CODE OF PRACTICE FOR THE CARE & HANDLING OF PIGS: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

JULY 2012

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Excerpt from Scientists' Committee Terms of Reference

Background

It is widely accepted that animal welfare codes, guidelines, standards or legislation should take advantage of the best available knowledge. This knowledge is often generated from the scientific literature, hence the term "science-based".

In re-establishing a Code of Practice development process, NFACC recognized the need for a more formal means of integrating scientific input into the Code of Practice process. A Scientists' Committee review of priority animal welfare issues for the species being addressed will provide valuable information to the Code Development Committee in developing or revising a Code of Practice. As the Scientists' Committee report is publicly available, the transparency and credibility of the Code process and the recommendations within are enhanced.

For each Code of Practice being developed or revised, NFACC will identify a Scientists' Committee. This committee will consist of 4-6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request one or two nominations from each of 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology.

Purpose & Goals

The Scientists' Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientists' Committee and the Code Development Committee. The report will be used by the Code Development Committee in drafting a Code of Practice for the species in question.

The full Terms of Reference for the Scientists' Committee can be found within the NFACC Development Process for Codes of Practice for the Care and Handling of Farm Animals, available at www.nfacc.ca/code-development-process#appendixc.

CODE OF PRACTICE FOR THE CARE AND HANDLING OF PIGS: REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

Pig Code of Practice Scientists' Committee
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1. APPROACHES TO DEFINING AND EVALUATING ANIMAL WELFARE

The scientific evaluation of animal welfare involves the use of empirical methods to obtain information about animals that can be used to inform ethical decision-making regarding their quality of life. One major challenge is that people have diverse views about what constitutes a good quality of life and therefore express a variety of ethical concerns and use different criteria for defining animal welfare. These have been grouped into three general categories: 1) biological functioning; 2) affective states; and 3) natural living. These form the bases for different approaches to animal welfare research (Fraser et al., 1997). The biological functioning approach emphasizes basic health and normal function and includes measures having to do with health and productivity, stress response and normal (or lack of abnormal) behaviour (Broom, 1991). Animal welfare defined in terms of affective states, often referred to as the feelings-based approach, concerns the subjective experiences of animals with an emphasis on states of suffering (pain, fear, frustration), states of pleasure (comfort, contentment) and the notion that animals should be housed and handled in ways that minimize suffering and promote positive experiences (Duncan, 1993). The concept of natural living emphasizes the naturalness of the circumstances that the animal experiences and the ability of the animal to live according to its nature (Fraser, 2008). While the natural living approach provides another viewpoint for what constitutes a good quality of life for animals, it is more difficult to derive specific measures from it that can be used to evaluate welfare (Fraser et al., 2008).

When possible, each section in this review covers research results from all three approaches for assessing pig welfare. Many animal welfare issues, especially those occurring for longer periods over the lifetime of the animal such as housing system or space allowance, have mainly been evaluated in the literature using measures of biological function. Other animal welfare issues have been studied using empirical research involving subjective states, for example, the degree of pain experienced by piglets undergoing castration, and whether some forms of anesthesia or analgesia reduce the degree of pain experienced. In general, criteria for “naturalness” are less frequently addressed in the scientific literature although considerations for freedom of movement, opportunities to engage in species-typical behaviour and daily activities have been considered here, and in particular when there is evidence that constraining these behaviour patterns results in signs of negative emotional states (e.g. fear or frustration) or results in disruption of biological function (e.g. stereotypies).

The mandate of the Scientists’ Committee was to address the implications for pig welfare within the topics identified. Few, if any, references are made to economic considerations or human health and welfare concerns as these were beyond the scope of the committee’s mandate and were rarely addressed in the papers reviewed. Certainly, some practices studied could have an effect on pig health, but the studies may not have focused on them. The Code Development Committee, for whom this report was prepared, represents considerable expertise in these areas, and is tasked with considering such factors in its discussions.

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2. CONTROLLING PAIN: A CASE STUDY OF CASTRATION

Conclusions

1. **Post-operative pain is a concern for at least several hours after castration and only analgesics, such as injection with ketoprofen or meloxicam, have been shown to be of value in controlling post-operative pain; more research is required to evaluate effectiveness and duration.**

2. **Castration of nursing piglets is painful regardless of age, but piglets castrated at ≥10 days of age show better weight gains than piglets castrated at 1 or 3 days of age.**

3. **Injection of a local anesthetic such as lidocaine into the testicles at least 3 minutes prior to surgery is the most practical and safe method to reduce the pain associated with the surgery but it requires handling the pig twice and is possibly associated with a certain amount of discomfort, so more research is required to refine this technique or find alternatives.**

4. **The application of topical anesthetics before castration is ineffective in relieving pain during castration.**

5. **Carbon dioxide anesthesia is effective in preventing pain during castration; however it is highly noxious to the piglets while they are inhaling it before losing consciousness, and piglet mortality is a concern.**

6. **General anesthetics are in general impractical for on-farm use and post-operative care is necessary to prevent crushing.**

7. **Isoflurane or halothane anesthesia alone is not effective to relieve pain during castration in all piglets. The addition of a lidocaine injection to halothane anesthesia relieves some of the pain associated with castration.**

8. **Immuno-castration has the potential to be an effective alternative to surgical castration of piglets but because errors will occur, immuno-castration will require additional safeguards and testing for boar taint at the plant. In addition, there are welfare issues associated with raising intact males because of increased aggression.**

9. **Production of entire males at lighter weights reduces boar taint, but does not guarantee its absence. Effective detection of boar taint on the slaughter line would be required. There are welfare issues due to increased aggression levels.**

10. **Other alternatives to castration (sexing semen, genetic selection) are, as of now, not viable options.**

Introduction: Measures used for evaluating the welfare of pigs experiencing pain with respect to castration can include their health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living). In general, different techniques to protect pigs from pain are compared, in terms of use of different anesthetics, anti-inflammatories, analgesics, gas anesthesia and alternatives to castration (immuno-castration, production of entire males, sexing semen and genetic selection).

1) In terms of biological functioning, studies generally used production and health parameters. Production parameters include: growth rate; feed conversion; and lean and fat deposition. Health parameters include: death; injury, including skin lesions and scratches; shock response (increased skin temperature and cortisol); and body condition (weight loss or gain, feed intake, back fat depth). Other parameters that can be considered functional include behavioural parameters, such as social behaviour (aggressive and mounting behaviours).

2) In terms of affective states, anti-pain techniques can be assessed as to how well they make pigs insensible to the surgical intervention and relieve pigs from post-surgery pain and result in positive emotional states, such as comfort. Pain or response of pigs to the application of pain relieving techniques or alternative production systems can be assessed in terms of: i) behavioural response, such as vocalizations, struggling movements, scratching, tail wagging, decreased time suckling and standing and increased time lying, increased time spent away from heat source, aggressiveness; and ii) physiological response, such as variation in blood cortisol, body temperature and heart rate.

3) In terms of natural living, both castration and pain relief are procedures that do not occur in free living animals. Thus, this approach cannot be used to evaluate the welfare of pigs with regards to castration and pain relief.

Because each of these approaches uses different criteria for evaluating animal welfare, recommendations for pain control or alternatives to surgical castration techniques may differ depending on which approach is used.

The impact of castration on the welfare of piglets: Castration ensures that the meat from male pigs does not present the unpleasant taste and smell known as boar taint upon cooking that result from the accumulation of androstenone and skatole in the fat of entire males European Food Safety Authority (EFSA) (2004). Boar taint is known to vary with breed and slaughter weight (Aluwé et al., 2011).

Similar to most parts of the world (excluding UK, Ireland, Australia and Spain), in North-America, castration without any form of pain relief is routinely performed on practically all male piglets within the first week of birth. Castration is usually performed by restraining by the hind legs to expose the testicles. Two incisions are then made with a scalpel to expose the testicles, which are then grasped and pulled away from the body and the spermatic cords are then severed either by using a scalpel or by tearing (Hay et al., 2003; Taylor et al., 2001). Surgical castration is a fairly rapid procedure, taking well under 2 minutes in duration to perform; tearing of the spermatic cords has been shown to take slightly longer (96.1 seconds) than cutting them with a scalpel (70.1 seconds) (Marchant-Forde et al., 2009).

The International Association for the Study of Pain (IASP) defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” and emphasizes that the inability of an individual to communicate the feeling of pain does not mean that no pain is experienced (IASP, 1994). There is substantial evidence that castration is highly painful given that the scrotum and spermatic cords are highly innervated and that piglets show strong endocrine, vocal and other behavioural responses indicative of pain during and after castration (Hay et al., 2003; Moya et al., 2008; Sutherland et al., 2010; Taylor et al., 2001).

Studies assessing pain during and after castration compare these piglets to sham-castrates, where all the handling of castration is performed, but there is no actual cutting of the skin (Kluivers-Poodt et al., 2007; Prunier et al., 2006). It is thus assumed that even though sham-handled piglets may be stressed, they will not experience the actual pain associated with tissue damage caused by surgical castration. Pain is assessed by measuring the acoustic characteristics of vocalizations during castration and by changes in activity (such as reduced suckling and udder massage, lying away from the heat source and isolation from the rest of the litter) and pain-specific behaviours (trembling, changes in body posture, rubbing or scratching the affected area following castration) (Gerritzen et al., 2008; von Borrell et al., 2009). Based on the rate and frequency of vocalizations, the pulling and severing of the spermatic cord appears to be the most painful part of the procedure (Taylor et al., 2001), although there is no difference between severing the cords by tearing or cutting with a scalpel (Marchant-Forde et al., 2009).

There is some behavioural evidence that castrating piglets after weaning is more stressful than during the pre-weaning stage (McGlone and Hellman, 1988; McGlone et al., 1993). Suckling piglets of 1 to 20 days of age show similar behavioural responses indicative of pain (increased vocalizations, decreased time suckling and standing and increased time lying, increased time spent away from the heat source compared to controls) regardless of age (McGlone & Hellman, 1988; McGlone et al., 1993; Taylor et al., 2001). This suggests that castration is no less painful for nursing piglets of younger ages. Despite this fact, older pre-weaned piglets may be better able to handle the ill effects of castration as piglets castrated at 1 or 3 days of age gained less weight than littermates compared to males castrated at 10 days of age or older (Kielly et al., 1999; McGlone et al., 1993). Kielly et al. (1999) also suggested that castration at 7-10 days may be easier to perform due to the increased testicle size; furthermore, this may improve the detection of inguinal hernias than in 3-day-old piglets.

The affective state of piglets during surgical procedures is measured mainly through vocalizations. Sound spectrograph analyses indicate that high pitched vocalizations (>1000Hz) occur most often during procedures likely to cause pain and that this class of calls is reduced when anesthesia is used (White et al., 1995; Weary et al., 2006). Due to pain specific behaviours performed during and after castration it is assumed that surgical castration of piglets results in highly negative subjective feelings (Hay et al., 2003; Weary et al., 2006). In terms of biological functioning, castration results in physical injury and may negatively impact growth rate in the following days (McGlone et al., 1993). Physiological measures of stress include adrenocorticotrophic hormone (ACTH) and cortisol and elevation in heart rate in response to castration (Hay et al., 2003). Finally, castration is not compatible with the view that animals should be raised in natural conditions and be able to behave “naturally”. Thus, to allow male pigs to grow and behave as entire males, immuno-castration or slaughter before sexual maturity could be two alternatives (Prunier & Bonneau, 2006).

PAIN RELIEF FOR THE SURGICAL CASTRATION OF PIGLETS

Local anesthesia: Lidocaine is the drug most commonly studied for local anesthesia during castration of piglets. Ranheim et al. (2005) reported that a lidocaine injection into the testicle was rapidly transported into the spermatic cord, and the highest concentration of lidocaine was found in the cord after 3 minutes. Two studies showed that piglets that received subcutaneous testicular injections of lidocaine 2 to 3 minutes before castration vocalized less and at lower intensities than castrated piglets without any anesthetic (Marx et al., 2003; White et al., 1995). Therefore it appears that an interval of approximately 3 minutes between injection of lidocaine and castration is necessary for the drug to take effect. Furthermore, in White et al. (1995), local anesthesia with lidocaine resulted in decreased heart rates during castration.

Kluivers-Poodt et al. (2007) compared the effects of the following treatments on the pain responses of piglets during castration: 1) castration without anesthesia, 2) castration with lidocaine injection, 3) castration with lidocaine and meloxicam injections, 4) castration with meloxicam injection and 5) sham castration. According to treatments, 15 minutes before castration, 0.8ml of lidocaine was injected in each testicle and 0.2ml under the skin and 0.2ml meloxicam was administered under the skin in the neck muscle 15 minutes prior to castration. It was found that piglets in all treatments with lidocaine had a decreased call rate compared to piglets that did not receive lidocaine (1.02±0.68 versus 1.20±1.05, $P<0.05$) whereas meloxicam did not impact piglet vocalizations. There was a greater increase in plasma cortisol concentrations due to castration in piglets without anesthesia and in piglets with meloxicam treatment compared to piglets that received lidocaine or that were sham-castrated (Figure 1) Even though piglets treated with lidocaine alone had the smallest increase in cortisol levels, it was still significantly higher than sham-castrated piglets. Skin temperatures in the groin of piglets (measured immediately after castration and 20 minutes later) did not differ between sham-castrated piglets and piglets that received lidocaine and meloxicam (average decrease in temperature: -0.3˚C). In all other groups of castrated piglets, however, the temperature decrease was significantly greater (no anesthetic: -1.2˚C, lidocaine: -1.7˚C, meloxicam: -1.0˚C, $P < 0.05$). This may be indicative of a greater shock response to the pain with more blood flow being redirected to the affected area. The authors thus concluded that the use of lidocaine reduced the pain and stress responses to castration but not to the level of sham-castrates. Furthermore, the use of the analgesic meloxicam was not effective in reducing pain during castration. Hansson et al. (2011) also examined lidocaine injected into the testicle and/or an injection of meloxicam to control post-operative pain and concluded that the most effective approach was to use local anesthesia to reduce surgical pain in combination with an analgesic to reduce post-operative pain. These researchers also evaluated the ability of herdsmen to carry out the procedures and concluded that the use of this protocol was feasible for on-farm use.

Leidig et al. (2009) investigated the impacts of injection of procaine, a local anesthetic (10mg of 2% procaine per testicle), 5 minutes before castration. The effects of the injection itself, of the castration after the injection and the effects of both combined were evaluated separately. It was found that when looking at the injection and the castration after injection separately, they did not elicit more vocalizations or struggling movements than sham-castration. When their effects were combined, they resulted in more vocalizations than sham-castration and as much as castration without anesthesia. However, struggling movements were decreased compared to castration without anesthesia. Thus procaine is effective in reducing some of the pain associated with castration.

In addition to the immediate pain caused by surgical castration, post-operative pain also occurs in the following hours and days (Hay et al., 2003). Zonderland and Verbraak (2007) investigated post-operative pain relief using the same treatments and piglets in the study by Kluivers-Poodt et al. (2007). Overall, it was found that castrated piglets that received lidocaine showed more tail wagging than all other treatment groups during the four days post-castration (mean % of scans: 8.2±2.3 versus 3.7±1.6, respectively, $P<0.001$). However, these negative effects of lidocaine were removed if meloxicam was added or used by itself. But no difference was found between treatments in any other pain-related behaviours in the days following castration.

Keita et al. (2010) also tested the effectiveness of meloxicam intramuscular injection (0.4mg/kg of 0.08ml/kg meloxicam solution) 10-30 minutes before castration on post-operative pain relief. Piglets that received the meloxicam injection had significantly lower plasma cortisol concentrations compared to the piglets castrated without anesthesia (206±104 versus 276±97ng/mL, $P=0.01$). However, the meloxicam treated piglets still had significantly higher cortisol concentrations than the uncastrated control piglets (65±50ng/mL). Meloxicam treated piglets also had significantly lower concentrations of ACTH than castrated piglets without anesthesia and did not differ from uncastrated control piglets (meloxicam: 17.0±26.3mg/mL, castration: 35.8±45.6mg/mL; no castration: 18.1±26.1mg/mL; $P<0.01$). There was a greater proportion of meloxicam treated piglets that did not show pain related behaviours 2 and 4 hours after castration compared to castrated piglets without anesthesia (82.7% versus 68.0%; $P<0.05$ for both periods). However, at 24 hours after castration, there was no difference between treatments with 21.3% of piglets in both treatments showing some pain-related behaviours. Thus meloxicam is effective in relieving some of the pain-related behaviours post-castration while lidocaine did not relieve pain post-castration.

Courboulay et al. (2010) compared the efficacy of lidocaine or ketoprofen treatment on pain relief during and after castration. Similar to the studies above, lidocaine was successful in relieving pain during castration compared to castrated controls, although not to the level as sham-castrated piglets in terms of struggling and intensity of vocalizations (Figure 2). Ketoprofen, similar to meloxicam, did not affect pain responses during castration, but post-operative pain was reduced in these piglets in terms of scratching and tail wagging on the day of castration and isolating themselves on the day after castration (

Figure **3**).

The application of topical anesthetics on the testicles prior to castration would be a fast and easy method to diminish pain during castration. However their effectiveness is poor as demonstrated by a number of studies: Sutherland et al. (2010) evaluated the two topical anesthetics, Cetacaine® (short acting) and Tri-Solften (long acting), applied on the scrotum and spermatic cord. There were no differences between treatments in terms of pain associated behaviours and vocalizations during castration. Rittershaus et al. (2009) conducted a study with the following topical anesthetics: an ethyl chloride vapocoolant spray, a combination of ethyl chloride spray and lidocaine spray or EMLA-cream (skin anesthetic, 2.5 % lidocaine and 2.5 % prilocaine). Castrated piglets in all treatment groups showed strong vocal and cortisol responses to castration. A third study by Schiele (2010) showed similar results using an ethyl chloride vapocoolant spray with or without a local anesthetic in the wound. The last two studies actually reported that the application of the cryogen spray itself was painful. Thus topical anesthetics are not a viable method to prevent pain due to castration in piglets.

Local anesthetic injections (lidocaine or procaine) do decrease the behavioural, vocal and physiological responses to surgical castration in piglets, although piglets still show stronger reactions compared to sham-castrated piglets. The anti-inflammatory drugs meloxicam and ketoprofen were not useful for relief of pain during castration, but did decrease pain-related behaviours in the hours and days following castration. Thus, local injected anesthetics are likely useful in preventing some, but not all of the pain associated with castration and anti-inflammatory drugs prevent some of the post-operative pain associated with castration. The injection itself may also be a significant cause of pain for the piglets. When given a local anesthetic, piglets have to be picked up and handled twice which results in extra stress. Lidocaine, ketoprofen and procaine are approved for use in pigs in Canada, and as of now, meloxicam is approved for use in cattle, but not yet in pigs (Health Canada, 2011). However, the use of topical anesthetics has shown to be ineffective in preventing pain during piglet castration.

General anesthesia through inhalation: The effectiveness of carbon dioxide anesthesia (70% CO_2, 30% O_2) to render piglets unconscious and insensible to surgical castration was evaluated by Gerritzen et al. (2008). Piglets were individually placed in a box pre-filled with the gas mixture and their behaviour was observed until loss of posture. Experimenters then waited 30 seconds before removing the piglet from the box and performing the surgical castration. It took on average 24±1 seconds for piglets to lie down (lose posture). Starting 11±1 seconds after immersion, piglets started to breathe heavily and this continued until 6 seconds after loss of posture. Furthermore, immediately after lying down, all piglets showed some convulsions. The heart rate of piglets started decreasing at immersion in the box and decreased to almost zero after loss of posture; it then increased again to normal at approximately 120 seconds after immersion. Minimal brain activity was only observed 33±2 seconds after induction, thus during loss of postures and the convulsions, the piglets were likely still conscious. Surgical castration took place 19±5 seconds after removal from the box and no piglets showed any behavioural, heart rate or brain activity reactions to the procedure. Piglets started to regain consciousness approximately 56 seconds after removal from the box.

Svendson (2006) also investigated CO_2 anesthesia for piglet castration (70% CO_2, 30% O_2) in terms of behavioural responses during castration and the number of Fos positive neurons in the spinal cord after castration (dorsal horn neurons express Fos upon noxious input, this is thought to roughly quantify the amount of pain experienced). Piglets were exposed to either 1 or 2 minutes in a box pre-filled with the gas mixture. In this study, piglets lost posture after approximately 15 seconds of exposure and regained consciousness 30-40 seconds after removal from the box. All piglets were seen to be breathing heavily before and after loss of posture and some piglets had convulsions. Piglets that were exposed to 1 minute of CO_2 prior to castration were found to express 1,152±778 Fos positive dorsal horn neurons and piglets that were exposed to 2 minutes only expressed 503±641 Fos positive dorsal horn neurons. Piglets that were castrated without anesthesia or with a local anesthetic on the scrotum and spermatic cord expressed greater numbers of Fos positive dorsal horn neurons (14,140 ± 5.69 and 4,760±4.46 neurons, respectively).

