turn, b) difficulty level and c) body angle and distance to the furthest wall. For all GLMMs, sow was the random factor and pen dimension and sow age category were fixed effect. The interaction between pen dimension and sow age category was also included. At each turn, the level of difficulty with which the sow turned around was analyzed binomially as it was grouped into two categories [unhindered (score 1); and hindered (score 2-6)]. As a supplementary analysis, level of difficulty was grouped into two other categories [easy (score 1 and score 2) or not easy (score 3-6)]. The secondary parameter, time to turn, was recorded in minutes and assumed to be Poisson distributed.

For analyzing the distance to the further wall at maximum curvature both angle and distance were assumed to be normally distributed, as test of residuals for normality was not rejected.

Any body curvature occurring in W2.2 was not caused by limited distance, as the sows' length was less than 2.2m which made it possible for sows to turn around without curving. Since the angle of curvature was expected to be least in the largest pen dimension, it was tested when the angle differed statistically from the angle measured in W2.2. The distance was expected to be least in W1.2, so it was tested if the distance was statistically the same as in W1.2.

3 Results

3.1 Animals

A total of 26 Danish crossbred sows in late gestation were included. There was limited variation within each age group category in the characteristics of the sows:

- Weight
  - SP2t4: mean/std: 295/28kg
  - SP5+: mean/std: 309/18kg
- Length
  - SP2t4: mean/std: 1.86/0.08m
  - SP5+: mean/std: 1.96/0.06m
- Shoulder width
  - SP2t4: mean/std: 0.41/0.017m
  - SP5+: mean/std: 0.42/0.029m.

Between the age groups, SP2t4 were shorter than SP5+ ($P < 0.001$), with narrower shoulder width ($P < 0.001$) and a tendency for lower weight (P=0.1). There were no differences between SP2t4 and SP5+ in terms of height or day of gestation (Supplementary Table S1).

3.2 Turning data

In the full design, the aim was to test 26 sows in six pen sizes, each on three occasions, giving a total of 468 potential turn observations. However, some sows did not collaborate on all tests and either laid down or tried to leave the pen and as such the total number of recorded turns was reduced to 426. The 42 potential turns were lost because four sows were not introduced to all of the pen widths as described:

- 1 SP2t4 sow x 4 pen dimensions x 3 turns = 12 turns lost
- 2 SP5+ sows x 3 pen dimensions x 3 turns = 18 turns lost
- 1 SP5+ sow x 4 pen dimensions x 3 turns = 12 turns lost

From the remaining 426 observation sessions, 24 potential turns were 'not attempted' (score 6) and 14 potential turns were 'not completed' (score 5):

The not completed turns were all in W1.2:

- SP4: 4 turns lost
- SP5+: 10 turns lost

Not attempted turns occurred in all pen widths, though more often in W1.2:

- SP2t4: 2 turns lost
- SP5+: 22 turns lost

The not attempted turns were in W1.2 (1 turn) and W2.2 (1 turn) for the SP2t4 sows and for SP5+ sows it was in W1.2 (10 turns), W1.4 (3 turns), W1.6 (2 turns), W1.8 (3 turns), W2.0 (1 turn) and W2.2 (3 turns).

3.3 Results - direct observations

In W1.2, SP2t4 completed 26 out of 30 potential turns, whereas SP5 + completed 22 turns out of 36 potential turns *(chi2-test gives P* = 0.07).

As listed in Table 1, the percentages of initiated turns scoring 'easy and unhindered' (Score 1) were significantly lower when sows turned around in smaller dimensions compared to turning around in larger dimensions (W1.2 and W1.4 differed from all other dimensions and W1.6 differed from W1.8, W2.0 and W2.2). In the supplementary analysis, the percentages of initiated turns scoring either 'easy and unhindered' (Score 1) or 'easy, but not completely unhindered' (Score 2) were significantly lower in W1.2 and W1.4 compared to the pens with larger dimensions. There was no difference ($P > 0.05$) for the sows in the registered degree of difficulty, according to whether it was the first, second or third turn they made in a given dimension.

Time was registered for 393 turns of which 139 turns took <1min; 200 turns took >1-2mins; 39 turns took from >2-3mins; 10 turns took >3-4mins and 15 turns took >4mins. A turn took longer ($P < 0.001$) in W1.2 and W1.4 compared to W2.2. It was especially SP5+ that were hindered when they turned around, as SP5+ sows took longer ($P < 0.001$) for W1.4, W1.6 and W2.0 than SP2t4 (Table 1).

