Managing alternative farrowing systems for optimised sow behaviour and piglet performance

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Abstract

Alternative farrowing systems encompass all indoor-based farrowing systems which provide extended periods of sow non-confinement to improve welfare.

As farms convert to alternatives, sows are often housed in different farrowing systems across parities. The first study utilised records from 753 sows on a farm using three farrowing systems - pens, crates or temporary crates - to determine if interchanging sows between systems increased piglet mortality. Total piglet mortality was lowest for sows who returned to the same system amongst pens and crates, confirming that farrowing system consistency is key to piglet survival.

The second study compared the farrowing behaviour, in a free farrowing pen, of 22 sows which had previously farrowed in either the same or a more confined system. Previously confined sows exhibited more posture changes during farrowing and subsequently showed a shorter average duration and a lower percentage of success during nursing bouts, indicating that sow nursing behaviour was impaired.

Temporary crates confine sows during farrowing and early post-partum, before being opened to provide additional space for the sow during lactation. The third study measured the impact of temporary crate opening on piglet mortality and sow behaviour amongst 416 sows, whilst trialling different crate opening procedures. Piglet mortality increased immediately after crate opening, and was reduced by opening crates within each farrowing house on an individual litter rather than batch basis.

During lactation, piglets are routinely cross-fostered between sows to facilitate piglet growth and survival. The final study compared sow behaviour and piglet weight gain after cross-fostering or sham-fostering amongst 48 crated and penned sows. Both foster piglet weight gain and successful nursing bout frequency were reduced to a greater extent amongst penned cross-foster litters.

The results will assist farmers in managing alternative farrowing systems, facilitating further commercial uptake and thus improving the welfare of sows and piglets.

Dedicated to my late father, Peter James King

Forever my biggest supporter, I know that this accomplishment would have mattered to you more than anyone

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List of Publications

Peer-reviewed publications

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Conference abstracts

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King RL, Baxter EM, Matheson SM, Edwards SA. 2018. Temporary crate opening procedure affects immediate post-opening litter mortality and sow behaviour. Proceedings of a symposium on Loose Lactating Sows 2018 (LLS18), 1-2 May 2018. Copenhagen, Denmark. Ed. V A Moustsen, SEGES, p313.

Ethical Statement on the Use of Animals

Experiments were approved under the Newcastle University Animal Welfare and Ethics Review Body, Approval 379 on 23rd June 2014.

Table of Contents

List of Tables

List of Figures

Chapter 1. General Introduction

1.1. The UK Pig Industry

The UK pig industry is fairly unique in structure, with effectively two separate industries involving either outdoor or indoor pig production. Whilst approximately 40% of breeding sows are housed extensively outdoors in individual paddocks with huts throughout farrowing and lactation, the other 60% are housed more intensively on indoor breeding units. Across Europe, it is estimated that 97% of breeding sows are housed indoors (Baxter and Edwards, 2016); almost all of which are accommodated in farrowing crates throughout each farrowing and lactation.

Over the past 15 years, whilst the number of breeding sows in the UK has decreased by 100,000 to approximately 400,000, the number of pigs slaughtered per annum has increased by one million to nine million (AHDB, 2018). These industry changes, which are reflective of many other Western countries, have occurred due to the genetic selection of sows to produce larger litter sizes at each farrowing as a means of increasing the efficiency and consequent profit margins of pig production. However, selection for larger litter sizes has had further implications for piglet and sow welfare, such as increasing piglet mortality and the need to cross-foster piglets between sows, as will be discussed in more detail in the literature review. Genetic selection for litter size at five days post-partum may be used to ensure the selection of dams with both large total born litter sizes and high rearing success (Su *et al.,* 2007). However, genetic selection of breeding sows in nucleus and multiplier herds only occurs in systems utilising farrowing crates. Thus, their progeny may have reduced rearing success if subsequently housed in a less confined farrowing system, requiring characteristics for which there has been no consideration during selection.

1.2. The Use of Farrowing Crates

Farrowing crates consist of metal bars forming a crate surrounding the sow whilst she is housed in farrowing accommodation, restricting sow movements to standing, sitting or lying in the same area. In the UK, farrowing crates were introduced during the 1960s (Robertson *et al.*, 1966), primarily to reduce piglet mortality from accidental crushing by the sow. Whilst originally utilised only during the first few days after parturition, when piglet mortality is most prevalent, the additional economic benefits of confining sows in farrowing crates meant their use was extended to the entirety of the lactation. These economic benefits remain today, such as a reduced floor space requirements per sow, greater safety and efficiency when handling animals and improved cleaning and sanitation capacities. However, there is now substantial evidence for the negative consequences of utilising farrowing crates on sow welfare outcomes (e.g. Jarvis *et al.*, 1997; Lawrence *et al.*, 1994).

1.3. Higher Welfare Farrowing Systems

Public perceptions about farm animal management are also a driving force for change. Growing numbers of consumers are becoming more aware of intensive farming practices, with more interest in and willingness to pay for products from animals which experienced higher standards of welfare throughout life (Napolitano *et al.*, 2010). One of the most important aspects of animal welfare for public acceptance is the freedom for animals to express their natural behaviours (Lassen *et al.*, 2006; Vanhonacker *et al.*, 2008); whilst the need to perform normal behaviours is described as one of the five basic needs that all captive animals should receive under the Animal Welfare Act (2006).

The UK is considered one of the global leaders in animal welfare, including protective legislation for farm animal welfare. For example, whilst the EU abolished the use of gestation crates (with the exception of a period of 28 days post-service) at the beginning of 2013, gestation crates were already legislated out of use in the UK by 1999. This move against close confinement has meant that the abolition of farrowing crates has become a hot topic for debate amongst farmers, farm animal charities and academics across Europe and beyond. Furthermore, farrowing crates have already been abolished in Sweden, Norway and Switzerland; meaning the UK would already be following their lead on improving sow welfare by prohibiting the use of farrowing crates.

1.4. Pre-Weaning Piglet Mortality

In their consideration of abolishing farrowing crates in the UK, the Farm Animal Welfare Committee (FAWC) – an expert, independent advisory committee for the British government – published an opinion on free farrowing systems (FAWC, 2016). Whilst the Committee agreed that transitioning to free farrowing should be the ultimate aim, it stated that further research is required to ensure the commercial viability of free farrowing, and especially to ameliorate the seemingly higher rate of piglet mortality in free farrowing systems. Despite this, some UK indoor breeding herds already utilise free farrowing systems, with varying degrees of success regarding pre-weaning piglet mortality rates.

Beyond research to reduce piglet mortality by perfecting the design of free farrowing pens, there is an additional focus on the role of sow farrowing and maternal behaviour. Sows display individual variation in behaviour during farrowing and lactation, with subsequent individual differences in piglet mortality (Wechsler and Hegglin, 1997). There is significant research describing sow farrowing and maternal behaviour across both extensive and intensive farrowing systems, whilst the details of which sow behaviours have the greatest effect on piglet mortality remain somewhat less conclusive. There is also little research regarding the best management practices for free farrowing systems in commercial settings, which should be developed to support sow farrowing and maternal behaviour in order to optimise piglet survival and performance in free farrowing systems.

1.5. Thesis Aims and Objectives

The central aim of this thesis is to provide scientific information necessary to facilitate greater commercial viability and uptake of existing higher welfare farrowing systems. To do this, the thesis will focus on how existing management practices – amongst free farrowing, traditional and temporary crating systems – affect both sow behaviour and piglet performance, in order to suggest and scientifically test promising improvements.

The starting point was to formulate an extensive review on the current literature of recognised sow behaviours which affect piglet mortality and the effect of different farrowing systems on these behaviours (Chapter two). This lead to identification of three management practices selected for scientific testing which were identified as likely to impact sow behaviour and piglet performance in higher welfare farrowing systems.

The first identified factor was sow experience. Commercial farms trialling free farrowing systems will often interchange breeding sows between the different farrowing systems from one parity to the next. However, this may disrupt the development of sow maternal behaviour, which develops over a number of farrowings. The objective of study one (Chapter three) was to test the hypothesis that sows which return to the same farrowing system will have lower piglet mortality than sows which have been interchanged between systems. Furthermore, the objective of study two (Chapter four) was to compare the free farrowing behaviour of sows previously housed in either the same or a different farrowing system.

The second identified factor was crate opening. Whilst not considered a true free farrowing system, temporary confinement systems, in which the sow is confined to a crate for farrowing and a few days post-partum before being released into a loose pen, improve sow welfare by minimising the duration of sow confinement. However, there are anecdotal reports that when temporary crates are opened, piglet mortality increases significantly. The objective of study three (Chapter five) was to quantify piglet mortality risk at different time points throughout lactation in a temporary crate system; and to determine the effect of different crate opening procedures on sow behaviour and piglet mortality.

The third identified factor was cross-fostering. Whilst cross-fostering, the exchange of new-born piglets between different litters, is common commercial practice amongst confined sows, the increased capability to perform characteristic maternal protectiveness may impede the effectiveness of cross-fostering amongst free farrowing sows. The objective of study four (Chapter six) was to determine the effects of late cross-fostering, performed when the piglets were a few days old, on sow behaviour and subsequent piglet growth in both farrowing crates and a free farrowing pen system.

Chapter 2. Literature Review

2.1. Piglet Mortality

2.1.1. Scale of piglet mortality

According to the Agriculture and Horticulture Development Board (AHDB, 2018), average total pre-weaning piglet mortality for indoor farms in the UK is currently 17.1%, consisting of 11.7% and 5.4% for live-born and stillborn piglet mortality, respectively. With around 240,000 indoor breeding sows and gilts – 60% of the total breeding animal population – producing an average of 30.8 piglets per sow per annum (AHDB, 2018), this equates to over 1.2 million piglets lost before weaning each year across UK indoor breeding herds alone.

However, piglet mortality rates also vary significantly between different farms. For example, the Australian Pig Manual (Australian Pork Limited, 2012) states farrowing house piglet mortality ranges from 5.0% to 16.8%, whilst a recent survey of 146 French farms by Pandolfi *et al.* (2017) found total pre-weaning piglet mortality to range from 5.2% to 40.1%. To further understand the basis for such variation, in order to successfully reduce pre-weaning piglet mortality, the different causes and known contributory factors must first be ascertained.

2.1.2. Main causes of piglet mortality

Whilst piglet mortality varies significantly between farms, the same predominant causes are responsible for the majority of pre-weaning piglet mortality. Firstly stillborn piglets, where death occurs shortly before or during parturition, represent one of the biggest categories, accounting for 30-35% of total born piglet mortality (KilBride *et al.*, 2012; Weber *et al.*, 2007; AHDB, 2018).

Within live-born piglet mortality, the main causes are usually described as crushing, starvation and hypothermia. A 2017 report from the Teagasc National Pig Farmers' Conference (Teagasc Pig Development Department, 2017) stated the top two causes of live-born mortality as crushing and starvation due to low piglet viability, whilst the 2015 report commissioned by the Swedish government cited hypothermia, malnutrition and trampling by the sow as the main causes of piglet mortality (O'Dwyer, 2015). Another study by Westin *et al.* (2015a) reported the top three causes of piglet mortality as starvation (34%), crushing (28%) and enteritis (24%), whilst Andersen *et al.* (2011) reported crushing (56%) followed by starvation (26%) as the top two causes of live-born piglet mortality. Both Hales *et al.* (2013) and

KilBride *et al.* (2012) also reported crushing as the main cause of piglet mortality (60% and 55%, respectively), followed by low piglet viability (25% and 14%, respectively).

Whilst less common, piglet mortality can also occur from piglets being attacked and bitten by the sow, termed savaging. Savaging can occasionally account for up to 25% of live-born piglet mortality (Cronin *et al.*, 1996) and, whilst savaging can occur at any time throughout farrowing and lactation, it predominantly occurs during the early stages of parturition (Ahlström *et al.*, 2002). Other less common causes of piglet mortality include birth defects such as splay legs, infectious diseases amongst piglets and poor sow health (Teagasc Pig Development Department, 2017).

2.1.3. Known contributory factors

Piglet mortality results from a complex relationship between the piglets, the sow and the environment (Edwards, 2002), therefore contributory factors associated with piglet mortality can be classified into three categories – piglet-based, sow-based and environmental factors (Muns *et al.*, 2016). An awareness of which factors are already understood to significantly affect piglet mortality facilitates the inclusion of these effects in statistical models in research studies and a focus on them in farm improvement strategies.

Piglet-based factors

The three predominant causes of live-born piglet mortality – crushing, starvation and hypothermia – are often inter-related (Edwards, 2002). This is especially true during the early post-partum period, where piglets are at high risk of hypothermia as they are born wet and possess a small body size. This risk has been exaggerated by selective breeding for larger litter sizes, resulting in more piglets being born with an initial low birth weight (Wolf *et al.,* 2008), whilst a lower birth weight is associated with a lower post-partum piglet body temperature (Caldara *et al.,* 2014; Kammersgaard *et al.,* 2011). Mild hypothermia also decreases piglet vitality, further increasing the risk of crushing and/or starvation (Edwards, 2002), whilst many piglets which ultimately die from crushing are often found to be malnourished. For example, whilst Hales *et al.* (2013) only attributed 1% of live-born piglet deaths to starvation, post-mortem examinations found 68% of the live-born deceased piglets had little or no milk in their stomachs.

Low piglet viability is also reported as a cause of piglet mortality, however low viability increases the susceptibility to other causes of piglet mortality. Low viability piglets are born with an exceptionally small body size, often showing signs of pre-partum growth restriction (Hales *et al.*, 2013). Piglets born small are more likely to be stillborn (Canario *et al.*, 2006) or to die during lactation (Hales *et al.*, 2013; Panzardi *et al.*, 2013; Galiot *et al.*, 2018) as they are less able to maintain their core body temperature, exhibit a longer latency to the first colostrum intake (Caldara *et al.,* 2014) and may have under-developed immune systems (Muns *et al.*, 2016). Small piglets are also less able to compete with their larger littermates at the udder, leading to a further reduced vitality and an increased risk of hypothermia, starvation, crushing and infectious diseases. The poor survival outlook for such piglets means that some farms routinely euthanise them shortly after birth.

Piglets may also exhibit reduced vitality for other reasons, such as from hypoxia during the birth process. Hypoxia during birth may slow post-partum recovery, and piglets exhibiting reduced vitality at birth have an increased risk of pre-weaning mortality (Panzardi *et al.*, 2013; Baxter *et al.*, 2008). Litters with a higher rate of stillbirths also exhibit increased live-born piglet mortality (Kilbride *et al.*, 2012), indicating that amongst litters where stillbirths occurred, mild hypoxia of live-born piglets during parturition may be a prevalent underlying factor for live-born piglet mortality attributable to secondary causes.

Sow-based factors

One of the most significant factors for higher piglet mortality is increasing total born litter sizes, caused by genetic selection to promote this trait amongst nucleus herd breeding sows, with a larger total born litter size associated with an increased prevalence of stillbirths (KilBride *et al.*, 2012), crushing (Weber *et al.*, 2009) and starvation (Rutherford *et al.*, 2013). A larger litter size often means a longer total farrowing duration, whilst a positive association exists between both the inter-piglet birth interval and total farrowing duration with the incidence of stillborn piglets (van Dijk *et al.*, 2005; Oliviero *et al.*, 2010). A longer inter-birth interval also increases the risk of hypoxia during birth (Herpin *et al.*, 1996), reducing piglet vitality and increasing the aforementioned risk of mortality from secondary causes. Larger total born litter sizes also increase the incidence of low viability piglets born with a low body weight, and increases the within-litter variation in piglet body size (Quesnel *et al.*, 2008), further decreasing the competitiveness and survivability of small piglets born within a large litter. After litter equalisation for piglet number and size, larger litter sizes throughout lactation continue to be associated with increased piglet mortality (KilBride *et al.*, 2012; Hales *et al.*, 2013). Thus, breeding sows in Danish nucleus herds are selected for their litter size at five days post-partum (Su et al., 2007), ensuring piglet survival traits and sow maternal ability are also selected for instead of total born litter size in isolation.

Sow parity is another recognised factor affecting piglet mortality outcomes. First parity primiparous sows (gilts) are often reported to have higher piglet mortality (Hales *et al.*, 2013; Wülbers-Mindermann *et al.*, 2002), especially mortality caused by sow savaging behaviour (Harris and Gonyou, 1998; Chen *et al.*, 2008). However, increased savaging amongst gilts is confounded by the fact that some farms cull sows which savaged their piglets before the subsequent farrowing (Marchant Forde, 2002). Older sows, typically categorised as fifth parity and older, have greater piglet mortality from stillbirths (KilBride *et al.*, 2012; Canario *et al.*, 2006) and crushing (Rangstrup-Christensen *et al.*, 2018; Weber *et al.*, 2009). The larger mass and weight of older parity sows would increase both the risk and severity of piglet crushing during posture changes, whilst the reduced mobility often seen amongst older sows may make posture changes more difficult and means sow posture is changed less frequently (Ostović *et al.*, 2012). Older sows may also have fewer functional teats, which are less accessible and a reduced milk yield (Devillers *et al.*, 2007; Vasdal and Andersen, 2012). Furthermore, older parity sows tend to have larger total born litter sizes (French *et al.*, 1979), thus increasing the mortality risk associated with this factor.

Sows also show individual variation in the expression of maternal behaviours shown to result in differences in piglet mortality (Wechsler and Hegglin, 1997; Andersen *et al.*, 2005; Ocepek and Andersen, 2017), with these behaviours discussed in more detail in later sections. These individual differences in maternal behaviour can result from genetics (e.g. Baxter *et al.*, 2011a), sow parity (Cronin *et al.*, 1993; Jarvis *et al.*, 2001) or previous farrowing experience (e.g. Thodberg *et al.*, 2002a, 2002b). Sow maternal behaviours are also affected by the farrowing environment, including the farrowing system (to be discussed below), the availability and type of nesting materials (e.g. Yun *et al.*, 2013, 2014a, 2014b, 2015) and the season when farrowing occurs (Jensen, 1989).