Given that Switzerland decided to ban castration without pain relief as of 2009, a large project (Pro Schwein) investigated pain relief during castration in piglets. Burren and Jäggin (2008) investigated the use of isoflurane anesthesia with a commercial pig restraining and inhalation system (PIGNAP from Agrocomp, AG, Andwil, Switzerland) in regards to pain sensitivity during surgical castration. The system involved placing piglets on their backs in a v-trough with an inhaler attached to it. Piglets' responses to introduction into the apparatus, to gas inhalation, to castration and during awakening were evaluated. It was reported that during the introduction into the apparatus and the start of isoflurane inhalation, piglets had an average score of 2.18 (0=calm, no adverse reaction to 3=strong struggling movements). It took an average of 17 seconds to complete the castration. During this procedure, 80.7% of piglets showed no reactions during castration, 11.6% of piglets showed only 1-2 movements, 5.5% showed several movements and some vocalizations and 2.2% of piglets showed violent struggles and strong vocalizations. Finally, it took piglets an average recovery time of 194 seconds (from removal of inhaler until standing) and they had an average score of 1.03 at awakening (1=calm and immediately ambulatory to 4=restlessness and ataxia observed).

Hodgson (2007) compared the anesthetic properties of two gases; isoflurane (1.82%) and sevoflurane (4.03%), during piglet surgical castration. Inhalation lasted for 120 seconds. After the surgery was completed and the 120 seconds elapsed, the piglet was placed individually in a cardboard box until it was standing. Induction time was calculated as the interval from the beginning of anesthetic inhalation with the piglets cradled under the experimenter's arm until it was relaxed enough to be placed in dorsal recumbency in a v-trough for surgery. Recovery time was measured from the time the inhaler was removed until the piglet was standing. Results showed that the isoflurane had a faster induction time than sevoflurane (44.0±7.5 versus 47.5±8.7 seconds, respectively; $P<0.05$). The recovery time was however longer for isoflurane than sevoflurane (140.6±51 versus 122.5±43 s, respectively; $P<0.05$).

Schultz et al. (2007) investigated the use of isoflurane general anesthesia using the Ferkel Pro-Anest ("Model Provet" from Prof. Schatzmann, FA. Provet AG, Lyssach, Switzerland). The treatments were the following: 1) control without anesthesia, 2) castration without anesthesia, 3) control with anesthesia, 4) castration with anesthesia, 5) castration with anesthesia and meloxicam (0.4mg/kg) injection. Given that there was no difference in cortisol concentrations between the control without or with anesthesia, the anesthesia itself was not more stressful than restraint alone. Interestingly, piglets castrated with anesthesia had a similar cortisol concentration to the ones castrated without anesthesia. However, piglets castrated with isoflurane anesthesia and injected with meloxicam had a lower cortisol concentration than the other castrated groups although it was still higher than the controls. Similar concentrations were obtained 1 hour after castration with the same statistical differences between treatments.

General anesthesia with injections: Waldmann et al. (1994) studied the effectiveness of general anesthesia using tiletamin/zolazepam, thiopental, and propofol to relieve pain during castration of piglets. The only treatment producing good anesthesia and pain relief was the intravenous injection of thiopental; however, there was a high rate of accidental crushing by the sow after the castration resulting in 9.5% of castrated piglets dying. In Canada, the only general anesthetic available with a license claim for pigs is thiotal (thiopental). However, this drug can only be used under veterinary supervision and has a low safety margin. More research is likely required before recommending this as a practical and effective method to produce relief from pain during castration of young piglets. Furthermore, the inherent difficulties in doing intravenous injections in neonatal piglets make this method not a practical one.

The use of carbon dioxide resulted in complete absence of pain during castration. It is also cheap, easily available for producers, and does not require veterinary attention. Unfortunately, it is the induction of anesthesia with this method that resulted in significant behavioural responses that are indicative of discomfort (gasping and convulsing) until unconsciousness is gained. In addition, in a preliminary experiment performed by Gerritzen et al. (2008), exposure times to the gas were evaluated and one out of four piglets that were exposed to more than 2 minutes in the box died. Thus, the safety margin of carbon dioxide is a problem. Isoflurane alone was not a good candidate to render all piglets insensitive to pain during castration. It is also an expensive gas that at this time is not approved for food animal use in Canada. The advantages of general anesthesia are that piglets are only handled once while awake and castration is easy as they are unconscious and not struggling. However, it is important to consider the time it takes for the piglets to recover, which may result in increased accidental crushing by the sow (Prunier et al., 2006). Furthermore, general anesthesia during castration does not relieve post-operative pain.

ALTERNATIVES TO SURGICAL CASTRATION OF PIGLETS

The European Commission, the European meat industry, scientists and animal welfare non-governmental organizations (NGOs) agreed on a voluntary ban of surgical castration of piglets as of 2018 with surgical castration without anesthesia to stop in 2012. This will require a move towards alternatives to surgical castration. These include immuno-castration, slaughter before sexual maturity, genetic selection against boar taint and sexing semen to use female semen only.

Immuno-castration: With the recent approval of Improvest® in Canada, immuno-castration to prevent boar taint has become an alternative to surgical castration of male pigs. This vaccine works by immunizing pigs against their own GnRH hormones, which inhibits testicular function and boar taint no longer occurs (Baumgartner et al., 2010). Numerous studies have demonstrated the effectiveness of immuno-castration in terms of a significant reduction in boar taint to the level of barrows compared to entire pigs (Dunshea et al., 2001; Jaros et al., 2005; Pauly et al., 2009; Schmoll et al., 2009; Warveille et al., 2011; Zamaratskaia et al., 2007). For this vaccine to effectively immunize entire male pigs, two doses have to be injected: the first is a primer dose usually injected around 10 weeks of age and the second one, which effectively inhibits testicular function, is injected 4 to 6 weeks before slaughter (Evans, 2006). Immuno-castrated pigs show more efficient growth than barrows with less fat deposition especially at high slaughter weights and a better feed conversion efficiency prior to the second dose of the vaccine (Dunshea et al., 2001; Jaros et al., 2005; Fàbrega et al., 2010; Pauly et al., 2009; Schmoll et al., 2009). Immuno-castration, when used in combination with ractopamine, does not adversely affect handling traits at slaughter (Rocha et al., 2012).

Immuno-castration of entire finishing pigs eliminates the acute pain experienced by surgically castrated piglets; however welfare concerns still arise due to the fact that immuno-castrated pigs grow and behave as entire males until the second vaccination. Increased levels of aggressive and mounting behaviours, as well as overall activity are reported in immuno-castrated males compared to barrows before the second dose of vaccine (Table 1) (Baumgartner et al., 2010; Cronin et al., 2003; Rhydhmer et al., 2006). In Fàbrega et al. (2010), there were no significant differences between immuno-castrated males and castrated males in terms of aggressive behaviour at or off the feeder before or after the second immunization at 21 weeks of age. However, continuous behavioural observations of aggressive behaviours only took place for a total of 20 minutes per week. After the second vaccination, immuno-castrated males behave like barrows and thus aggressive behaviour decreases (Table 1). The vaccine is also very well tolerated by the pigs and there is no observable reaction on the site of injection although some stress and local pain is likely to occur as a result of the two injections (Dunshea et al., 2001). A drawback of immune-castration is human error, such as vaccinating outside the recommended time period, missing a dose, waiting too long to ship the pigs (Fredriksen et al., 2011), or accidental self-injection. This may lead to aggression problems and boar tainted meat going through to consumers as pigs may not be effectively castrated.

In recent large scale surveys conducted in European countries, over 60% of surveyed consumers informed about the issue preferred immuno-castration to surgical castration with anesthesia and also reported they were confident in the efficacy of the vaccine against boar taint (Schmoll et al., 2011; Vanhonacker & Verbeke, 2011). Furthermore, a high level of coordination between producers and slaughter plants would be required to implement the use of immuno-castration. In addition, the cost of the vaccine that the producers will have to incur should be evaluated.

Other alternatives: Slaughter of entire male pigs at a lighter weight may decrease the risk of boar taint although there is a large variation in terms of sexual maturity within and between breeds (reviewed by Zamaratskaia & Squires, 2008). Slaughter at ≤75kg does not result in entirely boar-taint free meat although levels are lower than at high slaughter weights (>100kg) (Aldal et al., 2005; Aluwé et al., 2011; Nicolau-Solano et al., 2007). If entire males are to be slaughtered, it is imperative to have an effective system to detect boar taint on the slaughter line. However, for the past 20 to 30 years, the United Kingsom (UK) and Ireland have been rearing entire male pigs and Portugal, Spain and Cyprus do not castrate the majority of their male pigs (Fredriksen et al., 2009). Furthermore, slaughter weights of entire males in the UK and Ireland are relatively high at ~100kg (Department for Environmental, Food and Rural Affairs [DEFRA], 2011; The Irish Agriculture and Food Development Authority [Teagasc], 2010). In terms of welfare, similar to immuno-castrated males, a problem that occurs with raising entire boars is the increased level of aggression and mounting behaviours displayed by these animals which may result in decreased welfare (as reviewed by von Borrell et al., 2009). However, Rydhmer et al. (2011) reported that entire males that were kept in stable groups until slaughter showed little aggression.

Another alternative to castration is sexing boar semen and selecting only for female offspring which would totally eliminate the painful procedure of castration. In addition, rearing groups only composed of females results in less aggressive behaviour and thus improved herd welfare (Rydhmer et al., 2006). However, conventional artificial insemination methods require a very high volume of semen which is not feasible due to the current rate of output of semen sorting systems (Vazquez et al., 2009; von Borrell et al., 2009). Furthermore, boar semen is noticeably less robust than bull semen to manipulation, thus its quality after sorting is poorer compared to bull semen in addition to which it cannot be frozen (Vasquez et al., 2009). Overall, we are not yet at the technological stage in order to use sexed boar semen that would result in a similar pregnancy rate and litter size as artificial insemination with unsexed semen or natural breeding.

Boar taint is a heritable trait, and as such it may be possible to select against it. However, given that the genes selected against are sex-linked, decreases in sexual maturation and performances may be seen (Bonneau, 1998). The solution to this is to identify animals that have a low boar taint while keeping a normal sexual development and good productivity. This may be done by selecting genetic markers (Zamartskaia & Squires, 2009). More research is needed before entirely boar taint free animals can be consistently produced.

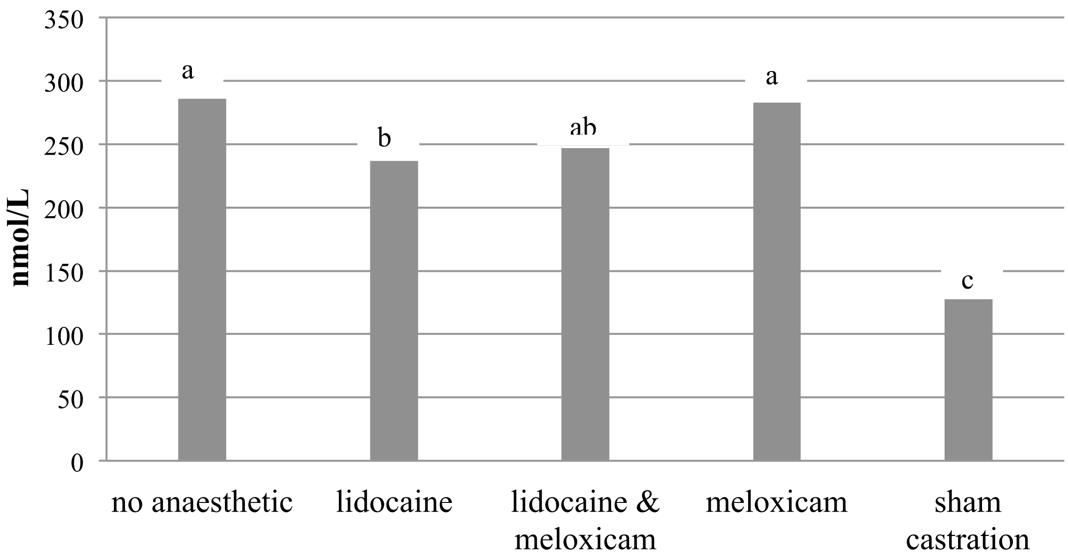

Figure 1: Increase in plasma cortisol concentrations 20 minutes after castration, different letters indicate significant differences between treatments (Kluivers-Poodt et al., 2007, permission to reproduce pending).

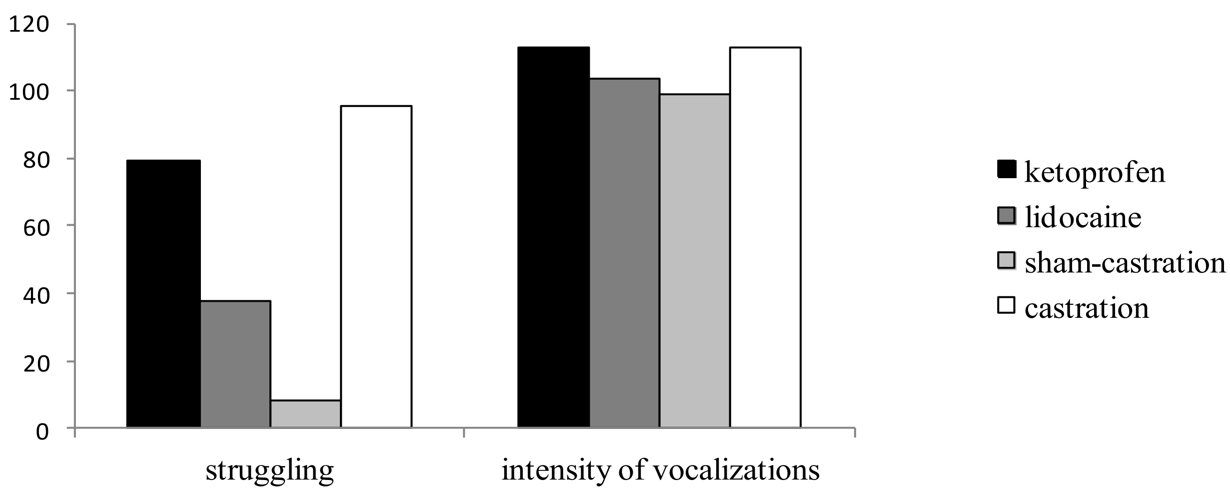

Figure 2: Frequency of struggling (in % of piglets) and mean intensity of vocalizations (in dB) during catration according to different treatments. Different letters represent a significant difference between columns ($P < 0.01$) (Courboulay et al., 2010, reproduced with permission).

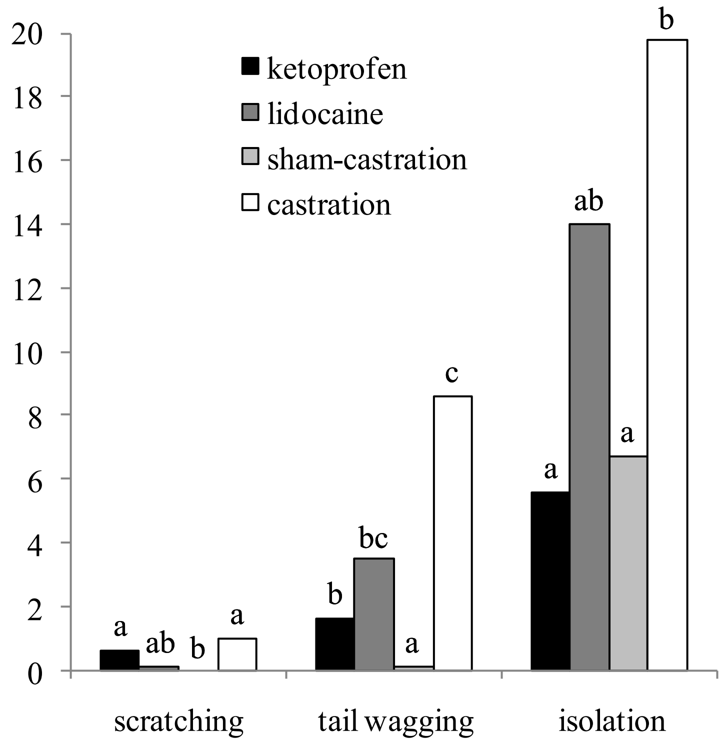

Figure 3: Frequency of behaviours after castration in % of scans observed during one hour according to treatments on the day of castration (scratching and tail wagging) and on the day after castration (isolation from other piglets) (Courboulay et al., 2010, reproduced with permission).

Table 1: Mean frequency of agonistic interactions per pig in 24 hours in two studies: Cronin et al., 2003 (behavioural observations at 17 and 21 weeks, 2nd dose of GnRH vaccine at 18 weeks) and Baumgartner et al., 2010 (behavioural observations at 18-21 and 22-25 weeks of age, 2nd dose of vaccine at 21 weeks).

	Before 2nd vaccine		**After 2nd vaccine**	
	Barrows	Immuno-castrates	Barrows	Immuno-castrates
Cronin et al., 2003	4.5[a]	28.6[b]	9.5	9.5
Baumgartner et al., 2010	16.44[a]	34.56[b]	30.72	24.6

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3. METHODS OF EUTHANASIA

Conclusions

1. **When applied with sufficient force, blunt trauma and non-penetrating captive bolt are effective methods of euthanasia for suckling piglets and result in immediate unconsciousness and death.**

2. **Penetrating captive bolt is effective as a single step method for euthanasia of pigs under 120kg that is safe for handlers and is cost-effective. For mature sows and boars, penetrating captive bolt causes loss of consciousness, but a secondary step (e.g. exsanguination) is necessary to ensure death.**

3. **When properly executed, gunshot to the head is effective for euthanasia. Human safety is a concern.**

4. **Electrocution for pigs ≥2.3kg causes immediate death: an electric current flow through the brain results in unconsciousness and through the heart in cardiac arrest. This can be done with a simultaneous electrocution of brain and heart, or in two-steps by electrocuting first the brain then the heart. Cost and maintenance of equipment may be a concern for this euthanasia method.**

5. **Exposure to carbon dioxide (>80% CO_2), to a mixture of CO_2:argon or argon gas (90%) in either pre-filled chamber or with a high flow rate are effective methods to kill pigs. However, CO_2 inhalation is highly noxious and causes signs of distress until loss of consciousness which may occur as long as 2 minutes following exposure to the gas. Piglets exposed to argon or argon mixed with CO_2 also show some signs of distress.**

6. **Anesthetic overdose is effective for a painless death, but euthanasia may be delayed because veterinary supervision and administration is required and it is expensive.**

Introduction: Euthanasia refers to a humane and painless death; rapid loss of consciousness should be followed by brain death, loss of breathing and cardiac arrest (American Veterinary Medical Association [AVMA], 2007). Assessment of animal welfare during euthanasia focuses mainly on the degree and duration of negative emotional states such as pain and distress, since aspects of the nature of the animal and its normal biological function are irrelevant at this time. Overall effectiveness of methods for on-farm euthanasia of pigs are assessed with regards to the duration of time until loss of consciousness and subsequent death, the size of the animal, safety for the human handlers, ease of application and cost.

Death can be induced by either: 1) hypoxia; 2) chemical depression of the central nervous system; or 3) physical destruction of brain tissue (AVMA, 2007). Euthanasia by hypoxia refers to a gradual decrease of oxygen levels in the blood and brain, leading to a state of analgesia and anesthesia eventually followed by respiratory and cardiac failure (Velarde et al., 2007). An overdose of anesthetic results in direct depression of the central nervous system leading to unconsciousness followed by death due to cardiac arrest and/or depression of the respiratory system. Physical destruction of brain tissue or depolarization of neurons by electrocution result in rapid loss of consciousness and subsequent death when brain structures controlling consciousness as well as those controlling cardiac and respiratory function are affected (Blackmore and Delany, 1988). Depending on the size of the animal, some methods of euthanasia (such as the non-penetrating captive bolt gun) require a secondary step such as exsanguination to kill the animal after it is rendered unconscious.

Assessing sensibility: Unconsciousness, or insensibility, refers to a temporary or permanent loss of brain function such that an animal is unable to perceive and respond to sensations, including pain. Following physical methods of euthanasia, pigs lose posture but may go into a tonic (rigid muscle extension) and/or a clonic (involuntary muscle contractions and spasms) phase of neuromuscular spasms. Following euthanasia by gas inhalation, pigs remain limp after losing posture (Grandin, 2010). Immediately after euthanasia, it is important to assess signs of sensibility to ensure that the animal is unconscious and dies without regaining sensibility.

