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Review of the influence of farrowing and lactation housing and positive human contact on sow and piglet welfare

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Farrowing crates continue to be the most common system of housing farrowing and lactating sows, however continuous confinement is one of the most contentious welfare issues in livestock production. This review aims to critically evaluate the scientific literature on the implications of two important determinants of sow and piglet welfare: housing and human contact. While the evidence in sows is contradictory, there is consistent evidence of a greater short-term cortisol response in gilts introduced to farrowing crates than pens and there is limited evidence of changes in the HPA axis consistent with sustained stress in gilts during the fourth week of lactation. Confinement of sows during lactation increases stereotypic behaviour, reduces sow-piglet interactions, nursing duration and lying behaviour, and may contribute to leg and shoulder injuries in sows. Piglets reared by sows in pens display more play and less oral manipulative behaviours and generally have better growth rates than those reared in farrowing crates. However, there is increasing interest in developing alternate housing systems with minimal sow confinement and reduced piglet mortality risk. Recent research on temporary crating of sows suggests that confinement briefly around farrowing may be the best compromise between continuous housing in farrowing crates and pens, as it may reduce live-born piglet mortality, while providing the opportunity for the sow to move more freely prior to parturition. Together with housing, the behaviour of stockpeople is a key determinant of pig welfare. Recent evidence shows that positive handling of piglets during lactation reduces fear behaviour and physiological stress responses of pigs to humans, novelty and routine husbandry practices, and thus may be enriching for piglets. As a source of enrichment, positive human interactions provide several advantages: close interactions with piglets usually occur several times daily, positive interactions can be combined with routine checks, human interactions invariably provide variability in their predictability which will minimise habituation, and positive interactions may not require

additional physical resources. There is a clear need for comprehensive research examining both the short- and long-term welfare implications and the practicality of less confinement of the sow, and positive handling of both sows and piglets during lactation.

KEYWORDS

housing system, human contact, farrowing, lactation, sows, piglets, welfare

1 Introduction

1.1 Farrowing and lactation housing

The farrowing crate reduces the risk of mortality of live-born piglets, saves space and labour, maintains hygiene and facilitates inspection of sows and piglets and thus intervention if needed (Barnett et al., 2001; Johnson and Marchant-Forde, 2009). However, criticisms of the farrowing crate have generally focused on compromised sow welfare (Heidinger et al., 2022), since crates restrict the movement of sows (e.g., the capacity to turn around) and the opportunity for sows to perform strongly motivated, species-specific behaviours, such as nest building and freely interacting with their piglets (Barnett et al., 2001). Consequently, there is continuing interest in developing housing systems with reduced (e.g., temporary confinement pens) or no confinement (e.g., loose pens) during farrowing and lactation (Baxter and Edwards, 2018; Baxter et al., 2018; Baxter and Edwards, 2021; Goumon et al., 2022).

Many types of loose farrowing-lactation pens have been developed and studied particularly over the last two to three decades. These pens normally include pen fixtures that protect the piglet and assist the sow during postural changes and enable provision of straw for nest-building. The more detailed farrowing pens include specialised areas for feeding, nesting and dunging (Baxter et al., 2011), such as the Werribee farrowing pen, Norwegian farrowing pen and the PigSAFE system (Baxter et al., 2018). Concerns about the mortality of piglets in loose farrowing and lactation pens, and concerns about the welfare of sows housed in farrowing crates throughout lactation, have led to research and development in the last decade on temporary confinement systems in which sows are crated in the prepartum and/or early postpartum period (reviewed in Goumon et al., 2022).

This review aims to critically evaluate the existing literature on the influence of confinement and loose housing of prepartum and postpartum sows and its timing and duration on the welfare of sows and their piglets. While the importance of developing a positive human-animal relationship on the welfare and productivity of farm animals is well recognised (Hemsworth and Coleman, 2011; Hemsworth et al., 2018; Rault et al., 2020), there is also emerging evidence of both short- and long-term effects of human contact early in the life of the pig and this literature will also be evaluated because of its implications on piglet welfare. While animal welfare science is an established discipline, there is an extensive range of different physiological and behavioural indicators that have been suggested as 'measures' of welfare and a considerable discussion about which of these indicators are most valid (Fraser, 2008a, Fraser, 2008b; Hemsworth et al., 2015; Dawkins, 2021). Therefore, it is useful in this review on sow and piglet welfare to begin by considering this multidisciplinary approach to assessing animal welfare and the strengths and weaknesses of the approach.

1.2 Animal welfare assessment

It is widely accepted that animal welfare is a state within an animal, and most directly relates to what the animal experiences (Mellor et al., 2009; Hemsworth et al., 2015). Subjective feelings are only available to the animal (or human) experiencing them (Rowan et al., 2021). The use of terms 'emotion', 'mood' and 'affect' is inconsistent in both human and animal literature (Kremer et al., 2020) but here we will use the term affect as an umbrella term for emotion and mood. Non-human animals are not capable of verbal speech to communicate to humans how they feel, and therefore scientists are reliant on behavioural and physiological indicators of animal welfare. Furthermore, as we will discuss later, because there is no one absolute indicator of good or bad welfare, it is increasingly argued that a broad range of behavioural and physiological indicators of welfare should be used to assess animal welfare (Dawkins, 2008; Fraser, 2008a; Nicol et al., 2009; Nicol et al., 2011). In reviewing the literature on sow and piglet housing and handling, we will utilise two broad conceptual frameworks used by scientists in studying animal welfare, the biological functioning and affective state frameworks.

The rationale underpinning the biological functioning framework is that difficult or inadequate adaptation will generate welfare problems for animals (Hemsworth et al., 2015). Animals use a wide range of biological responses, behavioural and physiological, to both regulate their lives and deal with challenges (Barnett, 1987; Broom and Johnson, 1993; Moberg, 2000; Sapolsky, 2000a; Ralph and Tilbrook, 2016; Tilbrook and Ralph, 2017). These behavioural and physiological responses are adaptive responses that may help an individual to cope with its environment. While failure to adapt may ultimately result in death, less severe challenges can result in less serious biological costs, such as impaired growth, reproduction, and health, and so both sets of consequences demonstrate that difficult

or inadequate adaptation can generate welfare problems for animals. Conceptualised in these terms, it is the biological cost of stress that is the key to understanding the associated welfare implications (Barnett, 1987; Moberg, 2000; Barnett, 2003). How well an animal is coping with the challenges it faces will be reflected in the normality of its biological functioning and fitness, with severe risks to welfare associated with the most extreme coping attempts (Hemsworth and Coleman, 2011; Hemsworth et al., 2015).

The two key frontline physiological systems activated during stress to confront challenges are the sympathoadrenal system and the hypothalamo–pituitary adrenal (HPA) axis. The sympathoadrenal system comprises the sympathetic nervous system and the adrenal glands and this system synthesises and secretes catecholamines. These include dopamine, epinephrine and norepinephrine (reviewed in Turner et al., 2012; Ralph and Tilbrook, 2016). Catecholamines evoke rapid neural, endocrine, behavioural, and muscular activity throughout the body (Sawchenko et al., 2000) in both mammals (Tilbrook and Ralph, 2017) and birds (Tilbrook and Fisher, 2020). The HPA axis consists of the hypothalamus, the anterior pituitary gland and the cortex of the adrenal glands (reviewed in Turner et al., 2012; Ralph and Tilbrook, 2016; Tilbrook and Ralph, 2017). The adrenal cortex synthesises glucocorticoids, which are steroids that have far-reaching effects throughout the body (Moberg, 2000; Tilbrook and Ralph, 2017). The predominant glucocorticoid is cortisol in most mammals (Ralph and Tilbrook, 2016) and corticosterone in birds (deRoos, 1961). In both mammals and birds, the HPA axis is regulated by extensive and multiple neuronal pathways within the central nervous system, as well as by negative feedback by the glucocorticoids (Sapolsky, 2000b; Tilbrook and Clarke, 2006; Turner et al., 2010; Tilbrook and Fisher, 2020). Our understanding of how stress challenges influence the mammalian and avian immune systems has advanced significantly since earlier assumptions of a simple stress-modulated immunosuppression (Kelley, 1980; Dantzer and Mormède, 1983). These interactions are now understood to be more complex (Moberg, 2000; Sapolsky et al., 2000; Salak-Johnson et al., 2007), for example, stress-induced hormones such as glucocorticoids do not simply suppress all immunity but contribute to a shift from T-helper 1 (Th1) driven cellular immunity toward Th2-mediated humoral responses (Salak-Johnson et al., 2007). Animals also show a number of behavioural characteristics of disturbance and the frequency and intensity of some of these behaviours provides information about the stress experienced by the animal (Olsson et al., 2018). For example, restricting specific strongly motivated behaviours, not only typically induces physiological effects, particularly those involving the sympathoadrenal system and the HPA axis (Mason and Burn, 2018), but leads to a number of behavioural changes including escape attempts, redirected movements, vacuum activities, and/or displacement activities (Hinde, 1970; Clubb et al., 2006), which can in turn develop into stereotypies (Mason, 2006).