3.4 Results - video analysis

Some turns were not included in the analysis as it was not possible to find pictures within the timeframe for the turn. Of the remaining 240 turns, some videos were not included because the turn could not be identified according to the definition of turn in the automated analyses. A total of 236 videos were included in the analysis; these were evenly distributed across sows, pen sizes and repetition number (Supplementary Table S2).

The sows curved their body significantly more (as shown by a higher measured angle) at W1.2 than at W2.2 ($P = 0.039$) and for both age-groups the highest curvature was observed at W1.2.

The curvature at the pen dimensions (W1.4, W1.6, W1.8 and W2.0) did not differ significantly from the curvature at W2.2 indicating that sows have a 'natural' curve in their body when turning and that except at the limited dimension of W1.2 it was not the dimension of the pen that forced them to bend. Figure 2 (left) illustrates how the mean curvature for SP2t4 during a turn varied from 42 degrees to 56 degrees and for SP5+ from 44 degrees to 56 degrees.

At the point in each pen dimension where the sow's back curved the most, the larger distance to the wall in W1.4 did not differ (P= 0.9) from the distance in W1.2. For W1.6 there was a tendency (P=0.08). Distance in W1.8 and upwards was significantly different from distance in W1.2 (W1.8 (*P=0.002); W2.0 and W2.4 (P*< 0.001) indicating that from 1.8m and onwards, distance increased when sows were given access to more space [Figure 2 (right)].

4 Discussion

Using both direct observations and more objective automated analysis from video recordings, this study provides the most comprehensive analyses to date of the turning behavior of late gestation sows.

The pen width was significant for the turning behavior for both SP2t4 and for SP5+ sows. When comparing the score 'easy and unhindered' (score 1) with the other scores, increasing the distance between the fixed and the movable wall from 1.2m to 1.4m, from 1.4m to 1.6m and from 1.6m to 1.8m made the turning behavior significantly easier with no further change at increasing pen width

TABLE 1 Directly observed number of initiated, uncompleted and completed turns, percentage of turns scored easy and unhindered (score 1) as well as 'easy and unhindered or easy, but not completely unhindered' (score 1 and 2) and time spent turning for each pen dimension (W1.2-W2.2) within age group (SP2t4 and SP5+).

Pen[3]	unit	SP2t4[2]						SP5+[2]					
		W1.2	W1.4	W1.6	W1.8	W2.0	W2.2	W1.2	W1.4	W1.6	W1.8	W2.0	W2.2
Number of turns (initiated/uncompleted)	no	29/4	30/0	33/0	30/0	30/0	320	26/10	36/0	43/0	36/0	38/0	39/0
Number of completed turns	no	25	30	33	30	30	32	16	36	43	36	38	39
Percent of initiated turns assigned score 1[1]	pct.	0 *a*	7 *a*	82 *b*	100 *c*	100 *c*	100 *c*	0 *a*	14 *a*	65 *b*	89 *c*	97 *c*	95 *c*
Percent of initiated turns assigned score 1 + 2[1]	pct	0 *a*	83 *b*	100 *c*	100 *c*	100 *c*	100 *c*	27 *a*	67 *b*	100 *c*	100 *c*	100 *c*	100 *c*
Time spent turning (completed turns)	Mean Std. (sec)	68 48 *a*	62 37 *ac*	38 24 *bc*	36 20 *b*	44 36 *bc*	34 22 *b*	54 50 *a*	58 34 *a*	63 52 *a*	53 24 *a*	43 25 *a*	51 46 *a*

Values lacking common superscript letters (within parity group) are significantly different ($P < 0.05$) determined by T-test, Bonferroni adjusted for multiple comparison.
[1]where 1 = easy and unhindered; 2 = easy, but not completely unhindered.
[2]where SP2t4 refers to parity two to four and SP5+ refers to parity five or older sows.
[3]where W1.2; W1.4; W1.6, W1.8; W2.0 and W2.2 refers to pen widths of 1.2m to 2.2m.