The brain stem, cerebral cortex and thalamus are the brain regions involved with arousal and consciousness in mammals (Seth et al., 2005). The brain stem is also involved in autonomic function including control of respiration and heart rate. In order for death to occur without the occurrence of pain or return to consciousness, irreversible damage needs to be caused to the neural tissue in these areas. To verify brain stem function the following reflexes can be assessed: the corneal reflex (eye blinking when the cornea is touched), the palpebral reflex (eye blinking when the edge of the eyelid is touched) and the pupillary light reflex (pupil constriction in response to shining light in the eye) (Erasmus et al., 2010; Grandin, 2010). The absence of these reflexes is indicative of loss of consciousness (Hall et al., 2001; Smith & Swindle, 2008). However, their presence does not necessarily indicate that the pig is sensible as is the case with head-only stunning when only the cerebral cortex is affected (Smith & Swindle, 2008; Vogel et al., 2011). Therefore, other indicators such as absence of spinal reflexes (examples: response to nose-pricks, anal reflex, toe and claw reflex) and measures such as rhythmic breathing and regular heart rate are useful to evaluate the effectiveness of an euthanasia method (Erasmus et al., 2010; Kaiser et al., 2006).

When to euthanize: The decision to euthanize a pig depends on the amount of suffering and the chances of recovery that a compromised pig presents. This decision is especially important to consider in low-birth weight piglets (<1kg, 2.2lbs) that have a much higher chance of mortality before weaning than heavier piglets (Quiniou et al., 2002; Gondret et al., 2005). Furthermore, Fix et al. (2010) showed that low birth weight was associated with increased occurrences of health problems and poor body condition as well as decreased survival to weaning and in the nursery. In Smith et al. (2007), weight at weaning and weight on day 42 post-weaning increased with increasing birth weight. In addition, Morrow et al. (2006) scored the welfare of piglets upon entry into the nursery according to physical conditions (Table 2**)**. Piglets presenting the following conditions had high rate of mortality if not euthanized: difficulty getting to feed and water (66.67% mortality), two or more joints swollen and lame on one leg (53.57% mortality), hernias (38% mortality). Piglets with two or more concurrent conditions had the greatest rate of mortality. Thus, euthanasia of low birth weight piglets and of compromised piglets at weaning presenting the above conditions is beneficial in terms of decreased suffering of the compromised piglets, improved overall herd welfare and increased economic viability (Morrow et al., 2006; Smith et al., 2007).

A descriptive study by Straw et al. (2009) reported the prevalence and mortality of pigs with scrotal and umbilical hernias and kyphosis (humpy-back) at entry into finishing pens. Twenty-five percent of pigs with scrotal hernias, 7.2% of pigs with umbilical hernias and 11.8% of pigs with kyphosis died within 80 days of being in the finishing pens; these mortalities being significantly higher than in healthy pigs. The authors concluded that euthanasia of pigs presenting these conditions at entry into the finishing barn was beneficial for productivity and animal welfare.

METHODS OF EUTHANASIA

Blunt trauma: A manual blow to the head, using either a heavy instrument or a hard flat surface, causes severe concussion and brain damage leading to immediate unconsciousness and death within minutes in young piglets (Chevillon et al., 2004a; Widowski et al., 2008). This method is very effective for neonates, economically viable, convenient and safe for the handlers given that the blow is applied accurately to the top of the head, with sufficient force and determination (Widowski et al., 2008). However, this method may be objectionable to the public and emotionally difficult for the stockperson. The AVMA (2007) recommends using this euthanasia method only for young piglets <3 weeks of age.

Blunt trauma to the head was evaluated as a method of euthanasia for piglets under 8kg (18lbs) using a 0.5kg (1.1lbs) hammer and piglets between 8-25kg (18-55lbs) using a 1.5kg (3.3lbs) hammer (Chevillon et al., 2004a). The authors reported that after the blow, all piglets immediately lost consciousness: they collapsed instantly, did not vocalize and their pupils were dilated. The animals showed convulsions and spasms, but they all became motionless within 1.5min (<8kg piglets) and 4 minutes (8-25kg piglets). Cardiac arrest occurred within 10 minutes in all piglets with no return to sensibility.

In Widowski et al. (2008), similar results were obtained in low viability newborn piglets (<24 hours of age). Manual blunt trauma was applied to the piglets by holding their hind legs and firmly and striking the top of their heads against a flat and hard surface. All piglets were immediately unconscious and none showed a return to sensibility; they showed leg movements for 1.14±0.12 minutes and cardiac arrest occurred after 2.85±0.31 minutes. In this study, 5 stockpersons performed the euthanasia and it was found that the piglets euthanized by one of them had lower skull fracture scores than all other handlers. This result demonstrates that the blunt trauma method may not be consistent depending on the force the handler applies to the piglet's skull. Furthermore, the authors suggested that given that this method may be unpleasant for some handlers to perform, it may result in a delay in euthanasia of compromised piglets. However, if performed with sufficient force and determination, blunt trauma to the head is very effective in causing immediate unconsciousness followed by death without a return to sensibility.

Captive bolt pistol: Euthanasia with a captive bolt pistol works by inflicting a concussion that causes irreversible damage to the brain stem leading to death (Blackmore & Delany, 1988). There are two types of captive bolt pistols: penetrating and non-penetrating. Captive bolts may be powered by cartridge, air pressure or by internal combustion. There is considerable variation in the design of captive bolts that affect the amount of force and damage they deliver (Woods et al., 2010a). For penetrating captive bolts this includes the length of the penetrating bolt, the muzzle design and the size of cartridge or pressure settings. For non-penetrating captive bolts this includes the muzzle size, shape and stroke length of the bolt head and size of cartridge or pressure settings. For both types of guns, the animal is restrained as the shot is precisely directed at the midline of the forehead, 4-5 cm above eye level with the gun directed perpendicular to the forehead (Chevillon, 2005); however, different designs may require adjustments to the placement on the skull (Woods et al., 2010b). Finnie et al. (2003) investigated the impact on brain damage of a non-penetrating captive bolt gun on the left temporal region in previously anesthetized 15-18kg pigs. It was found that this location of non-penetrating captive bolt impact was not successful in causing sufficient brain damage to kill the pigs; this study thus shows the importance of proper placement of the gun to the front of the head. Captive bolt guns are commercially available, are safe for handlers and cost per pig is fairly inexpensive; however, training is necessary (Chevillon et al., 2004b). It is critical that placement on the skull be appropriate for the type of device and that there is a proper match of equipment to the size and age of the animal.

In order for captive bolt guns to be effective without the need of a secondary step, the impact must be forceful enough to result in sufficient damage to the brainstem to cause depression of the cardiac and respiratory systems. Widowski et al. (2008) evaluated the use of a pneumatic non-penetrating captive bolt gun with a round head and 120psi for euthanasia of neonatal piglets (<24 hours). The piglets received two shots, one on the frontal bone and the second one immediately afterwards on the back of the skull. Results showed that all piglets became immediately insensible; however some showed signs of returning to consciousness. In a similar experiment on neonatal piglets (<3 days) using the same gun modified to have a cone-shaped bolt head with a greater depth of depression, Casey-Trott et al. (2010) found that all piglets became immediately insensible and none showed signs of regaining consciousness. Therefore the shape of the bolt head, the depth of depression at the point of impact as well as the force applied all determine the effectiveness of this euthanasia method.

Chevillon et al. (2004a) evaluated the use of a penetrating captive bolt gun for euthanasia of piglets (8-25kg, 18-55lbs.), growing pigs (>25kg, 55lbs.) and sows with or without subsequent exsanguination. All pigs immediately lost consciousness and none regained sensibility whether or not exsanguination was performed. Local haemorrhaging occurred in all pigs as well as spasms, convulsions and leg movements. Piglets became motionless within 1.5 minutes and cardiac arrest occurred within 6 minutes. Growing pigs became motionless within 2.5 minutes and cardiac arrest occurred within 7 minutes if exsanguination was not performed and within 2 minutes if it was. For sows, exsanguination reduced the spasms and convulsions, and cardiac arrest occurred after 2-8 minutes and without exsanguination within 5-7 minutes. The authors suggested that if exsanguination was performed, it was better to do it with a dagger blow to the heart to trigger internal haemorrhaging rather than cutting the animal's throat which would result in blood flow into the surrounding environment. There was some local haemorrhaging in all animals.

More recent work by Woods et al. (2010b, 2011a, b) evaluated the use of non-penetrating and penetrating captive bolt guns (The Euthanizer, Accles & Shelvoke) as one-step euthanasia procedures in a large scale study both in experimental and commercial settings. A non-penetrating bolt was used for pigs weighing 2-10kg (4.4-22lbs.) and a penetrating bolt for pigs 15-300kg (33-661lbs.). Muzzle design and cartridge size were specified for different weight classes of pigs. Results showed that clonic movements occurred for an average of 1.7 minutes and heart beats stopped 3.9 minutes after firing of the captive bolt gun regardless of body weight. A single shot of the penetrating captive bolt gun was effective in euthanizing pigs under 120kg (265lbs); above this weight a secondary step was necessary. This was shown both through assessment of traumatic brain injury of the thalamus (which was not observed in pigs over 120kg) and assessments of physiological responses to euthanasia. Placement of the gun required a different angle than that generally recommended for gunshot. Furthermore, the authors suggested that inadequate restraint or bolt placement may not result in proper euthanasia.

In conclusion, the captive bolt pistol is a fairly inexpensive and effective method in causing immediate loss of consciousness with irreversible brain damage and death of pigs <120kg. Access to a secondary method of euthanasia is however necessary if vital signs are still observed after captive bolt impact. For mature sows and boars, penetrating captive bolt can be used for stunning but a secondary step (exsanguination) is required for ensuring death (Woods et al., 2010b; National Pork Board, 2009).

Gunshot: A gunshot to the head has a similar mode of action as a penetrating captive bolt gun in that it causes a concussion and destroys vital parts of the brain but it uses a free projectile (Blackmore & Delany, 1988). The animal has to be restrained to ensure adequate positioning of the gun with the muzzle placed close to the animals head and aimed towards the brain (AVMA, 2007; Longair et al., 1991).

It is recommended to aim the shot at the front of the head (same as for captive bolt gun) or behind the ear but without the gun actually touching the head. These positions have been shown effective for euthanasia of large pigs by Blackmore et al. (1995). A gunshot to the heart is not an accepted method of euthanasia if no prior stunning is performed as the animal will not lose consciousness immediately (Woods et al., 2010b).

No scientific studies have been performed on the use of a shotgun to euthanize pigs, however, it is likely that if the animal is restrained, the shot is powerful enough and well-aimed, it will cause immediate insensibility and death in pigs. This method however has concerns for human safety (risk of ricochet), the person performing the euthanasia must be well trained, have a gun license and perform the euthanasia outdoors (AVMA, 2007). However, in the case of a compromised animal, it may be difficult to move it outdoors, thus this method may not be the most appropriate.

Electrocution: Electrical stunning by placing electrodes on the head and chest of the pig and allowing sufficient current to flow through the brain is commonly used in slaughterhouses (Faucitano, 2010). However, loss of consciousness is reversible unless a second step to kill the pig is performed within 15 seconds (McKinstry and Anil, 2004). Indeed, when using 150-200V for 3 seconds on pigs weighing 60-80kg (132-176lbs), the return to corneal reflex was on average 37 seconds with a minimum of 18 seconds (Anil & McKinstry, 1998; McKinstry & Anil, 2004). For on-farm euthanasia, the second step is generally another electrocution to the heart producing cardiac arrest and death of the pigs rather than bleeding as is done in slaughter pigs.

There are two methods to euthanize pigs with electrocution: the two-step system in which the pig is stunned then killed with electrocution through the heart; and the one-step system which requires more current and simultaneously electrocutes the brain and heart (head-to-back or head-to-chest electrocution). In the two-step system, two electrodes (such as a scissor-like clamp) are placed on either side of the head in the area between the corner of the eye and the base of the ear in order to ensure proper electric current flow through the brain (Anil & McKinstry, 1998; Eike et al., 2005; Faucitano, 2010). If the electrodes do not span the brain, for example if placed on either side of the jaw or the neck, stunning may not occur (Anil & McKinstry, 1998). The same electrodes used for the head are then immediately applied to the chest (close to and spanning the heart) which will kill the pig through cardiac ventricular fibrillation (Woods et al., 2010b).

Anil and McKinstry (1998) used an electrode application time of 3 seconds on the head only to study stunning efficacy with a 50Hz alternating current and a voltage of either 150 of 250V in market weight pigs. The higher voltage resulted in a longer time to return to rhythmic breathing (42.6 seconds versus 39.7 seconds), however there was no difference in response to nose pricks. Chevillon et al. (2004a) investigated the use of a two-step electric euthanasia system. Euthanasia of growing pig (>25kg) and sows was performed and evaluated using electrical stunning to the head (5 seconds) followed by electrocution to the heart (15 seconds). The electrocution to the head resulted in immediate collapse and pupil dilation; the electrodes applied to the heart resulted in cardiac arrest within 1.5 minutes with the animals becoming immobile within 30 seconds. Vogel et al. (2011) studied the stunning and euthanasia of market weight pigs using a commercially available stunning system with a scissor-like clamp with an application time of 3 seconds per electrocution at 313V and 2.3A. Pigs were then bled 32-33 seconds after electrocution at which time sensibility was assessed. None of the pigs showed rhythmic breathing, heartbeats, natural blinking, eye tracking to moving object or righting reflex. For two-step electrocution, the World Organization for Animal Health (OIE) (2010) recommends an electrode application of at least 3 seconds with a minimum of 125V for piglets younger than 6 weeks of age and 220V for older pigs.

Another method for electrocution is to apply simultaneous current flow through the head and the heart which will result in immediate unconsciousness and death (Wotton et al., 1992). The OIE recommends using a minimum of 250V and applying the front electrode in front of the eyes and the rear electrode to the back, above or behind the heart for at least 3 s. Wotton et al. (1992) euthanized finishing pigs using 300V at 50Hz for 3.5 seconds using a one-step head to back electrocution system with different placements of the rear electrodes. The front most placement of the rear electrodes on the cervical vertebrae was the only placement not resulting in a 100 % cardiac arrest; the other placements were further back on the thoracic vertebrae. However, this study did not measure signs of unconsciousness and only cardiac fibrillation as pigs were bled soon after euthanasia for carcass assessments. Denicourt et al. (2009) investigated the effectiveness of euthanizing pigs from 5-125kg using 110V for 5 seconds with electrodes at different contact points. Two methods of one-step electrocution were tested, both supplied current through the brain with a steel lasso attached to the upper jaw in conjunction with either an anal probe or a metal belt around the abdomen. Immediately after electrocution, all pigs showed dilated pupils, there were no corneal, nociceptive or respiratory reflexes and the electrocution induced cardiac fibrillation in all pigs. However, this method may not be humane due to the high amount of manipulations required before euthanasia is performed.

A recent report published by the National Pork Board investigated the use electrocution to euthanize piglets under 7kg (15lbs.) (Probst-Miller, 2010). The electrocution device consisted of a table with two plates on which the piglet was placed on its side, two spring loaded tongs gently close on the piglet (one on head, one on back end). The plate and tong for the head were positively charged and the ones for the rear end were negatively charged. This device also included a lid for safety and handler well-being. Electrocution of sedated piglets was carried out at a voltage of 110-120V and a frequency of 60Hz for 5 seconds. Three piglet groups were tested: less than 2.3kg (5lbs) (less than 3 days of age), less than 2.3kg (more than 3 days of age) and more than 2.3kg (more than 3 days of age). Euthanasia by electrocution was shown to be ineffective for the group of piglets less than 2.3kg and 3 days of age, however, for piglets of more than 3 days of age, electrocution reliably induced unconsciousness and death in 98.5% of piglets.

In conclusion, both one and two-step electrocution methods are efficient for an effective euthanasia of pigs without return to sensibility with the one-step method requiring higher voltage. The electrodes need to be kept clean, well designed and firmly applied to the skin before the current is started (Grandin, 2010; Sparrey & Wotton, 1997). However, this method of euthanasia may be too expensive to be practical for an on-farm use.

Gas Inhalation: Carbon dioxide is another method commonly used to stun market weight pigs before slaughter. Increasing exposure time to the gas will result in death (Chevillon et al., 2004a; Faucitano, 2010). Carbon dioxide causes unconsciousness by reducing the pH of cerebrospinal fluid and subsequent death results from hypoxia (Raj, 1999). There are two methods of causing death by carbon dioxide inhalation: introducing the pigs into a pre-filled CO_2 chamber; or gradually filling the chamber with gas (Woods, 2010b). Different flow rates can be used to fill the chamber with gas.

Pigs at all ages appear to find inhalation of this gas highly aversive: escape and retreat attempts, gasping, head shaking and vocalizations occur frequently prior to loss of consciousness (Chevillon et al., 2004a; Raj & Gregory, 1996; Rodriguez et al., 2008; Sadler et al., 2011a; Velarde et al., 2007). Carbon dioxide causes two different aversive states. The first is due to CO_2 sensitive receptors in the respiratory tract and brain which cause dyspnea, the feeling of breathlessness. The second is the irritation of mucus membranes by reaction of CO_2 with water to form carbonic acid causing a burning sensation (Rodriguez et al., 2008; Troeger & Woltersdorf, 1991).

The concentration of CO_2 and whether the pig is exposed to a chamber already filled with the gas or with a gradual fill of the gas influence its effectiveness. Growing-finishing pigs exposed to different concentrations of CO_2 (40% - 90%) showed less aversive reactions (high locomotor activity, escape attempts, respiratory distress, vocalizations) for a shorter time after immersion as the concentrations increased (Raj & Gregory, 1996; Terlouw et al., 2006; Troeger & Woltersdorf, 1991). Sadler et al. (2011a) exposed weaned piglets using 100% CO_2 in either a prefilled chamber (20%) or with flow rates of 20%, 35% or 50% chamber volume per minute. Piglets euthanized in the pre-filled chamber or with the fastest flow rate (50%) showed less aversive reactions and died sooner (last movement and loss of posture occurred sooner and there was less gasping) than if the flow rate was medium or low. This is supported by the findings of Sutherland (2010) who showed that brain activity (as measured by electroencephalography [EEG]) and loss of heart beat were significantly faster using a pre-fill method with a concentration of 90% CO_2 compared to gradual fill at a rate of 20% per minute (time to loss of brain activity: pre-fill 248.2 seconds; gradual 461.6 seconds; time to cardiac arrest gradual: pre-fill: 313.4 seconds; 464.7 seconds).

Chevillon et al. (2004a) showed that exposure to 80% CO_2 for 6 min resulted in death of suckling piglets, but it took at least 90 seconds for them to become unconscious. Sutherland (2010) found that loss of posture (used as a measure of loss of consciousness) occurred within 45 seconds (range 36 to 108 seconds) for piglets ranging from 1 to 6 weeks of age exposed to 90% CO_2 with no effect of piglet age. Similar results were found in another recent study on piglet euthanasia using 100% CO_2 with neonatal piglets (0-3 days) and weaned piglets (16-24 days), although neonates lost consciousness faster than older piglets (99 versus 142 seconds) (Sadler et al., 2011b). Furthermore, pigs gradually exposed to 90% CO_2 in a dip-lift system showed brain activity for up to 60 seconds after exposure (Rodriguez et al., 2008).

Argon has also been investigated for pig euthanasia. This inert gas kills the pigs through anoxia and hypocapnia (decrease in the blood levels of O_2 and CO_2) which leads to lack of oxygen to the brain and subsequent loss of consciousness and failure of cardiac and respiratory systems (Raj et al., 1997). Sadler et al. (2011b) compared the effectiveness of a mixture of 50:50 CO_2:argon to the 100 % CO_2; no difference was found between the types of gases in terms of percentages of piglets reacting aversively to the gases. However, preliminary results of the durations of aversive reactions show that there may be disadvantages of using the 50:50 CO_2:argon mixture compared to 100% CO_2 (L. Sadler, personal communication). In Raj (1999) and Raj et al. (1997), growing pigs that were exposed to 90% argon did not show any hyperventilation during inhalation, whereas pigs exposed to either 30% CO_2/60% argon or 80-90% CO_2 did show hyperventilation. In addition, somatosensory evoked potentials (indicative of brain activity) were abolished more quickly in pigs exposed to higher percentages of argon and lower levels of CO_2. Thus, pigs likely find inhalation of argon gas less noxious than CO_2 which is also the case in rodents (Leach et al., 2002).

A recent study has tested another gas mixture, nitrogen and CO_2, for stunning pigs at slaughter (Llonch et al., 2011). It was reported that a high concentration of CO_2 (90%) leads to a higher aversion and breathlessness than 70% N_2/30% CO_2, 80% N_2/20% CO_2 and 85% N_2/15% CO_2 gas mixtures. However, the time of unconsciousness was reduced with nitrogen gas mixtures with up to 30% CO_2 compared to 90% CO_2 when the same time of exposure was used.