Therefore, as indicated earlier, while biological regulation in response to challenges occurs continuously, successful adaptation is not always possible. Such maladaptation can result in biological costs, such as impaired growth, reproduction and health, and thus welfare problems for animals (Hemsworth et al., 2015). The majority of published studies on animal welfare have used one or more of a range of biological responses, such as behavioural measurements (e.g., stereotypies and other abnormal behaviours, and fear, pain and illness behaviours) and physiological stress measurements (e.g., activation of the sympatho-adrenal system and the HPA axis) and their fitness consequences (e.g., impairment of health and efficiency of growth and reproduction) to assess animal welfare (Hemsworth et al., 2015; Blache et al., 2018; Cockram and Hughes, 2018; Fraser and Nicol, 2018).

A common criticism in using the biological functioning framework to assess welfare risks is that the approach does not adequately identify the related or resulting affective states (Hemsworth et al., 2015). However, emotions are not independent of other biological processes: emotions are associated with activations of both the sympatho-adrenal system and HPA axis (Chrousos, 2009). In humans these physiological responses to stress are known to be sensitive to one's evaluation of a threat (i.e., one's subjective perception) (McEwen and Gianaros, 2010).

Using physiological measurements as indicators of challenges to biological functioning entails some general methodological considerations (reviewed in Barnett, 2003; Ralph and Tilbrook, 2016; Tilbrook and Ralph, 2017; Kremer et al., 2020). For example, the time course of responses in relation to the disturbance should be accounted for, as well as circadian and individual effects on baseline levels. Most welfare studies examining the stress physiology of pigs have generally focused on the HPA axis, with most meaningful interpretations being obtained from measuring concentrations of glucocorticoids (e.g., cortisol) in the blood. While the collection of invasive samples may induce confounding responses by the animal, it has become increasingly common to measure glucocorticoids in media other than blood, such as saliva, hair and faeces, often with varying relationships to concentrations in blood (Möstl et al., 2005; Lane, 2006; Burnard et al., 2016). It is therefore particularly challenging to understand the consequences of actions of glucocorticoids in matrices other than blood (Tilbrook and Ralph, 2017). Furthermore, some physiological changes may not necessarily accompany affective change, as is known in humans and certain single indicators may not be able to distinguish the subtleties of affect (Dawkins, 2000). However, methodological considerations are not unique to physiological measurements. Accurate behavioural observations and observer effects obviously need to be considered. Furthermore, there are examples of situations where behaviour that generally reflects either poor or good welfare shows the opposite relationship. For example, while play behaviour in animals is widely considered as an indicator of positive affect (Boissy et al., 2007; Held and Špinka, 2011), a recent review of the human and animal literature by Ahloy-Dallaire et al. (2018) concluded that while a wide variety of situations that cause negative affect also suppress many types of play, there are noteworthy counter-examples. For example, while the cases are less numerous than those where play is associated with a positive affective state, there is evidence that decreased maternal care is associated with increased object play in domestic kittens (Bateson et al., 1990) and decreased maternal care or increased social stress is associated with increased social play in non-human primates (Devinney et al., 2003; Antonacci et al., 2010).

The other main conceptual framework often labelled the affective state framework, emphasises that the welfare of an animal derives from its capacity for affective experiences (Duncan and Fraser, 1997). This approach has predominantly used preference and motivation tests and more recently cognitive bias tests which measure an animal's relative preferences for, or willingness to work for, particular resources, environments or stimuli (Fraser and Nicol, 2018) and an animal's tendency to respond with either positive or negative anticipation to ambiguous stimuli (Mendl et al., 2009), respectively. The rationale for these tests is that the animal's response is influenced by its affective state at the time. However, as recognised by others, measuring animal preference or motivations is not simple because of influences of familiarity, learning and information gathering, and animals, particularly domesticated animals, may not make choices that are always in their best interest (Fraser and Nicol, 2018).

The biological functioning framework has been used to assess risks to animal welfare, that is a negative welfare state, however a lack of suffering does not guarantee that animals are experiencing a positive welfare state. There has been an increased focus on promoting positive welfare states in contrast to a previous almost exclusive focus on ameliorating negative states (Mellor and Beausoleil, 2015). Indicators of positive welfare are conceptually and methodologically more challenging to identify than those of negative welfare (Lawrence et al., 2018). The valence of affective experiences in animals can be studied by observing their behaviour in specific situations such as approach and avoidance, freezing or play behaviour, behaviours in anticipation of a reward or punishment, consumptive behaviours, and affiliative behaviour such as allogrooming (reviewed in Boissy et al., 2007; Reimert et al., 2013; Kremer et al., 2020). These behavioural observations can be conducted on the whole or specific body parts. However, as concluded by Mellor and Beausoleil (2015) and Kremer et al. (2020), behaviour is an important component of affective experiences in animals, but caution is required as interpretation of behaviour is not always clear-cut and the relationships between affect and behaviour are complex.

Each of these two conceptual frameworks to assess animal welfare are not perfect: they have advantages and disadvantages. Animal welfare science is increasingly seen as a multidisciplinary exercise (Nicol et al., 2011; Siegford, 2013; Hemsworth et al., 2015) and we have previously proposed that biological functioning is taken to include affective experiences and affective experiences are recognised as products of biological functioning, and therefore a better knowledge of the dynamic interactions between the biological functioning and affective state frameworks is fundamental to our understanding of and thus managing and improving animal welfare (Hemsworth et al., 2015).

While the biological functioning framework has been extensively used to study farm animal welfare, to the authors' knowledge only a few studies have used preference and motivation tests to investigate what housing resources are important to sows and their piglets and these studies, which examined the behavioural demand of prepartum sows for nesting/foraging material, are reported in Section 3. In contrast, the majority of studies on farrowing and lactation housing of sows and piglets have employed behavioural, physiological, and/or fitness responses to assess risks to welfare and consequently we have predominantly relied on behavioural, physiological, and/or fitness responses in reviewing the literature on the welfare implications of farrowing and lactation housing.

2 Farrowing and lactation housing and physiological stress in gilts and sows

To avoid confusion when considering farrowing and lactation housing of nulliparous and multiparous female pigs, we will refer to parturient and lactating female pigs farrowing for the first time as gilts although technically a gilt is a pig that has not had a litter.

2.1 Short-term physiological stress

While evidence in sows is contradictory, there is considerable evidence that prepartum gilts experience a short-term physiological stress response on entry to farrowing accommodation, and that this short-term stress response is greater in gilts introduced to farrowing crates than those introduced to pens with straw. For example, pregnant gilts had higher plasma cortisol concentrations on entry to farrowing crates (day 110 of gestation) than those on entry to pens with straw (Cronin et al., 1991), however there was no difference in plasma cortisol concentrations 2 days later (day 112 of gestation). Similarly, gilts in farrowing crates had higher plasma cortisol concentrations 24-12 hours prepartum and during parturition compared to gilts in straw-bedded pens, however there was no evidence of elevated cortisol concentrations on days 1, 2 and 7 of lactation (Lawrence et al., 1994). Jarvis et al. (1997) found that plasma cortisol concentrations were higher in gilts in farrowing crates at 24-6 hours prepartum than those in pens with straw. Plasma adrenocorticotropic hormone (ACTH) concentrations were also higher in gilts in farrowing crates at 6 hours prepartum. Furthermore, while Jarvis et al. (1998) found no difference between crated and penned sows in baseline plasma cortisol concentrations from the onset of nest-building behaviour (approximately 12 hours prior to parturition) to the commencement of parturition, there was a tendency for crated gilts to have higher cortisol concentrations in the hour prior to parturition.

In a study examining the effects of confinement (crate versus pens) and straw (present versus absent), Jarvis et al. (2002) found that confinement, but not straw, affected both plasma ACTH and cortisol concentrations of gilts across the entire preparturient phase, with crated gilts having higher concentrations than penned gilts irrespective of straw availability, particularly at the peak of nest-building activity. The authors also observed that when housed in pens, but straw was absent, preparturient gilts redirected their nest-building behaviour to the floor and thus the authors proposed that the ability to express substrate-directed behaviour as a result of increased space is reflected in reduced physiological stress. In a similar study examining the same treatments, Jarvis et al. (2004) found that confinement and straw had no effect on plasma cortisol

concentrations or oxytocin concentrations during the first 8 hours following the birth of the first piglet, however crated gilts had higher plasma ACTH in the second hour after the birth of the first piglet.