Environmental factors

The ambient temperature in the farrowing accommodation will impact piglet mortality if too extreme. Farrowing houses which are too cold can increase the risk of hypothermia and subsequent starvation or crushing (Pedersen *et al.*, 2013), whilst farrowing houses which are too hot may also increase the incidence of stillborn piglets (Vanderhaeghe *et al.*, 2010). Piglet mortality may (Weber *et al.*, 2009) or may not (Pandolfi *et al.*, 2017) be affected by the season at birth. However, as the ambient temperature is artificially controlled in most commercial farrowing houses, seasonal temperature variations are minimised on most farms. Sow feed intake, and therefore nursing capacity, are reportedly compromised in hotter ambient temperatures (Black *et al.*, 1993) which could impact piglet mortality, whilst total born litter sizes (Tummaruk *et al.*, 2004) and the prevalence of stillborn piglets (Rangstrup-Christensen *et al.*, 2018) also exhibit seasonal variations, peaking when gestation occurs through the cooler months and when farrowing occurs in the summer, respectively.

There is also evidence of diurnal variations, as sows which farrow during the day have more stillborn piglets than those which farrow at night (Pandolfi *et al.*, 2017), whilst sows which started farrowing in the morning had higher piglet mortality from starvation than sows which started farrowing in the evening (Pedersen *et al.*, 2006). However, mortality differences were probably caused by increased human activity and/or disturbance in the farrowing accommodation during the day-time, rather than by diurnal cycles of temperature, natural light or artificial light.

Additional management practices performed at parturition can reduce piglet mortality, such as increased supervision, drying of piglets and placing piglets in the heated creep (Andersen *et al.*, 2009; Kirkden *et al.*, 2013). Arguably the most significant environmental factor affecting piglet mortality is the type of housing system used throughout farrowing and lactation. The section below will describe the three predominant indoor farrowing systems of commercial interest, followed by a comparison of the prevalence and causes of piglet mortality.

2.2. Indoor Farrowing Systems

As the name suggests, in indoor farrowing systems sows are housed in farrowing accommodation throughout farrowing and lactation. Housing farrowing sows separately from the gestation herd facilitates more efficient human supervision and biosecurity measures during this critical time. Pregnant sows are moved into the farrowing accommodation approximately five days before their expected farrowing date, remaining there until the piglets are weaned at four weeks of age. The farrowing accommodation must also accommodate the piglets, therefore farrowing systems will often include additional features such as heat lamps, piglet resting areas (creeps) and pen structures to minimise piglet crushing, which differ between farrowing systems. There are three predominant indoor farrowing systems of commercial interest globally: conventional farrowing crates, free farrowing pens and temporary confinement crates.

2.2.1. Conventional farrowing crates

Conventional farrowing crates consist of metal bars surrounding the sow whilst she is housed in a farrowing pen, restricting sow movements to standing, sitting or lying in the same area of the pen (Figure 2.1). In the UK, farrowing crates were introduced during the 1960s (Robertson *et al.*, 1966), primarily to reduce piglet mortality from accidental crushing by the sow. Whilst originally utilised only during the first few days after parturition, when the majority of live-born piglet mortality occurs (Marchant *et al.*, 2000; KilBride *et al.*, 2012), the additional economic and practical benefits of confining sows in farrowing crates meant their use was extended to the entirety of each lactation. These benefits remain today, such as a reduced floor space requirement per sow, greater stockperson safety and efficiency when handling animals, and improved cleaning and sanitation capacities. Thus, conventional farrowing crates remain the predominant indoor commercial farrowing system across the globe.

However, confinement induces an acute stress response amongst sows, shown by both behavioural and physiological stress indicators, such as increased restlessness, bar-biting and higher plasma cortisol (e.g. Jarvis *et al.*, 1997; Lawrence *et al.*, 1994). Commercially, farrowing crates are typically used without providing any manipulable materials. This can be particularly distressing for sows during the pre-partum period, as the motivation to perform nest-building behaviours before giving birth cannot be fulfilled (Yun and Valros, 2015; Damm *et al.*, 2003). Sows also show physiological stress responses to prolonged confinement throughout lactation, with plasma cortisol concentrations higher amongst confined than unconfined sows at the end of lactation (Cronin *et al.*, 1991).

Figure 2.1. Image of a sow in a conventional farrowing crate.

2.2.2. Free farrowing pens

Free farrowing pens provide a much larger pen space for each sow, without any form of close confinement, meaning that the movements and behaviours of the sow are unrestricted throughout the farrowing period (Figure 2.2). Farrowing pens are also routinely managed with provision of manipulable nesting materials during the pre-partum period, and often throughout farrowing and lactation, facilitating the natural farrowing behaviours of the sow. Historically, farrowing pens were the predominant system used before farrowing crates were introduced, being of a basic design comprising of a small room or stable with bedding materials, such as straw. More recently, research has focussed on optimising farrowing pens to ensure they meet the needs of the three main stakeholders: the sow, the piglets and the producer (Baxter *et al.*, 2011b, 2012; Guy *et al.*, 2012). This includes determining the most appropriate nest size (Baxter *et al.*, 2015), the best provision of nesting materials (Westin *et al.*, 2015a, 2015b), and the importance of piglet protection features to reduce the risk of piglet crushing, such as sloped walls (Edwards *et al.*, 2012).

Figure 2.2. Images of the sow nest and dunging areas in two different free farrowing pens: a kennel-and-run farrowing pen with outdoor access (a and b) and a fully indoor designed PigSAFE pen with slatted dunging area access (c and d; images courtesy of Emma Baxter).

Three countries – Norway, Sweden and Switzerland – already use free farrowing pens as the predominant commercial farrowing system, due to farrowing crates and/or sow tethering being prohibited. Other countries also interested in the ultimate prohibition of farrowing crates and the alternative use of free farrowing pens include the UK, Australia and Denmark (Baxter *et al.*, 2018). However, the Farm Animal Welfare Committee (FAWC), an independent advisory group to the UK government, concluded that the prohibition of farrowing crates in the UK should not occur until concerns regarding increased piglet mortality in free farrowing systems are addressed (FAWC 2015). Furthermore, Sweden recently trialled the use of farrowing crates again due to a 2014 state-commissioned report indicating unacceptably high levels of pre-weaning piglet mortality across Swedish farms (O'Dwyer 2015), which are currently required by law to use free farrowing systems.

2.2.3. Temporary confinement crates

Temporary confinement crates, also termed loose lactation pens, are a more recent farrowing system that provides an intermediate alternative between conventional farrowing crates and free farrowing pens. Whilst temporary crates look like conventional farrowing crates, the sides of the crates can be widened to allow the sow greater pen access and freedom of movement (Figure 2.3). Temporary confinement systems have increased in popularity amongst commercial farmers interested in higher welfare farrowing systems, as the sow is confined during the first few days after farrowing, meaning piglet protection is not compromised during the first 24-36 hours when the majority of piglet mortality occurs (Marchant *et al.*, 2000; KilBride *et al.*, 2012), whilst housing the sow unconfined throughout the majority of lactation also serves to improve sow welfare. Furthermore, after crate opening, the sow may be re-confined if required to improve stockperson and/or piglet safety in the case of an aggressive sow. In light of these benefits, many now believe that temporary confinement crates could be a more viable option for widespread commercial use than free farrowing pens (Moustsen, 2018). Temporary confinement crates are already in commercial use on a small number of farms in the UK and Denmark, whilst countries such as the United States and Australia are also showing an interest in loose lactation farrowing systems.

As temporary crates are a relatively new farrowing system, the best management practices have yet to be established. For example, whether sows are confined during the pre-partum period or not, when crates are opened after farrowing, whether manipulable materials are provided and how or when they are provided are all highly variable between farms. There are also fundamental differences between different temporary crate systems, such as the pen footprint being larger (e.g. SWAP pen, Danish Pig Research Centre) or similar to conventional farrowing crates (e.g. 360º Farrower, Midland Pig Producers), the mechanism for how the temporary crate is manipulable materials are provided and how or when they are provided are all highly variable between farms. There are also fundamental differences between different temporary crate systems, such as the pen footprint being larger (e.g. SWAP pen, Danish Pig Research Centre) or similar to conventional farrowing crates (e.g. 360º Farrower, Midland Pig Producers, Figure 2.3), the mechanism for how the temporary crate is opened, the pen arrangement within a room (e.g. Figure 2.3) and the amount of space available only to the piglets after crate opening, which may also affect the ease of management and economic viability of temporary crate farrowing systems.

Figure 2.3. Images of the 360° Freedom Farrower temporary confinement crate system a) with crates in both the open (left) and closed position (right) and room layout with pens neighbouring front-front (image courtesy of Emma Baxter) and b) alternative room layout with pens neighbouring side-side.

2.2.4. Piglet mortality in different farrowing systems

Many studies have reinforced the widely held belief that piglet mortality increases in farrowing systems with decreasing sow confinement. Thus, total piglet mortality is higher amongst sows in farrowing pens than crates (Marchant *et al.*, 2000; Hales *et al.*, 2014), whilst piglet mortality is also higher amongst sows that are kept unconfined than confined during the post-partum period in temporary crates (Moustsen *et al.*, 2013; Hales *et al.*, 2015a) and higher amongst sows housed in temporary confinement than conventional farrowing crates (Chidgey *et al.*, 2015). However, other within-farm studies report no significant difference in total piglet mortality between farrowing pens and crates (Melišová *et al.*, 2014; Cronin *et al.*, 2000), or higher mortality amongst farrowing crates than pens (Cronin *et al.*, 1991). Across-farm studies have shown piglet mortality on farms using free farrowing pens is unaffected by whether the farrowing system has the option of sow confinement or not (Weber, 2000), plus no significant differences in piglet mortality between farms using confined and unconfined farrowing systems (KilBride *et al.*, 2012; Weber *et al.*, 2007).

However, the main causes of piglet mortality differ between farrowing systems. Crated sows may (Oliviero *et al.*, 2010), or may not (KilBride *et al.*, 2012; Yun *et al.*, 2015; Hales *et al.*, 2014), exhibit an increased incidence of stillborn piglets. Furthermore, whilst live-born mortality from crushing may be lower (Bradshaw and Broom, 1999; Marchant *et al.*, 2000), live-born mortality from low piglet viability, savaging and infectious diseases is often higher amongst piglets housed in farrowing crates (Jarvis *et al.*, 2004; Weber, 2000). Thus, it is likely that the majority of crushed piglets in free farrowing pens are already suffering from reduced vitality from underlying issues, with a reduced chance of survival even if they had not been crushed by the sow (Weber *et al.*, 2009).

Finally, the timing of when piglet mortality occurs may also differ between farrowing systems. Whilst the majority of piglet mortality occurs within the first four days post-partum across all indoor farrowing systems (KilBride *et al.*, 2012; Marchant *et al.*, 2000), the percentage of total piglet mortality from birth until weaning which occurs during the first four days post-partum is higher amongst litters housed in conventional farrowing crates than temporary confinement crates (70% vs. 61%, respectively; Chidgey *et al.*, 2015). However, studies comparing farrowing crates and free farrowing pens report a similar percentage of total piglet mortality occurring during the first four (63% vs. 64%, respectively; Marchant *et al.*, 2000) and seven days post-partum (68% vs. 69%, respectively; Hales *et al.*, 2014).

In conclusion, differences in piglet mortality between farrowing systems may not only be due to the physical environment directly, but also via the effect of the farrowing environment on sow maternal behaviour. This is especially true amongst less confined farrowing systems, where sows have greater behavioural freedom and therefore the potential for a greater influence on piglet survival. With the continued interest in less confined farrowing systems, it is therefore vital to ascertain the best ways of managing unconfined sows to optimise their maternal behaviour to facilitate maximal piglet survival and performance.

2.3. Natural Peri-parturient Behaviour of Sows and Piglets

To ensure the behavioural needs of peri-parturient sows are adequately met on commercial farms, it is important to consider the normal behaviour of the species under natural conditions.

2.3.1. Pre-partum behaviour

Sows live in matriarchal groups, consisting of several sexually mature females and their offspring (Kurz and Marchington, 1972). A few days before parturition, the pregnant sow will leave the herd to search for a suitable nesting site, usually within, or on the edge of, a sheltered woodland area (Stolba and Wood-Gush, 1989). Thus, nest-building is performed alone, and therefore not learnt by observing the nest-building behaviours of older sows. The sow may walk for up to 6.5km in search of a suitable nesting site, and may begin to build her nest several times before moving onto a different area to start again (Jensen, 1986). Nest building itself starts approximately 24 hours before farrowing, reaching a peak of activity 4-12 hours pre-partum (Cronin *et. al.,* 1994; Rosvold *et al.*, 2018).

At the chosen nest site, the sow first paws and roots at the ground to form a shallow hollow in the earth, creating the centre of the nest. She will then forage for and collect large nesting materials, such as branches, and arrange them around the pre-formed hollow to create a banked nest perimeter (Jensen, 1993), before going back into the centre of the nest to arrange the materials by circling, rooting, pawing and mouthing. After collecting and arranging large nesting materials,, the sow will collect smaller and softer nesting materials, such as grass and moss, to line and insulate the centre of the nest (Gundlach, 1968).

Parturition, including the onset of nest-building, is associated with several hormonal changes in the sow. Decreasing progesterone levels cause prolactin levels to increase, with the latter associated with the onset of nest-building behaviours (Castrén *et al.*, 1993), such as rooting and pawing. The termination of collection and arranging of nesting materials is not hormonally controlled, as the sow will continue to perform these behaviours until the nest is adequately formed, determined via environmental feedback from the nest site (Jensen, 1993). If nest-building has not been performed satisfactorily, increasing pre-partum oxytocin levels as farrowing approaches may end nest-building behaviours around four hours pre-partum (Castrén *et al.*, 1993), when sow activity reduces before parturition.

2.3.2. Parturition behaviour

The sow gives birth to her piglets individually whilst lying laterally in the centre of the nest. Although the sow performs no overt maternal behaviours, such as licking performed by other species, she may stand up and turn around to sniff or vocalise towards the new-born piglets during the first few piglet births (Jensen, 1986), before resuming lateral lying for the next piglet expulsion. Each piglet expulsion coincides with a spike in sow oxytocin levels (Gilbert *et al.,* 1994), whilst the accumulation of oxytocin throughout parturition may be responsible for the increased passivity of the sow as parturition progresses (Jarvis *et al.,* 2004). Throughout parturition and for several hours after, there is a continuous supply of colostrum from the udder, with piglets quickly orientating and moving towards a teat to suckle after birth. Piglets develop a teat preference within hours of being born (McBride, 1963), which takes approximately 1.4 to 3.1 hours to complete (Jensen, 1986). The sow remains inactive in a lateral lying posture in the nest for around 24 hours post-partum (Jensen, 1986).

2.3.3. Post-partum behaviour

When the sow first leaves the nest, around 24 hours post-partum (Jensen, 1986), to eat and drink at nearby resources before returning, the piglets are left unattended in the nest. The sow becomes highly protective of the nest and piglets, and will chase out intruding group members during the first few days after farrowing (Stolba and Wood-Gush, 1989). The piglets start accompanying the sow to leave the nest at around one week of age (Stolba and Wood-Gush, 1989), with the sow and piglets abandoning the nest to return to the matriarchal group when the piglets are around two weeks old (Jensen, 1986). Thus, in a naturalistic setting, young gilts will experience the sights, smells and sounds from the piglets of older sows before experiencing their first farrowing alone.

The continuous supply of colostrum is replaced with discrete milk ejections by around 24 hours post-partum (Nielsen *et al.*, 2006). As sows produce a large number of offspring per parturition, limiting nutritive nursing to short but frequent nursing bouts better ensures that all piglets obtain milk. Conversely, a more continuous, reduced flow of milk would enable the strongest piglets to move across numerous teats, preventing smaller or weaker piglets from gaining sufficient milk. Furthermore, the continued development of a stable teat order, combined with sow nursing grunts to communicate nursing bouts to the piglets, further ensures that all piglets have more equal access to milk (Fraser, 1980; Algers, 1993).

At first, nursing bouts are initiated by the sow, however by ten days post-partum, almost half of nursing bouts are initiated by the piglets (Jensen *et al.*, 1991). Before a sow-initiated nursing bout, the sow performs short, repetitive nursing grunts to alert the litter of the impending nursing bout. Consequently, the litter line up along the udder at their preferred teat, and start to perform pre-nursing udder massage by repeatedly nuzzling the teat. Piglet-initiated nursing bouts also begin when the piglets perform pre-nursing udder massage, consequently stimulating sow nursing grunts. The nursing grunt rate of the sow steadily increases to a period of rapid grunting, signalling that milk let-down is imminent (Algers and Jensen, 1985). Milk let-down can be observed from the behaviour of the piglets, as individuals change from massaging their chosen teat to becoming relatively static whilst rapidly sucking the teat for the 20-40 second duration of milk let-down (Whittemore and Fraser, 1974). Post-nursing, the piglets will often return to performing udder massage. According to the “restaurant hypothesis” (Algers and Jensen, 1985), the post-nursing udder massage is a means for each individual piglet to “order” their milk requirements for the next nursing bout, with increasing post-nursing udder massage resulting in a greater milk yield from that specific teat. Subsequent studies have found evidence of this “restaurant hypothesis” existing during the early (Algers and Jensen, 1991) but not late lactation periods (Pedersen *et al.*, 2011).