Sutherland (2011) compared 100% CO_2, 90% argon in air, 90% N_2 in air, a mix of 30% CO_2 /60% argon in air , N_2 and a mix of 40% CO_2/50% N_2 in air for euthanasia of suckling piglets (18 days of age). In the 4 treatments containing residual air, the durations of laboured breathing, indicative of respiratory distress, was prolonged and piglets in three of those treatments exhibited conscious behaviour after the initial onset of convulsions. In a second experiment, Sutherland (2011) excluded gases containing residual air and compared the effects of 100% CO_2, 100% argon and 60% argon/40% CO_2 on piglets ranging from 14 to 20 days of age. A welfare index was determined from a combination of behavioural measures that included latency to onset of convulsions (concurrent with loss of posture), duration of escape behaviour, duration of increased respiratory effort and duration of squealing. Times to loss of posture were 14, 21 and 11 seconds for the 100% CO_2, 100% argon and 60% argon/40% CO_2 treatments respectively but piglets exposed to 100% CO_2, had a poorer score for the welfare index compared to the other treatments. The author suggested that piglets euthanized by the argon treatments were less compromised than those exposed to 100% CO_2 but that the degree of welfare compromise observed in all treatments suggests that other alternatives should be investigated.

Compared to physical methods of euthanasia, gas inhalation is more aesthetically pleasant as there is no blood and the killing is performed by the gas and not by a person. However, with the use of high concentrations of CO_2 unconsciousness is not immediate and some suffering occurs. Inhalation of mixtures of CO_2 and argon or nitrogen seem less aversive to the pigs than CO_2 alone.

Anesthetic overdose: Anesthetic overdose is considered to be a humane euthanasia method for all pigs as it depresses the central nervous system resulting in unconsciousness and subsequent death due to respiratory and cardiac arrest (AVMA, 2007). However, the type of anesthetic and method of administration can influence the effectiveness. For example, in an emergency mass killing of segregated early weaning (SEW) piglets, Whiting et al., 2011 found that 5 of 240 piglets regained consciousness and 11 of 240 failed to die following intraperintoneal (IP) injection of pentobarbital (Euthanyl) and therefore the authors did not recommend the use of anesthetic overdose in this type of application. Because it requires the use of controlled substance, anesthetic overdose must be performed by a veterinarian and is expensive, and therefore euthanasia may be delayed compared to other methods. There also may be problems with carcass disposal because of anesthetic residue.

Table 2: Conditions negatively affecting welfare of weaned piglets with severity (A-D) and welfare score assigned to each piglet at weaning (0-10, best to worse) (Morrow et al., 2006, reproduced with permission).

Weak pig		**Rectal prolapse**	
A Can get to feed and water with difficulty	3	A Recent, undamaged and occasionally protruding	1
B Unable to use two legs	10	B Recent, damaged and protruding	4
C Unable to use three or four legs	10	C Recent, damaged and protruding for > 2 days	7
Lame: swollen joint(s)		**Hernias (scrotal or umbilical)**	
A One leg joint swollen, lame on one leg	3	A Hernia is present but small	1
B Two or more joints swollen, lame on one leg	5	B Hernia is large, pig has problem moving	3
C Two or more joints swollen, lame on 2 or more legs	8	C Hernia is large, infected, or ulcerated, impedes mobility	8
Damaged digit		**Repaired hernias (scrotal or umbilical)**	
A One digit mildly damaged	1	A Repaired hernia, healing but mild swelling	1
B One digit severely damaged	3	B Repaired hernia, obvious swelling but healing	2
C Two digits damaged, open wounds	6	C Repaired hernia, serious swelling with exudate	5
Recently fractured leg		**Lightweight**	
A Suspect broken leg	4	A < 40% under normal barn average weight	0
B Leg obviously broken	10	B 40% - 49% under normal barn average weight	1
C Compound fracture	10	C 50% - 59% under normal barn average weight	2
		D ≥ 60% under normal barn average weight	3
Tail bitten		**Abscess (including inguinal, scrotal, jowl)**	
A Tail bitten only	1	A Any abscess, diameter 2.5 – 5 cm	1
B Tail end bloody, infected	3	B Any abscess, diameter > 5 cm, < 10 cm	2
C Tail end bloody, infected, most of tail missing	5	C Any abscess, diameter > 10 cm	3
D Tail-head open wound, no tail	7		
Ear- or flank-bitten:		**Respiratory disease**	
A One or both ears (flanks) bitten, both mild	1	A Coughing, sneezing, or both	1
B One or both ears (flanks) bitten, one > mild	1	B Difficulty breathing, thumping for 3 days	7
C One ear (flank) bloody, infected and necrotic	5	C Difficulty breathing, thumping for > 5 days	8
D Both ears (flanks) bloody, infected and necrotic	6	D Severe difficulty breathing, open mouth, thumping for > 2 days	10
Injured pig, numerous superficial skin wounds		**Gastrointestinal**	
A Skin wounds on one side only	2	A Loose stools	1
B Skin wounds, both sides but on all 4 quarters	3	B Profuse diarrhea	5
C Skin wounds, both sides and all 4 quarters	4	C Profuse diarrhea with dehydration	8
D Skin wounds, both sides, all 4 quarters, wounds infected	6	D Profuse diarrhea, straining and dehydration	8

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4. PIG SPACE ALLOWANCES

Conclusions

1. **Using the allometric formula A= *k* × BW$^{0.667}$, the minimum space allowance below which performance of nursery and growing-finishing pigs is negatively affected is equivalent to ~*k*=0.034.**

2. **The minimum space allowance below which resting behaviour of growing-finishing pigs is negatively affected is equivalent to *k*=0.039 for slatted floors.**

3. **Above the range of 23.4 to 27.5°C, pigs will spend more time lying laterally and the lying position changes to the coolest area of the pen; as a result more surface area will be used by pigs than at cooler temperatures.**

4. **When space allowances are adequate (e.g. *k*=0.06), housing nursery or growing pigs in groups of >20 animals may reduce aggression at mixing in addition to reducing aggression in subsequent groupings.**

5. **Large group sizes (>80 pigs) have a slight negative impact on performance but do not alter behaviour of pigs in established groups.**

Introduction: Measures used for evaluating the welfare of growing-finishing pigs with respect to space allowance can include their health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living).

1) In terms of biological functioning, a sufficient space allowance will result in healthy pigs that have a good daily gain, feed intake and growth to feed ratio as well as a low level of behaviour problems such as aggression and tail biting. Growth rates, rates of mortality, injury or disease, incidence of aggression or behaviour problems and thermoregulatory and stress responses can be evaluated.
2) In terms of affective states, a sufficient space allowance should prevent suffering from hunger, fear, frustration and pain and allow the pigs to experience positive emotional states. Access to feeders, drinkers, undisturbed lying areas and space that allows for formation of a stable dominance hierarchy can be evaluated. Comfort can be assessed by the use of preference tests, for example to determine what the amount and type of flooring pigs prefer at different temperatures.
3) In terms of natural living, the floor surface area available for pigs should take into account the space occupied by the body of the pig, the space required for feeding and dunging behaviours as well as the space required for the performance of social behaviours. Thus, space requirements can be assessed by determining time budgets and the floor surface area required for the unrestricted performance of each behaviour or by providing a range of different space allowances and determining the one at which freedom of movement or their day-to-day activities are affected. The type of social interactions, activity and sleep patterns and opportunities for rooting and foraging behaviour can also be evaluated.

Because each of these approaches uses different criteria for evaluating animal welfare, recommendations for space allowance may differ depending on which approach is used.

Calculating appropriate space allowance: Space allowance is usually expressed as floor surface area per pig (m^2/animal) or as stocking density which is the number of animals for a given floor surface area (animals per m^2). Because the floor surface area required per pig increases non-linearly as they grow, Petherick and Baxter (1981) suggested that the floor surface area be calculated using an allometric formula which relates weight to body surface area:

$$A = k \times BW^{0.667}$$

Where:
A = floor surface area in m^2
k-value = floor space allowance coefficient
BW = pig body weight in kg

The *k*-value has been used in several industry codes and in recent research articles (see Table 3 and Table 4) for space allowance according to pig weight and different *k*-values). The advantage of this approach is that the coefficient (*k*) is consistent across a wide range of body weights (Gonyou & Stricklin, 1998). The optimal *k*-value may change according to temperature, type of flooring and group size. In addition, the use of different indicators (e.g. productivity, adrenal function, behaviour) for assessing welfare could result in different *k*-values. For example, the behaviour and physiological responses of pigs may be negatively impacted at a higher space allowance than that which affects their performance (Averós et al., 2010a; Meunier-Salaün et al., 1987). The space allowances in the studies mentioned in this chapter are given as final *k*-values that are equivalent to the floor surface area available to the pigs at the end of the experiment unless mentioned otherwise.

From a broken-line analysis and linear regression of 21 studies of the performance of nursery and growing-finishing pigs at different space allowances, Gonyou et al. (2006) estimated the critical *k*-value to be 0.0317 - 0.0348 for nursery and growing-finishing pigs (Figure 4). Below these values, the average daily gains for growing pigs were significantly reduced. Similar results were found in other studies with nursery and growing-finishing pigs with a space allowance of $k < 0.034$ having a lower average daily gain and less frequent eating that those with a higher space allowance (Meunier-Salaün et al., 1987; Street & Gonyou, 2008; Wolter et al., 2000).

According to Petherick (1983), who used a theoretical approach based on body measurements, the space allowance necessary for all pigs to be able to lie laterally at the same time is equivalent to k=0.048. Given that this posture is the one that requires the most floor surface area, this *k*-value may also give sufficient space for other behaviours to be performed while the pigs are active. In Pearce and Paterson (1993) for example, pigs housed with a space allowance equivalent to k=0.048 spent more time lying laterally, more time exploring and less time lying ventrally than pigs with k=0.025. Similarly, Meunier-Salaün et al. (1987) found that pigs with a space allowance equivalent to $k \geq 0.059$ spent a higher percentage of time lying laterally and exploring and less time lying ventrally and feeding than pigs with $k = 0.03$. However, both of these studies examined extremes in space allowance with no intermediate levels. A *k*-value of 0.048 may thus overestimate the floor surface area required for pigs to be able to perform all the behaviours they are motivated to do given that it does not take into account the sharing of space in time (Ekkel et al., 2003).

The European Food Safety Authority (EFSA) (2005) proposed that a group of pigs in a thermoneutral zone required a minimum floor surface area equivalent to a *k*-value of 0.036 according to the space required for the performance of resting, exploratory, social and dunging behaviours. This value was calculated as follows:

- *k* = 0.033 for a group with 80% of pigs lying down (Ekkel et al., 2003).
- *k* = 2 * 0.019 = 0.038 for the remaining 20 % of active pigs. This was calculated by using the *k*-value of 0.019 estimated by Petherick (1983) for sternal lying pigs and doubling this value, assuming that for activities such as exploration, social interactions and walking to the feeder or dunging area at least twice that amount of space was required.
- *k* = 0.0019 was estimated to be the minimal amount of space required to allow a pig to strictly separate the dunging from the resting area (assuming that a group of 10 pigs would require approximately one body space of k=0.019 for dunging and not having to lie in their excrement).
- The final *k*-value of 0.036 was calculated as:

$$80\% * 0.033+20\% * 0.038+0.0019=0.036$$

However, this estimation is based on a theoretical approach of the behaviours pigs perform daily and has not been experimentally tested. In a meta-analysis of 22 studies of growing-finishing pigs, Averós et al. (2010a) reported a higher *k*-value than that suggested by the EFSA that would both accommodate the behaviour of the pigs and maximize performance. This *k*-value was calculated to be 0.039 for slatted floors. With smaller space allowances, the lying behaviour of pigs was negatively affected (Figure 5).

Therefore, depending on whether welfare evaluation is based on productivity or on the unrestricted ability to perform a variety of behaviours, the floor surface area offered to the pigs may differ. Published scientific studies indicate that for productivity to not be affected, a minimal space allowance equivalent to $k \geq 0.034$ is required whereas a *k* of 0.039 is likely a good estimate of the floor surface area required that would allow pigs more freedom of movement and the opportunity to perform a wider range of species-typical behaviour patterns. In addition, a number of factors such as floor type, temperature and group size may influence space allowance requirements.

Temperature, floor type and environmental enrichment: Animals rely on a variety of behavioural adjustments for thermoregulation. In warm ambient temperatures (>20 to 24°C depending on weight), pigs will attempt to increase evaporative and respiratory heat loss through behavioural changes: they will avoid physical contact with other pigs, wallow, reduce their general activity, rest by lying laterally preferably on wet and/or slatted floors and pant (Bracke, 2011; Huynh et al., 2004; Hillmann et al., 2004). If pigs are still too warm after these behavioural changes, feed intake is reduced with consequent reductions in weight gain (Huynh et al., 2005). In cooler temperatures on the other hand, pigs will huddle, prefer to lie ventrally on solid flooring or dry bedded areas and increase their physical activity (Ducreux et al., 2002; Fraser, 1985; Hillmann et al., 2004). Therefore, at high ambient temperatures, the floor surface area required by pigs may be higher than in cooler conditions (Spoolder et al., 2010).

Growing-finishing pigs spend upwards of 70% of their time resting, it is thus important to provide pigs with a floor surface area and a type of flooring that is adapted to their lying behaviour and the ambient temperature (Ducreux et al., 2002; Ekkel et al., 2003). Pigs have distinct resting and dunging areas, usually with the resting area on a solid or bedded area and the dunging area on slats. However, at high temperatures, these behaviours are altered and pigs start resting on the cooler flooring (Aarnink et al., 2006; Fraser, 1985). It is known that the coolest type of flooring is a concrete slatted floor which is generally 2 to 4ºC cooler than that of a solid concrete flooring in the same room, and straw bedding increases the temperature by up to 8 ºC (Huynh et al., 2004; Verstegen and van der Hel, 1974). In a preference test, Ducreux et al. (2002) found that growing pigs preferred resting in the straw bedded area at 18ºC, and on concrete flooring at 27ºC. Bedded systems can allow the accumulation of wet and soiled material, reducing floor space allowance that is available for resting.

Based on behavioural responses to a range of temperatures from 5 to 29°C, Hillmann et al. (2004) suggested the following thermal tolerance temperature ranges for growing-finishing pigs on partially slatted floors (floor space allowances used in the study are given in brackets):

19-21°C for pigs 25-35kg (0.46m^2/pig (4.95sq. ft.) – *k* ~ 0.047)

10-17°C for pigs 50-70kg (0.67m^2/pig (7.21sq. ft.) – *k* ~ 0.044)

5-17°C for pigs > 85kg (0.67m^2/pig (7.21sq. ft.) – *k* ~ 0.035)

Above these temperatures, pigs preferred to lie without contact with their pen-mates, started to lie in the slatted dunging area and pigs >85kg showed an increase in cortisol concentrations. Below these temperatures, pigs huddled together. This is fairly consistent with results from Huynh et al. (2005) that showed that the inflection temperature above which 60kg pigs started to spend more time lying on the slatted area of the pen was 18.8°C.

Once temperatures rise higher, pigs that are housed in pens with both slatted and solid flooring will alter their dunging and resting behaviour and the majority of pigs rest on the cooler slatted flooring and use the solid flooring as the dunging area. Aarnink et al. (2006) calculated the inflection temperatures above which a maximum of pigs lay on slatted floors (1.02m^2 [11.0sq. ft.] per pig – *k*-values used in the study are given in brackets):

27.5°C for 45kg pigs (*k*=0.119)

26.2°C for 65kg pigs (*k*=0.081)

25.4°C for 85kg pigs (*k*=0.063)

23.4°C for 105kg pigs (*k*=0.046)

This change of resting area also resulted in pigs using the solid flooring as their dunging area which is problematic in terms of extra labour that is required to clean the pens, hygiene and health concerns. The authors thus suggested using cooling methods when the temperature rises above the calculated inflection temperatures.

As mentioned above, the EFSA (2005) recommends a minimum *k*-value of 0.036 at a temperature up to 25ºC. Above this temperature, they recommend housing pigs at a floor space allowance equivalent to *k*=0.047 given that pigs will prefer to lie laterally without touching each other. However, with the use of cooling systems such as water sprinklers/fogging systems, floor cooling and higher air flow at temperatures above the thermoneutral zone, the recommended *k*-value of 0.047 can likely be reduced without negatively affecting pig welfare (Haeussermann et al., 2007; Huynh et al., 2004; Riskowski et al., 1990).

Group size and mixing: Growing-finishing pigs are increasingly housed in large groups of 50 or more animals in order to maximize profitability. Given that pigs in groups share space in time, such large groups have been suggested to require less floor surface area per pig than smaller groups or individual pigs (McGlone & Newby, 1994; Petherick, 2007; Wolter et al., 2000). In Street and Gonyou (2008), growing pigs were housed on fully slatted floors in small and large groups (18 versus 108 pigs) at two space allowances (0.034>*k*>0.025 versus *k*>0.034 depending on weight). There was a negative effect of large group size on performance and lameness and there were also negative effects of crowding, but at different times in the production period, and there were no interactions between the two. In Turner et al. (2001) growing pigs were housed in straw bedded pens in two group sizes (20 versus 80 pigs) and two space allowances (*k* = 0.062 and *k* = 0.097). It was found that average daily gain was lower in the large groups of pigs irrespective of space allowance and that lower space allowance resulted in a greater number of skin lesions. These two studies therefore do not support the hypothesis of McGlone and Newby (1994) that large groups require less floor surface area per pig than smaller groups or individual pigs due to the sharing of a larger total floor surface area. Contrary to the findings of reduced performance when groups size is larger in grower pigs, O'Connell et al. (2004) found no differences in performance in nursery pigs housed in groups of 10, 20, 30, 40 or 60 pigs at a floor space allowance equivalent to *k*=0.038.

In terms of behaviour, there is little evidence that large group sizes result in decreased welfare given that pigs adapt to different group sizes by altering their social behaviours (Estevez et al., 2007; Turner et al., 2001). In a meta-analysis of 22 studies looking at the impact of space allowance and group size on lying behaviour, group size did not impact total lying behaviour (Averós et al., 2010a). These results are consistent with Street and Gonyou (2008) where pigs in small groups spent more time lying ventrally and less time lying laterally than pigs in large groups with no difference in total lying time. Schmolke et al. (2004) did not find a difference in terms of the behavioural time budget of pigs housed in groups of 10, 20, 40 or 80 pigs.

Regrouping of pigs can occur at different points in pig production. Mixing pigs results in aggression which not only results in physical injuries, but also stress and decreased performance in addition to decreased meat quality if mixing occurs before slaughter (Faucitano, 2010; Leek et al., 2004; Samarakone & Gonyou, 2009). Strategies to reduce aggression at mixing may include managing group size (Faucitano, 2010). The floor space allowances mentioned for the following studies are the space allowance at mixing, not at the end of the growing phase.

Andersen et al. (2004) evaluated the effects of mixing unfamiliar nursery pigs in groups of 6, 12 or 24 animals at a floor space allowance equivalent to *k*=0.06; there were more fights per pig in the groups of 6 and 12 pigs than in the groups of 24 pigs, although the duration of fights was longer in groups of 24 than in the smaller group sizes. In addition there were fewer pigs not involved in any aggressive interaction in the groups of 24 pigs compared to the smaller groups.

Similarly, Nielsen et al. (1995) found a greater number of agonistic interactions at mixing in groups of 5 or 10 growing pigs than in groups of 15 or 20 growing pigs at a space allowance of *k*=0.1. In addition, when comparing more extreme group sizes of 18 versus 108 growing pigs at a space allowance of *k*=0.076, there was a higher percentage time spent in aggressive behaviour in small groups immediately after mixing (Samarakone & Gonyou, 2008). A subsequent study showed that pigs previously housed in large groups of 108 pigs displayed less aggression at regrouping with unfamiliar pigs than pigs previously housed in small groups of 18 (Samarakone & Gonyou, 2009). Thus housing pigs in large groups in the growing-finishing phase may result in decreased aggression at mixing in lairage pens before slaughter. However, Schmolke et al. (2008) found a lower number of fights in groups of 10 growing pigs vs. groups of 20, 40 or 80 pigs at a space allowance equivalent to *k* = 0.093 although the total duration of aggression did not differ. Similar results were found in a commercial setting. Rabaste et al. (2007) compared the effects of mixing pigs in groups of 10 or 30 after transport in the slaughter house at a floor space allowance equivalent to *k*=0.026. It was found that pigs in the larger groups spent more time standing in addition to displaying a higher frequency of aggressive interactions than the smaller groups of pigs. However, this increased aggressiveness in the larger groups did not impact skin bruising or pork quality which may have been due to fewer pigs being involved in agonistic interactions as in Anderson et al. (2004). Compared to the studies cited above, this experiment had a much smaller space allowance which could have resulted in the higher aggression levels due to decreased space to avoid aggressive interactions.