Similar to their findings on gilts, Jarvis et al. (2001) found that relative to sows in pens with straw, sows in farrowing crates without straw had elevated plasma cortisol concentrations from 48 hours prepartum to parturition, with the most significant difference occurring at 6-4 hours prepartum. However, this difference in prepartum cortisol concentrations between crated and penned sows was less than that previously seen between crated and penned gilts (Jarvis et al., 1997), suggesting some adaptation through prior experience of farrowing in a crate. Cronin et al. (1993) also suggested that sows may adapt to farrowing in crates because the nest-building behaviour of older sows in farrowing crates was not affected by the provision of sawdust, a resource that has been shown to elicit nest-building in gilts and sows.

In contrast to Jarvis et al. (2001); Yun et al. (2019) found that penned sows had higher salivary cortisol concentrations on day 3 prepartum, but not days 2 and 1 prepartum, than sows crated during this period. Yun and colleagues suggested that the elevated salivary cortisol concentrations observed in the penned sows on day 3 prepartum may be associated with more vigorous activities prepartum or hypocortisolism. As discussed earlier (Section 1.2), the most meaningful interpretation of activation of the HPA axis is likely to be obtained by measuring cortisol in the blood. Biensen et al. (1996) reported that plasma cortisol concentrations were highly variable for multiparous sows in pens and farrowing crates during week 1 prepartum. Oliviero et al. (2008) found that multiparous sows in farrowing crates and pens with straw bedding had similar cortisol concentrations from 5 days prepartum to 1 day postpartum, however, crated sows had higher cortisol concentrations from days 2-5 postpartum than penned sows during this period.

Three studies have examined stress physiology in both gilts and sows, without differentiating possible parity effects. Hales et al. (2016) found that loose-housed parity 1 and 2 pigs (i.e., prepartum gilts and sows) had higher salivary cortisol concentrations from 1 day prepartum to 3 days postpartum than those confined during this period, and Hansen et al. (2017) found the same effect on salivary cortisol concentrations 2 and 1 days prepartum. However, Nowland et al. (2019) found no differences in the plasma cortisol concentrations of parity 1-3 sows in pens and crates in the period from 24 hours prepartum to the birth of the last piglet.

In contrast to studies conducted exclusively on gilts, the above studies on both gilts and sows provide conflicting results on the effects of confinement on stress physiology around parturition. However, differences between studies in pen and crate design, provision of nesting/foraging materials and flooring, previous gestation housing, animal experience and genetics, variation in stockperson handling, husbandry and management and sampling method, including behavioural and physiological responses and fitness measures (growth, reproduction, and health), may contribute to these conflicting results. For example, one obvious difference between the studies by Jarvis et al. (2001) and Oliviero et al. (2008) and those by Hales et al. (2016); Hansen et al. (2017); Nowland et al. (2019) and Yun et al. (2019), was that of floor space in the loose pen: floor area of the pens in the former group of studies was markedly greater than in those in the latter group of studies. Further research on the effects of pen and crate design on the physiological stress response of sows around parturition may be informative.

While studies on sows are contradictory, those on gilts consistently indicate that prepartum introduction to farrowing crates results in a greater short-term stress response than introduction to pens. As far as the authors are aware, the only study that has examined the relative effects of prepartum housing and nesting/foraging material on stress physiology indicates that confinement rather than the presence of straw bedding is responsible for the greater short-term stress response in confined gilts (Jarvis et al., 2002). It should be recognised that it is difficult to determine the welfare consequences of a short-term stress response around parturition, since parturition in mammals is initiated by a sharp rise in glucocorticoids (Young, 2001; Nagel et al., 2019). During gestation, some maternal hormones cross the placental barrier and interact with the fetus in essential and adaptive ways: glucocorticoids, for example, have been implicated in a variety of roles during pregnancy including initiating parturition (Edwards and Boonstra, 2018).

2.2 Sustained physiological stress

Gilts in farrowing crates may experience sustained physiological stress by the end of the lactation period. While Cronin et al. (1991) found no evidence of prolonged stress on the basis of plasma cortisol concentrations in gilts in farrowing crates between the first, second and third weeks of lactation (days 1, 7, 14 and 21 of lactation), gilts in crates had higher cortisol concentrations by the end of the fourth week of lactation compared to gilts in straw-bedded pens. The authors suggested that while four weeks might be the 'natural' weaning age for piglets in confined conditions, the level of attention from the piglets to the sows after four weeks of lactation may result in this prolonged or sustained stress response in gilts in farrowing crates at day 28 of lactation. In an experiment examining the stress physiology of gilts housed in farrowing crates with or without straw bedding and large strawed pens, Jarvis et al. (2006) found no treatment effects on baseline plasma ACTH and cortisol concentrations in the first to fourth week of lactation (days 2, 8, 15, 22 and 28 of lactation). However, corticotrophic releasing hormone (CRH) challenge tests suggested changes in the HPA axis, consistent with sustained stress, by the end of the lactation period: cortisol concentrations increased following CRH injection on day 29 postpartum in gilts confined with straw bedding compared to gilts in large pens with straw bedding, and furthermore, cortisol concentrations tended to be higher in gilts confined without straw bedding compared to those in large pens with straw bedding.

In addition to the research presented above on gilts, to the authors' knowledge, four studies have compared the long-term effects of housing sows in farrowing crates and pens on physiological stress. With twice daily blood sampling from days 1 to 21 of lactation, sows housed in farrowing crates had elevated

plasma cortisol concentrations compared to those in farrowing pens (Biensen et al., 1996). Hair cortisol concentrations in sows were lower with a shorter period of sow confinement during lactation (3-10 days versus 13-24 days after farrowing) (Morgan et al., 2021). In contrast, Goumon et al. (2018) found that temporary confinement in farrowing crates from 5 days prepartum until 4 days postpartum had no effect on salivary cortisol concentrations in sows at 6 and 25 days postpartum, relative to sows housed in farrowing crates from 5 days prepartum until 25 days postpartum. While salivary cortisol concentrations were unaffected, sows temporarily confined until 3 days postpartum had less tear staining at weaning than those continuously confined in crates (Kinane et al., 2022), although salivary cortisol concentrations in sows temporarily confined were higher when introduced to treatment (day 108 of gestation) and tended to be higher on day 5 postpartum. Tear staining has been used as an indicator of stress in laboratory rats and recently in pigs (Larsen et al., 2019).

While there is limited evidence in lactating gilts in farrowing crates of changes in the HPA axis consistent with sustained physiological stress in the fourth week of lactation, the few studies that have been conducted on sows provide conflicting evidence of changes in the HPA axis with longer term (13-25 days) confinement during the lactation period. Clearly further research on the long-term effects of confinement on the stress physiology of lactating gilts and sows is required.

3 Farrowing and lactation housing and sow welfare

Considerable research has been directed at investigating the effects of the periparturient environment (particularly the effects of nesting/foraging material and space) on pre-farrowing nest-building behaviour. In the 24 hours prepartum, sows appear to be highly motivated to perform nest-building behaviour, seek isolation from other pigs, and walk further compared with the previous days (reviewed in Barnett et al., 2001; Baxter and Edwards, 2021). While sows will utilise nesting/foraging material if freely available, their motivation for straw increases as farrowing approaches (Hutson, 1988; Arey, 1992; Hutson, 1992). Although there is evidence that space is more important than substrate in allowing the behavioural expression of nest-building (reviewed in Barnett et al., 2001; Baxter and Edwards, 2021), pawing and rooting, two of the main components of nesting behaviour, increase if nesting/foraging material is provided (Burne et al., 1999; Burne et al., 2000; Bolhuis et al., 2018). Nest-building behaviour in terms of frequency, total duration, and bout duration from 72 hours before the expected parturition until the birth of the first piglet was greater in multiparous sows in pens with straw than those in pens without straw (Wang et al., 2020). More vigorous and intensive nest-building behaviour has been reported in penned sows with abundant nesting/foraging materials than penned or crated sows with minimal (Yun et al., 2014a) or no nesting/foraging material (Bolhuis et al., 2018). Plush et al. (2021) found that sows in pens provided daily with chopped straw displayed the highest level of nesting behaviours (pawing the floor and nosing the floor and fixtures) in the 18-hour period leading up to farrowing, but crated sows with straw or hessian displayed more nosing behaviour compared to that of crated sows without straw or hessian.