Sow hormonal changes also accompany each nursing bout, with prolactin levels reducing whilst a peak in oxytocin coincides with the peak of sow nursing grunts, stimulating milk let-down to occur (Castrén *et al.*, 1989; Valros *et al.,* 2004). A nursing bout may have no definitive end point unless the sow terminates a nursing bout by changing posture to prevent teat access. Sow-terminated nursing bouts gradually increase throughout lactation, increasing from zero to 50% of total nursing bouts during the first ten days post-partum (Jensen *et al.*, 1991) and reaching 90% by four weeks post-partum (Jensen, 1988). The sow will initially nurse the litter every 30 minutes (Stolba and Wood-Gush, 1989), with the inter-nursing interval increasing to one hour at four weeks of age (Jensen, 1988) and to two hours at 12 weeks of age (Stolba and Wood-Gush, 1989). Weaning of the entire litter was completed by 17 weeks of age (Jensen, 1986; Jensen, 1988).

2.4. Sow Maternal Behaviours of Research Interest

Whilst sows do not display overt maternal behaviours towards their piglets, a review of the literature indicated several sow peri-parturient behaviours of particular research interest for sow and/or piglet welfare and performance. The following sections provide a brief description of each of these behaviours, including their associated welfare benefits and observed differences between farrowing systems.

2.4.1. Pre-partum nest-building

Description

Whilst the evolutionary purposes of a farrowing nest –to protect the piglets from a harsh climate, to hide them from predators and to prevent them from going astray – are no longer imperative within the highly controlled environment of most commercial indoor breeding units, sows are still highly motivated to perform nest-building behaviours (Wischner *et al.*, 2009). In fact, in a naturalistic environment, nest-building behaviour is effectively unchanged between domesticated sows and their wild boar ancestors (Stolba and Wood-Gush, 1989; see Section 2.3.1. for a description of natural sow nest-building behaviour). Nest-building may be a behavioural need for the sow (Damm *et al.*, 2003), which is why restricting sow movement and substrate-directed behaviour during the pre-partum period can be so damaging for her welfare.

Welfare benefits

Although the expression of nesting behaviour is highly dependent on environmental constraints and feedback from the nest site (Damm *et al.*, 2000), the onset of nest-building is primarily dependent on internal cues (Algers and Uvnäs-Moberg, 2007). As nest-building is internally-motivated, preventing the sow from performing nest-building can cause physiological and behavioural indicators of stress and frustration, such as increased plasma cortisol, an increased heart rate and an increased occurrence of bar-biting or oral manipulation of pen fixtures (Jarvis *et al.*, 1997; Damm *et al.*, 2003; Burri *et al.*, 2009). Furthermore, repeated removal of the pre-partum nest before parturition increases the latency for piglets to first suckle after parturition (Pedersen *et al.*, 2003).

Beyond the main purposes of a farrowing nest for safeguarding piglets, allowing the sow to perform pre-partum nest-building improves post-partum maternal behaviour. Individual sows which perform more pre-partum nest-building exhibit reduced restlessness during parturition (Thodberg *et al.*, 1999), have shorter farrowing durations (Thodberg *et al.*, 2002a; Westin *et al.*, 2015b) and a lower incidence of piglet crushing events (Andersen *et al.*, 2005; Ocepek and Andersen, 2017; Wischner *et al.*, 2009b). An increased duration of pre-partum nest-building behaviour is associated with both increased post-partum pre-lying carefulness scores and a decreased average duration of successful nursing bouts (Yun *et al.*, 2014a).

The latency between nest-building activity and farrowing is also important. Thodberg *et al.* (2002b) found an earlier onset of rooting behaviour, and an earlier peak activity of restlessness and rooting behaviour, to be associated with reduced activity and dangerous posture changes during parturition. Four hours pre-partum, increased nest-building activity is associated with a longer latency until the first nursing bout, a shorter average nursing bout duration and lower piglet body weight gain (Illmann *et al.*, 2015), whilst increased nest-building activity two hours pre-partum is associated with increased restlessness during parturition and therefore an increased frequency of piglet crushing events (Illmann *et al.*, 2016). Sows which continue to perform nest-building during parturition perform more posture changes and spend less time in lateral recumbency (Damm *et al.*, 2000), have increased dangerous situations for piglet crushing (Burri *et al.*, 2009) and are less responsive during a piglet scream test (Illmann *et al.*, 2015).

System effects

During the pre-partum period, crated sows that are unable to perform appropriate nest building behaviour exhibit increased plasma cortisol levels (Jarvis *et al.*, 1997; Jarvis *et al.*, 2001), increased heart rates (Damm *et al.*, 2003), increased restlessness (Jarvis *et al.*, 2001) and perform more oral-nasal stereotypies (Damm *et al.*, 2003; Yun *et al.*, 2015) in relation to penned sows. Furthermore, penned sows exhibit an earlier commencement of pre-partum rooting (Thodberg *et al.*, 2002a) and an earlier peak intensity of nesting behaviours (Jarvis *et al.*, 2001). Penned sows also exhibit a longer duration of rooting (Thodberg *et al.*, 2002a) and more varied forms of nest-building behaviours (Damm *et al.*, 2003), whilst the total duration of pre-partum nest-building behaviours may be longer (Yun *et al.*, 2014a) or shorter (Damm *et al.*, 2003) than observed for crated sows.

The provision of appropriate nesting materials also influences the performance of nest-building behaviours, as sows with pre-partum access to straw performed less nesting behaviour during farrowing, had fewer piglets born before the final posture change during parturition and a lower incidence of piglet crushing or near-crushing events (Thodberg *et al.*, 1999; Damm *et al.*, 2010). The quantity of nesting material may also be important. Sows in a free farrowing pen provided with a large quantity of straw two days before farrowing, rather than multiple smaller quantities over consecutive days, spent more time nest-building, whilst nest-building also started earlier before parturition and was performed less once parturition had begun (Westin *et al.*, 2015b). However, in a similar experiment by Damm *et al.* (2005a), an additional provision of long-stemmed straw during the days around parturition had no effect on nest-building behaviour, posture changes during parturition inter-birth intervals or percentage of the litter who nursed during eight hours post-partum.

Finally, more complex nesting materials may also stimulate improved maternal behaviour. In comparison to gilts provided with straw alone, gilts provided with straw and branches had a longer latency between the termination of nest-building and parturition and a lower occurrence of nesting behaviour during parturition (Damm *et al.*, 2000). Furthermore, Yun *et al.* (2013, 2014a, 2014b) performed a series of experiments comparing the behaviour of sows in an open temporary confinement crate with either sawdust or complex nesting materials, with the latter showing an increased duration of nest-building, increased post-partum carefulness behaviours, increased sow serum prolactin and oxytocin concentrations and increased piglet serum IgG and IgM concentrations.

2.4.2. Responsiveness

Description

Responsiveness is primarily concerned with how reactive the sow is to her piglets, but may also include maternal aggression towards external threats such as stockpersons. When capable, crushed or trapped piglets will emit a loud, high-pitched vocalisation (scream); therefore, sow responsiveness studies often involve the playback of piglet vocalisation recordings in order to measure the responsiveness of the sow, termed the ‘piglet scream test’. However, the relevance of sow responses during a piglet scream test for determining the maternal abilities of individual sows has been questioned (Baxter *et al.*, 2011a; Held *et al.*, 2006) as they often don’t correspond to sow responses during real-time piglet crushing events. Other studies measuring sow responsiveness involve recording sow behaviour when separated from, or reunited with, the litter. Sow responsiveness towards stockpersons can also be measured during the aforementioned tests, when the piglets are handled during routine procedures, or more explicitly with a human approach test.

Welfare benefits

High sow responsiveness is considered both a detrimental and a beneficial maternal characteristic for piglet welfare, depending on the stage of farrowing or lactation.

During the mid to late stages of parturition and continuing for two to eight hours post-partum (Jarvis *et al.*, 1999; Pedersen *et al.*, 2003), the sow undergoes a period of quiescence as she remains in a lateral lying position and unresponsive to external stimuli. This period of passivity is considered a desirable maternal trait for two reasons. Firstly, it enables piglets to locate and obtain a teat for nutritive nursing, allowing piglets to obtain sufficient colostrum from the dam to acquire passive immunity, prevent starvation and minimise the risk of hypothermia. Secondly, the absence of dangerous posture changes by the sow reduces the risk of piglets being accidentally crushed by the sow. Moreover, the risk of crushing after the quiescent period is also likely to be reduced as two of the predisposing factors for piglet crushing – starvation and hypothermia – have been minimised.

Later in lactation, an increased level of sow responsiveness is considered a beneficial maternal trait for the litter. The majority of piglet deaths from accidental crushing are from prolonged asphyxiation rather than the immediate trauma (Weary *et al.*, 1996a). Farmers are often able to save crushed piglets by getting the sow to change posture to release the piglet underneath, as they are alerted to a crushing event by the distinctive piglet ‘scream’. Therefore, a sow which is responsive to a trapped piglet scream will herself change posture to release the trapped piglet without farmer intervention. Higher maternal responsiveness to piglet screams is associated with reduced crushing mortality amongst many (Wechsler and Hegglin, 1997; Andersen *et al.*, 2005; Harris and Gonyou, 1998) but not all studies (Illmann *et al.*, 2008). Whilst less relevant amongst indoor farrowing systems, greater sow responsiveness to separation from the litter is also associated with reduced crushing mortality (Andersen *et al.*, 2005).

However, sows which are hyper-responsive to piglets can have unintended detrimental consequences. A sow which exhibits an extreme response to a trapped piglet, such as changing posture too quickly or excessive turning around, may inadvertently injure or kill additional piglets in her litter. Sows which are hyper-sensitive to piglet screams may also respond to the vocalisations of trapped piglets in neighbouring pens, causing unnecessary risk to their own litter (Baxter *et al.*, 2011a). Finally, some sows – especially gilts – become hyper-responsive to the presence of piglets during the early stages of parturition (Chen *et al.*, 2008; Ahlström *et al.*, 2002), causing them to become more restless and aggressive towards their own piglets which sometimes results in infanticide, called savaging. Savaging amongst gilts may be relatively prevalent on commercial farms as, unlike in a natural setting, their first litter is usually their first experience of piglets. The maternal responsiveness of sows towards threats to the litter also means that some individuals can be excessively aggressive towards stockpersons. Whilst not directly affecting the piglets, stockperson aggression may also lead to inadvertent piglet injuries from sow movements or secondary to the increased reluctance of stockpersons to intervene with the litters of hyper-aggressive sows. Furthermore, a high maternal defensiveness score in response to piglets being handled by a stockperson is associated with other undesirable sow behaviours, such as increases in unsupported stand-lie and total posture changes during farrowing and increased mouthing of piglets (Baxter *et al.*, 2011a).

In summary, the desired degree of sow responsiveness can be difficult to define. Enabling sows to remain quiescent throughout parturition has significant benefits. Throughout the rest of lactation, the sow needs to be responsive to piglet screams in order to reduce crushing mortality. However, hyper-responsiveness can cause more problems than benefits, with an increased risk of piglet mortality from trampling and savaging, and conceivably increased stockperson reluctance to intervene.

System effects

Sows in free farrowing pens whose nests were repeatedly removed during the pre-partum period exhibited increased maternal responsiveness during the first 24 hours post-partum (Pedersen *et al.*, 2003). However, there are no comparative studies of confined and unconfined sow responsiveness during parturition only.

Post-partum, sow responsiveness during a separation response test is lower amongst crated than penned sows (Thodberg *et al.*, 2002b; Nowicki and Schwarz, 2010). Furthermore, sow responsiveness during a piglet scream test is lower amongst crated than both penned (Thodberg *et al.*, 2002b; Melišová *et al.*, 2014; Cronin *et al.*, 1996) and group housed sows (Grimberg-Henrici *et al.*, 2016; Arey and Sancha, 1996), whilst sows housed in outdoor farrowing huts are more responsive during a piglet scream test than sows in indoor farrowing pens (Wülbers-Mindermann *et al.*, 2015). This indicates that sow responsiveness to piglet screams increases with increasing space and naturalness of the farrowing system, and is perhaps positively associated with pre-partum nest-building opportunities similar to other maternal behaviours (Yun *et al.*, 2014a). However, not all studies have reported differences in piglet scream test sow responsiveness between farrowing systems (Harris and Gonyou, 1998). Moreover, although Melišová *et al.* (2014) found lower sow responsiveness amongst crated than penned sows during a piglet scream test, no sow behavioural differences were observed during real-time piglet crushing events amongst crated and penned sows.

Whilst post-partum sow responsiveness may be lower amongst confined sows, the risk of hyper-responsiveness may be greater. Piglet-directed aggression is reportedly higher amongst crated sows (Ison *et al.*, 2015), including significantly increased savaging amongst certain genetic lines only when the sows are housed in farrowing crates (Baxter *et al.*, 2011a). Further studies have also noted higher piglet mortality from savaging amongst crated than penned litters, albeit not significantly (Chidgey *et al.*, 2015; Cronin *et al.*, 1996; Cronin *et al.*, 1991). Thus, hyper-responsive aggression is more problematic when using confined than unconfined farrowing systems, suggesting that confinement may increase sow stress and frustration, perhaps from the inability to respond and interact with the litter appropriately.

2.4.3. Dangerous posture changes

Description

Dangerous posture changes refers to any posture change which has a significant risk for causing piglet crushing, and usually includes all downward transitions (stand-lie, sit-lie, stand-sit) and rolling movements (ventral-lateral, lateral-ventral). Studies may instead measure sow total posture changes, including both dangerous and non-dangerous posture changes, which may also be termed sow restlessness.

Welfare benefits

Sows which perform fewer dangerous posture changes, such as rolling (Wischner *et al.*, 2009b), should have a lower risk of piglet mortality from crushing. Furthermore, the quality rather than quantity of dangerous posture changes may also be of significance (Pedersen *et al.*, 2006). Sows which perform dangerous posture changes in a slow and controlled manner have fewer near misses and actual piglet crushing incidents (Burri *et al.*, 2009), as this may allow more time for piglets to avoid crushing and for piglets which become partially trapped underneath the sow to escape before further crushing occurs. Furthermore, an increased use of support structures by the sow during stand-lie posture changes was associated with reduced piglet mortality (Baxter *et al.*, 2011a).

Conversely, sows which ‘flop’ when lying have a higher percentage of stand-lie posture changes with a piglet in danger of being crushed than sows which lay down vertically (Wechsler and Hegglin, 1997). Moreover, piglets which are crushed during a stand-lie posture change are more likely to be fatally crushed if the sow descends quickly rather than slowly (Damm *et al.*, 2005b). This could be due to a more instantaneous death from the force of the sow lying down, or because these piglets had less time to escape crushing and therefore became trapped more centrally underneath the sow, reducing any chance of becoming freed. The use of support during stand-lie posture changes is therefore believed to reduce the risk of piglet crushing by decreasing the speed and angle of descent of the sow (Valros *et al.*, 2003).

System effects

Confined sows spend more time lying inactive than unconfined sows in temporary crates (Chidgey *et al.*, 2016), group farrowing systems (Arey and Sancha, 1996) and farrowing pens (Thodberg *et al.*, 2002b). There are also reportedly fewer dangerous posture changes performed amongst crated than penned sows (Andersen *et al.*, 2014; Melišová *et al.*, 2014), whilst the frequency of dangerous posture changes is also lower amongst penned than outdoor housed gilts (Wülbers-Mindermann *et al.*, 2015).

However, other studies report no farrowing systems effects on the frequency of dangerous posture changes (Harris and Gonyou, 1998; Weary *et al.*, 1996a; Bradshaw and Broom, 1999), whilst the incidence of certain dangerous posture changes does differ between crated and penned sows. Specifically, crated sows performed more sit-lie and lie-sit posture changes, whereas penned sows performed more partial rolling, lateral-ventral rolling and lateral-lateral rolling (Weary *et al.*, 1996a; Bradshaw and Broom, 1999). Hales *et al.* (2016) also reported observing confined sows to perform fewer stand-lie and rolling posture changes than unconfined sows in a temporary crate farrowing system.

Rolling resulted in significantly more piglet crushing events than stand-to-lie posture changes in a free farrowing pen (Danholt *et al.*, 2011), with rolling from ventral-to-lateral in the absence of piglet protection bars or sloped walls responsible for the most crushing events. A sloped floor reduced the frequency of the most dangerous rolling types and resulted in fewer crushing incidents.

The control and speed of dangerous posture changes is also affected by the farrowing system, with rolling posture changes performed more slowly amongst crated than penned sows (Weary *et al.*, 1996a). Indeed, both the increased frequency and speed of sow rolling posture changes may be why more piglet crushing mortality is attributable to rolling amongst free farrowing sows (Weary *et al.*, 1996a; Bradshaw and Broom, 1999). In contrast, a greater incidence of quick ‘flop’ stand-lie posture changes was observed amongst crated than penned sows (Andersen *et al.*, 2014), creating a greater risk for piglet crushing to occur, whilst lie-sit posture changes are also a significant source of piglet crushing events amongst crated sows (Weary *et al.*, 1996a).

2.4.4. Pre-lying behaviours

Description

Sow pre-lying behaviour refers to the characteristic behaviours performed within the 30-60 seconds prior to the sow lying down (Damm *et al.*, 2005b). This usually involves substrate-directed behaviour, such as sniffing, rooting and pawing (Pokorna *et al.*, 2008), looking around or scanning the nest (Wischner et. al., 2010), naso-nasal contact with the piglets (Jensen, 1986) and/or collecting and grouping (termed clustering) of the litter before lying down (Burri *et al.*, 2009).