No experimental studies have been performed on the space allowance required for mixing pigs in holding pens on the farm prior to loading. However the effects of different space allowances on aggressive behaviour in lairage pens in slaughterhouses have been studied and they may be applicable to on-farm holding pens. Moss (1978) reported higher levels of aggression immediately after mixing in small groups of 10 pigs at *k*=0.044 than in groups of 20 pigs at *k*=0.013. In addition, in recently mixed groups of 27 to 90 pigs at slaughterhouses, skin lesions were associated with greater space allowances (range of *k*=0.02 to *k*=0.05) (Geverink et al., 1996). These two studies also reported that the majority of the fighting occurred during the first 30 to 60 minutes. Thus, if the wait time in lairage pens is short, smaller stocking densities may help decrease aggressive behaviour in pigs before slaughter (Weeks, 2008). As a result, in Europe the Scientific Committee on Animal Health and Animal Welfare (SCAHAW) (2000) recommends keeping pigs in the landing lairage pens at the farm at *k* = 0.03 for more than 3 hours, at *k*=0.026 for 30 minutes to 3 hours and at *k*=0.0192 for up to 30 minutes.

Table 3: Floor Surface area (in m^2 per pig) according to body weight and *k*-value (calculated from the allometric formula [$A = k \times BW^{0.667}$] by Petherick and Baxter (1981).

BW	***k*-value**								
(kg)	**0.025**	**0.028**	**0.030**	**0.033**	**0.035**	**0.038**	**0.04**	**0.043**	**0.045**
5	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.13
10	0.12	0.13	0.14	0.15	0.16	0.17	0.19	0.20	0.21
15	0.15	0.17	0.18	0.20	0.21	0.23	0.24	0.26	0.27
20	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.31	0.33
25	0.21	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.39
30	0.24	0.27	0.29	0.31	0.34	0.36	0.39	0.41	0.43
35	0.27	0.29	0.32	0.35	0.37	0.40	0.43	0.46	0.48
40	0.29	0.32	0.35	0.38	0.41	0.44	0.47	0.50	0.53
45	0.32	0.35	0.38	0.41	0.44	0.48	0.51	0.54	0.57
50	0.34	0.37	0.41	0.44	0.48	0.51	0.54	0.58	0.61
55	0.36	0.40	0.43	0.47	0.51	0.54	0.58	0.62	0.65
60	0.38	0.42	0.46	0.50	0.54	0.58	0.61	0.65	0.69
65	0.40	0.45	0.49	0.53	0.57	0.61	0.65	0.69	0.73
70	0.43	0.47	0.51	0.55	0.60	0.64	0.68	0.72	0.77
75	0.45	0.49	0.53	0.58	0.62	0.67	0.71	0.76	0.80
80	0.46	0.51	0.56	0.60	0.65	0.70	0.74	0.79	0.84
85	0.48	0.53	0.58	0.63	0.68	0.73	0.77	0.82	0.87
90	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.91
95	0.52	0.57	0.63	0.68	0.73	0.78	0.83	0.89	0.94
100	0.54	0.59	0.65	0.70	0.76	0.81	0.86	0.92	0.97
105	0.56	0.61	0.67	0.72	0.78	0.84	0.89	0.95	1.00
110	0.57	0.63	0.69	0.75	0.80	0.86	0.92	0.98	1.03

Table 4: Floor Surface area (in sq. ft. per pig) according to body weight and *k*-value (calculated from the allometric formula [A = $k \times BW^{0.667}$] by Petherick and Baxter (1981) using metric measurements).

BW	*k*-value								
(lbs)	0.025	0.028	0.030	0.033	0.035	0.038	0.04	0.043	0.045
11	0.75	0.86	0.97	1.08	1.08	1.18	1.29	1.40	1.40
22	1.29	1.40	1.51	1.61	1.72	1.83	2.05	2.15	2.26
33	1.61	1.83	1.94	2.15	2.26	2.48	2.58	2.80	2.91
44	1.94	2.15	2.37	2.58	2.80	3.01	3.23	3.34	3.55
55	2.26	2.58	2.80	3.01	3.23	3.44	3.66	3.88	4.20
66	2.58	2.91	3.12	3.34	3.66	3.88	4.20	4.41	4.63
77	2.91	3.12	3.44	3.77	3.98	4.31	4.63	4.95	5.17
88	3.12	3.44	3.77	4.09	4.41	4.74	5.06	5.38	5.70
99	3.44	3.77	4.09	4.41	4.74	5.17	5.49	5.81	6.14
110	3.66	3.98	4.41	4.74	5.17	5.49	5.81	6.24	6.57
121	3.88	4.31	4.63	5.06	5.49	5.81	6.24	6.67	7.00
132	4.09	4.52	4.95	5.38	5.81	6.24	6.57	7.00	7.43
143	4.31	4.84	5.27	5.70	6.14	6.57	7.00	7.43	7.86
154	4.63	5.06	5.49	5.92	6.46	6.89	7.32	7.75	8.29
165	4.84	5.27	5.70	6.24	6.67	7.21	7.64	8.18	8.61
176	4.95	5.49	6.03	6.46	7.00	7.53	7.97	8.50	9.04
187	5.17	5.70	6.24	6.78	7.32	7.86	8.29	8.83	9.36
198	5.38	5.92	6.46	7.00	7.53	8.07	8.61	9.15	9.80
209	5.60	6.14	6.78	7.32	7.86	8.40	8.93	9.58	10.12
220	5.81	6.35	7.00	7.53	8.18	8.72	9.26	9.90	10.44
231	6.03	6.57	7.21	7.75	8.40	9.04	9.58	10.23	10.76
242	6.14	6.78	7.43	8.07	8.61	9.26	9.90	10.55	11.09

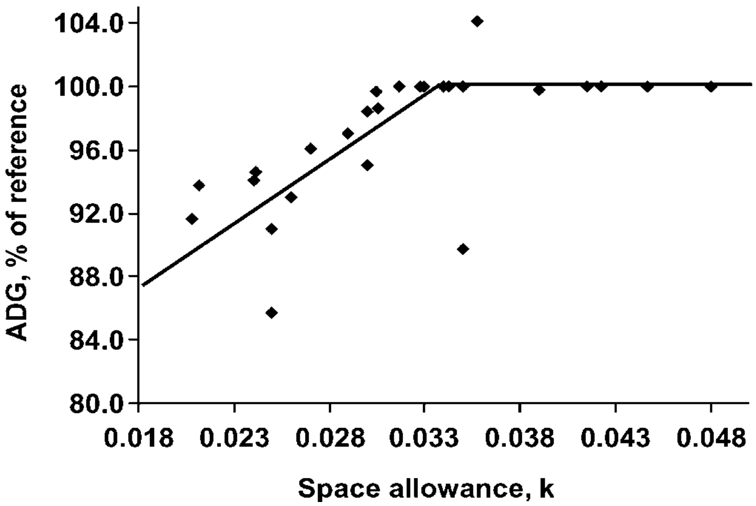

Figure 4: Broken-line regression analysis of averaged daily gain (ADG) for grower-finisher pigs at different space allowances (Gonyou et al., 2006, reproduced with permission).

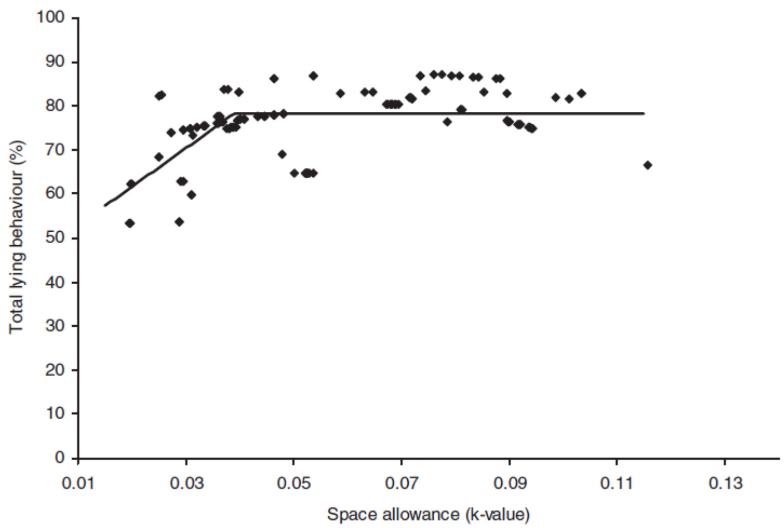

Figure 5: Broken-line regression analysis from 22 studies of the effect of space allowance on the percentage of total lying behaviour of growing-finishing pigs (Averós et al., 2010a, reproduced with permission).

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5. SOW HOUSING

Conclusions

1. **It is possible to achieve equal or better productivity and health in group-housing systems compared to individual gestation stalls provided that they are well designed and managed.**

2. **Sows housed in stalls show an increased performance of stereotypic behaviour, and spend less time resting, and more time sitting and drinking compared to group-housed sows.**

3. **Tethered sows show lower productivity and higher levels of stress compared to sows housed in gestation stalls or in groups.**

4. **Aggression resulting in skin lesions and physiological stress is the main welfare problem in group-housed sows, especially at introduction into the group and around feeding.**

5. **Feeding systems that do not provide protection from other sows result in competition and aggression around feeding which may result in unequal feed intake.**

6. **In unprotected feeding systems, trickle feeding may decrease aggression around feeding when compared with drop feeding.**

7. **Electronic sow feeders (ESF) may result in higher vulva biting than other protected feeding systems although ESF sows may be less anxious due to no expected scheduled meal time.**

8. **Gestating sows on a restricted diet experience hunger regardless of housing conditions. The addition of roughage to the sows' diets decreases their performance of stereotypies and increases the amount of time that they spend feeding compared to when they are fed a concentrate diet at a restricted level, but not to the point of sows fed a concentrate diet ad libitum.**

9. **Rubber mats improve the lying comfort and leg and foot health of gestating sows although at high ambient temperatures sows prefer to lie on concrete.**

10. **Straw bedding improves lying comfort, improves gait, decreases the occurrence of stereotypic behaviour but has no impact on aggressive behaviour. At high ambient temperatures, pigs prefer to lie on concrete rather than straw.**

Introduction: Measures used for evaluating the welfare of gestating sows with respect to housing can include their health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living). In general, housing systems are compared among each other by testing a few factors at a time. Different parameters can be tested: single versus group-housing, restriction or not in a stall or by tethering, different feeding systems providing protection or not against aggression during feeding, group sizes, floor types, pen design, and presence or not of enrichment.

1) In terms of biological functioning, studies generally use production and health parameters. Production parameters include: farrowing rate; live litter size; piglet survival; and return to estrus. Health parameters include: injury (including skin lesions and scratches), lameness culling rate and body condition (weight loss or gain, feed intake, back fat depth). Other parameters that can be considered functional include behavioural parameters such as aggression and low dominance status in a limited resource situation.

2) In terms of affective states, housing systems can be assessed as how well the system protects the animals from hunger, fear, frustration and pain, and provides for positive emotional states such as comfort. Housing can be assessed in terms of aggression and protection against aggression, aggression-induced injuries, ability to access feed and water, access to comfortable lying areas, access to enrichment and/or fibres, performance of abnormal behaviours indicative of frustration such as stereotypies, reactivity to humans, and degree of integration into the social group. Comfort can be relatively assessed by the use of preference tests, for example to determine the amount and type of flooring sows prefer at different temperatures.

3) In terms of natural living, the housing system should take into account the size of the animal, which is affected by both parity and stage of gestation, and the space required for resting, feeding and dunging behaviours as well as the space required for the performance of social and exploration behaviours. Consequently, housing systems can be assessed in terms of their effects on body posture, such as time spent lying and whether lying is lateral or sternal, time spent in different activities (feeding, resting, exploration) and location of activities, occurrence of social behaviours such as grooming, ability to perform thermoregulatory behaviour such as wallowing or crowding, and use of enrichment. It can also be assessed in terms of the restriction placed on movement as measured by possibility and time required to make postural changes, and the frequency of postural changes in a day. Systems can be compared in the way they affect freedom of movement or day-to-day activities.

Because each of these approaches uses different criteria for evaluating animal welfare, recommendations for housing systems may differ depending on which approach is used.

During gestation, sows are often housed in stalls but many farms employ a combination of loose housing and stalls (Gunn & Friendship, 2003). Standard gestation stalls usually have fully or partially slatted concrete flooring with a standard size of approximately 0.6m * 2m (24in * 79in) both in North America and Europe (Anil et al., 2002; European Food Safety Authority [EFSA], 2007). The housing of sows in individual stalls for the entire gestation period is often criticized because of the lack of space and social stimulation available to the sow. As a result of societal and ethical concerns over the welfare of gestating sows, European countries such as the United Kingdom (UK), Sweden, Switzerland, Denmark and the Netherlands restrict the use of gestation stalls from 30 days in gestation until 1 week prior to farrowing, and the European Union is putting a similar limitation on the use of gestation stalls effective in 2013, New Zealand in 2015 and Australia in 2017 (European Council, 2001; Primary Industries Standing Committee [PISC], 2008; National Animal Welfare Advisory Committee [NAWAC], 2010). In North America, seven United States [US] states (Arizona, California, Florida, Maine, Michigan, Ohio and Oregon) passed legislation concerning sow housing and some large industry groups such as

Smithfield Foods in the US and Maple Leaf in Canada have announced their intention to phase out gestating stalls (Centner, 2010; Stalder et al., 2007).

The alternatives to individual gestation stalls are group-housing systems which allow the sows to engage in social interactions, foraging and exploratory behaviours and to exercise; however, welfare problems, especially aggression between sows, do occur (Rhodes et al., 2005). Unlike individual gestation stalls that are fairly standard across the industry, group-housing systems can be highly variable. Thus, the welfare of sows in group-housing systems must be evaluated with regard to feeding system, type of flooring, pen design, group size, and stocking density. In all of the studies described in this report, sows were on a restricted diet, fed a concentrated diet once a day and were housed on solid or slatted concrete flooring unless stated otherwise.

INDIVIDUAL VERSUS GROUP HOUSING

Performance, health and stress physiology: Many studies have compared the performance of group-housed sows with sows housed individually in gestation stalls. Although results are somewhat inconsistent, most recent studies have reported that reproductive performance is equal or superior in group-housed sows in terms of back fat and weight gain, farrowing rate, litter size, piglet birth and weaning weights and weaning to oestrus interval (Table 5) (reviews by Barnett et al., 2001; McGlone et al., 2004; Rhodes et al., 2005). Furthermore, a field study of Ontario farms found an increase in the number of litters per sow per year in group-housing systems compared to stall housing; there were no other differences in terms of productivity or health (Gunn & Friendship, 2003).

Although less commonly used, the impact of tether stalls on sow welfare has also been reported. Similarly to stalls, sows are housed individually, but they are in a partial stall and attached by the neck or girth by a collar or chain (Barnett et al., 2001). It has been reported that the productivity of tethered stalls is poorer than that of sows housed in individual stalls (Barnett et al., 1987; den Hartog et al., 1993; McGlone et al., 1994).

Housing sows in stalls for a long period of time results in decreased muscle mass, lower bone strength and reduced physical fitness due to lack of exercise, as well as increased occurrence of abrasions (Barnett et al., 2001; Karlen et al., 2007; Marchant & Broom, 1996a, b). Group-housed sows on the other hand generally have a higher occurrence of superficial scratches and lesions due to aggressive behaviour at grouping and around feeding (Table 4.1). In addition, there has been a higher detection of lameness in group-housed sows than sows in stalls in three studies that housed sows on concrete (Anil et al., 2005; Chapinal et al., 2010a, Harris et al., 2006). Although Pluym et al. (2011) did not find a difference in lameness in a field study comparing group-housing with individual stalls, it was reported that group-housed sows had a lower number of lesions on their claws. When comparing group-housed sows on straw to sows housed in individual stalls on concrete, a field study found no difference in lameness (Ryan et al., 2010), but in an experiment, Karlen et al. (2007) found a lower occurrence of lameness in group-housed sows housed on rice hulls.

Plasma or salivary cortisol concentrations are often used as a measure of stress. Group-housed sows have been reported to have higher levels of cortisol at mixing and throughout gestation compared to sows in stalls (Anil et al., 2005; Geverink et al., 2003; Jansen et al., 2007). Karlen et al. (2007) reported a trend for higher salivary cortisol concentration during the first week of group-housing in large groups on deep bedding compared to stall-housed sows, but this difference was no longer present in late lactation, suggesting that group formation was stressful for the sows. In contrast, Zanella et al. (1998) found no difference in plasma cortisol levels between group-housed sows (38 sows with electronic sow feeders [ESF]) and stall-housed sows, and Pol et al. (2002) found no difference in urinary cortisol levels between sows housed individually in gestation stalls and small groups of six sows with individual feeders and partial stalls. These differences among studies may be due to differences in the type of feeding system and whether sows had to compete over feed or not (see Table 5 for details on studies), or to differences in the degree of physical exercise group-housed sows are likely to experience (Geverink et al., 2003). When comparing the stress response of tethered sows to either stall- or group-housed sows, the results are unequivocal. Tethering resulted in higher levels of plasma cortisol levels compared to the other housing systems in all reports (Barnett et al., 1985, 1987, 1989, 2011; Soede et al., 1997; van der Staay et al., 2010).

Behaviour: The introduction of unfamiliar sows generally results in aggressive interactions while sows establish their dominance hierarchy (Arey & Edwards, 1998). Although stall-housed sows are protected from physical aggression from neighbouring sows, agonistic interactions still do occur (Barnett et al., 1989; Jansen et al., 2007). Jansen et al. (2007) reported no difference in number of agonistic interactions (fights and non-reciprocated attacks) between stall-housed sows in the two days after relocation beside new neighbours and group-housed sows mixed with unfamiliar sows. Broom et al. (1995) also reported similar results with no difference in the number of agonistic interactions between 4th parity sows housed in stalls, small or large groups. Although Barnett et al. (1989) found more overall aggression to occur in group-housed sows; stall-housed sows showed more retaliation and less withdrawal after an agonistic interaction than group-housed sows. However in these studies, unlike group-housed sows, the aggression between neighbouring stall-housed sows did not result in elevated cortisol levels or physical injuries compared to controls. Thus gestation stalls not only protect sows from physical aggressive interactions, but may also prevent sows from performing submissive or avoidance behaviour (Barnett et al., 1987, 1989).

Many sows perform a variety of repetitive oral-nasal-facial behaviour patterns such as sham-chewing, bar-biting and manipulating the drinker or other pen fixtures. These behaviour patterns are referred to as stereotypies or abnormal repetitive behaviours and are often considered to be signs of poor welfare because they occur less frequently in natural environments and appear to reflect behavioural pathology (Bergeron et al., 2006). Most studies have found that stereotypies are performed by gestating sows at a similar level whether housed in stalls or tether stalls (Barnett et al., 1985; den Hartog et al., 1993; McGlone et al., 1994; Soede et al., 1997). However, recent studies reported that gestating sows fed the same restricted diet perform fewer oral-nasal-facial behaviours if housed in groups compared to stalls (Table 5). It is important to note that group-housed sows still do perform these behaviours and they have also been recorded in sows kept outdoors which suggests that they may be part of rooting and foraging behaviour (Bergeron et al., 2006; Dailey & McGlone, 1997). Furthermore, in a meta-analysis of 35 studies, there was no clear difference in terms of the occurrence of oral-nasal-facial behaviours between gestation stalls and group-housing systems. The authors suggested that other factors than housing system were likely involved (McGlone et al., 2004). It is thus likely that although housing plays a role in the performance of abnormal repetitive behaviour, feeding motivation is more important.

Sows housed in individual stalls have a limited ability for positive social interactions, they are not able to exercise due to the physical restriction of the stall and they have little opportunity to perform exploratory behaviours (other than around their feeder and drinker in front of them) (Barnett et al., 2001). In terms of the behavioural time budget of sows in different housing systems, group-housed sows generally spend more time lying, exploring and foraging and less time sitting, standing and drinking than sows housed in stalls (Table 5). Thus, the welfare of group-housed sows may be better due to increased time resting and the ability to root and forage in the entire pen especially if bedding is present. Furthermore, sitting has been suggested to be abnormal and possibly indicative of boredom (Dailey & McGlone, 1997; McGlone et al., 2004).