A number of authors have proposed that a function of nest-building behaviour is to influence the course of parturition, and thereby the survival of piglets (Cronin et al., 1993; Cronin et al., 1996; Yun and Valros, 2015; Baxter and Edwards, 2018). Provision of sawdust in the prepartum period has been shown to reduce the duration of parturition of sows in farrowing crates (Cronin et al., 1993), and a shorter farrowing duration has been reported in penned sows than in confined sows (Yun et al., 2015). However, Bolhuis et al. (2018) found no effects on farrowing duration or piglet survival of either housing sows in crates or pens or providing nesting/foraging material, even though nesting/foraging material reduced standing and increased lying during parturition. In fact, Jarvis et al. (2004) found that access to nesting/foraging material increased the duration of parturition of gilts housed both in crates and pens, but did not affect piglet survival. Jarvis and colleagues also found that the provision of increased space, rather than straw, resulted in maternal behaviour after the birth of the first piglet that more closely resembled that in free ranging sows, that is, a more active period involving interactions with piglets, followed by a more inactive and passive period. Furthermore, housing hyperprolific sows with nesting/foraging material in either farrowing crates or pens did not affect farrowing duration or piglet birth intervals, although penned sows spent more time nest building than confined sows (Hansen et al., 2017). Longer farrowing durations in crated sows have been reported to be associated with higher stillborn rates in some but not all studies (reviewed in Baxter et al., 2018). Edwards et al. (2019) found that stillborn rates in farrowing crates can be reduced by providing sows with lucerne hay prior to expected parturition. Higher incidences of savaging of piglets have been reported for sows confined in crates (Lawrence et al., 1992; reviewed in Johnson and Marchant-Forde, 2009).

Prepartum pigs spend considerable time foraging if suitable substrates are available, and gilts when deprived of nesting/foraging material have higher frequencies of vocalising, chewing fixtures, rooting walls and floors, and lying down (Burne et al., 2000). Housing preparturient pigs in farrowing crates without straw increased the proportion of time in which gilts and sows spent sitting in comparison to those in pens with nesting/foraging material such as sawdust or straw (Cronin et al., 1993; Jarvis et al., 1997; Jarvis et al., 2001) and, as suggested by several authors (Jarvis et al., 1997; Jarvis et al., 2001), this may represent motivational conflict in that the pig is motivated to nest but the environment prevents her from doing so. Furthermore, providing sows in farrowing crates with lucerne hay 2 days prior to expected parturition reduced prepartum sham chewing (Edwards et al., 2019). Prepartum sows housed in farrowing crates with sawdust had a higher frequency of bar-biting than those in pens with either limited sawdust or abundant sawdust, chopped straw and other substrates (Yun et al., 2015). Sows housed in farrowing crates without nesting/foraging material spent more time sham chewing and chewing fixtures on days 6 and 3 prepartum than those in pens with or without nesting/foraging material, and these behavioural differences were also apparent in the first 3 weeks of lactation

(Zhang et al., 2020). Similarly, crated sows without nesting/foraging material displayed more bar biting, champing and sitting in the prepartum period than sows in pens and crates with nesting/foraging material (Cronin et al., 1993; Andersen et al., 2014; Plush et al., 2021). It has been suggested that increased incidence of floor and fixture-directed behaviours may be indicative of either intended nest-building behaviour to cope with the prepartum environment or physiological stress induced by thwarting prepartum natural behaviour (Lawrence et al., 1994; Lawrence et al., 1997). Yun et al. (2019) found no relationship between prepartum salivary cortisol concentrations and postpartum bar-biting. Furthermore, as discussed earlier, space, but not straw, affected both plasma ACTH and cortisol concentrations prepartum, with crated gilts having higher ACTH and cortisol concentrations than penned gilts irrespective of straw availability (Jarvis et al., 2002; Jarvis et al., 2004).

In terms of disruption of parturition, provision of an abundance of sawdust to sows in pens, compared to those in pens or crates with limited sawdust, has been shown to increase oxytocin concentrations from day 3 prepartum until day 7 postpartum (Yun et al., 2013; Yun et al., 2014a). In a similar study with mini-pig hybrid sows by Wang et al. (2020), multiparous sows in farrowing pens with straw had higher serum cortisol, oxytocin and prolactin concentrations day 1 prepartum and weekly over the 5 weeks of lactation, than sows in farrowing pens without straw. However, while the authors reported that cortisol and prolactin concentrations generally declined as lactation proceeded, it is unclear from the paper whether or not there was a treatment by time interaction. In other studies, housing preparturient and parturient sows in farrowing crates did not affect plasma oxytocin and prolactin concentrations sampled at 0, 2, and 4 minutes after delivery of each of the first five piglets (Yun et al., 2015) and from 24 hours prepartum until 2 hours after the birth of the first piglet (Damm et al., 2002; Yun et al., 2015).

Confinement during parturition and early lactation may also disrupt the establishment of nursing behaviour (Cronin and Smith, 1992). Sows that were temporarily confined for 5 days postpartum spent less time lying down, and more time nursing their piglets from 6 to 13 days postpartum than those that were continuously confined (Loftus et al., 2020). Pedersen (2015) found that penned sows nursed more frequently and had a shorter inter-nursing interval than sows that were temporarily confined until 3 days postpartum. Nursing frequency has also been shown to be less for sows with shoulder ulcers (Larsen et al., 2015) and confinement in farrowing crates may contribute to the development of leg and shoulder lesions in sows (Rioja-Lang et al., 2018). Furthermore, Pedersen et al. (2011) reported more piglet fights for access to teats in farrowing crates than pens, and when teat fights occurred in farrowing crates, more piglets missed the milk let down. The authors proposed that reduced accessibility to the udder in farrowing crates increases competition and fighting for teats which in turn disrupts the sow. Housing sows in pens compared to crates has been shown to increase colostrum ingestion in piglets, and while live-born mortality was unaffected, piglets born in pens were heavier at weaning (Nowland et al., 2019). There is considerable literature indicating better growth rates in piglets reared by sows in pens (reviewed in Yun and Valros, 2015; Baxter et al., 2018; Baxter and Edwards, 2021). Provision of abundant nest-building material, such as chopped straw and shredded paper, increased and tended to increase ($p<0.10$) piglet serum IgM and IgG concentrations, respectively early in lactation (Yun et al., 2014b). Plush et al. (2021) also found that provision of straw to sows in farrowing crates resulted in piglets ingesting more colostrum.

There is evidence that sows in pens with nesting/foraging material have improved maternal behaviour, based on increased interactions with their piglets and increased responsiveness to piglet vocalisations (Cronin and Smith, 1992; Cronin et al., 1996; Thodberg et al., 2002). In comparison to multiparous sows and their litters remaining in farrowing crates, transferring sows from farrowing crates without bedding to pens without bedding at 3 days postpartum resulted in increased sow–piglet interactions and increased maternal responsiveness based on the behavioural response of sows to audio recordings of unfamiliar piglet screams (Singh et al., 2017). Similarly, when presented with audio recordings of a screaming piglet, Cronin et al. (1996) found that crated primiparous sows vocalised less towards their own piglets in comparison to those penned with straw, and Thodberg et al. (2002) found that crated sows took longer than penned sows with straw to react as they moved to a lying position when the recording was played. Nest-building activity by sows, as well as their behavioural response to piglet distress calls, nose contact with piglets during posture changes and restlessness when piglets are removed, has been shown to be negatively correlated with the risk of piglet crushing (Andersen et al., 2005). However, as recently recognised by EFSA et al. (2022) and discussed later (Section 4.2), while there is considerable variability in pre-weaning piglet mortality in loose farrowing and lactation systems, the mortality of live-born piglets in loose farrowing and lactation systems is usually higher than that in farrowing crates. Therefore, while loose housing of the sow increases maternal behaviour as assessed by increased interactions with piglets and increased responsiveness to piglet vocalisations, the implications of this on piglet survival have not been well demonstrated.

More space during lactation offers increased opportunity for sows to display more interactions with their piglets, such as nosing or nuzzling piglets, and in addition to their relationship to maternal behaviour, these interactions are likely to provide sows (and piglets) with positive experiences. Nowland et al. (2019) found that sows in pens displayed more interactions with their piglets, such as nosing or nuzzling piglets, than crated sows. Sow-piglet interactions on days 11 and 18 postpartum were more frequent in litters where the sow was temporarily confined until 3 days postpartum than in litters where the sow remained crated (Singh et al., 2017). Chidgey et al. (2016), Ison et al. (2015) and Martin et al. (2015) also found more sow-piglet interactions in pens than crates, and furthermore Martin et al. (2015) found that these interactions between sows and piglets occurred earlier in life in pens than crates.