Welfare benefits

Pre-lying behaviour may facilitate the sow to ensure piglets are out of the dangerous area surrounding her before she descends into lying. This helps to avoid accidentally crushing any of the piglets, as piglets located close to the sow whilst she lies are at a significantly greater risk of being crushed (Pokorná *et al.*, 2008; Weary *et al.*, 1996b).

Sows show adaptive responsiveness to the piglets, with the performance of pre-lying behaviours increased when piglets are present in the lying area (Pokorná *et al.*, 2008). The performance of pre-lying behaviours increases the probability of piglet clustering (Pokorná *et al.*, 2008), allowing the sow to avoid accidental crushing by lying down on the opposite side of the pen to where the litter are clustered (Wechsler and Hegglin, 1997). Furthermore, Marchant *et al.* (2001) reported that stand-lie posture changes were more likely to result in piglet crushing if the sow performed less pre-lying piglet-directed behaviours, and/or if the piglets were spread out in the pen rather than clustered together.

When comparing the behaviour of sows which crushed one or more piglets with the behaviour of sows which crushed no piglets, the latter were found to perform significantly more looking around and more sniffing and nosing of piglets before lying down (Wischner *et al.*, 2010), whilst Ocepek and Andersen (2017) found that higher scores for general sow carefulness, including pre-lying, are associated with fewer crushing incidents and lower piglet mortality.

However, not all studies have found pre-lying behaviours to affect the incidence of piglet crushing. Whilst Pokorná *et al.* (2008) found an increased performance of pre-lying behaviours was associated with increased piglet clustering, pre-lying behaviours had no effect on moving piglets out of the sow lying area or on the incidence of piglet crushing. Melišová *et al.* (2011) found no association between the performance of pre-lying carefulness behaviours, piglet clustering or piglet location on the frequency of piglet crushing events amongst sows. Moreover, sniffing and vocalising increased the proportion of the litter located in the danger zone.

System effects

Whilst the majority of the aforementioned studies concerning pre-lying behaviour involved sows housed in free farrowing pens (Melišová *et al.*, 2011; Ocepek and Andersen, 2017; Marchant *et al.*, 2001; Wechsler and Hegglin, 1997), some were conducted with crated sows (Wischner *et al.*, 2010; Pokorná *et al.*, 2008), which appear to show similar results across both farrowing systems. However, Yun *et al.* (2014a) found a positive association between the frequency and duration of pre-partum nest-building behaviour and sow post-partum pre-lying carefulness scores, whilst pre-partum nesting behaviours were also directly associated with the space and complexity of the farrowing environment (see pre-partum nest building). The literature search found no other comparative studies involving sows in both pens and crates concerning sow pre-lying behaviours.

2.4.5. Other piglet-directed behaviours

Description

Sows may also perform other piglet-directed behaviours. These are similar to sow pre-lying carefulness behaviours, such as vocalising and nose-to-nose contact with individual piglets.

Welfare benefits

Andersen *et al.* (2005) found that sows which crushed no piglets during the early post-partum period exhibited more nasal contact with piglets after a piglet scream test and during posture changes than sows which crushed two or more piglets. Furthermore, higher scores for sow-piglet communication are associated with lower piglet mortality, with fewer crushing incidents and fewer piglets dying from starvation (Ocepek and Andersen, 2017). However, piglet-directed behaviours can also be aggressive, with increased frequencies of sows pawing, rooting or mouthing their piglets associated with increased piglet mortality (Baxter *et al.*, 2011a).

System effects

On day one post-partum, crated sows performed less investigating and vocalising towards their piglets than penned sows (Cronin *et al.*, 1996), or investigating and nosing of their piglets than sows housed in temporary crates (Chidgey *et al.*, 2016). However, as the temporarily crated sows were confined from three days before until four days after farrowing in the study conducted by Chidgey *et al.* (2016), all experimental sows would have been confined to a crate on day one post-partum. No other comparative studies between confined and unconfined sows were identified from the literature search regarding general piglet-directed behaviours.

2.4.6. Nursing behaviour

Description

Nursing behaviour has been described in detail in Section 2.3.3. Common measures of sow nursing behaviour include the frequency or duration of all nursing bouts, frequency, duration or percentage of successful nursing bouts, the frequency, duration or percentage of sow-terminated nursing bouts and the nursing interval between successive nursing bouts.

Welfare benefits

Successful sow nursing behaviour is not only of vital importance for preventing starvation and facilitating growth, but also contributes to increasing the body temperature and vitality of the new-born piglets (Nielsen *et al.*, 2006). Dyck and Swierstra (1987) reported that malnutrition was a significant underlying cause of piglet mortality, with 93.7% of piglets which died within three days post-partum having no increase in body weight since birth, and a further 84.6% of piglets which died after three days post-partum having an inadequate increase in body weight. Moreover, piglet weight gain throughout lactation is positively associated with individual piglet milk intake from the sow (Skok *et al.*, 2007).

Whilst individual piglets may fail to gain adequate milk intake for numerous reasons, including low vigour and sibling competition (Andersen *et al.*, 2011; Rutherford *et al.*, 2013), differences in sow nursing behaviour also affect piglet growth. Piglet weight gain is positively associated with the total nursing bout frequency (van den Brand *et al.*, 2004), the successful nursing bout frequency (Valros *et al.*, 2002) and the total duration of nursing bouts (Illmann *et al.*, 2015). However, other studies have found no definitive association between sow nursing behaviour and piglet growth (Valros *et al.*, 2003) or with early post-partum piglet mortality (Johnson *et al.*, 2007).

System effects

Multiple studies have demonstrated piglet weight gain to be lower amongst litters of confined sows than amongst litters reared in less confined systems, such as temporary crates (Chidgey *et al.*, 2015) and farrowing pens (Melišová *et al.*, 2014; Oostindjer *et al.*, 2011; Pedersen *et al.*, 2011), whilst others reported no differences in piglet weight gain (Oliviero *et al.*, 2008) or lower weight gain amongst penned than crated litters (Marchant *et al.*, 2000).

Yun *et al.* (2014b) found increased piglet serum IgG and IgM concentrations amongst litters of unconfined sows provided with complex nesting materials, indicating that piglet colostrum intake was increased amongst these litters. The authors previously found the average duration of both successful and all nursing bouts to be longer amongst confined than unconfined sows, either with or without additional nesting materials (Yun *et al.*, 2013). In another study, unconfined sows exhibited a higher frequency of nursing bouts than confined sows on the days following parturition, and an increased frequency of sow-terminated nursing bouts on day three post-partum (Hales *et al.*, 2016).

In a group farrowing system, sows tended to spend a higher percentage of observations performing nursing behaviour, specifically a decreased frequency but increased duration of nursing bouts, in comparison to crated sows (Arey and Sancha, 1996). The study also reported that group housed sows exhibited an increased percentage of successful nursing bouts, with a higher percentage of piglets present at the udder during nursing bouts. Pedersen *et al.* (2011) compared the nursing behaviour of crated and penned sows, and also found the nursing bouts of penned sows to have a longer milk let-down, whilst pen-reared piglets missed fewer nursing bouts and had fewer teat fights. The post-nursing udder massage phase was also longer amongst penned sows, with fewer sow-terminated nursing bouts. Amongst first parity sows housed in crates or farrowing pens, whilst the farrowing system had no effect on the total duration of nursing or the percentage of successful nursing bouts, penned gilts exhibited a lower mean duration of nursing bouts, a higher frequency of nursing bouts and a higher percentage of sow-terminated nursing bouts than crated gilts (Thodberg *et al.*, 2002b).

The total duration of sow pre-partum nest-building behaviour was negatively associated with the average duration of early post-partum successful nursing bouts, whilst piglet weight gain tends to increase with an increasing frequency and duration of pre-partum nest-building behaviours (Yun *et al.*, 2014a). Furthermore, repeated removal of the farrowing nest during the pre-partum period results in an increased latency to the first successful nursing bout for the new-born piglets (Pedersen *et al.*, 2003).

2.5. Management Factors of Interest

Whilst there have been several studies comparing the undisturbed maternal behaviour of sows in different farrowing systems, there are fewer studies which also consider the interactive effects of how routine management practices affect sow behaviour in different farrowing systems. Three such practices have been identified as being of particular importance. These are outlined below, along with a review of the current literature regarding their effects on sow maternal behaviour and piglet performance.

2.5.1. Sow housing strategy: effects of previous experience

Description

Whilst performance of the previously described sow maternal behaviours is subject to the constraints of the immediate farrowing environment, further studies have shown that a change between confined and unconfined environments can also influence sow behaviour at farrowing. It is imperative to understand these effects in order to inform best management, especially for farms which transition from conventional farrowing crates to less confined farrowing systems, to account for the potential consequences of sow previous experience on future sow and piglet welfare.

Effect on sow maternal behaviour

When returned to the same farrowing system as experienced during the previous farrowing, there is evidence of sow farrowing behaviours adapting to the farrowing system. Pre-partum, sows express more elaborate nest-building behaviours or reduced restlessness when returned to farrowing pens or crates, respectively (Jarvis *et al.*, 2001). Furthermore, the physiological stress of confinement may be less elevated after previous farrowing experience in confinement, as crated sows exhibited longer inter-piglet birth intervals than penned sows in their first but not second parity (Thodberg *et al.*, 2002a), and a greater elevation in plasma ACTH when confined to a farrowing crate in the first than second parity (Jarvis *et al.*, 1997; Jarvis *et al.*, 2001).

Other studies have shown that the previous farrowing system, or an interaction of the previous and current farrowing systems, has a greater effect on sow farrowing behaviour than the current farrowing system alone. During parturition, previously crated sows exhibited a decreased ventral lying duration and a decreased frequency of dangerous posture changes (Thodberg *et al.*, 2002a), and took longer to complete stand-lie posture changes post-partum (Thodberg *et al.*, 2002b), than previously penned sows. Furthermore, post-partum frequencies of activity, ventral lying and lateral lying were affected by an interaction of the current and previous farrowing systems (Thodberg *et al.*, 2002b).

The previous gestation environment can also affect sow behaviour in the farrowing accommodation. In a study by Boyle *et al.* (2002), sows were housed in either small groups or individual stalls throughout gestation before all sows were moved to farrowing crates. On entry into the farrowing crates, previously confined sows showed more difficulty in lying down and spent more time either lying laterally or standing inactive; whilst previously unconfined sows exhibited increased restlessness during parturition and an increased frequency of sitting, ventral lying and lateral lying on day ten post-partum. Finally, another study on gilts housed in wide crates found a higher frequency and total duration of ventral lying during the pre-partum period if gilts had been housed in group pens instead of crates during gestation (Harris and Gonyou, 1998).

Effect on piglet performance

Whilst there are currently no published studies investigating the effect of an interaction between the current and previous sow farrowing systems on piglet performance, one study investigated the interaction between the current farrowing and previous gestation environment. Cronin *et al.* (1996) housed sows in either stalls or group pens during gestation, then either farrowing pens or crates throughout farrowing and lactation in a 2x2 cross-over design. Sows which were group housed in gestation and crated for farrowing had higher stillborn and live-born piglet mortality during the first three days post-partum than all other treatment combinations. However, treatments had no significant effect on measured sow maternal behaviours (Cronin *et al.*, 1996).

2.5.2. Sow management strategy: effect of temporary crate opening routine

Description

If sows behave differently in confined and unconfined farrowing systems, and a change of farrowing system between successive parities affects sow maternal behaviour, a change to the farrowing environment that occurs during an ongoing lactation may also affect sow maternal behaviour. This environmental change occurs with temporary confinement systems, where the accommodation is manually converted from confined to unconfined when the temporary crate is opened a few days post-partum. Review of the literature identified a knowledge gap on this subject, with currently few published studies explicitly examining the immediate effect of temporary crate opening on sow behaviour or piglet performance in these systems.

Effect on sow maternal behaviour

As sow behaviour is dependent on the constraints of the farrowing system, it would be expected that sow maternal behaviour in a temporary crate system will differ depending on whether the crate is open or closed. Furthermore, sows may perform a rebound of increased activity in immediate response to being released from confinement.

In comparison to permanently crated sows, temporarily crated sows exhibit increased activity and rolling behaviour on the day after crate opening (4 days post-partum) but show no behavioural differences to crated sows later in lactation (25 days post-partum; Goumon *et al.*, 2018). This indicates that temporary crate opening elicits a short-term behavioural response by the sow, which requires further investigation to determine for how long after crate opening key sow behaviours are altered. Furthermore, releasing confined sows provokes a reduction in salivary IgA concentrations but no significant cortisol response (Goumon *et al.*, 2018), suggesting that crate opening during lactation may also be mildly stressful or arousing for sows.

Other studies involving temporary confinement farrowing systems have also shown the immediate effect that crate closing has on the sow. Confining loose-housed sows shortly after parturition results in increased salivary cortisol (Hales *et al.*, 2016) and increased total farrowing durations and inter-piglet birth intervals (Yun *et al.*, 2015) in comparison to sows that are confined from entrance into the farrowing accommodation. These studies provide further evidence that a sudden change to the environment causes physiological stress amongst parturient and post-parturient sows.

Effect on piglet performance

During the first four days post-partum, piglet mortality is higher in an open than closed temporary confinement crate (Hales *et al.*, 2015a; Moustsen *et al.*, 2013). Loose housed sows that are confined immediately after farrowing exhibit higher piglet mortality during four days post-partum than sows confined from entry into farrowing accommodation (Hales *et al.*, 2015a). Furthermore, when temporary confinement crates are opened four days post-partum, sows confined either from entry into the farrowing accommodation or from immediately after farrowing exhibit increased piglet mortality after crate opening in comparison with sows which are loose housed throughout farrowing and lactation (Hales *et al.*, 2015b). These results indicate that piglet mortality increases in response to abrupt closing or opening of temporary confinement crates. However, Goumon *et al.* (2018) found no effect of crate opening on piglet weight gain or mortality in comparison to permanently crated sows.

2.5.3. Piglet fostering

Description

Fostering of piglets is performed on almost all indoor commercial farms (Straw *et al.*, 1998), but less so amongst extensive farrowing systems. Fostering can involve the movement of one or more piglets from their birth litter onto another litter, an exchange of multiple piglets between two litters (cross-fostering) or the movement of an entire litter from the maternal sow onto another sow (nurse sow). The fostering of single piglets is often performed to standardise the number of piglets in each litter, whilst cross-fostering between litters is performed to group piglets of a similar age and body size into the same litter. Although routinely performed shortly after birth (Straw *et al.*, 1998; Rosvold *et al.*, 2017), fostering and/or cross-fostering may be repeated throughout lactation due to inter-litter variability in piglet mortality or intra-litter variability in piglet growth and performance. With live-born born litter sizes increasing (Baxter and Edwards, 2018), the requirement to perform late fostering and cross-fostering is also likely to increase, in order to minimise the impact of increased piglet competition for resources. Furthermore, the utilisation of nurse sows to rear younger litters once their own litter has been weaned is becoming increasingly common practice in European countries where total born litter sizes are larger than the UK, such as Denmark (Baxter and Edwards, 2018).

Effect on sow maternal behaviour

When piglet fostering is performed within 24 hours of birth, fostering has no significant consequences on the behaviour of confined (Heim *et al.*, 2012) or unconfined sows (Pedersen *et al.*, 2008). However, amongst crated sows, fostering performed seven days post-partum results in increased restlessness, increased aggression towards both foster and resident piglets, and a simultaneous increase in sow-terminated and unsuccessful nursing bouts (Horrell, 1982; Robert and Martineau, 2001). Penned sows exhibited similar responses, such as increased restlessness, increased sniffing and chasing of piglets and an increased frequency of unsuccessful nursing bouts when cross-fostering was performed four days post-partum (Pedersen *et al.*, 2008). There are no further published studies regarding the effect of late cross-fostering on sow behaviour in free farrowing pens, and no comparative studies on the immediate behavioural responsiveness of sows to late cross-fostered piglets between crated and penned sows.

Effect on piglet performance

When performed within 24 hours post-partum, piglet behaviour and weight gain are not adversely affected by fostering in crates (Robert and Martineau, 2001; Heim *et al.*, 2012), however the foster litter composition is of importance. When Huting *et al.* (2017) cross-fostered piglets at birth to create litters of entirely small piglets, entirely large piglets or mixed litters, growth rates were increased for small but decreased for large piglets in uniform litters in comparison to mixed litters. Furthermore, the mortality of small piglets is increased when fostered onto a litter with large piglets, but only when the litter size is also large (12 vs. 8 piglets; English and Bilkei, 2004).

Analogous to sow behaviour, late cross-fostering has a significant impact on piglet performance. Late cross-fostering results in an acute behavioural disturbance amongst cross-fostered piglets, such as vocalising, pacing around the pen and repeated escape attempts (Horrell, 1982). Fostered piglets are also more likely to miss nursing bouts (Horrell, 1982) and to be involved in teat disputes at nursing (Horrell and Bennett, 1981; Robert and Martineau, 2001). Consequently, fostered piglets and their littermates show reduced weight gain at weaning in comparison to intact litters (Horrell and Bennett, 1981; Giroux *et al.*, 2000). Conversely, penned piglets exhibit behavioural changes in response to cross-fostering on both one and four days post-partum, such as reduced litter integration and an increased frequency of missed nursing bouts (Pedersen *et al.*, 2008). However, increased teat disputes were only observed after cross-fostering at four days post-partum (Pedersen *et al.*, 2008). There are currently no published studies regarding the effect of late cross-fostering in farrowing pens on subsequent piglet weight gain, nor comparative studies between penned and crated litters.

