An Ellipsoid Farrowing Crate: Its Ergonomical Design and Effects on Pig Productivity

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ABSTRACT: An ellipsoid farrowing crate was designed and compared to the conventional rectangular crate with regard to its effect on sows' production traits. The main features of this crate are its oval horizontal frame and bowed vertical bars. Thirty-two sows farrowed in each system. Those in the ellipsoid crates raised 318 pigs and those in the rectangular crates raised 304. Stillbirth rate was lower in the ellipsoid crates than in the rectangular crates (P < .05). Among pigs born live, no significant difference due to crate was found on the deaths by crushing, infection, and other causes. The overall pigs' weaning rate from total births was also similar in both crates (P > .05). The daily weight gains of pigs for the 1st wk in the ellipsoid crate did not differ from those of pigs in the rectangular crates (P > .05) but were higher for the period from d 7 to d 21 (P < .05). The ellipsoid crate allowed the sow to turn around and have more freedom to move. However, the increase in sow movement did not cause a higher pig crushing rate than that in the traditional crate (P > .05). Behavioral observations also showed that the ellipsoid farrowing crate permitted easier visual and tactile contact of dams with their pigs and offered pigs better access to the sow's teats.

Key Words: Sows, Farrowing, Piglets, Mortality, Crates, Behavior

Introduction

The restriction of the sow's movement during parturition and lactation in conventional rectangular farrowing crates is mainly intended to protect pigs from being crushed by the sow (Robertson et al., 1966; English, 1977). However, as Clough (1984) argued, most conventional farrowing crates are usually too small to accommodate the normal standing-up and lying-down movements of a sow. Such a spatial "containerization" of sows may create as many problems as it solves. Besides challenges from animal welfare proponents on humane grounds, these rectangular farrowing crates are also questionable in terms of their overall production efficiency (English and Smith, 1975; Baxter, 1984; Svendsen et al., 1986). The escalating research work in recent years focusing on the assessment of the existing farrowing systems largely reflects this dissatisfaction with the present farrowing environment (e.g., Heckt et al., 1988; Curtis et al., 1989; McGlone and Morrow-Tesch, 1990; Phillips et al., 1991; Cronin and Smith, 1992; Phillips and Fraser, 1993).

Small modifications to the rectangular crate that do not change its fundamental configuration have proven unsatisfactory in solving the problems, but a complete banning of its use is also not practical now. An acceptable model seems to be a moderate crate system, in which such important factors as sow's comfort, pig protection, productivity, and investment requirement are all considered in a balanced way. However, up to now, only a few scientific attempts have been made in this direction (e.g., Peo, 1960a,b; Fraser et al., 1988; Lou and Hurnik, 1991). The main objective of this study was to develop an ergonomical model of a farrowing unit to meet the behavioral requirements of pigs and compare it to the predominantly used rectangular crate.

Materials and Methods

Crate Design. Two prototype ellipsoid crates were installed in the Swine Research Station, University of Guelph. To minimize abrasions and physical injury to the sow, the shape of the ellipsoid crate (Figure 1) was streamlined and the interior of the crate had no protrusions, dead corners, or sharp edges. The crate
was made large enough for a sow to turn around, to change postures more easily, and to visually monitor her pigs in all directions.

Except for the supporting legs, the crate is made of two types of steel: round pipes (42 mm in diameter) for the horizontal oval rings, and round solid steel (15 mm in diameter) for the vertical bowed bars. The whole crate is composed of three separate segments, one front piece and two side pieces. The front piece, mounted with a feeder, can swing open to serve as an entrance to the crate. The frame of the side pieces is so shaped that it is analogous to the dorsal curvature of the sow in a lateral recumbent position. This maximizes the contact surface between sow body and the crate and minimizes high pressure points on the sow’s body, facilitating more comfortable lying down actions and resting.