Environmental enrichment, that is an increase in the biological relevance of captive environments by appropriate modifications (Newberry, 1995), has been shown to mitigate deleterious stress effects on neurobiological systems and

endocrine profiles and promote stress adaptability in rodents (Abou-Ismail et al., 2010; Lehmann and Herkenham, 2011; Abou-Ismail and Mendl, 2016). The European Commission directive 2008/120/EC (European Union, 2009, p.8) states that "pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals. However, several authors have questioned the extent to which this provides effective enrichment (Marchant-Forde, 2009; van de Weerd and Day, 2009). While the utilisation of enrichments has been studied in the growing pig, the effects of enrichment have not been extensively studied in farrowing and lactating sows. Enrichment opportunities are currently limited for gilts and sows in farrowing crates, however as discussed here, the farrowing and lactation environment may be improved by providing more floor space and material that can be orally manipulated. Providing lucerne hay or straw reduced prepartum sham chewing and plasma cortisol concentrations in confined sows (Edwards et al., 2019; Plush et al., 2021). As several authors (Barnett et al., 2001; Plush and Nowland, 2022) have proposed, the provision of material such as straw or lucerne hay for pigs is a complex topic as it may provide one or a combination of the following benefits: nesting/foraging material for prepartum sows, nutritive value, thermal and physical comfort during rest and sleep periods, and environmental enrichment for pigs. Indeed, when it comes to the value of straw as a nesting/foraging material pre-farrowing, Plush and Nowland (2022) suggest that an underappreciated aspect is the amount of straw that sows may consume during this period, and the effect of increasing dietary fiber on the parturition process, gut microbiota and energy availability, and colostrum composition. Provision of straw obviously meets the European Union Commission directive (EU, Council Directive 2008/120/EC) as straw meets enrichment criteria of stimulating investigation and manipulation activities. Additionally, although there are likely to be superior sources of dietary fibre to promote various reproductive and gut health benefits (e.g., reviewed in Jarrett and Ashworth, 2018; Li et al., 2021), the provision of straw to prepartum sows does provide some additional fibre which is also recommended in the EU directive (EU, Council Directive 2008/120/EC). The implications of non-enriched environments for the welfare of farrowing and lactating gilts and sows remain unclear, since there is little evidence that provision of straw, rather than space, affects stress physiology of prepartum and lactating gilts and sows (Sections 2.1 and 2.2). Further research is clearly required to examine effective enrichment opportunities for gilts and sows during farrowing and lactation.

A major difficulty in reviewing research on the effects of farrowing and lactation housing systems is the considerable variation in housing design features, including floor space, floor type, piglet protection features, timing and duration of confinement pre- and post-farrowing, and the amount and type of nesting/foraging materials during farrowing and lactation as well as gestation housing, and management by stockpeople including handling (Section 4.1.2), which all may affect sow behaviour and welfare. Nevertheless, a lack of both space and nesting/foraging materials can reduce maternal behaviour in sows, such as responsiveness to piglets, sow-piglet interactions, as well as nesting behaviour, sustained lateral lying, and carefulness when changing posture, which have implications on piglet mortality and welfare (reviewed in Barnett et al., 2001; Johnson and Marchant-Forde, 2009; Baxter and Edwards, 2021). Furthermore, confinement may result in a range of physical implications for the sow including reducing the ability of sows to thermoregulate, increasing risk of hoof, leg and shoulder lesions and lameness and reducing muscle mass due to prolonged reduction in movement (reviewed in Barnett et al., 2001; Baxter et al., 2018; Baxter and Edwards, 2021). In several European countries, selection for increased litter size has led to the use of nurse sows, whereby lactation and subsequent confinement may be extended by up to 21 days (Baxter et al., 2013). In a cross-sectional study conducted on 57 sow herds in Denmark, Sørensen et al. (2016) found nurse sows were at greater risk of swollen bursae on legs and udder wounds than non-nurse sows. The authors suggested these findings were due to extended confinement of the sows in farrowing crates.

4 Farrowing and lactation housing and piglet welfare

4.1 Piglet behaviour and physiology

4.1.1 Housing and social behaviour

There is considerable evidence that loose housing of the lactating sow and the provision of enrichment during rearing provides piglets with benefits relating to social development. Piglets reared by sows in pens with abundant straw showed more play behaviour during lactation than those reared by sows in farrowing crates with less straw (Martin et al., 2015; Clarkson et al., 2021), and play behaviour occurred earlier in life in pens with straw (Martin et al., 2015; Clarkson et al., 2021). Housing farrowing and lactating sows in large pens (60% more floor space than standard farrowing crates) with straw tended ($P<0.10$) to increase pre-weaning play behaviour of piglets in comparison to standard farrowing crates but not farrowing crates with more floor space (20% more space than standard farrowing crates) and straw (Chaloupková et al., 2007). In an experiment studying two main effects, enrichment (straw, other substrates and increased pen space versus absence) and housing (sow confined versus loose), Oostindjer et al. (2011) found that provision of enrichment such as straw, wood shavings and peat, but not confinement of the sow, resulted in piglets showing more play and less oral manipulative behaviours, such as belly nosing as well as nibbling, sucking or chewing litter mates during the lactation period. Similarly, piglets reared by sows in farrowing crates and released into pens with increased floor space but without bedding at 3 days postpartum, played more and manipulated others less during lactation than piglets remaining in farrowing crates until weaning (Singh et al., 2017). Lucas (2022) found that piglets reared by sows in pens displayed more play behaviour during lactation than those reared by sows in loose pens, with no nesting/foraging material provided in either system. Kinane et al. (2021) found no effects on piglet play behaviour of housing sows in farrowing crates or temporary

confinement pens, both with hessian sacks and fibre plant pots, however the total floor area in loose pens was only slightly larger than that in farrowing crates. These studies indicate that a more complex environment, in terms of provision of nesting/foraging material and less restricted sow-piglet interactions, may improve overall piglet welfare and therefore the piglet's motivation to engage in play. Furthermore, as suggested by (Chaloupková et al., 2007), increased floor space may make it physically easier for play behaviour to be expressed. Similarly, poorer welfare in piglets may lead to increased oral manipulative behaviours, such as belly nosing as well as nibbling, sucking or chewing on other piglets.

There is limited evidence of the effects of sow housing on piglet aggression and injuries during lactation. Oostindjer et al. (2011) in their experiment examining effects of enrichment and confinement, found no main effects on piglet aggression during lactation and Kinane et al. (2021) found no effect of sow confinement on piglet aggression during lactation and hoof injuries at weaning. Piglets reared by sows in farrowing crates displayed less aggression and had fewer injuries at 2 weeks of age than piglets reared by sows in pens, both without nesting/foraging material (Lucas, 2022), although aggression at 1 and 3 weeks of age and injuries at 4 weeks of age were not affected by lactation housing. Similarly, piglets reared by sows in farrowing crates had less injuries at 2 weeks of age than piglets reared by sows in pens, both without nesting/foraging material (Hayes et al., 2021b). Nesting/foraging material has been shown to reduce leg injuries in piglets during suckling (reviewed in Baxter and Edwards, 2018). For example, straw bedding prevents fore-knee and sole lesions (Westin et al., 2014). Lohmeier et al. (2019) and Andersen and Ocepek (2022) found that piglets reared by sows in farrowing crates had more facial and carpal injuries at 1 and 4 weeks of age and 2 days of age, respectively than piglets reared by sows in pens. The authors of both studies commented that treatment differences in the type of flooring in the sow's lying area may have contributed to these treatment effects on carpal injuries.

Although the provision of nesting/foraging material and more floor space for piglets has been shown to increase play behaviour and reduce piglet-directed oral manipulative behaviours during lactation, there is limited but conflicting evidence of the effects of sow confinement on the stress physiology of piglets. A shorter period of sow confinement during lactation (3-10 days versus 13-24 days) was associated with reduced hair cortisol concentration in piglets, as well as increased numbers of piglets weaned per sow (Morgan et al., 2021). Piglet faecal cortisol concentrations sampled at 5, 12, 19 and 26 days of age were similar in piglets reared by sows confined in crates during lactation and sows temporarily confined in crates and released into pens at 4 days postpartum (Kinane et al., 2021). Similarly, Lucas (2022) found no differences in serum cortisol concentrations at 4 weeks of age between piglets reared by sows in crates and pens, both without nesting/foraging material. However, at this age, the piglets reared by sows in farrowing crates with routine human contact had considerably lower concentrations of serum brain-derived neurotrophic factor, a neurotrophin linked to stress resilience, compared to piglets reared by sows in pens with frequent opportunities for positive human contact.

4.1.2 Housing and human-animal interactions

The impact of the lactation housing system on fear responses in pigs has received little attention, but it has been recently shown that piglets reared by sows in pens were more reactive to routine husbandry procedures, and were more fearful of novel and human stimuli during rearing and after weaning compared to piglets reared by sows in farrowing crates, both without nesting/foraging material (Hayes et al., 2021b; Lucas, 2022). The loose pens in these two studies had higher solid walls than the farrowing crates and thus less contact with stockpeople in the aisles and adjacent sows and piglets, and less stimulation in general may have contributed to the increased fear of novelty and humans in piglets reared by sows in pens. In another study, Kinane et al. (2021) found no effect of rearing piglets in farrowing crates compared to temporary confinement pens on fear of humans. However, the temporary confinement system in this study was similar in design to the farrowing crate system, and thus there was presumably little difference in stockperson contact and visual stimulation between the housing treatments, which is in contrast to the aforementioned research. Another factor in considering how the early housing system may impact fear responses in piglets, particularly towards humans, is that of stockperson behaviour. For example, stockpeople inexperienced with loose-housed sows may be less willing and confident interacting closely with sows in pens and therefore may use less positive and more negative tactile, auditory and visual interactions with sows which may increase the fear responses of both sows and piglets. Stockperson-directed aggression has been shown to be higher in sows housed in farrowing pens than farrowing crates (Marchant Forde, 2002).