2.6. Conclusions and Knowledge Gaps

In conclusion, the reviewed literature demonstrates the complex nature of piglet mortality, including the numerous causes, contributory factors and the subsequent interactions between them. Whilst piglet mortality may be reduced by restricting sow movements and behaviour through confinement, the continued use of farrowing crates is under question due to sow welfare implications. However, concerns remain over the increased risk of piglet mortality in less confined farrowing systems. The problem is further intensified as sow prolificacy continues to increase, resulting in larger total born litter sizes of often smaller and/or lower vitality piglets. As sow behaviour is less restricted and more influential on piglet outcomes in less confined farrowing systems, a greater understanding of how fundamental management practices affect sow behaviour is essential to mitigate piglet mortality in free farrowing systems. One area requiring further research is how the previous housing experience of the sow, both within and between lactations, affects current maternal behaviour. This is especially important as more farms transition from farrowing crates to less confined farrowing systems, including the use of temporary crating as an interim step towards free farrowing. Another area requiring further research is how routine management practices, such as the cross-fostering of piglets, affects sow maternal behaviour in different farrowing systems. Late cross-fostering is of particular interest, as the practice of using nurse sows becomes progressively required to support increasing total born litter sizes.

Chapter 3. Consistency is Key: Interactions of Current and Previous Farrowing System on Litter Size and Piglet Mortality

3.1. Abstract

Global interest in alternative indoor farrowing systems to standard crating is increasing, leading to a growing number of farms utilising such systems alongside standard crates. There is evidence that interchanging sows between different farrowing systems affects maternal behaviour, whilst the subsequent effect of this on piglet mortality is unknown. The current study hypothesised that second parity piglet mortality would be higher if a sow farrowed in a different farrowing system to that of her first parity. Retrospective farm performance records were used from 753 sows during their first and second parities. Sows farrowed in either standard crates (crates), temporary crates (360s) or straw-bedded pens (pens), with mortality recorded as occurring either pre- or post-processing, whilst inter- and intra-parity sow consistency in performance were also investigated. Overall, total piglet mortality reduced from the first to the second parity, being significantly higher in the crates and higher in the 360s during the first or second parity, respectively. In the second parity, an interaction of the current and previous farrowing systems resulted in the lowest incidence of crushing for sows housed in the same system as their first parity for the crates and pens, but not the 360s. Post-processing mortality was significantly higher in the crates if a sow previously farrowed in the 360s and vice versa. Sows which previously farrowed in a pen had a significantly larger litter size and lower pre-processing mortality from crushing in their second parity than sows previously housed in the crates or the 360s. No inter-parity consistency of sow performance was found, whilst intra-parity consistency was found in the first but not second parity. In conclusion, returning sows to the same farrowing system appears to reduce piglet mortality, whilst farrowing in a pen during the first parity significantly increased second parity litter size without increasing piglet mortality.

3.2. Introduction

Consumers prefer livestock to have freedom of movement and the opportunity to perform natural behaviours (Lassen *et al.*, 2006), which has contributed to the increase of outdoor breeding sows in the UK from 19% to 42% of the national herd size in the past two decades (Farm Animal Welfare Council, 1996; Royal Society for the Prevention of Cruelty to Animals, 2016). Globally, indoor pork producers are increasingly interested in transitioning to less restrictive systems, particularly for farrowing and lactation (Farm Animal Welfare Committee, 2015). However, piglet mortality is often considered to be higher in alternative farrowing systems (Hales *et al.*, 2014), although this is not always the case (KilBride *et al.*, 2012). Furthermore, a recent Opinion of the UK Farm Animal Welfare Committee recommended further research to reduce piglet mortality in free farrowing systems before the abolition of farrowing crates in the UK can be considered (FAWC, 2015).

Research has developed multiple indoor alternatives to the farrowing crate, some of which are already in commercial use (e.g. PigSAFE pen, Edwards *et al.*, 2012; SWAP pen, Hales *et al.*, 2015a). However, alternative farrowing systems are sometimes used alongside more traditional farrowing crates within the same herd, causing sows to be housed interchangeably between farrowing systems. This can occur acutely whilst a farm transitions to a new farrowing system, or chronically as multiple farrowing systems are used long term. Whilst some higher-welfare Assurance Scheme standards recommend continually housing sows in the same farrowing system to avoid negatively impacting sow welfare (RSPCA, 2016), very little research has investigated the effect that a change in farrowing system has on the sow.

Extensive research has shown the immediate farrowing environment to affect the behaviour and physiology of the sow during farrowing and lactation (e.g. Cronin and van Amerongen, 1991; Arey and Sancha, 1996; Yun *et al.*, 2013). Consequently, the farrowing system not only affects piglet mortality directly via the level of physical protection from accidental crushing, but also indirectly by influencing the maternal care that a sow will provide. Indeed, proficiency of sow behaviour is considered even more critical for piglet survival in less restrictive systems, where physical and human intervention are often more difficult to implement (Arey, 1997). Sow productivity is considered an individually stable trait, measurable via piglet survival in early lactation (Wechsler and Hegglin, 1997; Su *et al.*, 2007). However, sow maternal behaviour may develop over successive parities, as the previous farrowing environment influences subsequent maternal behaviour (Jarvis *et al.*, 2001; Thodberg *et al.*, 2002a and 2002b), meaning sow welfare and productivity may be optimised by routinely returning individuals to the same farrowing system.

The aim of the current study was to determine if the farrowing system used during the first and second parity affected current and future piglet mortality. Individual consistency in sow performance between different phases of the same parity and across parities was also explored. It was hypothesised that second parity sows which return to the same farrowing system would have lower piglet mortality than sows which changed farrowing systems, and that mortality would be particularly high for sows which change from a restrictive to less restrictive farrowing system.

3.3. Materials and Methods

3.3.1. Animals and dry sow management

Data were collected on a commercial pig breeding unit in the north east of England. The farm consisted of 1 300 Camborough (Genus PIC, Basingstoke) breeding gilts and sows, bred with Hampshire semen. During gestation, all animals were kept in straw pens in groups according to age, for gilts, or by size for multiparous sows, and were fed via dump-feeders once daily with approx. 3kg of pelleted feed per sow per day (gilts = 12.42% CP, 12.52 DE MJ/Kg ; sows = 11.85% CP, 12.47 DE MJ/Kg). Animals were moved into the farrowing accommodation one week before the expected farrowing date.

3.3.2. Farrowing sow housing and management

During farrowing and lactation, sows were housed in one of three farrowing systems within the same farm: standard farrowing crates (crates), a temporary crate system (360s; 360º Freedom Farrower®, Midland Pig Producers, Burton-on-Trent) or a kennel-and-run straw-based pen system (pens). Photos of all three systems are provided in Figure 2.1, Figure 2.2(a,b) and Figure 2.3. Data collection was performed as the farm transitioned from using crates to 360s; with 132 crates and zero 360s at the beginning of data collection, and 20 crates and 168 360s by the end of data collection; whilst 62 pens were used throughout the study period.

Crates on the farm consisted of two types, in either one of three older buildings or two new PortaPig cabins. The old farrowing crates were 2.65m x 0.60m within a 2.70m x 1.90m pen with solid concrete flooring and metal slats to the rear of the pen and contained a 1.40m x 0.60m heat pad to the top right of the pen and covered in wood shavings for old crates only (Figure 3.1a). The new farrowing crates were 2.50m x 0.60m within a 2.50m x 1.80m fully plastic slatted pen including a 1.20m x 0.40m heat pad centrally located along the pen side adjacent to the central walkway.

The 360s were comprised of a stainless steel crate (2.50m x 0.90m when closed, 2.50m x 1.60m at sow shoulder height when opened) within a 2.50m x 1.80m pen

(Figure 3.1b). Pens with 360s had plastic slatted flooring with a solid panel containing drainage slots in the sow lying area plus a 1.80m x 0.40m heat pad to one side of the crate. Two parallel vertical bars were positioned at the rear of the crate for additional piglet protection. The 360s crates were closed from sow entry into the farrowing house until approx. ten days post-partum, with handfuls of shredded paper provided on the floor of the 360s crate from two days before expected farrowing and removed at first litter handling (4-16h post-farrowing). Of the 168 360s on the farm by the end of data collection, 120 were located in six PortaPig cabins containing 20 farrowing places each. The remaining 48 places were in a converted farrowing house (previously farrowing crates) of three adjoining rooms containing 16 360s each (refer to Chapter five for additional details of the 360s configuration). Buildings containing crates and 360s were kept at 22 ± 1°C, with the additional heat mat along one side of each pen starting at 36°C and reducing to 30°C by weaning. Room temperature was gradually reduced automatically to 18 ± 1°C by day ten post-partum and to 16 ± 1°C by weaning.

The pens were in rows of individual units constructed from timber in the 1960s, each consisting of a 2.30m x 1.20m indoor nest area with adjacent 2.30m x 0.70m separate covered piglet creep area and access to a 2.55m x 2.00m outdoor run (Figure 3.1c). Pens had a solid concrete floor throughout, whilst the nest area contained farrowing rails and piglet protection bars across three sides to reduce piglet crushing risk. The nest area contained 5kg of long straw from sow entry, whilst the creep floor was covered in wood shavings. The pens had no central heating system, however a 400w electric heater was placed at one end of the creep, which was individually switched off three to five days post-partum. Pens were routinely cleaned out weekly with straw and wood shavings replenished. Pre-partum, additional straw or wood shavings were added to nests when required and soiled straw was removed and replenished post-partum.

3.3.3. Farrowing sow and piglet husbandry

Sows were fed once daily in the morning until all sows in the building had farrowed, after which sows were fed twice a day (15.98% CP, 13.69 DE MJ/Kg). All animals were hand fed, either into a feed trough in both crated systems or onto the nest floor in the pen system. Feed was gradually increased from 2kg to 10kg per sow per day

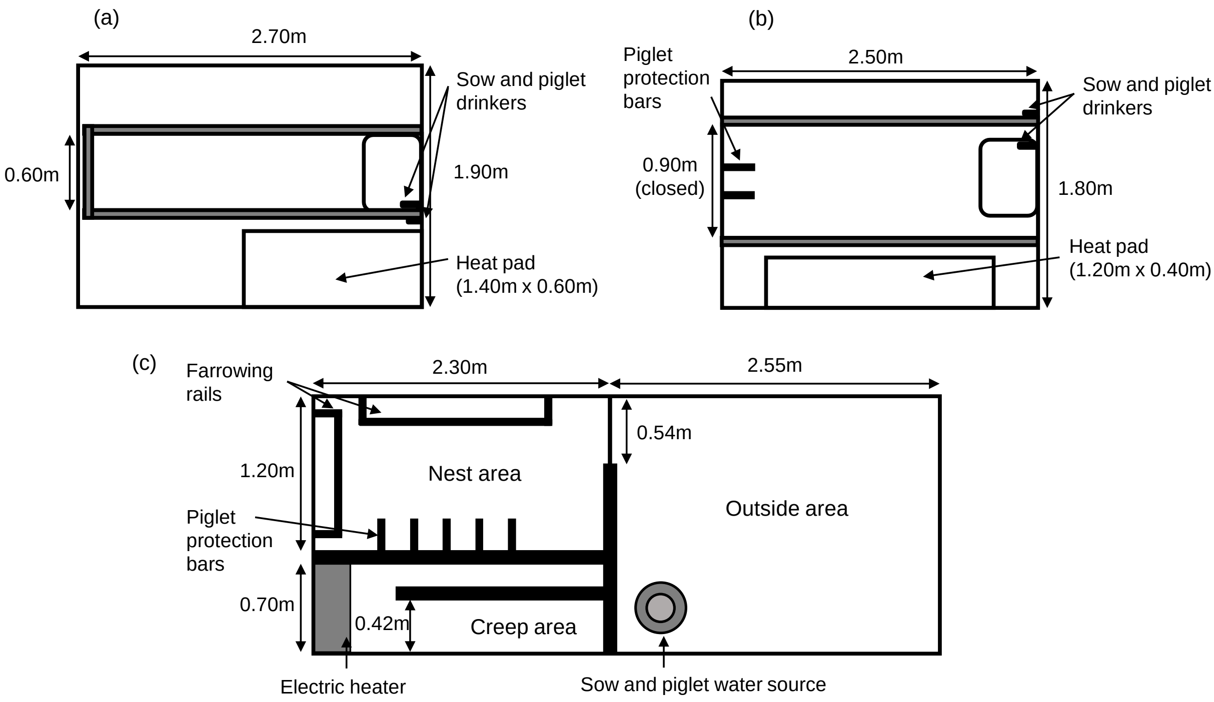


Figure 3.1. Sow farrowing system pen layouts to scale for (a) the standard farrowing crate, (b) the 360º Freedom Farrower and (c) the straw-based pen with outside run.

in 1kg increments during lactation. Water was provided ab libitum, either from drinkers in the two crated systems or from a floor trough in the outdoor area of the pen system. In accordance with veterinary recommendation, piglets were tail docked, teeth clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd, Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24 hours of birth. Placentae and deceased piglets were removed, and live litter size was equalised for both piglet number and size by cross-fostering piglets of a similar age. Super Dry Klenz powder (A-One Feed Supplements Ltd, Thirsk) was distributed across crates and 360s daily to minimise bacterial infections. A handful of creep feed (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed Supplements Ltd, Thirsk) was provided once daily on the floor in all systems from approx. ten days of age until weaning. The farm's management routines included piglet cross-fostering throughout lactation as necessary to ensure piglet and litter sizes remained similar.

3.3.4. *Experimental design*

Sows were housed in one of the three described farrowing systems during their first and second farrowings, creating a 3 x 2 factorial design of farrowing system and parity. Animals were allocated to whichever farrowing system was in rotation at their time of housing. Experiments were approved under the Newcastle University Animal Welfare and Ethics Review Body, Approval 379 on 23rd June 2014.

3.3.5. *Data collection*

Data were collected from farm records for farrowings which occurred from November 2013 to January 2016. Sows which did not complete their first two lactations in full were excluded from the database. Variables recorded for both parities were: animal ID, farrowing system, farrowing date, litter size (live-born and stillborn), number and cause of piglet mortality, weaning date and number of piglets at weaning. Piglet mortalities were recorded as occurring either before or after litter processing, when litters were first handled by staff at 4-16h post-partum. Cause of death was recorded as either crushing, low viability, savaged or miscellaneous (including hypothermia, congenital defects, or unknown cause) according to standard practice for the mortality records on-farm.

3.3.6. *Statistical analysis of results*

Litter size and piglet mortality data were analysed in SAS 9.2 using the GLIMMIX procedure. Models for first parity litter size (total born and live-born) included season at farrowing (Spring = Mar, Apr, May; Summer = Jun, Jul, Aug; Autumn = Sep, Oct, Nov; Winter = Dec, Jan, Feb), whilst models for second parity litter size included first parity season at farrowing, first parity litter age at weaning and first parity farrowing system. Due to a low incidence of mortality caused by savaging and by other miscellaneous reasons, cause of mortality was grouped as either crushing or all other causes (low viability, savaged and miscellaneous). All models regarding mortality (including stillborn) included an underlying Poisson distribution. First parity mortality models included total born litter size, the current farrowing system, the season at farrowing and an interaction of the current farrowing system and season at farrowing. Second parity base models also included the previous farrowing system and an interaction between the current and previous farrowing system. For models concerning post-processing and total mortalities, lactation length was also included in the base model for both parities. Variables were excluded in a step-wise manner, with all variables of $P < 0.10$ and interactions of $P < 0.05$ included in the final models.

Sow consistency between and within parities was analysed in SAS 9.2 using the GENMOD procedure. Repeated measures models were created with sow ID as the repeated subject. For between parity consistencies, the final second parity models from the GLIMMIX procedure were used plus the corresponding first parity variable as an additional independent variable (e.g. first parity pre-processing crushed to predict second parity pre-processing crushed). For within parity consistencies, the pre-processing variable was used to predict the post-processing variable (e.g. first parity pre-processing crushed to predict first parity post-processing crushed) for both the first and second parities independently.

3.4. Results

Data were collected from 753 sows across the three farrowing systems in parity one and parity two, however system combination groups were not ideally balanced as increasing numbers of 360s came into use on the farm (see Table 3.1).

Table 3.1. Distribution of sows across farrowing systems in first parity (columns) and second parity (rows).

Second parity system	First parity system			
	Crate	360s	Pen	Total
Crate	37	33	55	125
360s	143	172	116	431
Pen	67	115	15	197
Total	247	320	186	753

Parity one mean total born litter size was 13.72 ± 0.10, and did not differ across seasons at farrowing ($P < 0.10$). Parity two mean total born litter size was 12.94 ± 0.11, and also did not differ across seasons at farrowing ($P < 0.10$). However, there was a tendency for parity one farrowing season to affect parity two total born litter size ($P = 0.068$; spring = 13.01 ± 0.22; summer = 13.43 ± 0.23; autumn = 12.54 ± 0.24; winter = 13.03 ± 0.21), being significantly higher for sows that previously farrowed in the summer than the autumn ($P < 0.01$). Parity two total born litter size also tended to increase with increasing parity one weaning age (+0.056 ± 0.031 piglets per day; $P = 0.075$).

Total piglet mortality across all farrowing systems was significantly higher in the first parity (16.85%; 14.84% of live-born piglets, 2.36% stillborn of total born piglets) than the second parity (12.72%; 10.59% of live-born piglets, 2.38% stillborn of total born piglets; Wilcoxon signed-rank test; $P < 0.0001$). Litter age and litter size at weaning were similar for both parities (parity one: litter age = 24.85 ± 0.13 days, litter size = 12.79 ± 0.03 piglets; parity two: litter age = 25.61 ± 0.12 days, litter size = 12.78 ± 0.03 piglets).