The vertical bars of the crate are bowed outward 200 mm, forming a “two-tier” structure (Figure 2). This structure creates a slope for the sow to lean on when she changes her posture from standing to lying. With this slope, the crate encloses a smaller plane space at floor level and a larger plane space at the sow’s standing height. The space difference between the maximum and the minimum of the plane sections is an overlapped area \( OA \), which accounts for

\[
OA = \pi(AB - ab) = 3.14(1.00 \times .80 - .85 \times .60) = .91 \text{ m}^2
\]

where \( A \) and \( B \) represent the long and short radii of the two horizontal oval frames. The overlapped area effectively uses 26% of the total available pen floor space as both activity space for standing sows (space marked \( M \) in Figure 2) and protected area for pigs (space marked \( N \)). At the cross-section \( O \) (Figure 1), the crate reaches its maximum plane space that accounts for 2.51 m\(^2\) (1.60 + .91), 72% of the floor space available in the whole pen.

Four crate legs are attached to the midpoints of the bowed side bars (Figure 1). The legs are made of two differently sized round pipes, the pipe smaller in
diameter inserted into the one larger in diameter. These legs, therefore, can be adjusted both for orientation of their foot bases so that they can be easily fixed to any slatted or perforated metal floor and for leg length so that the height of the crate is adjustable. In this experiment the lower horizontal oval ring of the crate was set to 250 mm above the pen floor so that pigs could move freely underneath.

A commercial rectangular crate used in this study served as a control. The crate has a floor dimension of 2,100 × 600 mm, with lower rails turnable and flared to a maximum 750 mm in width. The space allowance for both the sow and piglets is summarized in Table 1. Both ellipsoid and commercial rectangular crates were located in the same temperature-controlled farrowing room and placed on the same plastic-coated, perforated metal pen floor, which was elevated 250 mm above the solid concrete room floor. All farrowing pens, each defined as one of the above crates and the rest area, were enclosed by galvanized steel partitions 600 mm high. Feeders and nipple drinkers of similar type were provided for all pens. Every pen was equipped with a heat bar suspended 700 mm above the floor.

**Animals and Variables.** Altogether 64 Yorkshire sows from the station’s “specific-pathogen-free” herd were assigned to two treatments, 32 each to ellipsoid and rectangular crates. Efforts were made to keep the sow parity in balance between two treatments. At the end of the experiment there were 14 gilts and 8, 5, 2, and 3 sows in parities 2, 3, 4, and 5 or up, respectively, in the ellipsoid crate; the corresponding numbers were 16, 8, 4, 2, and 2 for the rectangular crates. Sows were weighed for pre-farrowing body weight and moved into the crates 5 d before the expected parturition (109 d of pregnancy). The pre-farrowing weights were 211 ± 6 kg for sows in the ellipsoid crate and 206 ± 6 kg for those in the rectangular crate. The sows were fed 2 kg of the balanced diet before farrowing and to appetite thereafter. Sows stayed in farrowing crates for 33 ± 4 d and were weighed again for their postweaning weight at the end of lactation.

Pigs were subjected to routine management procedures: tooth clipping, tail docking, iron injection, and ear notching. They were weaned at 28 ± 3 d of age. Day 1 weight was taken within 14 h after birth and the other two were done on d 7 and d 21 after birth. All pigs were weighed individually.

Sows in both types of crates were monitored by video cameras mounted above the farrowing units for their behavioral performance. Observations, for a period of 8 h commencing at 0900, were made on d 1 prepartum and d 1 postpartum. Behavioral data consisted of 20 sows for each crate type.

Farrowing records included the number of live-born and stillborn pigs. A stillborn pig could be detected by the presence of meconium and fetal membranes on the body surface, mucous on the head, and prominent external cartilage still on the hooves. A “lung floating test” was carried out to ensure the correctness of the external examination whenever necessary. The lung of a stillborn pig is unaerated and thus sinks in water and is dark purple, easily distinguishable from the pink and floating lung of a live-born pig. Any mummified pigs were included in this group.