While affecting pig welfare, the farrowing and lactation housing design may also affect the stockperson's work performance. There is evidence in the livestock industries that improved human–animal interactions may enhance job-related characteristics, such as job satisfaction, motivation and commitment, thereby potentially improving the stockperson's job performance (Hemsworth and Coleman, 2011; Hemsworth et al., 2018). Therefore, if the stockperson's attitude towards interacting with farrowing and lactating sows is negative as a consequence of sow handling difficulties, personal safety issues and inexperience (Marchant Forde, 2002; Baxter and Edwards, 2022), the stockperson's job satisfaction and commitment is likely to deteriorate with adverse consequences on work motivation and commitment and consequently work performance.

A negative human–animal relationship, primarily through fear and stress, can impair animal welfare with negative consequences on the animal's productivity, health, and welfare (reviewed in Hemsworth, 2003; Hemsworth et al., 2018). While the benefits of a positive human–animal relationship from the animal's perspective are poorly understood, there is a growing body of evidence that positive handling may enhance the welfare of farm animals. Some authors have proposed that positive human contact may provide a source of enrichment that confers stress resilience for farm animals (and indeed other domesticated and zoo animals) in challenging situations (reviewed in Hemsworth, 2003; Marchant-Forde, 2009;

Hemsworth et al., 2018; Rault et al., 2020). In addition to reducing the short-term stress associated with husbandry practices imposed by humans, positive handling may also endow an ongoing positive affective state with broader stress resilience.

There is evidence in some species that the age at which handling occurs is influential. Human contact of a positive nature during early life or at weaning has been shown to have persistent effects on fear of humans in many animals, including pigs (reviewed in Hemsworth et al., 2018). Our recent research has shown that brief regular positive human contact with piglets from 0-4 weeks of age reduced their fear of humans at 3, 6, 9 and 14 weeks of age (Lucas, 2022). Our research has also shown that brief regular positive human contact with piglets improves their resilience to stressors during lactation and after weaning: positive handling of piglets during lactation reduced their reactivity to husbandry procedures including vaccination and piglet processing, fear responses to novelty, and the cortisol response to weaning and isolation (Hayes et al., 2021b; Lucas, 2022). Positive handling of piglets also reduced injuries during lactation, and furthermore, piglets reared in farrowing crates with only routine human contact had considerably lower brain-derived neurotrophic factor concentrations during lactation compared to piglets reared with positive human contact in pens (Lucas, 2022). In an earlier study, Muns et al. (2015) showed that positive handling of piglets on the first day of life reduced escape behaviour in piglets during tail docking on the subsequent day.

These recent studies on early positive handling of piglets involved positive handling in terms of gently patting, stroking and scratching piglets that approached the handler, although a small proportion of the handling bouts involved handling piglets that were sleeping. Forced handling of piglets which involved capturing, holding and stroking piglets during lactation, has been shown to reduce fear of humans, increase play behaviour and reduce vocalisations in a novel arena, and increase body weight at 12 weeks of age (de Oliveira et al., 2015; Zupan et al., 2016).

The literature on early handling of rodents is very extensive and these studies involving the brief removal of pre-weaned animals from their home cages and the associated handling generally report increased growth and accelerated development, reduced activity and defecation in open-field tests, improved performance in learning tasks, and physiological stress responses of a lower magnitude to subsequent stressors (Dewsbury, 1992). These results have often been interpreted as a consequence of either direct stimulation or acute stress advancing the rate of development of some behavioural and physiological processes (reviewed in Schaefer, 1968). Extrapolating these findings to the development of behavioural and physiological processes in the pig should be done cautiously because the brain develops earlier in relation to birth in the pig than in the rat (Merat and Dickerson, 1973). Nevertheless, the effects of early handling, including those on the fear of humans, may not necessarily be due solely to handling *per se* but may, in part, be a consequence of acute stress early in life associated with the separation and handling involved in the handling treatment, maternal care after handling, and perhaps also early weaning in some studies (reviewed in Hemsworth et al., 2018). Similarly, the effects of early handling on pigs in the studies by de Oliveira et al. (2015) and Zupan et al. (2016) may be a consequence of acute stress early in life associated with brief removal of the sow from the farrowing pen and capture of the piglets as well as handling of the piglets in the form of stroking and maternal care after handling.

Therefore, there is emerging evidence that brief regular positive human contact with piglets improves the resilience of pigs to stressors during lactation and later in life. However, an understanding of human contact of a rewarding nature for piglets and the nature of stockperson tactile and visual contact associated with routine husbandry practices is critical in minimising risks to pig welfare and optimising the opportunity for positive affective experiences. Furthermore, while positive human handling of piglets may provide a source of enrichment for piglets, the impact of this on the sow or indeed positive handling of the sow during lactation on subsequent sow welfare are unknown and warrant investigation.

4.1.3 Space, nesting/foraging material and group lactation

There is also evidence that floor space and nesting/foraging materials during rearing may affect post-weaning social behaviour, but some of the findings are contradictory. For example, housing sows in standard farrowing crates (0.6 x 1.6 m) in pens (1.6 x 2.5 m), enriched farrowing crates (2.2 x 1.4 m) in pens with more space (2.2 x 2.0 m, 20% more) and straw, and farrowing pens with substantially more space (2.5 x 1.9 m, 60% more) and straw had no effect on piglet aggression and injuries after mixing at weaning (Chaloupková et al., 2007). Kutzer et al. (2009) found that pigs reared by sows in farrowing crates had more injuries that those reared by sows in pens at 4 days after weaning, based on higher injury scores 3 days post-weaning, than piglets reared by sows in farrowing crates provided daily with straw postpartum (Martin et al., 2015). However, between 3-7 days post-weaning, the lesion scores of piglets reared by sows in pens had dramatically reduced while lesion scores were sustained in the piglets reared by sows in farrowing crates, suggesting less chronic aggression in the former piglets from 3-7 days post-weaning. In the study by Hayes et al. (2021b), rearing piglets by sows in farrowing crates or pens, both without nesting/foraging material, had no effect on aggression in the first 26 hours post-weaning and injuries at 2 days post-weaning. In contrast in a subsequent experiment, piglets reared by sows in farrowing crates displayed more aggression in the first 30 minutes after weaning, but not the second 30 minutes after weaning, than piglets reared by sows in pens, both without nesting/foraging material (Lucas, 2022). However, injuries were not affected 1 week post-weaning. While the findings on the effects of housing during rearing on aggression and injuries of pigs post-weaning are contradictory, there is little evidence that lactation housing affects the physiological stress response of piglets to weaning. In comparison to piglets reared by sows in loose pens without nesting/foraging material, piglets reared by sows in farrowing crates without nesting/foraging material had similar concentrations of cortisol at 1.5- and 49-hours post-weaning (Hayes et al., 2021b; Lucas, 2022), but lower concentrations at 2 hours post-weaning (Lucas, 2022).

One of the challenges in examining effects of lactation housing on pig welfare post-weaning is understanding the impact of a mismatch in housing conditions that pigs can experience before and after weaning. The welfare of pigs reared in an enriched environment and then moved to a more barren environment appears to be worse than pigs housed continuously in a barren environment (Day et al., 2002; Luo et al., 2020). Therefore, housing in enriched lactation pens pre-weaning may result in greater stress post-weaning if pigs experience a dramatic downgrade in the quality of housing conditions after weaning. This is discussed in more detail in a recent review on longer-term impacts of the pig's early environment (Lucas et al., 2023).

To the best of the authors' knowledge, there has been only limited research conducted on the effects of positive handling of sows during gestation. Daily positive handling, involving a feed reward, gentle touching of and softly talking to sows individually late in gestation, did not affect nesting behaviour and activity around parturition, nursing behaviour, farrowing duration, piglet mortality or piglet weight gain in comparison to routine human contact during this period (Andersen et al., 2006). Daily positive handling, involving daily patting and scratching of gestating sows in pens did not affect farrowing rate or the number of piglets born alive, stillborn or weaned in comparison to sows that received routine human contact (Hayes et al., 2021a).