Significance levels of all variables from the final piglet mortality models are provided in Table 3.2. Total born litter size, litter age at weaning, season and the interaction between farrowing system and season were included in models only to account for their possible effects on piglet mortality, and therefore will not be discussed further.

3.4.1. Parity one

Effect of the current farrowing system

Total born litter size did not differ significantly between farrowing systems (crate = 13.76 ± 0.18; 360s = 13.86 ± 0.16; pens = 13.43 ± 0.20). Figure 3.2 presents all mortality by category and current farrowing system for parity one and two. There were significantly fewer stillbirths (number per litter) in the pens than the 360s ($P < 0.01$) or the crates ($P < 0.001$). Pre-processing mortality from crushing was significantly lower in the 360s than in the pens or the crates (both $P < 0.01$), whilst no significant difference in pre-processing mortality from other causes across farrowing systems was observed. This meant that pre-processing mortality from all causes was significantly higher in the crates than the 360s ($P < 0.0001$), whilst mortality in the pens tended to be both lower than the crates ($P = 0.066$) and higher than the 360s ($P = 0.063$). Farrowing system had no significant effect on post-processing mortality (crushing, other or all). Total piglet mortality from crushing was lower in the 360s than the crates ($P < 0.05$) but not the pens; whilst total piglet mortality from other causes did not differ significantly between farrowing systems. As a result of these individual components, total live-born mortality and total born mortality were significantly higher in the crates than both the pens (live-born: $P < 0.05$; total born: $P < 0.01$) and the 360s (both $P < 0.01$).

Table 3.2. Significance level of independent variables for piglet mortality in the first and second parity. Mortality is classified by cause and whether it occurred prior to (Pre-) or subsequent to (Post-) piglet processing at 4-16 hours after birth. The direction of association for continuous variables is positive in all cases.

	Parity one					**Parity two**						
Mortality type	Total born	System (current)	Season	Syst* Seas[1]	Wean age	Total born	System (current)	System (previous)	System (interaction)	Season	Syst* Seas[1]	Wean age
Stillborn	****	**			-	****						-
Live-born												
Crushed												
Pre-	***	**		*	-	****		*			**	-
Post-	*		****		****	*	**		**	*		**
Total	****			*	****	****	*		*		**	**
Other causes												
Pre-	***		**		-	**						-
Post-	****			**			****	**			*	****
Total	****		**	*		*	**		**	****	***	**
All live-born												
Pre-	****	***			-	****						-
Post-	****		**	*	****	*	****	***	****	****	***	****
Total	****	*	*	**	****	****	**		**	**	***	****

* (P<0.05), ** (P<0.01), *** (P<0.001), **** (P<0.0001), - (not included in base model).

[1] Current system and current season interaction.

3.4.2. Parity two

Effect of the current farrowing system

Total born litter size did not differ significantly between farrowing systems (crate = 12.89 ± 0.29; 360s = 13.06 ± 0.15; pens = 12.94 ± 0.23). Figure 3.2 presents all mortality by category and current farrowing system for parity two. There was no effect of the current farrowing system on the incidence of stillborn piglets. Pre-processing mortality from crushing was significantly higher in the crates than the pens ($P < 0.05$); whilst pre-processing mortality from other causes was significantly higher in the crates than the pens or the 360s (both $P < 0.05$). Post-processing mortality from crushing was significantly higher in the 360s than both the crates and the pens (both $P < 0.05$), however, in combination, total crushing mortality was significantly higher in the 360s than the pens only ($P < 0.05$). Post-processing mortality from other causes, and therefore total mortality from other causes, was significantly higher in the 360s than the pens (pre-other: $P < 0.0001$; total-other: $P < 0.01$). Post-processing mortality from all causes was significantly higher in the 360s than both the crates and the pens (both $P < 0.001$), whilst total live-born mortality and total born mortality were significantly higher in the 360s than the pens (live-born: $P = 0.001$; total born: $P < 0.01$), but not the crates.

Effect of the previous farrowing system

Parity two total born and live-born litter sizes were significantly affected by the parity one farrowing system, being higher if a sow previously farrowed in the pens than both the 360s (total born: $P < 0.001$; live-born: $P < 0.01$) and the crates (both $P < 0.01$; Table 3.3). There was no effect of the previous farrowing system on the incidence of stillborn piglets, pre-processing mortality from other causes or total pre-processing live-born mortality. However, sows that previously farrowed in the pens had significantly lower pre-processing crushing mortality (0.27 ± 0.04) than sows that previously farrowed in the 360s (0.41 ± 0.04; $P < 0.05$), with previously penned sows also tending to be lower than sows that previously farrowed in the crates (0.38 ± 0.05; $P = 0.055$). Whilst post-processing crushing mortality was not significantly affected by the previous farrowing system, post-processing mortality from other causes was significantly higher if a sow had previously farrowed in the 360s (0.017 ± 1.48) than the pens (0.008 ± 0.68; $P < 0.01$), but not the crates (0.012 ± 1.04). Moreover, post-processing mortality from all causes was significantly higher for sows that previously farrowed in the 360s (0.94 ± 0.08) than either the pens (0.60 ± 0.09;

P < 0.01) or the crates (0.61 ± 0.07; P < 0.01). There was no effect of the previous farrowing system on total mortality from crushing or total mortality from other causes, however total live-born mortality from all causes was significantly higher if a sow had previously farrowed in the 360s (1.40 ± 0.10) than the pens (1.06 ± 0.11; P < 0.05), but not the crates (1.17 ± 0.10).

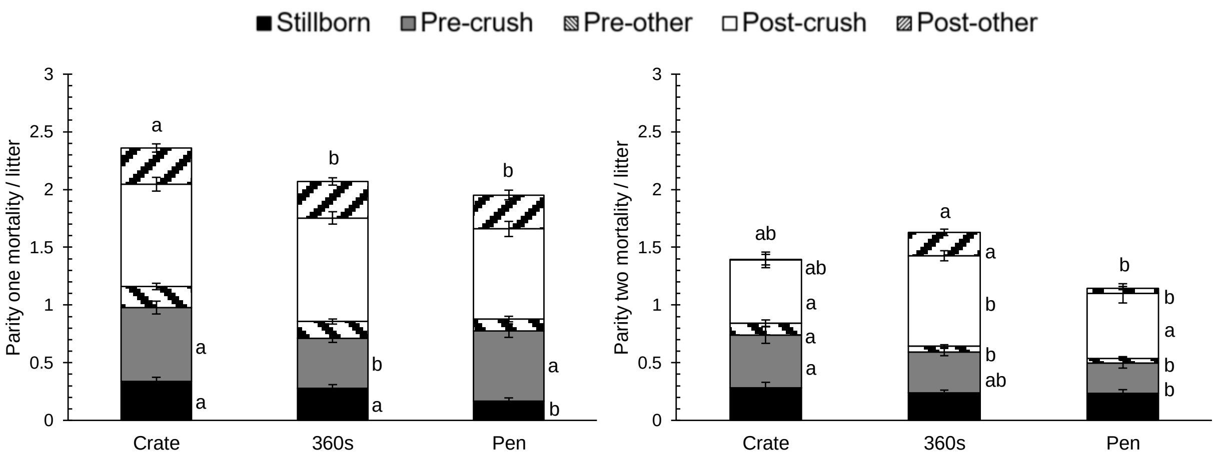


Figure 3.2. Least square means (± s.e.) for total piglet mortality by type and current farrowing system for parities one (left) and two (right). Piglet mortality type is classified by both cause (stillborn, crushing or other) and whether it occurred pre- or post- piglet processing at 4-16 hours after birth. Significantly different frequencies (P < 0.05) between farrowing systems are indicated with different letters for each piglet mortality type (alongside each system) and total piglet mortality (above each system).

Table 3.3. Table of least square means (± s.e.) for second parity sow total born and live-born litter size by first parity farrowing system.

	First parity farrowing system			P value
Second parity litter size	Crate	360s	Pen	
Total born	12.73 ± 0.19^{a}	12.65 ± 0.17^{a}	13.62 ± 0.22^{b}	< 0.001
Live-born	12.39 ± 0.19^{a}	12.46 ± 0.16^{a}	13.24 ± 0.21^{b}	< 0.01

^{a,b} Values within a row with different superscripts differ significantly as indicated.

Effect of a farrowing system interaction

*T*otal born litter size did not differ significantly between farrowing system combinations (crate-crate = 12.27 ± 0.52; 360s-crate = 11.89 ± 0.54; pen-crate = 14.14 ± 0.42; crate-360s = 12.94 ± 0.25; 360s-360s = 12.72 ± 0.23; pen-360s = 13.48 ± 0.28; crate-pen = 12.51 ± 0.37; 360s-pen = 12.78 ± 0.28; pen-pen = 12.77 ± 0.80). The interaction of the first and second farrowing systems had no significant effect on the incidence of stillborn piglets, pre-processing mortality (crushing, other or all) or post-processing mortality from other causes. However, an interaction of the first and second farrowing systems did affect post-processing mortality from crushing ($P < 0.01$) and therefore post-processing mortality from all causes ($P < 0.001$; Figure 3.3). Consequently, total mortality from crushing ($P < 0.05$), total mortality from other causes ($P < 0.01$) and total live-born mortality ($P < 0.01$) were affected by the farrowing system interaction (Figure 3.3).

Effect of individual consistency of sow performance

Parity two live-born litter size and total born litter size increased with increasing parity one litter sizes (parity two live-born piglets = +0.156 ± 0.042 parity one live-born piglets, $P < 0.001$; parity two total born piglets = +0.155 ± 0.043 parity one total born piglets, $P < 0.001$). The incidence of piglet mortality in parity two was not associated with the same category of piglet mortality in parity one, except for the case of savaging (parity two savaging frequency = +0.281 ± 0.139 parity one savaging frequency, $P < 0.05$). Within the same parity, first parity post-processing mortality (crushing, other and all) was significantly associated with pre-processing mortality (post-crushing = +0.083 ± 0.039 pre-crushing, $P < 0.05$; post-other = +0.235 ± 0.067 pre-other, $P < 0.001$; post-all = +0.126 ± 0.035 pre-all, $P < 0.001$). However, in the second parity, there was no association between pre- and post-processing mortality.

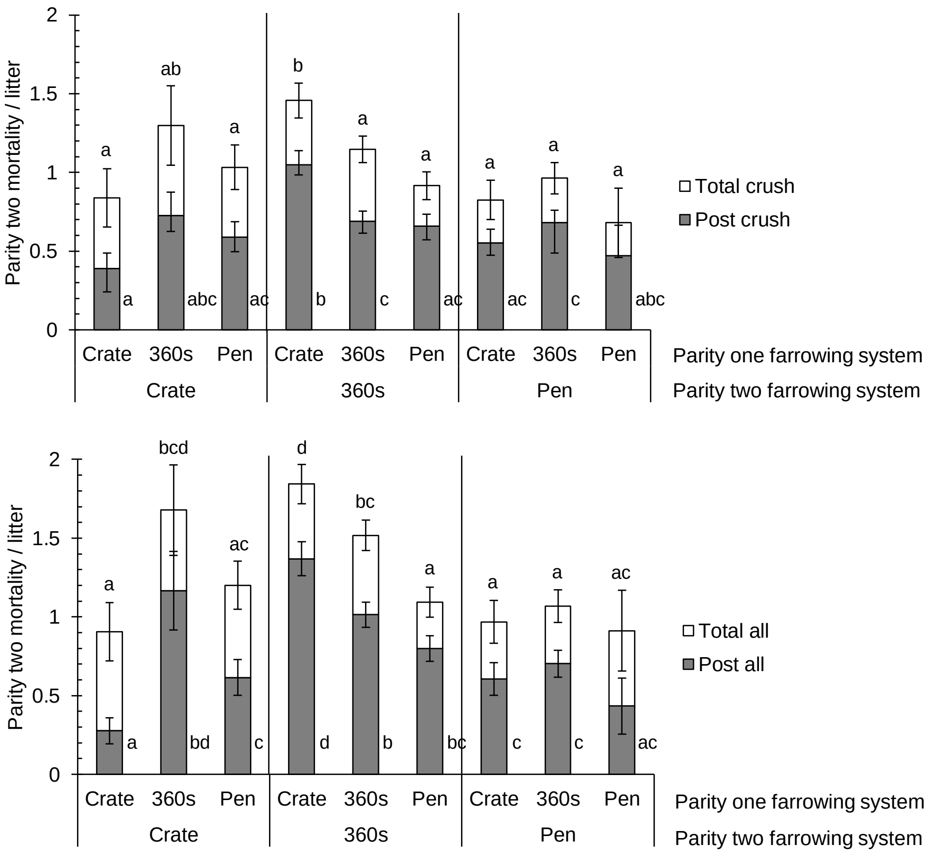


Figure 3.3. Least square means (± s.e.) of second parity live-born piglet mortality from crushing (upper graph) and all causes (lower graph). Bars indicate mortality during the post-processing period (grey bars) and total live born piglet mortality (grey plus white bars) for each parity one and parity two farrowing system combination. Different letters indicate significant differences (*P* < 0.05) across all farrowing system combinations.

3.5. Discussion

To our knowledge, this is the first research paper to report a significant effect of an interaction between the current and previous farrowing systems experienced by the sow on current piglet mortality. Specifically, in the second parity, post-processing mortality in the crates was significantly decreased if a sow previously farrowed in a crate, whereas post-processing mortality in the 360s was significantly increased if a sow previously farrowed in a crate. These findings support our primary hypothesis that inter-parity farrowing system consistency is important for sow performance, in some cases more so than the specific farrowing system used. Previously crated sows may have increased piglet mortality in less confined systems as they have had no previous experience of learning to avoid the increased risk of piglet crushing associated with reduced confinement. Moreover, sows that previously farrowed in the pens or 360s have no experience of prolonged confinement, which is associated with increased physiological stress (Jarvis *et al.*, 2006). Sow maternal behaviour is considered an important factor for piglet survival (Wechsler and Hegglin, 1997; Andersen *et al.*, 2005), and its performance is highly dependent on the physical constraints of the immediate farrowing environment. Earlier studies have also shown sow farrowing behaviour to be affected by the preceding environment of the sow, including during gestation (Boyle *et al.*, 2002), farrowing (Thodberg *et al.*, 2002a, 2002b) and rearing (Chidgey *et al.*, 2016), indicating that sow maternal behaviour develops according to previous environmental experiences. Repeated housing in the same farrowing system would therefore enable sows to adapt and perfect their maternal behaviours for that specific farrowing system, resulting in optimised reproductive success. However, in the current study, this reasoning was not entirely supported, as post-processing mortality in the 360s was lowest if a sow previously farrowed in a pen. Therefore, prior experience of farrowing without confinement may be important for reducing piglet mortality across systems with periods of non-confinement. The condition of repeated housing in the 360s may not have reduced piglet mortality as data collection occurred whilst this system was being introduced on-farm, meaning that management routines fluctuated across the study period as stockpersons developed the most appropriate management.

Second parity post-processing piglet mortality in the pens was also lowest for sows that had previously farrowed in the pens. However, this result was not significant, which may be attributable to the small sample size of the pen-pen group (15 sows) and hence the larger standard error around the numerically lower mean value. Alternatively, differences in mortality caused by the previous farrowing system may have been less pronounced due to the pen system being a distinctly different farrowing system. Consequently, second parity sows which previously farrowed in a crate or 360s may have easily discriminated the pen as a different environment and not used their prior experience to adapt farrowing behaviour, opting instead to relearn how to optimise behaviour for the new environment. This reasoning would also explain why post-processing mortality was particularly high for sows that interchanged between the crate and 360s systems. When these sows were housed for farrowing in their second parity, they would have been less able to discriminate a change of environment and therefore relied upon previous farrowing experience. In later lactation, this would be problematic as the behaviours adapted for prolonged confinement or reduced confinement may not be optimal for piglet survival in the contrasting environment (crate-360s or 360s-crate). Our suggestion would be that if farms do require to change sows between farrowing systems, they should ensure the farrowing systems are sufficiently different for sows to easily discriminate between them.

The majority of piglet mortality occurs during the first 24 hours of life, with a predominant cause being accidental crushing by the sow (Marchant *et al.*, 2000). In the current study, pre-processing crushing mortality was significantly lower in the 360s than the crates or pens in first parity gilts. Earlier studies have shown gilts to exhibit increased sensitivity to the farrowing environment (Jarvis *et al.*, 2001; Thodberg *et al.*, 2002a), whilst pre-partum confinement without nesting material in crates causes physiological stress (Jarvis *et al.*, 1997). Conversely, gilts in both the 360s and pens may have had sufficient space and material to perform pre-partum nesting, leading to increased sow responsiveness towards the piglets (Cronin and van Amerongen, 1991; Thodberg *et al.*, 2002b). Therefore, the lower mortality observed in the 360s may have resulted from the combined benefits of both facilitated nest-building for the dam and increased protection from crushing for the neonates. However, pre-processing crushing mortality in the second parity was unaffected by the current farrowing system, but lower if a sow had previously farrowed in a pen than a crate, further suggesting that early peri-parturient behaviour adapted to the farrowing system experienced during the first farrowing. The prior experience of unconstrained nest-building and/or farrowing in previously penned sows may have resulted in improved maternal behaviour in the second parity, whilst behaviour later developed to reflect the previous and current environments as sows continually try to adapt their behaviours to the farrowing system in use.