Crushed pigs were judged mainly by external examination. Usually, the tongue protrudes from the mouth of a crushed pig. Bruising at several points on the body of these pigs was obvious. The pattern of the flooring material was often imprinted on one side of the body. Some of those pigs were completely flattened or severely deformed. In several uncertain cases video tape recording was used further to verify the crushing. Pigs that were savaged by sows or soon died as a result of initial injuries caused by sows were included in this group. Infected pigs were detected when disease symptoms were apparent. These pigs usually had normal body shape and no visible injuries on their body surface. They usually isolated themselves from the group activities of other littermates and were different from those categorized as starved-weak that were small and emaciated. Deaths due to scouring were classified in this group. The category “others” included congenital defects, starved-weakness, and other unidentifiable deaths.

**Statistical Analyses.** The data analyses were carried out with GLM procedures (SAS, 1990), based on least squares estimates unless otherwise indicated. The sow

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**Table 1. Comparisons of space allowances between ellipsoid and rectangular farrowing crates**

<table>
<thead>
<tr>
<th>Item</th>
<th>Ellipsoid</th>
<th>Rectangular</th>
<th>Increase,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pen floor space</td>
<td>3.5</td>
<td>3.2</td>
<td>9%</td>
</tr>
<tr>
<td>Floor space for sow, m²</td>
<td>1.6</td>
<td>1.2</td>
<td>33%</td>
</tr>
<tr>
<td>Floor space for pigs, m²</td>
<td>1.9</td>
<td>2.0</td>
<td>-5%</td>
</tr>
<tr>
<td>Maximum plane space for sow, m²</td>
<td>2.5</td>
<td>1.5</td>
<td>67%</td>
</tr>
<tr>
<td>Maximum plane space for sow and piglets, m²</td>
<td>4.4</td>
<td>3.2</td>
<td>38%</td>
</tr>
<tr>
<td>Room enclosed by crate, m³</td>
<td>2.3</td>
<td>1.3</td>
<td>77%</td>
</tr>
</tbody>
</table>

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The total enclosed volume (VT) of the ellipsoid crate consists of two parts, the volume of oval cylinder (V1) and the volume of the surrounding arc belt (VB) excluding the volume for the sow feeder:

\[ V_T = V_S + V_B = \pi ab (B + 20) + \frac{4}{3} \pi \left[ \frac{1}{2} R^2 \theta - \theta \left( \frac{R^2 - (B/2)^2}{2} \right) \right] \]

where a, b = long and short radii of oval ring = 850, 600 mm; B = height of the crate = 800 mm; R = radius of the arc of the bowed side bar = 445 mm; \( \theta \) = the corresponding angle of the arc of the bowed side bar; H = the distance from the inner edge of oval ring to the inner edge of the bowed side bar = 25 mm.

The largest plane space enclosed at midpoints of the bowed side bars.

3Sum of maximum plane space for sow and floor space for pigs.

4Calculated up to 1 m high. The detailed calculation for the ellipsoid crate is given in footnote a.
Table 2. Least squares means (LSM) of the production performance of pigs in the ellipsoid and rectangular farrowing crates