There is consistent evidence that social experience with unfamiliar piglets during lactation may be beneficial for piglets when mixed with unfamiliar pigs at weaning. In comparison to piglets reared by sows in farrowing crates, piglets reared by sows in multi-litter group lactation systems both with and without nesting/foraging material, were less aggressive and displayed more play behaviour and less damaging oral manipulation post-weaning (including tail biting and ear biting) than piglets reared by sows in farrowing crates (Li and Wang, 2011; Bohnenkamp et al., 2013; Van Nieuwamerongen et al., 2015; Verdon et al., 2016; Verdon et al., 2020). Furthermore, piglets reared by sows in multi-litter group lactation systems fought less and had fewer skin lesions post-weaning and a lower increase in cortisol concentrations from pre-weaning to post-weaning, than piglets reared in single litter farrowing systems in which the sow was either crated or loose (Grimberg-Henrici et al., 2018; Lange et al., 2020). Providing piglets housed in farrowing crates with enrichment objects, such as ropes and rubber objects, and social experience by removing the barrier between two adjacent pens to allow co-mingling of pairs of litters, has also been shown to reduce aggression, skin lesions and salivary cortisol, chromogranin A and α-amylase on days 1 and 2 post-weaning (Ko et al., 2021). However, some of these comparisons of housing systems are confounded by space allowance in the multi-litter group lactation systems. There is also evidence that piglets reared by sows in multi-litter group lactation systems are less aggressive towards unfamiliar piglets in a social confrontation test than piglets reared by sows in farrowing crates (Hillmann et al., 2003). It has been suggested that piglets housed in large multi-litter group lactation systems may adapt to be more tolerant of unfamiliar pigs (Van Nieuwamerongen et al., 2014), and the increased space and environmental complexity may improve their social development by enabling the expression of more submissive behaviour (Lammers and Schouten, 1985) and play behaviour (Bolhuis et al., 2005; Oostindjer et al., 2011). Verdon et al. (2016) also suggested that socially experienced piglets appear better able to recognise their fighting ability relative to others and thus form a dominance hierarchy more quickly and with less aggression.

While there is considerable evidence that piglets reared in multi-litter group lactation systems are less aggressive when mixed with unfamiliar piglets at weaning, recent research has shown that in comparison to farrowing crates, multi-litter group lactation increased piglet mortality and injuries after mixing during lactation (Verdon et al., 2020). Thus, the negative consequences of mixing occur at a different stage (lactation) rather than being reduced or prevented altogether. Furthermore, sows in multi-litter lactation groups also had higher cortisol concentrations and injuries after mixing during lactation (Grimberg-Henrici et al., 2018; Verdon et al., 2020).

There is also evidence that providing piglets with opportunity to explore, forage and socialise may affect post-weaning health outcomes, including immune responses and gut health. The combination of environment enrichment, such as foraging materials, co-mingling with other litters and increased space, positively affect the development of the immune system and the establishment of gut microbiota (van Dixhoorn et al., 2016; Wen et al., 2021; Gavaud et al., 2023).

These behavioural studies indicate that both loose housing of sows accompanied by more floor space for piglets and provision of enrichments, such as nesting/foraging materials, increase play behaviour and reduce piglet-directed oral manipulative behaviours in piglets during lactation. While there is consistent evidence that multi-litter group lactation systems reduce aggression in piglets when mixed with unfamiliar piglets at weaning, recent evidence indicates increased stress and skin injuries in lactating sows after mixing during lactation than in sows remaining in farrowing for the entire lactation. Positive human contact during lactation may also provide a source of enrichment for piglets as well as sows. More research is needed on how farrowing and lactation housing systems impact the development of fear responses in young pigs, as well as the longer-term impacts of early housing on pig aggression and injuries.

4.2 Piglet mortality

Piglet mortality continues to be a major welfare and economic concern (Baxter and Edwards, 2021). In general, there have been no significant improvements in piglet mortality over the last three decades, with total mortality (i.e., stillborn and live-born deaths) per litter averaging between 16% and 20% (Baxter and Edwards, 2018), and therefore piglet mortality continues to be a significant risk to piglet welfare (Baxter and Edwards, 2021). While there is some discussion about the welfare implications of mortality *per se*, many causes of piglet mortality are a welfare concern as they are associated with noxious subjective experiences such as breathlessness (crushing), weakness and hunger (starvation) and pain (physical trauma) (Edwards, 2002; Mellor and Stafford, 2004). The majority of piglets that do not survive to weaning die within the

first 3-4 days of life and the main cause is attributed to crushing and weakness/starvation (Dyck and Swierstra, 1987; Marchant et al., 2000). As some have argued (e.g., Baxter and Edwards, 2018), the least welfare concerns relate to those piglets that never develop full breathing (i.e., never gain full consciousness because they die during parturition or immediately after), intermediate welfare concerns relate to piglets that develop full breathing but descend quickly into hypothermia (and thus a reduced level of consciousness), and high welfare concerns relate to piglets that develop full breathing, are not hypothermic, but suffer deaths from crushing, hunger, injury or disease. It is this third group of piglets that have the potential to suffer and for a considerable period. There is considerable variability in pre-weaning piglet mortality in loose farrowing and lactation housing systems (Baxter et al., 2012; Moustsen et al., 2013; EFSA et al., 2022), presumably partly due to variability in management and housing design features and differences in genetics, and the mortality of live-born piglets in loose farrowing and lactation systems is usually higher than that in farrowing crates. A meta-analysis of published research on the effects of farrowing and lactation housing on piglet mortality found that the relative risk of pre-weaning mortality was 14% higher in pens when compared with farrowing crates (Glencorse et al., 2019). A recent review of pig welfare made the following conclusions based on expert opinion and existing literature, using quantitative or qualitative criteria (EFSA et al., 2022). It was concluded that pens with temporary confinement, with an average of $4.5m^2$ – $6.3m^2$ available to the sow and a minimum period of confinement of 7 days after farrowing, could achieve the same level of piglet survival as a permanent crating system. Data from various published sources on preweaning mortality from European countries showed that piglet mortality increases by 24% for sows in pens compared to sows in farrowing crates (EFSA et al., 2022, pg. 154).

The importance of management by stockpeople on piglet welfare and mortality has been recognised by many authors. For example, because most deaths occur around the time of farrowing and during the first few days of life, Kirkden et al. (2013) listed the following management interventions to reduce piglet mortality: (1) a number of the procedures used to assist piglet welfare and survival require a stockperson to be present during and immediately after farrowing; (2) supervision in general but particularly those methods for the treatment of dystocia and programs of piglet care, such as fostering; and (3) the need for good stockmanship, which consists of not only technical skills but also positive attitudes and behaviour towards pigs and working with pigs. Rosvold et al. (2017) found in a survey of 52 Norwegian commercial herds that piglet mortality was related to several management factors, including stockpeople attending farrowings and at least twice daily positive interactions in terms of tactile and auditory contact with sows in farrowing pens. High levels of fear of humans have been reported to be associated with longer durations of farrowing and longer inter-piglet birth intervals (Janczak et al., 2003) and an increased incidence of piglets stillborn (Hemsworth et al., 1999), crushed (Lensink et al., 2009), savaged (Forde, 2002), and dying without milk in their stomach (Janczak et al., 2003). Furthermore, in relation to housing, management interventions intended to reduce piglet mortality are easier in farrowing crates than loose farrowing and lactation systems (Baxter et al., 2018).

Since the majority of live-born piglet mortality occurs in the first few days of lactation (Marchant et al., 2000; Johnson and Marchant-Forde, 2009), there is interest in brief confinement of sows during parturition and early lactation for two reasons: improving piglet welfare and improving productivity through minimising live-born piglet deaths. During nest building, the activity level of the sow increases, whereas in early lactation the activity level of the sow is generally low, and her behaviour is characterised by prolonged (over 75% of observation time) lying, particularly laterally lying (Jensen, 1986; Cronin et al., 1994; Weary et al., 1996; Baxter et al., 2011; Danholt et al., 2011; Nicolaisen et al., 2019). As discussed earlier (Sections 2.1. and 2.2), the welfare implications of an increased short-term stress response around parturition in farrowing crates are uncertain, the effects of housing system on physiological stress of farrowing sows are contradictory, and sows appear to show some adaptation through prior experience of farrowing in a crate. Therefore, confinement of the sow in early lactation may not be a serious risk to her welfare. However, this clearly requires further research.