Piglet mortality was lower in parity two across all farrowing systems, suggesting improvements in maternal behaviour with prior experience across all treatment combinations. However, the reduction in piglet mortality was the least in the 360s, specifically due to higher post-processing mortality in this system. When the 360s crates are opened at ten days post-partum, sows are required to adapt their behaviour mid-lactation due to the abrupt environmental change from confinement to non-confinement. A separate study conducted by the authors on the same farm found significantly increased piglet mortality during the period immediately after temporary confinement crates are opened (King *et al.*, submitted), therefore temporary confinement systems may not have improved piglet survival over free farrowing systems, as found in the current study. The effect of crate opening in increasing piglet mortality may not have been observed in the first parity where post-processing mortality was equally high across all systems, as all gilts were learning how to cope with lactation irrespective of the farrowing system. Piglet mortality in the second parity may also have been higher in the 360s due to the relatively small area available to the larger sow after crate opening in comparison to the pen, as piglet mortality has been found to increase in loose lactation pens smaller than 5.0m² (Weber *et al.*, 2009). The results from the second parity sows in the current study are consistent with this, with total piglet mortality higher than crates in the 360s (4.0m²) but not pens (total 7.86m²).

Whilst the current study relied on stockperson records regarding the incidence and cause of piglet mortality, data were collected on a single farm by the same staff. Therefore, any inaccuracies regarding piglet mortality incidence and diagnosis would have been similar across farrowing systems and parities, and consequently should not have confounded the final results. However, stockperson biases regarding the different farrowing systems might subconsciously affect the reported cause of piglet mortality, i.e. stockpersons may attribute more deaths to crushing in free farrowing systems as they believe crushing to be more prevalent in these systems. Whilst stockpersons in the current study were unavoidably aware of which farrowing system a sow was currently housed in, stockpersons were predominantly unaware of which system a sow had previously farrowed in.

The farrowing system used can also have longer term effects on sow performance, as sows which farrowed in the pens during their first parity had a significantly larger total born and live-born litter size in their second parity. To our knowledge, only one other study has investigated the effect of the lactation environment on subsequent litter size, and found no difference between standard and temporary confinement crates (Chidgey *et al.*, 2015), which was also found to be the case in the current study. A lower weight loss during lactation results in improved subsequent reproductive performance (Thaker and Bilkei, 2005), which may have occurred in penned gilts. For example, voluntary feed intake of sows is sometimes higher in free farrowing than crated systems (Cronin *et al.*, 2000), whilst sows housed in nonrestrictive systems exhibit more control over nursing behaviour (Arey and Sancha, 1996; Thodberg *et al.*, 2002b), and therefore may begin weaning the litter and reducing metabolic demand before on-farm weaning occurs. In the current study, increasing first parity lactation length also tended to increase second parity litter size, which has been found previously and postulated to result from an improved metabolic status at service (Hidalgo *et al.,* 2014).

Sows are believed to show individual consistency in reproductive performance. Total born and live-born litter sizes are known to be individually consistent across parities, as found in the current study, meaning this trait is already used within commercial breeding indices (Su *et al.*, 2007). However, piglet survival to five days post-partum has also become a selected indicator of reproductive performance (Su *et al.*, 2007). The current study found no sow consistency in piglet mortality across parities, whilst piglet mortality did show individual consistency between pre- and post-processing mortality in the first but not second parity. Sow behaviour during the first parity will be highly dependent on the immediate farrowing environment, but also the individual reaction pattern of the sow (Thodberg *et al.*, 2002a), and therefore it would be expected for piglet mortality to show individual consistency throughout the first farrowing and lactation. In contrast, pre-processing mortality in the second parity is more affected by the previous than the current farrowing system; whilst individual differences in behavioural adaption of sows to the second parity system may mean pre- and post-processing mortality are not consistent. To our knowledge, no previous studies investigating the consistency of sow performance did so across different farrowing systems; therefore the observed consistencies in previous studies may actually reflect the sows' individual ability to adapt to the particular farrowing system used. This highlights the need for farms using multiple farrowing systems to ensure sows return to the same system over repeated farrowings to express individual consistency in reproductive performance.

In conclusion, housing second parity sows in the same farrowing system as their previous farrowing may reduce piglet mortality. Sows which farrowed in the pens during their first parity had additional production benefits of a significantly larger litter size and lower pre-processing crushing mortality in their second parity. It is recommended that commercial farms rehouse sows in the same farrowing system to maximise consistency in sow performance. However, if sows must be changed between farrowing system, the systems should be sufficiently different to enable sows to discriminate between, which may reduce the impact on piglet mortality.

Chapter 4. Sow Free Farrowing Behaviour: Experiential, Seasonal and Individual Variation

4.1. Abstract

Although sow confinement at farrowing is inherently stressful, farrowing crates remain in widespread commercial use. Sows adapt to their environment, however adaptation may be counter-productive if the farrowing system changes. The current study observed the behaviour of second parity sows throughout farrowing in a straw pen system to determine if their previous farrowing experience, in either the same pen system (n = 11) or a temporary confinement crate system (n = 11), affected current nest-building, farrowing and nursing behaviour. Data were analysed using PROC MIXED, with sow ID as the repeated subject. Sows which previously farrowed in pens tended to have a higher pre-partum peak nesting intensity ($P = 0.081$), and throughout parturition exhibited increased lateral lying ($P < 0.01$), decreased ventral lying ($P < 0.001$), decreased sitting ($P < 0.01$) and a decreased frequency of dangerous posture changes ($P < 0.05$). Post-partum, sows that previously farrowed in pens had a lower percentage of sow-terminated nursing ($P < 0.01$), a longer average duration of successful nursing bouts ($P < 0.05$) and a lower frequency of sow-terminated nursing bouts ($P < 0.001$). Seasonal effects were also seen in this naturally-ventilated system, both pre- and post-partum, with autumn/winter farrowings associated with more pre-partum nesting ($P < 0.01$), a higher pre-partum peak nesting intensity ($P < 0.05$), a longer average duration of successful nursing ($P < 0.05$) and a higher percentage of nursing bouts ending with piglets asleep at the udder ($P < 0.05$) than in the spring/summer. Individual variation in pre-partum nesting behaviour was associated with differences in parturient and post-partum behaviours. The results show that the prior experience of confinement, or a change of farrowing system, significantly affects sow farrowing behaviour in free farrowing pens, which may compromise the welfare of both sows and piglets.

4.2. Introduction

Research has demonstrated that prolonged confinement of the farrowing sow causes physiological stress and compromises sow welfare (Jarvis *et al.*, 2006), however farrowing crates remain the predominant system used throughout farrowing and lactation on commercial indoor pig farms (Baxter and Edwards, 2016). Although three countries have banned the use of farrowing crates (Norway, Sweden and

Switzerland), in other countries concerns about increased piglet mortality in free farrowing systems remain (e.g. the UK, Farm Animal Welfare Committee, 2015). Whilst the primary reason for sow confinement is to reduce the risk of piglet crushing (FAWC, 2015), some surveys of commercial farms have found no significant benefit of using crated farrowing systems in reducing overall piglet mortality (Weber *et al.*, 2009; KilBride *et al.*, 2012).

Whilst temporary confinement systems, whereby the sow is confined in a crate from entry into the farrowing house until approximately 2-7 days post-partum, provide a compromise between the requirements of farmers and livestock, the sows' behavioural need to perform pre-partum nest-building behaviours is rarely met in such systems. Pre-partum, confined sows without access to suitable substrates will still attempt to perform nest-building behaviour and show increased physiological stress responses (Lawrence *et al.*, 1994; Damm *et al.*, 2003), which may result in a prolonged farrowing duration (Wülbers-Mindermann *et al.*, 2002; Oliviero *et al.*, 2008) and increased savaging of piglets by gilts (Jarvis *et al.*, 2004). Provision for pre-partum nest-building has further benefits for the new-born piglets, being associated with improved maternal responsiveness to piglet distress calls (Herskin *et al.*, 1998; Thodberg *et al.*, 2002a), enhanced piglet serum IgG and IgM levels from increased colostrum intake (Yun *et al.*, 2014b) and reduced pre-weaning piglet mortality (Cronin and Van Amerongen, 1991).

Although sow pre-partum nesting behaviours are affected by the immediate farrowing environment, including seasonal climatic variations (Jensen, 1989), behaviour also develops over successive parities as the sow adapts to repeated housing in the same system (Damm *et al.*, 2003; Jarvis *et al.*, 2001; Thodberg *et al.*, 2002a). This may also be true post-partum, as the maternal behaviour of previously crated and penned sows remained dissimilar when subsequently housed in the same farrowing system (Thodberg *et al.*, 2002b), demonstrating that prior confinement may impact the development of sow farrowing behaviour. However, no differences in pre-partum or maternal behaviours were observed amongst outdoor sows which were previously housed outdoors or in indoor pens (Wülbers-Mindermann *et al.*, 2015). Whilst the majority of commercial sows return to the same farrowing system throughout their reproductive life, some farms move sows between farrowing systems in consecutive parities, especially as interest in alternatives to conventional farrowing crates increases and new systems are trialled or adopted. However, a change of farrowing system is postulated to be detrimental for sow welfare (RSPCA, 2016), may disrupt the appropriate adaptation of sow farrowing behaviours to the farrowing system over successive parities and ultimately result in increased pre-weaning piglet mortality (Chapter three).

The purpose of the current study was to investigate the effect of the first parity farrowing system, either a temporary confinement crate system or straw-based free farrowing pen, on the pre-partum nesting, farrowing and post-partum nursing behaviour during the second parity when all sows were housed in the same straw-based free farrowing system. As the farrowing system used was in a naturally ventilated building and thus subject to seasonal temperature fluctuations, behavioural observations were conducted throughout the year to determine any seasonal variation in sow farrowing behaviours. The effect of individual differences in pre-partum nest-building behaviour on partum and post-partum behaviour was also explored.

4.3. Materials and Methods

4.3.1. Animals and dry sow management

Data were collected on a commercial pig breeding unit in the north east of England. The farm consisted of 1300 Camborough (Genus PIC, Basingstoke) breeding gilts and sows, bred with Hampshire semen collected on-site for artificial insemination. During gestation, all animals were kept in straw pens in groups according to body size. Animals were generally moved into the farrowing accommodation one week before their expected farrowing date.

4.3.2. Farrowing sow housing and management

During farrowing and lactation, second parity sows were housed in a straw-based free farrowing pen (Figure 4.1a), whilst for their previous farrowing they had either been housed in the same farrowing system (free farrowing pens) or a temporary crate system (360s; 360º Freedom Farrower®, Midland Pig Producers, Burton-on-Trent; Figure 4.1b; see Figure 2.2(a,b) and Figure 2.3 for images of these systems).

Pens were in rows of individual units, each consisting of a 2.30m x 1.20m indoor nest area with adjacent 2.30m x 0.70m separate covered piglet creep area and access to a 2.55m x 2.00m outdoor run (Figure 4.1a). Pens had a solid concrete floor throughout, whilst the nest area contained farrowing rails and piglet protection bars across three sides to reduce piglet crushing risk. The nest area contained 5kg of long straw from the day of sow entry into the farrowing system, whilst the entire creep floor was covered in wood shavings. The pens had no ambient temperature controls, however a 400w electric heater was located at one end of each creep, these being individually switched off three to five days post-partum. Pens were routinely cleaned out weekly with straw and wood shavings replenished. Pre-partum, additional straw or wood shavings were added to nests when required and soiled straw was removed and replenished post-partum.

The 360s comprised of a stainless steel crate (2.50m x 0.90m when closed, 2.50m x 1.60m at sow shoulder height when opened) within a 2.50m x 1.80m pen (Figure 4.1b). The 360s had plastic slatted flooring with a solid panel containing drainage slots in the sow lying area plus a 1.80m x 0.40m heat pad to one side of the crate. Two parallel vertical bars were positioned at the rear of the crate for additional piglet protection. The 360s crates were closed from sow entry into the farrowing house until approx. ten days post-partum, with no nesting materials provided. Buildings containing 360s were kept at 22 ± 1°C, with the additional heat mat along one side of each pen starting at 36°C and reducing to 30°C by weaning. Room temperature was gradually reduced automatically to 18 ± 1°C by day ten post-partum and to 16 ± 1°C by weaning.

4.3.3. Farrowing sow and piglet husbandry

Sows were hand-fed once daily in the morning, onto the floor of the nest area in straw pens or troughs in the 360s, until all sows in a building had farrowed, after which sows were fed twice a day (diet composition: 15.98% CP, 13.69 MJ DE/Kg). Feed was gradually increased from 1kg to 6kg per sow per day throughout lactation, whilst water was provided ad libitum, either from drinkers above the trough in the 360s or from a floor trough in the outdoor area of the pens (Figure 4.1a and Figure 4.1b). A handful of creep feed (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed Supplements Ltd, Thirsk) was provided once daily on the floor in all systems from approx. ten days of age until weaning.

In accordance with veterinary recommendation for this farm, piglets were tail docked, teeth clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd, Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24 hours of birth. Placenta and deceased piglets were also removed at this time, and live litter size was equalised for both piglet number and size by cross-fostering piglets of a similar age. The farm's management routines included piglet fostering, which occurred throughout lactation as necessary to ensure piglet and litter sizes remained similar.

4.3.4. Experimental design

The behaviours of 22 sows were recorded during their second parity when all sows farrowed in straw pens, using a 2x2 factorial design for the previous farrowing system (pens or 360s) and current season (spring/summer = Apr-Sep, autumn/winter = Oct-Mar) to produce four combination groups – pens-spring/summer (n = 6), pens-autumn/winter (n = 5), 360s-spring/summer (n = 5) and 360s-autumn/winter (n = 6). This subgroup of sows was selected for behavioural observation from our preceding larger study investigating the effect of the previous farrowing system on piglet mortality (Chapter three). Experiments were approved under the Newcastle University Animal Welfare and Ethics Review Body, Approval 379 on 23rd June 2014.

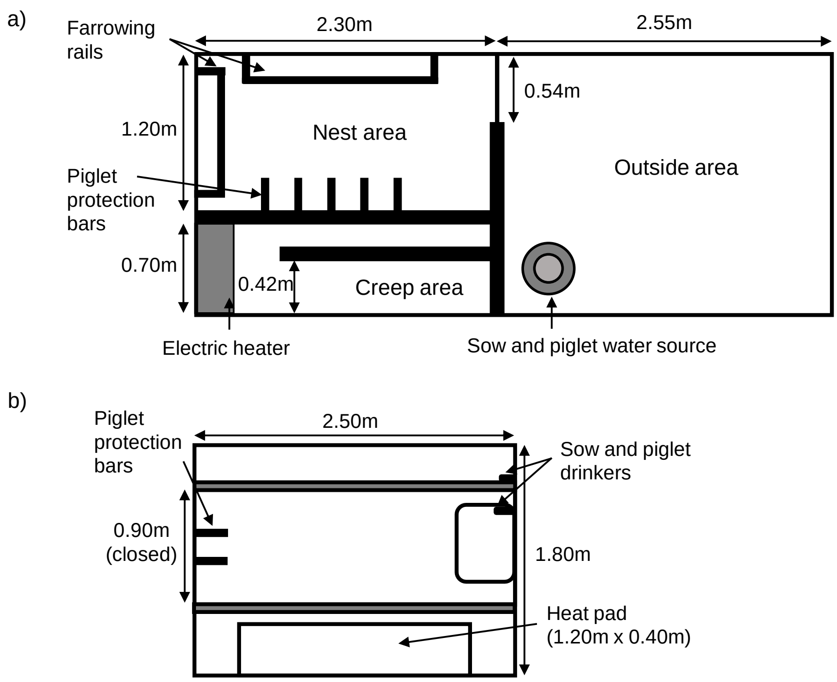


Figure 4.1. Sow farrowing pen layouts illustrating dimensions for (a) the straw-based pen with outside run and (b) the 360º Freedom Farrower.

4.3.5. Data collection

Behavioural observations were recorded during the period from January 2015 to July 2016. CCTV cameras (Gamut Professional Sony Effio E Bullet CCTV Camera 700 TV Line, 15m Infrared Night Vision (Gamut, Open24 seven Ltd, Bristol, UK)) were installed above each pen to observe the indoor nest area only. Cameras recorded continuously from two days before until two days after farrowing. From the video recordings, time of birth of first piglet (BFP) was identified, with the period of analysis for nesting behaviour comprising the 24 hours before BFP, farrowing behaviour analysis from the BFP until the last liveborn piglet, and the post-partum nursing observation occurring from 24 hours until 48 hours after the birth of the last live born piglet. Video data were analysed for all 22 sows during the nesting period, however three sows were excluded from some parts of analysis due to spending a significant proportion of time out of view in the outside area (two sows during parturition: one from each of the previous systems; one sow post-partum: previously in the 360s).

Pre-partum nesting analysis was performed using five minute scan sampling for the 24 hours before the birth of the first piglet (BFP), with sow postures (lateral lying, ventral lying, standing, sitting, out of sight (outside)) and nesting behaviours (straw-directed, pen-directed, turning around in nest, none) recorded as percentages of total pre-partum observations. Additional nesting behaviour measures were calculated using adapted measures from Thodberg *et al.* (2002a; Table 4.1). The first 60 minutes (12 observations) after feeding were eliminated from analysis, so as not to confound feeding with straw rooting behaviour.

Measures during farrowing were adapted from Thodberg *et al.* (2002a), using continuous recording. Total farrowing duration was from the first until the last born piglet, excluding any final stillborn piglet in a litter. From this, the early (first three piglets), late (last three piglets) and overall mean inter-piglet birth intervals were calculated. Frequency of dangerous posture changes throughout parturition (stand-to-lie, sit-to-lie, rolling, total), latency to the first posture change after BFP and the frequency of posture changes during the early birth interval (first three piglets) were recorded, whilst the percentage of duration of parturition in each posture (lateral lying, ventral lying, standing or sitting) was also recorded.