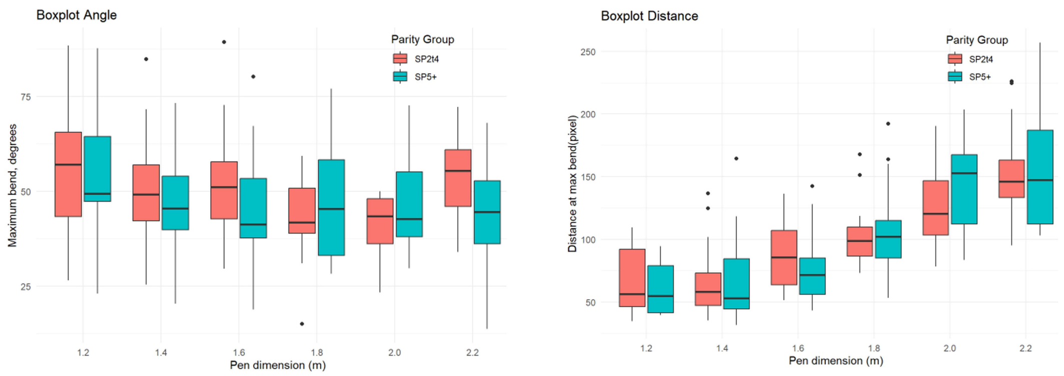

FIGURE 2
Left: Maximum curvature of body during a turn (degrees) in pen dimensions W1.2 to W2.2 for SP2t4 and SP5+. The box of the boxplot spans from the first quartile to the third quartile (with the line intersecting the box marking the median). The whiskers show the 5th and 95th percentiles, and values beyond these upper and lower bounds are outliers. Right: Distance (in pixels) to the further pen wall at the point of maximum curvature of the body during a turn (degrees) in pen dimensions from W1.2-W2.2 for SP2t4 and SP5+. The box of the boxplot spans from the first quartile to the third quartile (with the line intersecting the box marking the median. The whiskers the 5th and 95th percentiles, and values beyond these upper and lower bounds are outliers. [2] where SP2t4 refers to parity two to four and SP5+ refers to parity five or older sows. [3] where W1.2; W1.4; W1,6; W1,8; W2.0 and W2.2 refers to pen widths of 1.2m to 2.2m.

beyond 1.8m. When combining the 'easy turning scores' (score 1 and score 2), increasing the distance between the fixed and the movable wall from 1.2m to 1.4m and from 1.4m to 1.6m made the turning behavior significantly easier with no further change at increasing pen at increasing pen width beyond 1.6m.

Occasions when the sow attempted to turn but were not successful in completion (14 attempts) occurred only at a width of 1.2 m and were more common (10 of the 14 incidences) in older sows. Where a turn was successfully completed, both the time required and the difficulty score assigned clearly indicate that widths of 1.2m and 1.4m were inadequate to allow unhindered turning, whilst the lowest difficulty scores were observed at widths >1.6m. Older sows experienced greater difficulty scores, as might be expected from their larger size, although turning times did not reflect this. The video analysis showed that, although sows always showed some degree of curvature when turning, even if pen width was greater than their body length, a width of 1.2m necessitated greater bending. The maneuvering space that they had when executing a turn was reflected in the distance to the further of the two pen walls. Increasing pen dimensions from 1.2m to 1.6m and thereby access to an additional 0.4m did not increase this distance indicating that space was equally limiting. This distance was significantly greater in pen widths of 1.8m and above. Taken overall, these results might suggest that a minimum width of 1.6m within a pen should be provided to allow the unhindered turning of late gestation sows, for example during nest building behavior, and would also allow appropriate expression of piglet gathering behavior in lactating sows, which is important to reduce crushing risk (Burri et al., 2009; Melišová et al., 2011). A width of 1.8m provided some additional benefit in reducing the proportion of turns which had slight hindrance through closer proximity to pen walls, but did not further reduce the turning success, turning time or number of turns rated with some difficulty. The recommendation might appear to be somewhat greater than that of Bøe et al. (2011), but their sows were in mid pregnancy and therefore likely to be less hindered by the presence of a gravid uterus. Their body length (means of 1.74m and 1.82m in two experiments) was also slightly less than sows in the current study (mean 1.86m).

Even though a width of 1.6m would seem to be the break point for most measures in this study, it must be borne in mind that this interpretation relates to the averages for the population as a whole. It could be argued that a pen should be sufficiently large to accommodate every individual in the population. It is therefore relevant to consider the variation of sow size within the sample observed with the median, minimum and maximum length for S2t4 being 1.9m; 1.7m and 2.0m and for SP5+ being 2.0m; 1.8m and 2.0m respectively. Both the length and width of sows showed limited variation within parity groups, however, the body dimension measurements in this study and elsewhere (Moustsen et al., 2011; Nielsen et al., 2018; Hannius et al., 2024) indicate that sows achieve mature body size at around 5-6th parity. Since pen dimensions do not change according to which sow enters the pen, the pen should accommodate at least the 95th percentiles of full-grown sows, and ideally the largest sow on farm.