Experiments utilising several pen systems with an option to confine sows in crates have examined the effects of confining sows before, during and after farrowing on piglet mortality. Danish researchers have shown that brief confinement of sows around parturition and in early lactation, when the risk of piglet mortality is greatest, can be effective in limiting live-born piglet mortality in this period to rates similar to those achieved with continuous confinement in crates. The results of studies by Moustsen et al. (2013) and Hales et al. (2015b) demonstrated that crating sows for 4 days postpartum was sufficient to reduce live-born piglet mortality in comparison to pen housing. Hales et al. (2015a) however, found that while confinement for the first 4 days of lactation reduced piglet mortality in this period, the lowest live-born piglet mortality to weaning was achieved when sows were confined before farrowing (day 114 of gestation) and for 4 days after farrowing. This study also suggests that live-born piglets are at risk during the farrowing process and highlights the importance of confinement from the time of the birth of the first to the last piglet. Sows that were temporarily confined from 5 days prior to expected parturition until 3 or 7 days postpartum had similar live-born piglet mortality compared to those continuously confined in a farrowing crate (Condous et al., 2016). Similarly, Heidinger et al. (2022) found that confining the sow from 1 day prior to expected parturition until 3 days postpartum reduced live-born piglet mortality relative to pen housing during this period. However, confinement from the end of parturition until 3 days postpartum and confinement from 1 day prior to expected parturition until 5 days postpartum were also as effective, relative to pen housing. In a recent comprehensive review of the scientific literature on temporary confinement of sows, Goumon et al. (2022) concluded that temporary confinement appears beneficial in reducing piglet mortality relative to pen housing. The authors also conclude that there are short-term benefits for sows based on reported increases in motivated behaviours, such as exploration and interactions with piglets, when not permanently crated, but noted that it is uncertain whether the observed short-term benefits translate to other improvements to sow welfare. The scientific opinion by the

European Food Safety Authority (EFSA et al., 2022) also highlights the potential benefits of temporary confinement of sows in reducing piglet mortality relative to pen housing.

In a New Zealand study, Chidgey et al. (2015) found that total mortality of piglets prior to weaning was higher in sows in temporary crating from day 112 of gestation (3 days prepartum) until 4 days postpartum than sows in conventional farrowing crates. A greater proportion of piglets aged 4 days or older were found to have died after sows were released from confinement in temporary crating than in farrowing crates. In an UK study, King et al. (2019) found that the period following crate opening in temporary confinement was a high-risk time for piglet mortality, presumably due to accidental crushing by the sow. However, increases in piglet mortality after crate opening were reduced by opening crates individually rather than simultaneously, and particularly in the afternoon. The authors concluded that sow habituation to disturbance before crate opening may have reduced post-opening piglet mortality, perhaps by reducing the difference in pre- and post-opening sow behaviour patterns.

The temporary crating systems that have been studied to date vary in pen size and shape (reviewed in Goumon et al., 2022). The only study that the authors are aware of that has examined the effects of pen size of temporary crates found no effects on live-born piglet mortality in five different pen types (Heidinger et al., 2022). These five different pen types provided similar conditions for piglets, such as protection rails and creep area, but total floor space varied from 5.5–7.3 m^2. Some attempts have been made to qualitatively determine minimum pen size by considering physical sow size, posture and behaviour during different phases of parturition. The greatest requirement for space occurs during the nest building phase, assuming the sow is loose at this time, and was calculated to be at least 4.9m^2 to enable turning, activity and separation of nesting from the dunging area. Sows need 2.79m^2 during parturition to lie comfortably on their side, and 3.17m^2 in early lactation to enable nursing, turning around to inspect piglets, get up and lie down unimpeded and defecate away from the lying area (Baxter et al., 2011; Baxter et al., 2018). These values are based on the original biometric equations to determine space requirements developed in the early 1980s (e.g., Petherick, 1983). More recently, the physical dimensions of crossbred Danish sows were measured by Moustsen et al. (2011) and again years later by Nielsen et al. (2018), with no apparent change in sow size between these two publications. This information was used to update the recommended space requirements of sows during farrowing and lactation (Baxter et al., 2018). A more recent review by Baxter et al. (2022) emphasised the importance of the quality of space also, in terms of pen design and functionality and enabling the expression of fundamental behaviours including locomotion, nest building, and sow-piglet interactions.

Baxter et al. (2018) considered that while temporary confinement systems are the least costly, least risky 'alternative' to farrowing crates, they offer less in the way of improving sow welfare compared to loose farrowing and lactation housing systems. It was further suggested that as temporary confinement systems tend to have a smaller footprint than farrowing and lactation pens and lack design features, such as space, to promote good maternal behaviour, it is likely that when operated with the sow completely free, piglets will be at risk of crushing resulting from a combination of poor maternal behaviour and limited space. However, the studies reported earlier generally indicate that temporary confinement of sows in crates around parturition and early lactation may be an effective strategy in reducing live-born piglet mortality to weaning in comparison to loose housing. While Chidgey et al. (2017) reported increased mortality in piglets aged 4 days or older after sows were released from confinement, Hales et al. (2015b) reported reduced live-born piglet mortality to weaning when sows were confined prepartum to 4 days postpartum and King et al. (2019) showed that management practices to reduce sow disturbance around releasing sows from confinement can be effective in reducing piglet mortality at this time.

Therefore, research to date indicates that short-term temporary confinement may offer considerable opportunity to reduce the risk of live-born piglet mortality in early life associated with continuous loose housing of the sow, while simultaneously improving welfare outcomes for sows. However, research examining both the short- and long-term effects of the design and management of temporary sow confinement on sow and piglet welfare is clearly required.

5 Conclusions

The scientific literature indicates that continuous housing in both farrowing crates and loose pens with or without enrichment has welfare advantages and disadvantages because of the conflicting needs of sows and piglets. Farrowing crates can safeguard piglet welfare by limiting live-born piglet mortality in early life. However, farrowing crates have a number of disadvantages with respect to sow and piglet welfare during other stages of lactation.

There is consistent evidence in gilts, but not sows, that prepartum introduction to farrowing crates results in a greater short-term cortisol response than introduction to pens. The welfare consequences of this acute stress response are unclear, since a short-term cortisol response at this time is implicated in a variety of roles during pregnancy, including initiating parturition. While studies on gilts and sows are scarce, two studies on gilts suggest housing in farrowing crates results in changes in the HPA axis consistent with sustained stress in the fourth week of lactation, and clearly further research is required on the effects of longer-term confinement on the stress physiology of gilts and sows.

Housing preparturient gilts and sows in farrowing crates without nesting/foraging material reduces pre-farrowing nest building behaviour. While it has been proposed that a function of nest building behaviour is to influence the course of parturition and thereby the survival of piglets, the consequence of reduced nest building behaviour in farrowing crates on piglet survival has not been well demonstrated. Nevertheless, restricting preparturient gilts and sows of opportunities to perform behaviours that appear to be highly motivated, such as nest building and freely interacting with their piglets, deprives pigs of the opportunity for positive affective experiences that presumably arise from such interactions. Furthermore, a more complex environment, through the provision of nesting/foraging materials and more floor space,

appears to be responsible for increased play and interactions with sows and less piglet-directed oral manipulative behaviours in piglets. Stockperson handling difficulties, personal safety issues and inexperience associated with the farrowing and lactation housing system may affect stockperson job satisfaction and thus work motivation and commitment, and consequently stockperson work performance.

Enrichment opportunities, such as provision of nesting/foraging material, are limited for confined gilts and sows, although there is recent evidence that positive human contact may provide a source of enrichment for piglets that confers stress resilience in both the short and long term. As an enrichment strategy, positive human interactions with pigs provide several advantages: they can potentially occur several times daily, can be combined with routine animal and facility checks, provide variability which will minimise habituation, and may not require additional physical enrichment resources, such as nesting/foraging material. Further research identifying human contact that is rewarding for piglets, particularly human contact that can be practically incorporated in routine animal husbandry practices including inspection, is critical in optimising the opportunity for positive affective experiences. While positive handling of piglets may provide a source of enrichment for piglets, the welfare implications of positive handling of piglets on the sow or indeed positive handling of the sow during lactation on the sow require further research.

There is also evidence that social experience during rearing affects post-weaning behaviour of the pig. Social experience with unfamiliar piglets in multi-litter group lactation systems reduces piglet aggression and injuries following mixing with unfamiliar piglets at weaning. However, there is evidence in group lactation systems of increased piglet mortality and injuries early post-mixing during lactation as well as increased injuries and cortisol concentrations in sows during this time. The effects of rearing piglets in pens with single loose housed sows on post-weaning behaviour are contradictory. Overall, a better understanding of how the early housing environment impacts pig welfare in the longer term is needed.

Continuous confinement of the farrowing and lactating sow is one of the most contentious and persistent welfare issues in livestock production. Recent research on temporary confinement of sows suggests that confinement briefly around farrowing may be the best compromise between continuous housing in farrowing crates and loose pens, by reducing the risk of piglet crushing while still providing opportunities later in lactation for more space for the sow, increased sow-piglet interactions, and improved social development of piglets during rearing, such as increased play and less piglet-directed oral manipulative behaviours. In conclusion, more comprehensive research examining both the short- and long-term welfare implications and practicality of less confinement of the sow and early positive handling of piglets is clearly required.

Author contributions

The conceptual work was led by PH with the support provided from LH, RG and AT. Review work and manuscript drafting by PH, LH, RG, ML, KC, and AT. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

Publisher's note

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