<table>
<thead>
<tr>
<th>No./litter (percentage)</th>
<th>Ellipsoid</th>
<th>Rectangular</th>
<th>Pooled SE of LSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSM</td>
<td>%</td>
<td>LSM</td>
</tr>
<tr>
<td>Total births (Tb)</td>
<td>9.72</td>
<td>—</td>
<td>9.97</td>
</tr>
<tr>
<td>Stillbirths (% Tb)</td>
<td>.81a</td>
<td>8.3</td>
<td>1.57b</td>
</tr>
<tr>
<td>Live births (Lb, % Tb)</td>
<td>8.91a</td>
<td>91.7</td>
<td>8.40b</td>
</tr>
<tr>
<td>Live loss (% Lb)</td>
<td>1.37</td>
<td>15.4</td>
<td>1.26</td>
</tr>
<tr>
<td>Crush (% Lb)</td>
<td>.46</td>
<td>5.2</td>
<td>.39</td>
</tr>
<tr>
<td>Infection (% Lb)</td>
<td>25.7</td>
<td>2.8</td>
<td>.37</td>
</tr>
<tr>
<td>Others (% Lb)</td>
<td>.34</td>
<td>3.8</td>
<td>.28</td>
</tr>
<tr>
<td>Total loss (% Tb)</td>
<td>2.17</td>
<td>22.3</td>
<td>2.83</td>
</tr>
<tr>
<td>Weaned (% Tb)</td>
<td>7.54</td>
<td>77.6</td>
<td></td>
</tr>
</tbody>
</table>

a,bMeans between crate designs with different superscripts differ significantly \( P < .05 \).

was regarded as the experimental unit for sow traits, the litter for pig traits.

Net sow lactation weight loss \( (w_{\text{Net}}) \) was first corrected for the pig litter weight at birth \( (w_{\text{tp}}) \) from gross sow lactation weight loss \( \text{LW}_{\text{Net}} = \text{LW}_{\text{Weaning}} - \{w_{\text{Day} 109} - w_{\text{tp}}\} \). The \( w_{\text{Net}} \) was then subjected to statistical analysis, with \( w_{\text{Day} 109} \) and pig litter size as covariates.

It is conceivable that the body weight gains of pigs can be influenced by the quantity of sow milk available to each piglet. As more deaths occur during the preweaning period the share of milk available to these pigs is redirected to nourish the remaining piglets. Therefore, in addition to the adjustment for pig birth weight, mean pig litter weight has been adjusted for the number of live pigs lost at periods between any of two consecutive weighings in the analysis of covariance procedure. Similarly, comparisons among crates on pig mortality rate were based on the means adjusted for litter size and birth weight of pigs.

Results

A total of 304 pigs were born in the ellipsoid and 318 in the rectangular crates. The stillbirth rate was lower in the ellipsoid crates than in the rectangular crates (Table 2). A similar result was also obtained in our test of a circular crate, in which sows also had freedom to turn around (unpublished data), compared to a rectangular crate. Among live-born pigs, no significant differences were found in the causes of individual deaths. The greatest loss of live-born pigs (approximately 75%) occurred during the first 3 d of life (Figure 3). Most crushed pigs were also found in these days. The temporal patterns of the losses for both live-born and the crushed pigs were similar in the two types of crates. Temporal patterns for the loss of pigs born live, using the pooled data from both crates, could be expressed as \( Y = 2.07 - 0.53 \ln d \) \( (r = .37, P = .02) \), and, for the crushing, \( Y = 2.61 - d - \ln^3 d \) \( (r = .37, P = .05) \).

The differences due to treatment in the live weight of the pigs were within sampling error \( (P > .05) \) at any of three weighing dates \( (d 1, 7, \text{and } 21) \). Their daily weight gains were not affected by crate difference in the 1st wk of birth \( (P > .05) \) but were affected for the time intervals of \( d 7 \text{ to } d 21 \ (P < .05) \) (Figure 3).
Figure 4. Daily weight gains of pigs in the two types of crates.

The overall treatment difference in weight gains from d 1 to d 21 was not significant \( (P > .05) \). During the farrowing-nursing period, the average weight loss of sows in the ellipsoid crate was similar to that of those in the rectangular crate, -11 vs -10 kg, respectively \((P > .05)\).

The behavioral observations are summarized in Table 3. Unlike the rectangular crate, in which sows were unable to turn, the ellipsoid crate allowed the sow to turn around freely. On average, sows made 40.7 ± 4.9 complete circles (360°) during 8 h on the day before parturition, which significantly outnumbered the 8.0 ± .9 turns they made during the same time period on the day after parturition \((P < .01)\). However, the number of sow posture transitions in the ellipsoid crate, 89.5 ± 11.2/8 h, did not differ from that in the rectangular crate, 87.7 ± 10.1/8 h \((P > .05)\).