Feeding systems for group-housed sows: The most important distinction between feeding systems for group-housed gestating sows is whether they are competitive or non-competitive in terms of the sows being protected or not from other sows while they are feeding. In competitive feeding systems, all sows have access to feed at the same time and can displace other sows. In non-competitive feeding systems, the sows are protected in a closed stall and cannot be displaced by other sows while they are feeding. In the latter system, sows can either all be fed at the same time, or one at a time as in electronic sow feeders (ESF). Furthermore, two types of feed delivery systems exist: drop feeding (all the feed is given at once) which is the conventional method, or trickle feeding (delivering the ration in small increments).

The cheapest method of feeding sows that also requires the least amount of space and equipment is drop-feeding directly on the floor or in communal troughs. This system can be further subdivided in two: concentrated drop with the feed being dropped on a small surface area; or scattered where the feed is distributed over a large area (Jansen et al., 2007; Séguin et al., 2005). The disadvantage of floor feeding is that competition and aggression over feed are frequent and dominant sows are likely to defend feed piles which may result in decreased feed intake of subordinate sows (Brouns et al., 1994; Csermely & Wood-Gush, 1990). In Jansen et al. (2007), group-housed sows that were fed in communal troughs (concentrated drop) displayed more aggressive behaviours around the time of feeding than upon introduction into the pen. However, Séguin et al. (2005) reported that there was no difference in body condition score in group-housed sows that received feed that was widely distributed on the floor versus stall-housed sows.

Competition over feed can also occur with individual feeders with partial or full stalls without a rear gate (Table 5). Sows that eat faster may displace sows that take longer to eat which is the case in groups of sows with gilts present given that gilts take longer to eat their daily meals than multiparous sows (Kruse, 2010). This problem can be solved by restraining the sows in individual stalls during feeding by using rear gates, which allows individual feeding without displacement by other sows (Harris et al., 2006). Such individual stalls can either be located in the home pens or as in Karlen et al. (2007) as a cafeteria system where sows are released daily from their pens into another pen with individual feeding stalls into which they are locked for the time of feeding. Alternatively, a trickle feeding system can be used where feed is delivered sequentially to all sows at the same time in individual feeders. The daily ration can either be delivered at the sows' intake rate as in Chapinal et al. (2010a) (156g/min) or slowly within a given time (example, 30 minutes as in Hulbert & McGlone, 2006). Given that the sows have to wait until each portion is delivered, they are less likely to displace other sows. However, this system does not guarantee that no displacement or aggression will occur at feeding (Cerneau et al., 1997).

Electronic sow feeders consist of a single feeding station for up to 60 sows, with each sow having an electronic identification tag through which they gain access to their daily ration (Edwards et al., 1988). There are many different types of ESF systems which make studies difficult to compare, especially older ones given that technologies have evolved over time. However, they generally have a rear gate that closes to allow sows to eat their entire meal without being disturbed. Unprotected ESF result in much higher levels of aggressive behaviour around the feeder compared to sows fed in individual feeders with partial stalls (Chapinal et al., 2010b). Edwards et al. (1988) compared the behaviour of group-housed sows with ESF that had either a front-exit or a back exit. The back-exit ESF was found to be less desirable for welfare due to sows wanting to enter the feeding station blocking the exit. Electronic sow feeders may be advantageous in that sows do not expect a scheduled meal and may thus be less anxious when feeding time approaches compared to sows fed all at the same time that have been shown to increase their activity prior to feeding (Chapinal et al., 2010b). However, it may be more difficult to train sows to use the feeding station compared to sows being fed together with individual feeders (Chapinal et al., 2010b).

Comparisons of feeding systems: Cerneau et al. (1997) studied the productivity and behaviour of small groups of 7 to 8 sows drop-fed in individual feeders with protective stalls and groups of sows trickle-fed in individual feeders with partial stalls (feed delivery: 120g/min). There was no difference between feeding systems in sow productivity. In terms of behaviour however, the number of aggressive interactions was higher in the trickle-fed sows and occurred mostly around feeding. There were no differences in terms of the postural time budget, activity or sham-chewing. For the performance of stereotypies on pen fixtures, sows fed with the trickle feeding system displayed fewer such stereotypies than sows housed in pens with individual protected feeders. Similarly, Hulbert and McGlone (2006) investigated the effects of a drop versus trickle-feeding system for gestating sows housed in groups of five fed in individual feeders with partial stalls. In terms of performance, only one difference between treatments was found: drop-fed sows weaned heavier piglets than trickle-fed sows. There were no differences in lesion scores, behavioural time budgets, aggressive or stereotypic behaviours. However at feeding, trickle-fed sows entered and exited their feeding stalls more frequently than drop-fed sows.

In Chapinal et al. (2010a, b), sows in groups of ten that were trickle-fed in individual feeders with partial stalls were compared to sows housed in groups of 20 fed with an unprotected ESF. In this study, feed delivery and group size were confounded with the feeding system. There were no effects on reproductive performance apart from fewer piglets born dead from sows in the ESF system. There were also no differences between systems in the occurrence of lameness and vulva injuries. However in a field study, Leeb et al. (2001) did report a greater incidence of vulva biting and other skin lesions in ESF systems compared to group-housing systems with individual feeders. This is also in accordance with a study using a survey of 410 pig farms in England that showed that feeding sows with an ESF was associated with a higher risk of vulva biting (Rizvi et al., 1998). In terms of behaviour, Chapinal et al. (2010a, b) reported that ESF sows spent a smaller proportion of scans interacting with the floor and equipment, sham-chewing and manipulating bars than trickle-fed sows although this may have been due to the greater size of the pen. In addition, there were more aggressive interactions between sows in the ESF system especially around the feeder.

Broom et al. (1995) compared sows housed in small groups of five sows fed within individual feeders with stalls to sows housed in large groups of 38 sows fed with an ESF. Observations took place in the first and fourth pregnancy (results reported for both gestations unless otherwise stated). Both pens had resting areas deep bedded with straw. This study also confounded group and pen size with feeding system. No major differences in reproductive performance were found over four gestations. For sow behaviour, it was reported that sows with the individual feeders and in the small groups spent more time being active, more time rooting, chewing at the straw and pen fittings and spent less time in social behaviour than sows with the ESF system. In the first gestation only, sows with the individual feeders performed more oral stereotypies than sows in the ESF system. Aggressive interactions were observed in detail and it was reported that sows housed with the ESF system were involved in more intense aggressive interactions but which had a clearer outcome than sows housed in the small groups and that sows with the individual feeders in the small groups were involved in more aggression in total. The authors suggested that these differences in behaviour may have been due to the larger pens that the ESF sows were in.

Weng et al. (2009b) compared sows housed in groups of 40 sows with an ESF to groups of five sows with individual feeders with partial stalls. Again, group size was confounded with feeding system in this study. As in Broom et al. (1995), sows in the ESF spent less time rooting and more time lying than sows in the small groups. Unfortunately no observations of aggressive behaviour took place.

HIGH FIBRE DIETS AND FLOORING

Gestating sows are fed a restricted diet due to reproductive and lameness problems that can result from too much weight and body condition gain during gestation (Dourmad et al., 1994). On most commercial farms, the gestation ration is relatively energy dense and finely ground so that only small quantities are required. This daily ration is thus consumed very quickly as sows are hungry, and the foraging and rooting behaviours that sows usually perform in natural settings are redirected towards pen fixtures or bedding (Broom et al., 1995; D'Eath et al., 2009; Stolba & Wood-Gush, 1989). The performance of oral-nasal-facial stereotypies (such as sham-chewing and bar-biting) that are commonly seen in confined gestating sows, are thought to be linked to an inadequate nutrition and/or environment (see Barnett et al., 2001 and Bergeron et al., 2006). Methods to alleviate hunger without affecting productivity and to decrease the performance of stereotypies have focused on providing sows with feeds high in fibres that increase bulk of the diet and environmental enrichments that allow sows to root and forage (Meunier-Salaün et al., 2001; Whittaker et al., 1998).

As seen in Table 6, increasing the amount of roughage and daily feed allocation generally results in a lower performance of stereotypies and more time spent resting and eating. However, Bergeron et al. (2000) reported that these effects of diet on stereotypies and resting were more pronounced when feeding sows a concentrate diet ad libitum than when increasing the dietary fibre content. Furthermore, more fibre in the diet while keeping the same feed allocation (in weight) does not result in a difference in stereotypies or resting behaviour (Whittaker et al., 1998). Thus, in order to improve welfare, diets high in fibre and an increase in daily feed allocation are required.

In addition to feeding high fibre diets, the provision of a substrate such as straw can help in decreasing the amount of stereotypies given that sows will spend more time rooting and foraging as well as ingesting some of the straw (Barnett et al., 2001; Whittaker et al., 1998). The provision of roughage to sows (0.1-1.5kg per sow daily) resulted in less severe lameness and in an increased fertility (Heinonen et al., 2006). Similar results were obtained in group-housed sows provided with a diet with added roughage (hay or straw) in terms of increased fertility (Peltoniemi et al., 1999). Spoolder et al. (1995) showed that providing 1.5kg of straw per sow during feeding to group-housed sows in groups of six with feeding stalls resulted in decreased performance of stereotypic behaviours and higher activity level. In a similar study, sows that were provided with 1.5kg of fresh straw per sow daily (distributed in entire pen) performed less stereotypic behaviours than sows on bare concrete flooring (Whittaker et al., 1998). This decrease in stereotypic behaviours was also seen in tethered sows deep bedded with straw (Fraser, 1975).

The comfort and thermal characteristics of different types of flooring are important to consider when evaluating gestating sow welfare as resting behaviour, foraging behaviour and the health of feet and legs will be affected (Fraser, 1975; Tuyttens, 2005). Elmore et al. (2010) compared the health and behaviour of groups of four sows with rubber mats in their feeding stalls versus sows with partially slatted concrete flooring. Although lameness was not affected, sows with the rubber mats had a decreased number of lesions on their body. Furthermore, the rubber mats resulted in more time lying laterally, more time lying in the stalls and a higher frequency of standing up and lying down. Similarly, in Tuyttens et al. (2008) sows in a large group spent more time lying laterally than ventrally on rubber mats and changed posture more often than if lying on concrete. However they did not spend more time overall lying on the mats than on the concrete. Tuyttens et al. (2008) reported that the surface temperature of the rubber mats was higher than the concrete (>1.2ºC to 6.7ºC). Indeed, in Elmore et al. (2010), as the ambient temperature rose above 25ºC, sows spent less time lying on rubber mats. No effects on lameness, productivity or activity time budget were reported.

Deep straw bedding on the other hand, while not only beneficial for improved lying comfort, is also a means to add fibre to the diet and acts as a foraging substrate (Tuyttens, 2005). In terms of health, straw bedding resulted in a decreased number of callosities on the limbs of group-housed sows compared to group-housed sows on concrete (Leeb et al., 2001). Better gait scores have also been reported of group-housed sows on straw than on concrete (Andersen & Bøe, 1999). When comparing group-housed sows on deep litter versus sows kept on concrete in individual stalls, fewer abrasions and less lameness were observed in the group-housed sows, although other factors than bedding were at play (Karlen et al., 2007). Furthermore, in two field studies of lameness in group-housed sow, deep bedding of straw or sawdust decreased the occurrence of lameness compared to a full or partially slatted concrete flooring (Heinonen et al., 2006; Holmgren et al., 2000). Andersen and Bøe (1999) reported no difference in aggressive behaviour, lesions or productivity between groups of sows (>10 sows) with feeding stalls housed on concrete flooring or deep bedded with straw. However, there was some aggression between sows after fresh straw was provided daily which indicates that sows consider straw as a valuable resource. Similar to rubber mats, straw provides insulation to the lying area that results in a surface temperature that is higher than concrete flooring (up to 8ºC). Thus at high ambient temperatures, pigs prefer to lie on concrete flooring (Huynh et al., 2004; Verstegen & van der Hel, 1974). Finally, it should also be considered that straw could be a vector for the transmission of parasites (Damriyasa et al., 2004).

Table 5: Performance and behavioural results of studies comparing the productivity, health and behaviour of gestating sows housed in different types of group-housing systems and sows housed in standard individual gestation stalls. Results in the table are given for group-housed sows compared to sows housed individually in stalls.

	Feeding system	Flooring	Group size/space allowance	Performance and health of sows in groups compared to sows in stalls	Behaviour of sows in groups compared to sows in stalls
Séguin et al., 2006	Drop feeding on floor, scattered	30% concrete slats, 70% solid concrete	11-31 (2.3 – 2.8m^2 [25 – 30sq. ft.] per sow)	↑ litter size and birth weight ↔ in body condition	n/a
Schmidt et al., 1985	Drop feeding on floor	35% concrete slats, 65% solid concrete	4 - 5 (1.5 – 1.9m^2 [16 – 20sq. ft.] per sow)	↑ farrowing rate ↓ weaning to oestrus interval ↔ on litter characteristics	n/a
Jansen et al., 2007	Drop feeding in communal troughs	70% concrete slats, 30% solid concrete	50 (2.1m^2 [23sq. ft.] per sow)	↑ of lesions and average increase in cortisol concentrations after relocation ↔ on backfat, farrowing rate, or wean-to-estrous interval Trend for ↓ litter size	On two days post-mixing: ↔ on number of attack and fights ↑ number of passive aggressive encounters At feeding: ↑ aggression
Geverink et al., 2003	Drop feeding in communal trough	35% concrete slats, 65% solid concrete deep bedded with straw[1]	6 gilts (2.0m^2 [22sq. ft.] per gilt)	↑ salivary cortisol concentrations (4 months after being in housing), especially around feeding ↑ heart rate response to feeding ↑ body weight ↓ incidence of stomach mucosal lesions	
Vieuille-Thomas et al., 1995	Individual feeders, no stalls	Partial concrete slats/solid flooring	5-9 (3.1m^2 [33sq. ft.] per sow)	n/a	↓ performance of oral-nasal-facial behaviours
Pol et al., 2002	Trough with partial stalls	Slatted concrete	6 (2.2m^2 [24sq. ft.] per sow)	↔ on urinary cortisol levels in early or late gestation ↔ on bursitis ↑ lesions on body	↓ time spent standing and sitting ↓ performance of stereotypies ↑ time spent lying laterally ↑ social interactions

[1] Stall-housed sows in this study received a handful of straw in the morning

	Feeding system	Flooring	Group size/space allowance	Performance and health of sows in groups compared to sows in stalls	Behaviour of sows in groups compared to sows in stalls
Weng et al., 2009a, b	Individual feeders, partial stalls	Partial concrete slats/solid flooring	5 (1.8m^2 [19sq. ft]) per sow)	↔ on weight or back fat gain and losses in gestation and lactation respectively, no effect on weaning to oestrus interval ↓ number of stillborn piglets ↔ on other litter characteristics	↓ time spent standing, sitting and drinking ↑ time spent moving and lying
Harris et al., 2006	Individual feeders, unprotected stalls	Concrete slats	4 (2.4m^2 [26sq. ft.] per sow)	↔ in production parameters (backfat, body weight, weaning to oestrus interval) ↓ backfat depth in early gestation Trend for ↑ weight gain and backfat depth in mid-gestation ↑ lesions in group-housed sows but no vulva biting Poorer leg conditions and trend for poorer gait score	↔ in behavioural time budgets
Broom et al., 1995	Individual feeders, stalls	60% straw lying area, 40% solid concrete	5 (2.2m^2 [24sq. ft.] per sow)	↔ in productivity over 4 parities	↓ performance of sham-chewing and bar-biting, decreased social behaviours ↑ time spent active, trough biting and increased aggression
Cerneau et al., 1997	Individual feeding stalls, protected	Concrete slats	7-8 (space allowance not mentioned)	↔ in body weight, backfat or reproductive performance	↑ in social interactions ↓ time spent lying ↓ sham-chewing and tongue-rolling ↑ bar-biting in the hour before feeding
Karlen et al., 2007	Individual feeding stalls, protected	Deep bedded with rice hulls	85 (2.4m^2 [26sq. ft.] per sow – not including stalls) stalls only opened for feeding	↓ culling rate, less abrasions and lameness ↑ number of scratches and lesions Trend for ↑ salivary cortisol concentrations during the first week of gestation but no difference in week 9 ↓ farrowing rate and weaning weights ↑ number of weaned piglets	↔ in behaviour in week 1 of gestation, but in week 9 ↓ bar and trough biting, licking and nosing objects ↑ exploration and foraging

	Feeding system	Flooring	Group size/space allowance	Performance and health of sows in groups compared to sows in stalls	Behaviour of sows in groups compared to sows in stalls
Lammers et al., 2007	Individual feeding stalls, protected	Concrete, deep bedded cornstalks	32 (3.4m^2 [37sq. ft.] per sow – including feeding stalls)	↑ piglets born alive trend for decreased number of stillborns. ↔ in birth or weaning piglets weights ↑ weight and backfat before farrowing and at weaning, ↑ backfat loss during lactation ↑ weaning to oestrus interval	n/a
Chapinal et al., 2010a, b	Trickle feeding system with partial feeding stalls	Partial concrete slats/solid flooring	10 (2.3m^2 [25sq. ft.] per sow)	↔ in body weight and backfat ↑ detection of lameness	↓ oral-nasal-facial behaviours ↓ sham-chewing
Cerneau et al., 1997	Trickle feeding system with partial feeding stalls	Concrete slats	7-8 (space allowance not mentioned)	↔ in body weight, backfat or reproductive performance	↑ in social interactions ↓ time spent lying ↓ sham-chewing and tongue-rolling ↓ bar-biting 4 hours after feeding
Hulbert & McGlone, 2006	Trickle feeding system or drop feeding in individual feeders with partial stalls	Concrete slats	5 (1.3m^2 [14sq. ft.] per sow)	↑ backfat thickness ↔ on body weight, litter size or piglet weights and performance ↔ in plasma cortisol concentrations	↓ oral-nasal-facial ↓ active behaviours
Chapinal et al., 2010a, b	Unprotected ESF	Partial concrete slats/solid flooring	20 (2.3m^2 [25sq. ft.] per sow)	↔ in body weight and backfat ↓ number of piglets born dead ↔ on other piglet performance ↑ ability to detect of lameness	↑ time spent lying ↓ oral-nasal-facial behaviours and sham-chewing ↓ interactions with floor and equipment
Broom et al., 1995	Protected ESF	70% straw lying area, 30% concrete dunging area	38 (2.4m^2 [26sq. ft.] per sow)	↔ in productivity over 4 parities	↓ performance of sham-chewing and bar-biting ↑ aggressive behaviours
Bates et al., 2003	Protected ESF	50% concrete slats, 50% solid concrete	30-60 sows (1.5 – 2.9m^2 [16 – 31sq. ft.] per sow)	↓ % of sows returned to oestrus after breeding, greater farrowing rate ↑ piglet birth and weaning weights ↔ difference in other litter characteristics	n/a

	Feeding system	Flooring	Group size/space allowance	Performance and health of sows in groups compared to sows in stalls	Behaviour of sows in groups compared to sows in stalls
Marchant & Broom, 1996a	Protected ESF	Straw lying area, concrete dunging area	38 (2.4m^2 [26sq. ft.] per sow)	Over 8 parities: ↑ body and muscle weights, ↑ bone strength (humerus and femur) Tendency for ↓ live born and fewer weaned piglets	n/a
Weng et al., 2009a, b	Protected ESF, liquid feed	Partial concrete slats/solid flooring	40 sows (2.27m^2 [24sq. ft.] per sow)	↑ backfat gain in gestation, ↑ backfat losses in lactation, shorter weaning to oestrus interval ↓ number of stillborn piglets, no effect on other litter characteristics	↓ time spent standing, sitting, drinking and rooting ↑ time spent moving and lying
Anil et al., 2005	Trickle feeding, ESF full stall with rear gates	Concrete slats	44-55 sows (1.6 – 2.2m^2 [17 – 24sq. ft.] per sow)	↑ scratches and lesions and greater salivary cortisol concentrations ↑ culling (major reasons: lameness and poor reproductive performance) ↔ in farrowing rate, piglet performance, decreased pre-weaning mortality	n/a

Table 6: Impact of additional roughage in the diet of gestating sows on the performance of stereotypies, resting behaviour and time spend feeding.