As a population, the sows in this study do seem to be reasonably representative of modern genotypes. In Hannius et al. (2024) the length of Swedish sows ranged from 1.29m to 2.38m whereas Nielsen et al. (2018) reported Danish sow lengths (5th and 95th percentiles) to be 1.84-2.05m. Hannius et al. (2024) suggest the discrepancy could be the result of reporting dimensions from the largest sows rather than the 95th percentile as per Nielsen and colleagues. Norwegian crossbred sows in the study of Bøe et al. (2011) ranged from 1.55-2.07m, whilst Irish crossbred sows reported by O'Connell et al. (2007) ranged from 1.56-2.01m and the longest American sows of McGlone et al. (2004) were 2.05m. Whilst it seems that body size of sows has not increased greatly in recent years (Moustsen et al., 2011; Nielsen et al., 2018) it must be considered whether future selection strategies, such as for increased teat number, might have size implications.

The present study had some limitations. Not all of the planned data were finally available for analysis. A number of scheduled turning events failed to occur. This was sometimes due to total refusal of the sows to co-operate in the test arena (42/468 or 9% of planned observations). In other cases it was because sows showed no interest in the feed and therefore motivation to turn (22 turns not attempted, 5% of the observed sessions), and this occurred at all pen widths and therefore were not specifically related to available space. Furthermore, not all videos could be analyzed due to technical issues or poor picture quality. Despite these losses, the sample obtained was representative (Supplementary Table S2) of the experimental design and the statistical model took account of the unbalanced nature of the final dataset. The nature of the data collected could also be improved. The timing taken for each turn was registered only to the nearest minute and analyzed as such. This was because it was seldom clear when the exact start and endpoint of each turn occurred due to the variation in the behavior of the animals which did not allow an unambiguous definition. For this reason, a more conservative approach to timing was therefore considered more appropriate. It is also important to note that, in analyzing the videos, body curvature was based on the angle of the spine and this does not take into account the head tuck that the sows would do as part of the turning process which might have also varied. A final factor to bear in mind is that the data in this study came from food-motivated turns. Previous research has demonstrated that voluntary turns are much more sensitive to pen space than food motivated turns (Bøe et al., 2011) and so the recommendations from studies such as the present one should be considered as an absolute minimum.

When discussing the implications of this conclusion on turning space for the overall design of a farrowing pen, various considerations come into play. It can appear logical that, to ensure sows the option to turn unhindered, there should be a circle within a pen to turn with the diameter of at least the length of the sows. However, the data here underlines that the distance the sows used when turning around was less than their body length, indicating that a smaller ellipse-or triangular-shaped turning area width will suffice. This is important, as increasing pen dimensions leads to significantly higher investment costs and higher emissions during use, which can represent a barrier for implementation of pens for loose lactating sows and thereby for improving pig welfare (Moustsen et al., 2023).

It is also important to consider the design of the pen as a whole and the effect of any pen furniture on floor space. If the planar space available is greater than the actual floor space, e.g. due to the possibility to extend the head over the creep box area or a separating wall, the actual floor level space may be less, allowing for other fixtures like sloped walls or farrowing rails. Whilst nest building and piglet gathering take place at floor level, the body length of a sow with the head down is less than that when the neck is fully extended horizontally. It must be further remembered that, whilst the pen should be able to accommodate unhindered turning in all dimensions, this alone is not enough for the entire dimensions of the pen as space is required for other functional and highly motivated behaviors of both sows and piglets (Nielsen et al., 2022). Distances within the pen must allow for comfortable resting, hygienic excretion and dynamic posture changes, including important pre-partum nesting behaviors and pre-lying piglet gathering behaviors post-partum. Whilst some of these can be accommodated by shared space, like dunging and feeding, or use of fully slatted flooring which allows greater overlap of lying and dunging areas, there are risks with choosing the smallest possible square footage based on taking results in isolation. These include if litter size and/or sow size increase further and/or policy decisions are made which are based on recommendations incorporating e.g. a wider interpretation of behavioral needs.

In conclusion, the experiment indicated that a minimum turning width of 1.6m should be provided perpendicular to the long axis of the pen to allow unhindered turning for the great majority of late pregnant sows and this should be factored into a suitable overall pen design to avoid any negative impact on sow and piglet welfare.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by SEGES Innovation, Livestock, The Strategic Group, Pigs and The SEGES Animal Welfare Body for the studies involving animals because it was a non-invasive observational study of adult sows in their home-barn. Food rewards were used as a positive reinforcer to observe them turning in a test-pen in their home-barn. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

VM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. EB: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SB: Conceptualization, Formal Analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. MN: Conceptualization, Data curation, Formal Analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. SE: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

Authors VM, SB and MA were employed by company SEGES Innovation P/S.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fanim.2025.1588436/full#supplementary-material

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