The sow frequently used the lower oval ring in the ellipsoid crate as a supportive object to lean against when lying down, which accounted for 81% of all body descendence in an observation of 52 samples. Lateral nursing position adapted from such body descendence assumed the sow’s dorsum close to one side of the oval ring. This left a space of about 400 to 600 mm on the teat side between the sow’s body and the opposite half of the lower oval ring. Such a space could accommodate the whole litter of any size or at any age prior to weaning. Snout-snout contacts between the sow and her pigs were also observed in all directions in the ellipsoid crate, in contrast to those in the rectangular crate, in which such contact could only be seen in the front part of the crate. Some of these contacts were actually made outside the ellipsoid crate when the sow stuck out her snout tip between the bowed side bars or under the lower oval ring.

**Table 3. Observations of behavior in the ellipsoid and rectangular farrowing crates**

<table>
<thead>
<tr>
<th>Behavioral traits</th>
<th>Ellipsoid</th>
<th>Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sow turning</td>
<td>Possible</td>
<td>Impossible</td>
</tr>
<tr>
<td>Support for sow lying down</td>
<td>Available</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Supervision of pigs by sow</td>
<td>Unrestricted</td>
<td>Restricted</td>
</tr>
<tr>
<td>Vacuum nest building</td>
<td>Permitted</td>
<td>Frustrated</td>
</tr>
<tr>
<td>Teat impediment</td>
<td>Not observed</td>
<td>Observed</td>
</tr>
</tbody>
</table>

**Discussion**

Recent work on the space requirements for pigs (Baxter, 1986; Curtis et al., 1989; Hurnik and Lewis, 1991) can prompt a further assumption that the overall space required by an animal can be divided into two components: static and dynamic space. Static space requirement is simply based on the animal’s physical body dimensions. This is the absolute minimum provision and cannot be further reduced. Dynamic space is determined by the individual behavior patterns of the animal that are considered. The amount of dynamic space that should be provided for an animal or a group of animals depends on what kind of behavioral activities the animals are allowed to perform. As a baseline, the space provision of a farrowing unit should satisfy animals with the minimum of five freedoms for their body maintenance: lying down, getting up, turning around, stretching limbs, and grooming themselves (Brambell, 1965).

Our previous observations showed that the traditional rectangular crate could interfere with the smooth completion of the whole sequence of lying-down and getting-up actions, making sows’ posture changes less controllable and more difficult. Sows in such crates usually struggled vigorously to get up but often slipped off balance onto the floor again. These uncontrollable or excessive movements could not only make the sow less comfortable but also add more chances of trapping or crushing the pigs.

With these considerations in mind, the ellipsoid crate was designed to a dynamic space limit of accommodating a sow’s circling action, which apparently demands the largest space among the above activities. There are several reasons to consider the circling as a key behavioral element: a) to promote the amount of physical exercise necessary to maintain the sow’s muscle strength and general health; b) to permit easier expression of vacuum nest-building activities before farrowing; c) to enlarge the sow-pig interaction zone, facilitating snout-snout contact between the sow and pigs; d) to ease frustration resulting from the inability to visually inspect unexpected external stimuli such as pigs’ squealing or sudden noise at the back of the rectangular crate; and e) to increase environmental complexity, thereby reducing boredom and boredom-related vices.
A sow cannot circle around unless she is first in a standing position. While in a standing or turning position, the space below the cranial and caudal ends of a sow (approximately 200 mm from rear legs to the base of tail, 550 mm from front legs to snout tip) was not used (see Figure 2). This implies that a sow can turn around as long as the upper space is still large enough and the lower space is not shorter than the distance between her front and rear legs. The use of the bowed side bars of the ellipsoid crate permits sows to use the upper room for turning without interfering or endangering the pigs below. This design has made it feasible to save space by narrowing the crate in one direction. The sow in such a narrowed crate may more frequently use the side slope for leaning down. In addition, she can only face the front or the back of the ellipsoid crate during nursing or resting because of the insufficient space for her to lie across the width of the crate.