Article	Feed	Feed offered	Stereotypies	Resting	Feeding time
Bergeron et al., 2000 [1]	Control	2.5kg d^{-1} 20.5% NDF	49.8% a	3.5% d	6.08% b
	+ oat hulls and alfalfa	3.53kg d^{-1} 42.5% NDF	30.2% ab	16.2% c	11.67% b
	++ oat hulls and alfalfa	4.5kg d^{-1} 49.5 % NDF	17.9% b	43.8% b	18.5% a
	Control	*ad lib* (6-8kg d^{-1}) 20.5% NDF	6.3% c	78.6% a	15.42% a
Holt et al., 2006 [2]	Control	1.88kg d^{-1} 7.5% NDF	61.8%	24.0%	13.3% b
	+ soybean hull	2.19kg d^{-1} 27.4% NDF	61.4%	17.2%	17.2% a
Ramonet et al., 1999 [3]	Control	2.4kg d^{-1} 13.5% NDF	41.5% c	11.1%	7.4% c
	+ wheat bran, beet pulp, soybean hull	2.7kg d^{-1} 25.7% NDF	28.4% b	10%	16.8% b
	++ wheat bran, beet pulp, soybean hull	3.0kg d^{-1} 39.4% NDF	7.5% a	4.2%	42.6% a
Robert et al., 1993 [4] (Girard et al., 1995 – NDF values)	Control	2.2kg d^{-1} 8.75% NDF	24.9% b		2.5% b
	+ wheat bran+ corn cobs	3.2kg d^{-1} 23.85% NDF	9.6% a	↑ 12.8% than other diets	5.2% a
	++ oat hulls and oat	3.7kg d^{-1} 38.8% NDF	13.7% a		5% a
Whittaker et al. 1998 [5]	Control	2.0kg d^{-1} 20% NDF	40.0%	36.1%	20% b
	+ beet pulp	2.0kg d^{-1} 22.5% NDF	30.6%	36.5%	29.4% a

Control: concentrate diet; + fibre added; ++ high level of fibre added to diet

Different letters in columns per study represent a significant difference ($P < 0.05$)

1 % of performance of behaviour in 2 hour following afternoon feed delivery, stereotypies are chain manipulation, vacuum-chewing, nose-rubbing, object-biting

2 % of performance of behaviour in 3 hours around feeding, stereotypies are sham-chewing, bar-biting and nosing the floor

3 % of scans in 4 hours post-feeding performing each behaviour, stereotypies are sham-chewing only

4 % of performance of behaviour over 24 hours, stereotypies are chain manipulation only

5 % of performance of behaviour in 4 hours, stereotypies are bar and chain manipulation, both diets contain same energy per kg

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6. SOCIAL MANAGEMENT OF SOWS

Conclusions

1. **Mixing of unfamiliar sows results in intense short-term aggression which is a welfare concern due to stress and injuries.**

2. **Mixing sows in the week after breeding or at approximately 35 days of gestation does not result in a difference in reproductive performance.**

3. **Mixing sows into groups ≥ 35 days after breeding results in less aggressive behaviour, lower eating order and more time spent resting in less preferred areas compared to mixing in the week after breeding.**

4. **Sows with three or more experiences of regrouping alter their behavioural strategies and become involved in fewer agonistic interactions at regrouping than sows with none or few mixing experiences.**

5. **Gilts introduced into a new group receive more lesions, are lower in the feeding order and spend more time resting in the dunging area than older sows mixed into the same group.**

6. **Lower ranking sows experience more restricted access to feed, water and preferred lying areas and poorer reproductive performance than higher ranking sows.**

7. **Housing sows in dynamic groups may result in more overall aggression and poorer health due to injuries than housing sows in static groups. However, based on studies using dynamic groups of 20 or more sows and smaller stable groups of sows, there are no clear differences for sow reproductive performance.**

8. **The presence of a boar in a group of sows does not significantly influence overall levels of aggression.**

9. **Feeding stalls decrease aggressive behaviour both at mixing and around feeding.**

10. **Odour masking agents have no effect on aggression and azaperone or amperozide reduce aggression in the short-term but with adverse side-effects.**

Introduction: Measures used for evaluating the welfare of group-housed gestating sows with respect to social management can include their health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living). Different parameters of social management can be tested: static versus. dynamic group-housing, group size, group composition, previous experience of sows, and mixing practices.

1) In terms of biological functioning, studies generally use production and health parameters. Production parameters include: farrowing rate, live litter size, piglet survival and return to oestrus. Health parameters include: injury (including skin lesions and scratches), lameness, culling rate and body condition (weight loss or gain, feed intake,

back fat depth). Other parameters that can be considered functional include behavioural parameters such as aggression and low dominance status in a limited resource situation.

2) In terms of affective states, social management practices can be assessed as how well the system protects the animals from fear, frustration and pain. It can be assessed in terms of aggression and protection against aggression, aggression-induced injuries, ability to access feed and competition for feed, water and other resources, and degree of integration into the social group.

3) In terms of natural living, the social management can affect the performance of resting, feeding, dunging, and social and exploration behaviours and the location of these behaviours. Consequently, social management can be assessed in terms of its effect on body posture, time spent in different activities, and their location.

Because each of these approaches uses different criteria for evaluating animal welfare, recommendations for social management practices may differ depending on which approach is used

GROUPING

Sow responses to grouping: One of the major risks to the welfare of group-housed sows is the aggression that results from mixing unfamiliar sows that lasts until their social order is established (Meese & Ewbank, 1973). Agonistic interactions result in a stress response as demonstrated by increased cortisol and catecholamine levels and heart rate which indicate an activation of the HPA axis and the sympathetic nervous system (Couret et al., 2009; Jarvis et al., 2006; Marchant et al., 1995; O’Connell et al., 2003). Behaviourally, sows react to mixing by engaging in aggression for the first 1 to 3 days until the establishment of a social order that prevents further overt aggression (Table 7) (Arey, 1999; Krauss & Hoy, 2011; Moore et al., 1993).

As a result of aggressive interactions between sows, superficial skin scratches and lesions occur; these can thus be used as an indirect measure of aggression (Barnett et al., 1996; Leeb et al., 2001). During the first few days after introduction into an established group, newly introduced sows are highly agitated, show more standing up and lying down events (due to disruption by other sows) and often do not rest in the lying area but stay together and rest in the less preferred dunging area (Krauss & Hoy, 2011; Moore et al., 1993; O’Connell et al., 2003). Given that the frequency of agonistic interactions decreases quickly within a few days of mixing, the negative consequences on the welfare of sows are only seen in the short-term (Anil et al., 2005; Krauss & Hoy, 2011). Once the social hierarchy is established, sows will remember each other and re-grouping with previously familiar sows within 6 weeks of separation does not result in any major aggression (Arey, 1999).

Influence of the timing of grouping: Mixing of sows in early gestation is often thought to negatively impact reproductive performance in terms of a higher risk of return to service as the implantation phase occurs between days 11 to 16 of gestation (Arey & Edwards, 1998; Spoolder et al., 2009). However, as the following studies suggest, mixing sows prior to implantation does not affect reproductive performance. Mixing gilts 3 to 4 days or 8 to 9 days after insemination did not affect pregnancy rate or litter size compared to gilts in individual stalls or stable groups (van Wettere et al., 2008). Mixing sows in groups immediately after breeding (Karlen et al., 2007); between days 2-4 after breeding (Bates et al., 2003), on day 7 (Harris et al., 2006) or 10 after breeding (Anil et al., 2005) resulted in a lower or equal return to oestrus rates and higher or equal litter sizes than those of sows housed in individual gestation stalls. Furthermore, Cassar et al. (2008) did not find a difference in farrowing rate or litter size of sows mixed at either 2, 7, 14, 21 or 28 days after breeding or housed in individual stalls. However, Spoolder et al. (2009), reporting on a survey of commercial farms, noted considerable variation in the farrowing rate of sows on farms that re-grouped animals prior to 28 days after breeding. The lowest farrowing rates were most common on farms mixing during the 2nd or 3rd week after breeding.

In terms of behaviour, Hemsworth et al. (2006) found more aggression being displayed by sows that were mixed on the day of mating compared to sows mixed on day 35 of gestation. Strawford et al. (2008) also found that sows that were moved into groups at 2 to 9 days post-breeding were more aggressive around the feeder and ate sooner in the feeding order than sows that were mixed 37 to 46 days post-breeding. It was suggested that the sows that were mixed later in gestation were less willing to compete for feed and lying areas and that this may have been due to a change in their hormonal status.

AGGRESSIVE BEHAVIOUR

Influence of individual factors on aggressiveness: Experience with frequent introduction into a new home pen and to unfamiliar sows may result in sows changing their social behavioural strategies and a decrease in agonistic interactions over time (Bolhuis et al., 2004). Van Putten and Buré (1997) showed that gilts that had been regrouped three or four times before five months of age were involved in fewer agonistic interactions and had fewer lesions at mixing into a new group than gilts that had no or two prior experiences of regrouping. Similarly, in a study that mixed sows eight times during gestation, there was a progressive decline of aggressive behaviours and lesions after the third mixing; however, it must be noted that the sows were only housed in pairs (Couret et al., 2009). Finally, it has been showed that pre-mixing sows in small groups before introduction in a large dynamic group reduces aggression at mixing and strengthens subgroup formation within the large dynamic group (Durrell et al., 2003).

Sow age also impacts how well animals integrate into new groups, Spoolder et al. (1997) reported that although newly introduced gilts were involved in fewer aggressive interactions, they initiated and won less agonistic interactions, had higher lesion scores and spent less time sleeping than newly introduced second parity sows. Similarly, in Strawford et al. (2008), younger sows spent less time in aggressive interactions after introduction into a new group but they spent more time lying in the less preferred lying area (slats) and were lower in the feeder entry order than newly introduced older sows. First parity sows may also have a lower social status than older sows, especially if they are introduced into the home pen of older sows (Jarvis et al., 2006).

Social rank of group-housed gestating sows impacts their reproductive performance and welfare. In Kranendonk et al. (2007), high ranking sows gained more body weight during gestation but lost more body weight in lactation than low ranking sows. However there was no impact on farrowing rate or litter size. O'Connell et al. (2003) reported that low ranking sows were lighter and had more lesions one week after mixing than other sows. They were also displaced from the drinker and the feeding queue at the electronic sow feeder (ESF) more often, and spent more time lying in the dunging area. Similarly, in a group floor feeding system, Verdon and Hemsworth (2011) reported that lower ranking sows had the most fresh lesions and spent less time eating compared to more dominant sows. Finally, subordinate sows, although they are similarly motivated for access to enrichment, are often displaced from it by dominant sows (Elmore et al., 2011). Thus the welfare of low ranking sows is poorer than that of higher ranking sows as access to preferred lying areas and feed and water are more restricted.

Influence of environmental factors on aggressiveness: Group stability will have an impact on sow welfare, especially concerning aggressive behaviour. In a static group structure, once the group is formed no sow is added; such groups are usually small and are composed of sows that are all weaned at the same time (den Hartog et al., 1993). In contrast, in a dynamic group structure, sows are frequently added and removed according to their reproductive phase (Anil et al., 2006). Dynamic groups are thus usually larger than static groups.

When new sows are introduced into dynamic groups, over 85% of all agonistic interactions involve at least one of the new sows (Krauss & Hoy, 2011; Moore et al., 1993; Spoolder et al., 1997). Consequently, very little aggression occurs among resident sows. Although there was no difference in the number of aggressive encounters on the day of mixing between static and dynamic groups, Strawford et al. (2008) showed that the duration of aggressive encounters tended to be longer at mixing of static groups than introduction of sows into dynamic groups. However, dynamic groups result in more aggression overall as some sows will be involved in agonistic interactions at each new introduction, while in static groups aggression to establish a social hierarchy occurs only once (Durrell et al., 2002).

In addition to group stability, group size may also influence aggression. Anil et al. (2006) studied stable groups of 25 sows, groups of 50 sows that were mixed twice and dynamic groups of 100 sows (all fed with ESF). Sows in the dynamic and largest groups had more lesions and displayed fewer non-aggressive social interactions than sows in the smaller stable groups. In terms of total aggression or stereotypic behaviour however, there were no differences between treatments. Chapinal et al. (2010a) compared sows housed in groups of 10 sows with individual stalls and trickle feeding to sows housed in groups of 20 with an unprotected ESF. There was more aggression in the larger groups especially around the feeder. On the other hand, Broom et al. (1995) found that sows housed in a large static group of 38 sows with an ESF were involved in fewer aggressive interactions than sows in smaller static groups of 5 sows with individual feeding stalls. Although providing interesting results, the studies above have confounding factors whether they are group stability, group size or feeding system. Conclusions on the effect of group size on aggression have thus to be limited and it is likely that feeding method and management have a greater impact on aggression than group size.

In a field study, Anderson and Bøe (1999) found no difference in reproductive performance of sows housed in small groups of less than 10 sows compared to larger groups of more than 20 sows. However, sows housed in the small groups had higher lesion scores than sows housed in groups of more than 20 sows. In another field study, Heinonen et al. (2006) found no difference of group size (<84 sows versus ≥84 sows) on lameness, however large groups had a tendency to have a greater return to oestrus rate than small groups. Furthermore, Turner et al. (2001) reported that housing growing pigs in groups of 80 compared to 20 resulted in decreased aggressiveness in mixing tests with unfamiliar pigs. These authors suggested that this decreased aggression in large groups may be due to the increased space available and that pigs were not able to recognize all individuals thus more avoidance behaviour instead of agonistic behaviour was displayed.

Strategies to reduce aggression: Given that aggression is a major problem of welfare in group-housed sows, strategies can be used to reduce aggression at the establishment of a social hierarchy and during the rest of gestation. The impact of space allowance is reviewed in the next section.

The presence of a boar at mixing of small groups has been shown to result in decreased aggressive behaviours and skin lesions in newly weaned sows (Docking et al., 2001) and number of aggressive interactions in ovariectomized pigs (Barnett et al., 1993b). However, other studies found no effects of boar presence. When mixing four unfamiliar gilts together with a boar, no effects on scratch and lesion scores or aggressive behaviour was found (Luescher et al., 1990). Similarly, Séguin et al. (2006) did not find a difference in terms of aggressive behaviour at mixing of 15 gestating sows with or without a boar although boar presence did result in fewer scratches. Furthermore, the presence of a boar resulted in elevated salivary cortisol concentrations in the sows compared to control groups. A third study also found little overall impact of boar presence at mixing of sows after weaning; although there were fewer fights when boars were present, there was no effect on total agonistic interactions or on lesion scores (Borberg & Hoy, 2009). The studies also reported that the boars were only involved in a very small percentage of aggressive behaviour.

Barnett et al. (1994) investigated the impact of time of day and presence of feed on grouping behaviour of ovariectomized gilts. It was found that there was less aggression immediately after grouping at dark than in the morning or afternoon. However, no observations of aggression behaviour were taken in the following days, thus grouping after sunset could simply have delayed the occurrence of agonistic interactions. Feeding the daily ration during mixing did not alter the occurrence of aggression unless they were fed ad libitum in which case there was less aggression during feeding.

Avoidance behaviour may be a strategy that sows use to prevent being involved in agonistic interactions (Jensen, 1982). Thus, designing pens in a way that allows sows to perform this behaviour more easily and to provide sufficient surface area to do so may be important to reduce aggression. For example, in Séguin et al. (2006), pens were designed to allow sows to escape aggression from other sows by including two or four concrete half walls (1m (3.3ft) high) depending on pen size. Although no comparative study on aggression was conducted with other pens, it is thought that these half walls help in avoidance behaviour. Furthermore, sows prefer to lie against a wall (Strawford et al., 2008), thus providing more walls against which sows can lie may improve welfare. Individual feeding stalls have also been shown to reduce aggression both at mixing and during feeding (Barnett et al., 1992; Chapinal et al., 2010b). Barnett et al. (1993a) also found that a rectangle design compared to square shape reduces aggressions during the 15 to 90 minute period after mixing in ovariectomized pigs at a space allowance of $1.4m^2$ (15.1sq.ft) per animal.

Use of chemicals or drugs have also been tested to mask odours and interfere in the recognition process or to reduce aggressive behaviour in pigs. Odour masking agents did not show any effect on aggressions (Luescher et al., 1990; Barnett et al., 1993b). On the other hand, drugs such as amperozide or azaperone showed a limited effect in reducing aggression but only in the short-term where as they can have adverse side effects such as vomiting of reduced productivity (Csermely & Wood-Gush, 1990; Luescher et al., 1990; Barnett et al., 1993b, 1996).

Table 7: Number of resident sows and number of new sows introduced into their home pen with observed aggressive interactions (fights) in frequency and duration (mean).

	Resident sows	**New sows**	**Number of fights**	**Mean duration of fights**
Arey, 1999[1]	0	6	3 fights per group 1 fight per sow Over 24 hour	70 seconds (range 8-425 seconds)
Krauss & Hoy, 2011[2]	10	5	45.2 fights per group 6.02 fights per sow Over 24 hour	n/a
Moore et al., 1993[3]	30	10	47 fights per group 2.35 fights per sow Over 3 h	71.4 seconds
Séguin et al., 2006[4]	0	15	1.3 fights per group per h (average over first 24 hours)	38.1 seconds
Strawford et al., 2008[5]	0	34-41	3.72 fights per sow Over 4 hours	16.4 seconds

[1] fight: starts with one sow attempting to bite the other sow and the other sow retaliating by attempting to bite the attacker or adopting a parallel pushing defensive posture
[2] fight: starting with first aggressive contact (bite, knock, lateral fighting, etc.) between two sows and ending with submissive behaviour
[3] fight: begin with open-mouthed contact and concludes when sows loose contact with each other for at least 5 seconds
[4] fight: included all three components of aggressive interactions: bite, head knock and body knock between two sows
[5] fight: parallel and inverse pressing, head to head, head to body knocks and levering

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7. SOW SPACE ALLOWANCES

Conclusions

1. **The conventional gestation stall width of 58 – 60cm (22.8 – 23.6in) is not wide enough to contain the majority of sows while lying laterally especially at the end of gestation, but providing sows with wide stalls of 75cm (29.5in) results in a higher stress response than a width of 60cm (23.6in) as sows try to turn around but are not able to do so.**

2. **Gestation stall lengths < than 200cm (78.7in) may result in decreasing comfort of the sows.**

3. **In group-housed gestating sows, space allowances of ≥2.3m² (24.7sq. ft.) per sow do not improve reproductive performance.**

4. **Space allowances of ≥ 2.3m² (24.7sq. ft.) per sow do not result in a further decrease in lesions, in a better body condition, increased body weight or backfat depth.**

5. **Space allowances of ≥ 2.4m² (25.8sq. ft.) do not result in a further decrease in aggressive behaviour.**

Introduction: Measures used for evaluating the welfare of gestating sows with respect to space allowance can include their health and productivity (biological function), their subjective experiences (affective states) and their ability to express species-typical behaviour (natural living). In general, space allowances are assessed by providing different amounts of space for sows in groups and comparing the parameters mentioned below. In the case of stall housing, studies have either used different sizes of stalls (and sows within those stalls), or observed different sizes of sows in a standard sized stall.

1) In terms of biological functioning, studies have relied on production and health parameters. Production parameters include: farrowing rate, live litter size, piglet survival and return to estrus. Health parameters include: injury (including skin lesions and scratches), lameness and body condition. Other parameters that can be considered functional include behavioural parameters such as aggression and low dominance status in a limited resource situation.

2) In terms of affective states, space allowance can be assessed as to how well the system protects the animals from hunger, fear, frustration and pain, and provides for positive emotional states such as comfort. Space allowance has been assessed in terms of aggression, aggression induced injuries, ability to access feed, access to comfortable lying areas, and degree of integration into the social group.

3) In terms of natural living, the floor surface area available for sows should take into account the size of the animal, which is affected by both parity and stage of gestation. Floor space allowance has been assessed in terms of its effect on body posture, such as time spent lying and whether lying is lateral or sternal. Space allowance has also been assessed in terms of the restriction placed on movement as measured by time required to make postural changes, and the frequency of postural changes in a day.

Because each of these approaches uses different criteria for evaluating animal welfare, recommendations for space allowance may differ depending on which approach is used.

Although the floor surface area available for sows housed in standard gestation stalls is fairly standard between 1.2m^2 and 1.5m^2 (12.9sq. ft. – 15.8sq. ft.), different widths and lengths of stalls may impact productivity, health, stress and postural time budgets. The time spent in each posture and the time taken for making postural changes may be linked to sow comfort. In group-housing systems, an adequate floor space allowance results in good productivity, the ability to avoid aggression and provides equal access to resources. Feeding systems for group-housed sows have a major impact on the required floor space allowance for sows.

In the European Union, group-housed gilts and sows must be kept at a minimum space allowance of 1.6m^2 and 2.3m^2 (17.6sq. ft. – 24.2sq. ft.) respectively. This space allowance must be increased by 10% if groups are composed of fewer than six animals and can be decreased by 10% in groups of 40 or more sows (Mul et al., 2010). Furthermore, given that floor-feeding and electronic sow feeder (ESF) systems take up little surface area compared to individual feeding stalls, the required space allowance may be greater if feeding stalls are present.