The lower parts of most commonly used rectangular crates more or less impede pigs’ access to the sow’s udders. This has been suggested to contribute to lower teat fidelity and greater litter variability, which further lead to higher pig mortality (Fraser and Thompson, 1986). The lower oval ring of the ellipsoid crate is a key design feature to deal with this problem. When a sow resumes lateral recumbency the oval ring curves away from sow’s teat line, which allows full exposure of the sow’s udders and leaves enough space for suckling pigs. In our experiments obstruction of teats has not yet been observed. The lower oval ring can also comfortably support the sow’s descending action from standing to recumbency, thus encouraging the sow to use it. Leaning down on the oval ring and the bowed side bars obviously creates a time delay that may help pigs to escape the impending danger. Because the supporting legs are placed outside the ellipsoid crate, the whole crate completely “floats” above the pigs, minimizing the opportunity of squeezed or trampled pigs.

Attaching the legs to the bowed bars also adds slight elasticity to the crate, which buffers the sow’s descending strength. Despite the much lighter steel materials used, the ellipsoid crate is solid enough to resist any force applied by the sows. The physical strength of the crate is increased by its geometric structure. The crate can be installed or dismantled by one person because it can be taken apart to three segments. These segments can also be stacked onto one another to save space when they are in shipment and storage.

One undesirable feature of the ellipsoid crate is that it is more difficult to catch the pigs and to restrict sows when necessary. Manure spreading may also require the entire pen floor to be slatted or perforated. But feeder fouling by sows was rare in the experiment (eight occurrences for 32 sows over the 5-wk experimental period). Since sows’ excreta do not ac-cumulate at certain spots, they soon dry up and fall through the pen floor due to the movement of the sow and her piglets. Therefore, in an unsupervised parturition, the pigs may not have to be born into the piled wet manure usually seen at the rear of rectangular crates. This helps keep a more hygienic environment for the newborn pigs, thereby reducing the possibility of infection.

Most stillbirths occur at the intrapartum period (Randall, 1972; English and Smith, 1975), suggesting that some as yet unknown detrimental factors exist at this stage. Increasing the physical fitness of sows in general and the muscle contraction of the uterus in particular may shorten the birth process. Also, stress hormones such as adrenalin, as antagonists of oxytocin, could weaken the strength of the uterus during farrowing. Therefore, the lower stillbirth rate in the ellipsoid crates might be explained by 1) reduced frustration and lower adrenalin output due to allowing the sow to perform vacuum nest building, easier movements, freer inspection of the litter and surroundings; 2) adopting more comfortable postures or expressing natural instincts (e.g., turning before lying during farrowing) during birth; or 3) more prepartum exercise due to increased space compared with rectangular crates.

Deaths associated with crushing represented a significant cause of neonatal mortality. The restlessness or “awkwardness” of the sow was reported to be the main factor responsible for these deaths (English and Smith, 1975). More than 75% of crushes occurred within 3 d of birth, so supervision of farrowing and provision of a comfortable environment for the sow in this period may reduce these losses.

Implications

Compared to the conventional rectangular crate, the ellipsoid farrowing crate permits the sow to perform a broader spectrum of behavioral activities. It allows the sow to turn around, easily communicate with her young, freely monitor her surroundings, and lie down more smoothly. These differences have been achieved on an amount of floor space similar to that occupied by the traditional rectangular crate. The crate not only retains the protective environment for both sows and pigs and can at least be as productively efficient as the conventional rectangular crate.

Literature Cited