SPACE ALLOWANCES FOR SOWS HOUSED IN INDIVIDUAL GESTATION STALLS

Stall width: Anil et al. (2002) studied the effect of standard gestation stall sizes (mean width: 59cm [23in]) relative to the physical size of the sow in four different farms on sow postural time budgets. The width of the stall relative to the breadth of the sow did not affect the time spent in each posture; however, Li and Gonyou (2007) found that sows housed in 70cm (28in) wide stalls spent more time standing and less time sitting than sows in ≤65cm (26in) wide stalls. Similarly in Barnett et al. (2011), sows in 75cm (30in) wide stalls spent more time standing and less time lying than sows in 60cm (24in) wide stalls.

In terms of postural changes, sows in wider stalls relative to their width took less time to lie down and to stand up from sitting than sows in narrower stalls although there was no difference in other postural changes (Anil et al., 2002). Li and Gonyou (2007) reported that sows in stalls ≤65cm (26in) wide performed more postural changes compared to sows in 70cm (28in) wide stalls. However, in Barnett et al. (2011) there was no difference in the time taken for sows to lie down between stall widths of 60cm (24in) and 75cm (30in).

McGlone et al. (2004) suggested that in conventional stalls with a 58cm (23in) width, less than 40% of sows are able to lie laterally without protruding in neighbouring stalls given that the maximum depth of sows can reach 78cm (31in) at the end of gestation. The mean depth of sows measured in that study was 58cm (28in), thus, many sows were wider than the standard gestating stall width. They thus recommended a minimum stall width of 72cm (28in) which would in theory accommodate up to 95% of sows. This is consistent with the formula suggested by Li and Gonyou (2007) to calculate required stall width: 10.7cm × BW (kg)$^{0.333}$. This formula was based on the ability of sows to lie laterally without protruding into the next stall and determined using several sizes of stalls and sows. However, when comparing the effects of housing sows in 60cm (24in) or 75cm (30in) wide stalls, Barnett et al. (2011) found that sows in the larger stalls had elevated cortisol concentrations, an increased responsiveness to an adrenocorticotrophic hormone (ACTH) challenge and a decreased immunoresponsiveness. These are indicative of a chronic stress response. The authors suggested that this was likely due the frustration of the sows in the larger pens trying to turn around but not being able to. Indeed, 75cm (30in) is close to the width required for sows to be able to turn around (approximately 88cm (35in) for a 200kg (441lbs) sow) (Curtis et al., 1989). Bøe et al. (2011) also found that some sows were still able to turn around with a width of 80cm but no longer with 70cm. Sows in unrestricted conditions turn around very frequently (up to 200 times per 24 hour) which Bøe et al. (2011) suggested to be indicative of a need to move around in the pen.

Stall length: Anil et al. (2002) reported that sows in longer stalls spent more time standing and less time lying (mean stall length: 180cm [71in]). However, Barnett et al. (2011) did not find any effect of stall length (200cm [79in], 220cm [87in] or 240cm [94in]) on the time spent in each posture although there were trends for fewer occurrences of standing and sitting episodes in longer stalls. In terms of postural changes, sows in longer stalls took less time to lie down than sows in shorter stalls in Anil et al. (2002) but there was no difference in Barnett et al. (2011). Given that all treatments had longer stalls in Barnett et al. (2011) than in Anil et al. (2002), stall lengths ≥200cm (79in) likely do not hinder the performance of postural changes as shorter stalls do. Marchant and Broom (1996) investigated postural changes in sows housed in 200cm (79in.) long stalls according to the sow length. It was found that the longer the sow, the longer it took for her to lie down. In addition, stall-housed sows took more than twice as long to lie down than loose-housed sows.

Furthermore in Barnett et al. (2011), stall length did not affect total cortisol concentrations, but free cortisol concentrations were higher in the longest stalls of 240cm (94in) compared to 200cm (79in) and 220cm (87in). In addition, sows in the 220 cm (87 in) long stalls showed a lower responsiveness to ACTH and a greater immunoresponsiveness than sows housed at the other 2 lengths. The intermediate length of 220cm (87in) was thus suggested to result in the least amount of stress.

SPACE ALLOWANCES FOR GROUP-HOUSED GESTATING SOWS

Productivity: Salak-Johnson et al. (2007) housed static groups of five sows at a floor space allowance of 1.4m^2, 2.3m^2 or 3.3m^2 (15sq. ft., 25sq. ft. or 36sq. ft.) per sow. Pens were partially slatted and sows were drop-fed on the ground. Sows housed at ≥2.3m^2 (25sq. ft) had greater body weights, backfat depths and body condition than sows at 1.4m^2 as well as lower body lesion scores. In addition, sows housed at 3.3m^2 (15sq. ft.) had the largest litters but litter weaning weight was lowest in sows housed at 2.3m^2 (25sq. ft.) compared to the other two space allowances. There was no other difference in reproductive performance. Séguin et al. (2006) evaluated the productivity and welfare of sows in static groups of 11-31 sows at 2.3m^2, 2.8m^2 or 3.2m^2 (25sq. ft., 30sq. ft. or 34sq. ft.) per sow with drop-feeding system on the ground. There was no effect of space allowance on body lesion scores, body condition or farrowing performance. Similarly, when comparing the performance of sows housed in static groups of five at 2.5m^2 or 3.0m^2 (27sq. ft. or 32sq. ft.) on deep-bedded straw and with individual feeding stalls, there was no difference between treatments (Philippe et al., 2010). Furthermore, in a field study, Heinonen et al. (2006) did not find a difference in terms of lameness or rate of return to oestrus in group-housed sows kept at floor surface areas of <2.0m^2, 2.0 – 3.0m^2 or >3.0m^2 (<22sq. ft., 22-32sq. ft. or >32sq. ft.) Feeding systems were not mentioned.

Remience et al. (2008) evaluated the productivity of dynamic groups of 34 sows at space allowances of 2.3m^2 or 3m^2 (24sq. ft. or 32sq. ft.) per sow. Every five weeks, a third of sows per group were replaced by newly bred sows. Sows were fed with an ESF in pens with a straw bedded resting area and a concrete dunging area. There was no difference between treatments for sow performance including weight gain, backfat, farrowing rate, piglet weights or numbers of weaned piglets. In addition, salivary cortisol levels did not differ between the two treatments.

Behaviour: Weng et al. (1998) studied the lesions and behaviour of sows housed in static groups of six at space allowances of 2.0m^2, 2.4m^2, 3.6m^2 or 4.8m^2 (22sq. ft., 26sq. ft., 39sq. ft. or 52sq. ft.) per sow. The pens were deep-bedded with straw and had individual feeding stalls in which sows were only allowed for the 1hr during and after feeding. Sows housed at ≥3.6m^2 (39sq. ft.) spent less time standing inactive, sows housed at 2.0m^2 (22sq. ft.) spent the most time sitting, followed by sows at 2.4m^2 (26sq. ft.) and 3.6m^2 (39sq. ft.) and sows at 4.8m^2 (52sq. ft.) spent the least amount of time sitting. The time spent rooting also increased with increasing floor surface area. In terms of aggression, an increasing floor space allowance resulted in a decreasing frequency of agonistic interactions between sows. In particular, for head-to-head with bite, head-to-body (with and without bites), threats and withdrawals, sows housed at ≥2.4m^2 (26sq. ft.) showed less agonistic interactions than sows housed at 2.0m^2 (22sq. ft.). For the total number of interactions as well as head-to-head, nose-to-body and head tilts, sows housed at 4.8m^2 (52sq. ft.) showed the least of these interactions compared to sows housed at ≤3.6m^2 (39sq. ft.). As a result of the decreased aggression levels, sows with higher space allowances also had decreased lesion scores. The authors concluded that a minimum space allowance between 2.4m^2 (26sq. ft.) and 3.6m^2 (39sq. ft.) per sow was required in order for no negative effects on welfare to be seen.

This is in accordance with Remience et al. (2008) that evaluated the behaviour of dynamic groups of 34 sows fed with an ESF at floor space allowances of 2.3m^2 or 3m^2 (24sq. ft. or 32sq. ft.) per sow. Although there was no difference in overall aggression levels at grouping and the subsequent days, one-way aggressive behaviour was more frequent in the sows housed at 2.3m^2 (24sq. ft.) per sow on days 3 and 8 after mixing. Sows in the smaller space allowance also showed higher lesion scores 1 and 2 weeks after mixing, but not during the first week or after the third week. In addition, a recent study comparing smaller space allowances did not find a difference in the aggressive behaviour or postural budgets of groups of four sows at 1.6m^2, 2.0m^2, 2.4m^2 or 2.8m^2 (17sq. ft., 22sq. ft., 26sq. ft. or 30sq. ft.) (Rioja-Lang et al., 2011).

Table 8: Space allowances and housing system used by studies comparing different space allowances in group-housed sows.

	Space allowances	**Group size, static or dynamic groups**	**Feeding system, flooring**
Heinonen et al., 2006	< 2.0m^2 (22sq. ft.) 2.0-3.0m^2 (22-32sq. ft.) >3.0m^2 (32sq. ft.)	Not specified (field study)	- Not specified
Philippe et al., 2010	2.5m^2 (27sq. ft.) 3.0m^2 (32sq. ft.)	- 5 sows - Static	- Individual feeding stalls, sows locked in them for 1h during feeding, stalls were closed for rest of day - Pens bedded with straw
Remience et al., 2008	2.3m^2 (24sq. ft.) 3.0m^2 (32sq. ft.)	- 34 sows - Dynamic system: 1/3 of sows replaced every 5 weeks	- ESF - Straw bedded resting area and concrete dunging area
Rioja-Lang et al., 2011	1.6m^2 (17sq. ft.) 2.0m^2 (22sq. ft.) 2.4m^2 (26sq. ft.) 2.8m^2 (30sq. ft.)	- 4 sows, newly mixed	- Drop fed in troughs - Concrete slats
Salak-Johnson et al., 2007	1.4m^2 (15sq. ft.) 2.3m^2 (25sq. ft.) 3.3m^2 (36sq. ft.)	- 5 sows - Static	- Drop feeding on floor - Flooring not specified
Séguin et al., 2006	2.3m^2 (25sq. ft.) 2.8m^2 (30sq. ft.)	- 11-31 - Static	- Drop feeding on floor - Solid concrete resting area and slatted dunging area
Weng et al., 1998	2.0m^2 (22sq. ft.) 2.4m^2 (26sq. ft.) 3.6m^2 (39sq. ft.) 4.8m^2 (52sq. ft.)	- 6 sows per group - Static	- Individual feeding stalls, sows locked in them for 1 h during feeding, stalls were closed for rest of day - Pen bedded with straw

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8. GLOSSARY OF TERMS

Abnormal repetitive behaviours	Behaviours performed in a repetitive and unvarying manner that appear to have no function (e.g. repetitive biting of metal bars by sows).
ACTH (adrenocorticotrophic hormone)	A hormone that is secreted in response to stress by the pituitary gland and stimulates the release of other stress hormones such as cortisol.
ACTH challenge	A test that measures cortisol concentration after an injection of ACTH, the response to this test gives an indication of the level of chronic stress experiences by the animal.
Aggression	A sow threatening or physically biting, pushing or knocking another sow.
Agonistic interactions	Interactions between two animals that includes both aggression and avoidance behaviour.
Anesthetic	A general anesthetic causes a reversible loss of consciousness and a local anesthetic causes a reversible loss of sensation for a limited part of the body while maintaining consciousness.
Androstenone	A steroid hormone produced by the testes with an urine/perspiration like odour, it is one of the main components responsible for boar taint.
Anti-inflammatory	A drug that reduces inflammation.
Argon (Ar)	An inert gas that can cause death by leading to a lack of oxygen to the brain.
Avoidance behaviour	Moving away from another animal that is dominant without directly confronting it.
Barrows	Castrated male pigs.
Behavioural response	The active response of an animal to a stimulus.
Behavioural time budgets	Often used in behavioural studies this measures how much time an animal spends performing daily behaviours (such as feeding, drinking, laying, walking, etc.).
Blunt trauma	A manual blow to the head that can cause a concussion and brain damage leading to unconsciousness and death if enough force is used.
Boar taint	Unpleasant taste and smell that results from an accumulation of androstenone and skatole in the fat of uncastrated male pigs, it is detected when cooking meat from these pigs.

Body condition score	Reflects the fat reserves carried by an animal. Sows can be scored according to their body fat from 1-5 (1 - emaciated, 2 - thin, 2.5 - somewhat thin, 3 - normal, 3.5 - good condition, 4 - fat, 5 - overfat).
Brain activity	Determines the state of consciousness (can be measured by electrical activity of the brain or somatosensory evoked potentials).
Brain stem reflexes	The brain stem is involved in consciousness which can be measured by the corneal reflex (eye blinking when the cornea is touched), the palpebral reflex (eye blinking when the edge of the eyelid is touched) and the pupillary light reflex (pupil constriction in response to shining light in the eye).
Breed	A group of domestic animals with characteristics that distinguish them from other animals of the same species.
Broken Line Analysis	A statistical method that separates the range of a resource variable (e.g. floor space) into a range that affects an outcome variable (e.g. growth rate) and a range that does not.
Cafeteria system	A type of feeding system for group-housed gestating sows where sows are released from their home pens into another pen that has individual feeding stalls for feeding. This feeding area is used by all groups of gestating sows in that barn.
Captive bolt	See non-penetrative captive bolt and penetrative captive bolt.
Carbon dioxide (CO_2)	An inert gas that can cause unconsciousness and death by a lack of oxygen to the brain.
Cardiac (ventricular) fibrillation	An uncontrolled twitching of the lower heart muscles that results in blood not being removed from the heart and leads to cardiac arrest and death.
Cardiac arrest	Occurs when the heart fails to contract effectively and prevents normal blood circulation that can lead to a lack of oxygen delivery to the body and eventually unconsciousness and death.
Castration	Removal or destruction of both testicles.
Catecholamines	Hormones and neurotransmitters (e.g. Epinephrine, norepinephrine, dopamine) involved in the sympathetic nervous system that are mainly released by the medulla of adrenal glands particularly when an animal is stressed (in the “fight-or-flight” response).
Cerebral cortex	A large region of the brain that is involved with consciousness.
Chronic stress	Long-lasting, recurrent exposure to an uncontrollable negative stimuli.
Concussion	A head injury causing a temporary loss of brain function.
Consciousness	Awareness of feelings, sensations and emotions including pain and distress.

Cortisol	A steroid hormone released by the cortex of adrenal glands when an animal is stressed.
Deep straw bedding	A thick layer of straw that is accumulated on a pen floor.
Dominance hierarchy	Also known as a social order, it is formed when unfamiliar animals are grouped through aggression which establishes the dominance status of each animal. A stable group of animals with a stable hierarchy experiences very little aggression.
Drop feeding	The daily feed ration is given at once to the animal.
Dynamic groups	Groups of gestating sows in which animals are added and removed at regular intervals.
Electrocution	An electric shock through the body that can result in death.
Environmental Enrichment	A way of changing the environment of captive animals to their benefits.
ESF (electronic sow feeders)	Automated feeding stations shared by all sows in a group; sows are equipped with an electronic transponder that allows them to eat their daily feed ration individually.
Euthanasia	The deliberate killing of an animal that results in a humane and painless death.
Exsanguination	Blood loss resulting in death.
Feeding stalls	Metal crate that protects the sow while feeding.
Foraging behaviour	Searching for food by pigs by using their snouts and walking around.
Full stalls	Metal crate protecting the sow while feeding with both sides as long as the body of sows.
Genetic selection	Intentional breeding for specific traits.
Gestation stall	A metal enclosure or crate used to confine pregnant sows.
GnRH (gonadotropin-releasing hormone)	A hormone that triggers the release of other hormones (luteinizing hormone [LH] and follicle stimulating hormone [FSH]) that act on the testes to regulate testicular hormones in the boar.
Heart rate	Number of heart beats per unit of time (usually in heart beats per minute).
HPA axis (hypothalamic-pituitary-adrenal axis)	A part of the neuroendocrine system made up of the hypothalamus, the pituitary gland and adrenal gland that controls stress reactions through the release of stress hormones.
Hypoxia	A gradual decrease of oxygen levels in the blood and brain that leads to respiratory and cardiac failure.

Immuno-castration	A process in which the male pig is immunized against its own GnRH. The resulting low levels of GnRH result in the regression of the testes and reproductive function. It is not actual castration as the testes are not removed or destroyed, and will recover function over time.
Immunoresponsiveness	The response of the immune system to a challenge, can be evaluated by injecting a toxin and measuring the increase in skin thickness.
Implantation Phase	During early gestation, when the embryo adheres to the uterine wall.
Inflection point	The point on a curve where the curvature changes sign, in terms of temperature and animals, it is the point above or below which animal behaviour is significantly affected.
Intact males	Males that are not castrated.
Intraperitoneal (IP) injection	The injection of a substance into the body cavity.
K-Value	When using the allometric formula: $A = k \times BW^{0.667}$, the k-value is the floor space allowance coefficient that relates body weight to floor space requirements.
Lairage	An animal holding pen at the slaughterhouse.
Lameness	A condition that is caused by multiple factors and results in varying degrees of locomotion impairment.
Meta-analysis	A statistical method that combines the results of several studies that have a set of related measures.
Mortality rate	A measure of the number of deaths in a group.
Non-penetrating captive bolt	A device that propels a blunt, mushroom-shaped bolt with great force against the forehead of the animal which causes a concussion.
Ovariectomized gilts	Females pigs that have had their ovaries surgically removed
Pain relief	Alleviating suffering, usually through medication
Pain responses	Behavioural responses to tissue damage such as trembling, changes in body postures, subbing or scratching the affected area, vocalizations, etc.
Partial stalls	Metal crate protecting the sow while feeding with two sides extending only to the level of the sow's shoulders.
Partially slatted floors	A concrete flooring with an area made of solid concrete and an area with narrow gaps allowing manure to pass through.
Penetrating captive bolt	A device used for stunning that propels a pointed bolt into the skull of the animal.
Physical fitness	Measured by factors such as muscle mass and body fat and is dependent on exercise.

Positive social interactions	Non aggressive mutual actions between sows such as sniffing.
Postural changes	In pigs, moving between the following postures: lying on the side, lying on the sternum, sitting, standing.
Reflex	An involuntary and rapid movement in response to a stimulus.
Regrouping	Mixing pigs together that have already been mixed with other pigs previously.
Repetitive oral-nasal-facial behaviour	A type of abnormal repetitive behaviour in sows involving repetitive and unvarying movements of the mouth and snout of the sow (sham-chewing, bar-biting, etc.).
Retaliation	After receiving an aggressive act (such as a bite or head knock), reciprocating in an aggressive manner.
Righting reflex	Arching of the back in an attempt to regain a lateral position with the floor by animals that have been improperly stunned and are suspended by their rear legs prior to exsanguinations.
Rooting behaviour	Manipulating soil or other materials with the snout by pigs.
Scans	When observing behaviour, recording the behaviour of the animal(s) at specified times (example: every 5 minutes).
Scratches and lesions	Superficial injuries to the skin that are usually occasioned by bites from other pigs.
Sensibility	Awareness towards environmental stimuli.
Sexing semen	A process by which sperm cells are separated according to sex.
Sexual maturity	The age at which an animal can reproduce.
Sham-chewing	Open mouthed chewing without any food in a repetitive and unvarying manner by sows.
Skatole	A compound produced by bacteria in the large intestine with a faecal like odour, it is one of the components responsible for boar taint.
Slaughter weight	Live weight of animals immediately before slaughter.
Social order	See dominance hierarchy.
Somatosensory evoked potentials	Electrical signals generated by the nervous system in response to mechanical or electrical stimulation of peripheral nerves.
Space Allowance	The amount of floor surface area that is available for animals.
Stable groups	Groups of pigs which have an established social hierarchy (they have been together for some time) with no new pigs being added or removed.

Stereotypies	Abnormal, repetitive and unvarying behaviours caused by known factors such as frustration, coping attempts or dysfunction of the central nervous system.
Stocking density	The number of animals for a given floor surface area.
Stunning	The act of rendering an animal unconscious.
Submissive behaviour	Similar to avoidance behaviour, a pig moving away from a more dominant pig without a direct interaction.
Suffering	A negative affective state brought about by harm or threat of harm, it may be physical (example: tissue damage, hunger) or mental (example: fear).
Surgical castration	In pigs, it is the removal of both testes by cutting through the skin and tearing out the testes or cutting the spermatic cord.
Sympathetic nervous system	A part of the nervous system that is turned on when stress is experienced, it is involved in vigilance, arousal and energy mobilization to the muscles.
Thermoneutral zone	The temperature tolerance range above and below which the metabolic rate increases significantly for cooling or warming the organism.
Trickle feeding	An automated method of providing feed in a gradual way.
Unconsciousness	Lack of responsiveness to environmental stimuli.
Vaccine	A biological agent that stimulates the immune system to produce specific antibodies against the agent. The immune system will "remember" it so that it can be destroyed the next time it is encountered.
Withdrawal (behaviour)	See avoidance and submissive behaviour.