Post-partum, total duration in each posture and frequency of dangerous posture changes were recorded in the same manner, and also included the total duration and frequency of the sow going into the outside run. Descriptions of nursing behaviour are shown in Table 4.1. The frequency and average duration of sow-terminated nursing, successful nursing and all nursing bouts were calculated, as were the mean time interval between successful nursing bouts, and the percentage of all nursing bouts which were sow-terminated, successful, occurring with the udder facing the creep and ending with piglets asleep at the udder.

Table 4.1. Description of pre-partum behavioural measures adapted from Thodberg *et al.* (2002a), and post-partum sow nursing behaviours.

Behavioural measure	Description
Pre-partum nesting	
Peak intensity	Frequency of nesting observations during peak hour of nesting (max. 12)
Peak nest	Latency between peak hour of nesting and BFP (hours)
Last nest	Latency between last two consecutive nesting bouts and BFP (hours)
Last posture	Latency between last posture change and BFP (mins)
Last stand	Latency between last standing observation and BFP (mins)
Turning	Sow is turning around by 180º or more whilst standing
Post-partum nursing	
Nursing bout	Starts/ends when over/under 50% of the litter are active at the udder, respectively
Successful nursing bout	Piglets perform rapid sucking behaviour for > 20 seconds (Whittemore and Fraser, 1974)
Sow terminated nursing bout	Sow ends nursing bout by changing posture (includes both successful and unsuccessful nursings)
Udder facing creep	Sow lying laterally with back towards farrowing rail and udder facing towards the piglet creep area
Piglets asleep at udder	>5 piglets asleep within one piglet's length of the sow's udder after nursing (includes both successful and unsuccessful nursings)

4.3.6. Statistical analyses

Analyses were performed by producing mixed linear models using PROC MIXED in SAS 9.4. Models for describing nesting behaviour included the fixed effects of previous system (pen or 360) and the current season (spring/summer = Apr-Sep, autumn/winter = Oct-Mar). The base models for farrowing and nursing behaviours included individual sow ID as the repeated subject, the fixed effects of previous farrowing system and season and the six measures of pre-partum nesting behaviour as continuous variables. Variables were eliminated in a step-wise manner, with all final models including variables of $P < 0.10$. Only significant effects ($P < 0.05$) are presented for continuous variables, whereas tendencies ($P < 0.10$) are also discussed for fixed effects.

Farrowing models for duration measures included the base model plus total born litter size as a continuous variable. Farrowing models for postures and posture changes included the base model plus total farrowing duration as a continuous variable. Models for latency to first posture change after BFP and total posture changes during the early farrowing interval included the duration of the early farrowing interval instead of the total farrowing duration.

Post-partum models for nursing behaviour (excluding percentage of nursings with the udder facing the creep and percentage of nursings where piglets fell asleep at the udder), posture changes and total duration of postures included the base model plus total born litter size as a continuous variable. The model for the percentage of nursings where the udder faced the creep included the base model, total born litter size and creep location as a fixed effect (left or right), whilst the model for the percentage of nursings where piglets fell asleep at the udder included the base model plus total born litter size and the frequency of both successful and sow-terminated nursing bouts as continuous explanatory variables.

4.4. Results

4.4.1. Nesting behaviour

Nesting peak intensity tended to be affected by the previous farrowing system (P = 0.081), being higher for sows that previously farrowed in the pens (8.09 ± 0.52) than the 360s (6.73 ± 0.52). The last standing bout latency before BFP also tended to be affected by the previous farrowing system (P = 0.084), being longer for sows which previously farrowed in the pens (47.7 mins ± 10.4) than the 360s (20.9 mins ± 10.4).

No effects of the previous farrowing system were observed for the percentage of observations in each posture, or on the timing of peak nest building, timing of the last nest building, or the last posture change latency before BFP. A number of pre-partum postures and nesting activities were affected by the current season, with significant effects displayed in Table 4.2.

Table 4.2. Least square means, standard error and *P* value for nest-building behaviours during the 24h before the birth of the first piglet which were significantly affected by season.

Nesting behaviour	Spring/Summer (Apr-Sep)	Autumn/Winter (Oct-Mar)	s.e.	*P*
Standing (%)	17.4	27.2	2.01	0.01
Nesting (%)	12.0	17.5	1.12	0.01
Turning (%)	0.17	1.07	0.16	0.001
None (%)	87.1	80.3	1.25	0.001
Peak intensity*	6.39	8.43	0.52	0.05

*Frequency of nesting behaviour during peak hour of nesting, scale of 0-12 observations

4.4.2. Farrowing behaviour

The significant associations of the six measures of pre-partum nesting behaviour with farrowing duration measures, percentage of time in different postures and frequency of dangerous posture changes are shown in Table 4.3. The most significant associations were that with increasing time to BFP after the last nesting bout, latency to first posture change after BFP increased (+28.2 mins ± 5.2; $P < 0.001$), whilst an increased percentage of pre-partum observations performing nesting behaviours was associated with an increased duration of ventral lying (+1.23 mins ± 0.30; $P = 0.001$) and a decreased duration of lateral lying (-1.65 mins ± 0.40; $P < 0.001$) during parturition.

Duration of farrowing

The mean total farrowing duration was 266.0 mins ± 42.1, which increased with increasing total born litter size (+26.8 mins ± 11.6 per piglet; $P < 0.05$), whilst the early farrowing interval decreased with increasing time since the last pre-partum nesting bout (-6.52 mins ± 3.10 per additional hour of latency; $P = 0.05$). No other variables were found to affect measures of farrowing duration.

Postures during farrowing

The effect of the previous farrowing system on the percentage duration of farrowing spent in each posture is shown in Figure 4.2. Sows that had previously farrowed in the pens spent an increased percentage of farrowing lying laterally ($P < 0.01$) and a decreased percentage of farrowing spent lying ventrally ($P < 0.001$) or sitting ($P < 0.01$) than sows which previously farrowed in the 360s. The percentage of time spent sitting decreased ($P < 0.01$), whilst the percentage of time spent standing also tended to decrease ($P = 0.068$), with increasing total farrowing duration.

Table 4.3. Associations between pre-partum nesting and partum behaviours (see Table 4.1 for definitions of pre-partum behavioural measures).

	Pre-partum behavioural measure					
Farrowing behaviour	Nest%	Peak intensity	Peak nest	Last nest	Last stand	Last posture
Percentages of postures						
Standing						
Sitting			**(-)			
Ventral	***				***	
Lateral	***(-)				*(-)	
Early posture changes						
First posture				***		
Early interval	*		**(-)		*	
Dangerous posture changes						
Rolling						
Stand-to-lie				*(-)		
Sit-to-lie						
Total	*					

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$

(-) denotes a negative association

Frequency of dangerous posture changes

The effect of the previous farrowing system on the frequency of dangerous posture changes during farrowing is shown in Figure 4.2. Sows that had previously farrowed in the pens performed fewer rolling (P < 0.05) and sit-to-lie posture changes (P < 0.05), and therefore fewer total dangerous posture changes (P < 0.05), during farrowing than sows which previously farrowed in the 360s. Frequency of posture changes during the early farrowing interval increased with increasing early farrowing interval duration (P < 0.01). The total frequency of dangerous posture changes increased with increasing total farrowing duration (+0.041 ± 0.010 per min; P < 0.001), specifically the frequency of rolling (+0.018 ± 0.006 per min; P = 0.01) and sit-to-lie (+0.018 ± 0.005 per min; P < 0.01), but not stand-to-lie posture changes.

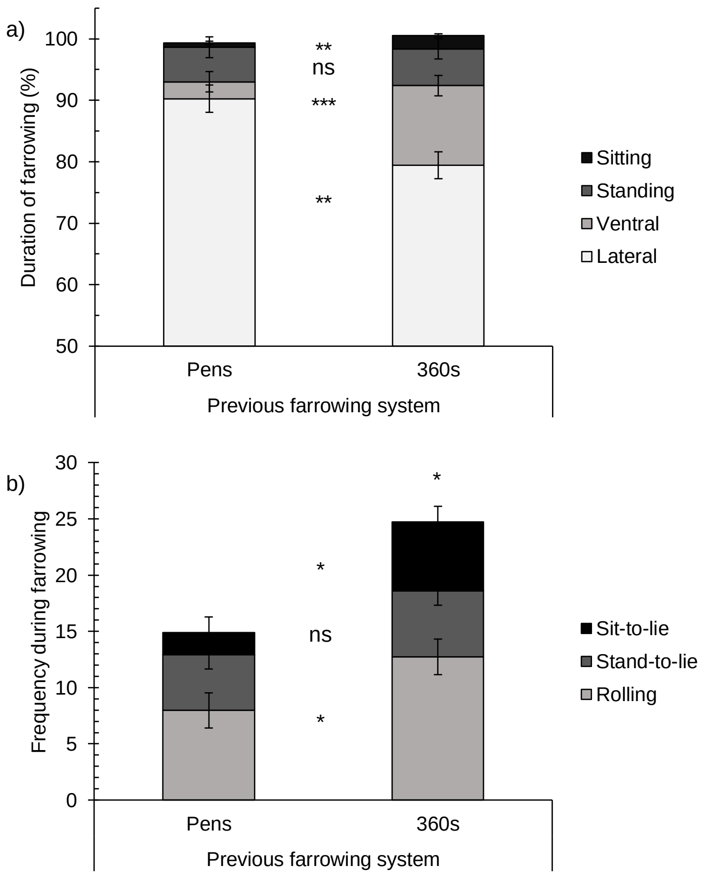


Figure 4.2. Least square means (± s.e.) for the effect of the previous farrowing system on partum (a) duration of sow postures (%) and (b) frequency of sow dangerous posture changes. Differences are indicated for each posture (a and b; between systems) and total posture changes (b only; above latter system; ns(*P* > 0.05), *(*P* < 0.05), **(*P* < 0.01), ***(*P* < 0.001)).

4.4.3. Post-partum nursing

The effect of pre-partum nesting behaviour on post-partum behaviour is shown in Table 4.4. The percentage of successful nursing bouts decreased as the percentage of pre-partum nesting observations increased ($P < 0.01$), and with earlier final nesting and standing bouts (both $P < 0.05$); whilst the average duration of successful nursing bouts increased with a lower peak nesting intensity ($P < 0.01$), an earlier peak hour of nesting ($P < 0.05$) and a later final posture change before BFP ($P < 0.05$).

Table 4.4. Associations between pre-partum nesting and post-partum sow behaviour (see Table 4.1 for definitions of pre-partum behavioural measures).

	Pre-partum behavioural measure					
Post-partum behaviour	Nest%	Peak intensity	Peak nest	Last nest	Last stand	Last posture
Nursing behaviour						
Successful frequency	*(-)			**(-)	*(-)	
Terminated frequency	*					
All nursing frequency						
Successful avg. duration		**(-)	*			*(-)
Terminated avg. duration						
All nursing avg. duration		*(-)	*			*(-)
Successful nursing interval	*			***	*	
%age successful	*(-)			**(-)	*(-)	
%age terminated						
%age towards creep					***(-)	
%age asleep at udder						
Percentages of postures						
Standing						
Sitting	*(-)	*				
Ventral						
Lateral						
Outside				***		
Dangerous posture changes						
Rolling	**					
Stand-to-lie						
Sit-to-lie						
Total						

** P < 0.05 ** P < 0.01 *** P < 0.001*

(-) denotes a negative association

Nursing behaviours

The effect of the previous farrowing system on post-partum nursing behaviours is shown in Table 4.5. Most notably, sows which previously farrowed in the 360s displayed an increased frequency of sow-terminated nursing (*P* < 0.001), decreased duration of successful nursing bouts (*P* < 0.05) and a longer interval between successful nursing bouts (*P* < 0.05) than sows which previously farrowed in the pens. The average duration of successful nursing bouts was significantly longer in the autumn/winter (10.21 mins ± 0.37) than the spring/summer (8.92 mins; *P* < 0.05). The percentage of nursing bouts which ended with more than five piglets asleep at the udder was also significantly higher in the autumn/winter season (53.1% ± 3.8) than the spring/summer (39.1% ± 4.0; *P* < 0.05). The percentage of nursing bouts with the udder facing the creep tended to be higher with the creep on the left than the right side of the pen (89.5% ± 5.5 vs. 75.8% ± 4.8; *P* = 0.076). The percentage of nursing bouts ending with more than five piglets asleep at the udder decreased with an increasing frequency of both successful nursing bouts (*P* < 0.05) and sow terminated nursing bouts (*P* < 0.0001).

Table 4.5. Least square means (± s.e.) and *P* value (ns(*P* > 0.10)) for the effect of the previous farrowing system on post-partum nursing behaviour.

Sow nursing behaviour	Pens	360s	*P*
Nursing frequency			
Successful	21.68 ± 0.93	18.95 ± 0.98	0.10
Sow-terminated	7.20 ± 0.58	10.98 ± 0.62	0.001
All nursing bouts	33.45 ± 1.20	33.90 ± 1.26	ns
Average nursing duration (mins)			
Successful	10.42 ± 0.37	8.72 ± 0.40	0.05
Sow-terminated	6.24 ± 0.55	6.23 ± 0.58	ns
All nursing bouts	9.51 ± 0.38	7.80 ± 0.40	0.05
Percentage of all nursing bouts			
Successful	67.29 ± 3.63	55.58 ± 3.85	0.10
Sow-terminated	24.02 ± 1.25	30.58 ± 1.32	0.01
Udder facing creep	79.04 ± 4.98	84.66 ± 5.27	ns
Asleep at the udder	39.22 ± 3.60	53.32 ± 3.94	0.10
Successful nursing interval (mins)	65.97 ± 4.69	83.10 ± 4.97	0.05

Percentage of time in different postures

Sows that had previously farrowed in the pens spent significantly longer lying laterally (72.5% ± 2.3; $P < 0.05$), and tended to spend less time lying ventrally (12.5% ± 2.0; $P = 0.090$), than sows that had previously farrowed in the 360s (lateral = 64.0% ± 2.5; ventral = 17.7% ± 2.1). Sows that farrowed in the spring/summer spent less time lying ventrally (11.8% ± 2.1; $P < 0.05$) and more time outside (5.83% ± 0.64; $P < 0.001$) than sows that farrowed during the autumn/winter season (ventral = 18.4% ± 2.0; outside = 1.99% ± 0.61).

Frequency of dangerous posture changes

The frequency of rolling was lower for sows that previously farrowed in the pens (17.4 ± 2.6) than the 360s (26.3 ± 2.7; $P < 0.05$). No other effects of the previous farrowing system, current season or total born litter size were found on the percentage of time in different postures or the frequency of dangerous posture changes.

4.5. Discussion

The current research confirms findings by earlier studies that the previous farrowing system affects current sow behaviour throughout farrowing (Thodberg *et al.*, 2002a, 2002b). However, this is the first study to find such a profound effect of the previous farrowing system on sow farrowing behaviour. These experiential effects on sow behaviour may have contributed to the differences in piglet mortality related to previous farrowing experience which were observed in a more extensive analysis of production results on the same farm (Chapter three). A strength of the current study is that sow behaviour is compared within the same farrowing system, and therefore the only difference between experimental treatments is the previous farrowing system of the animals. However, a limitation of this experimental design is that it cannot be elucidated whether the poorer maternal behaviour of previously confined sows was caused by the previous experience of farrowing in confinement or an inherent effect of changing the farrowing system between parities, regardless of the direction of change. Either way, the behavioural differences observed are suggestive of a detrimental response occurring within the previously confined sows.

Whilst there were no experiential effects on the total amount of nest-building behaviour, results showed a tendency for prior free farrowing experience to result in a higher nesting intensity peak. This might suggest that the nest-building behaviour of these sows was less fragmented, and therefore more proficient. The nest-building behaviour of previously penned sows may have been more developed during the second parity due to learning and subsequent improvement of these behaviours with prior experience; whereas previously confined sows may have adapted their nest-building behaviours to the constraints of their previous farrowing environment. Alternatively, as sow nesting behaviour is internally motivated by pre-partum hormonal changes (Algers and Uvnäs-Moberg, 2007), its progress may be disturbed by an animal's physiological responses to stress, similar to the effects of stress on the progress of parturition (Lawrence *et al.*, 1992). Although internally-motivated, nest-building is terminated by sufficient external feedback from the nest site to affirm that the nest has been completed (Jensen, 1993). Therefore, the less proficient nest-building of previously confined sows may have delayed the termination of nest-building, resulting in the observed tendency for a shorter latency between standing and the start of farrowing and later increased restlessness throughout farrowing, due to unsatisfactory environmental feedback from the nest to terminate the nest-building behaviour, often seen amongst confined sows (Damm *et al.*, 2003; Jarvis *et al.*, 2001).

Whilst previously confined sows displayed increased restlessness during parturition, there were no observable differences in the frequency or duration of standing behaviour, therefore the increased restlessness is unlikely to have resulted from a continued performance of nest-building behaviour after the commencement of farrowing. Increased sitting behaviour during parturition has been found previously within crated sows (Damm *et al.*, 2003; Jarvis *et al.*, 1997; Jarvis *et al.*, 2004), and may be indicative of a motivational conflict from the inability to nest-build in confinement (Jarvis *et al.*, 2004). Confined sows also exhibit increased restlessness and physiological stress responses in comparison to free farrowing sows (Jarvis *et al.*, 1997; Lawrence *et al.*, 1994). As previous studies have already shown farrowing behaviour to develop over successive parities (Jarvis *et al.,* 2001; Thodberg *et al.,* 2002a, 2002b), previously crated sows may have performed increased sitting and restlessness during parturition in response to confinement in their first parity, with these behaviours persisting during the observed subsequent parturition in a free farrowing pen. This may be similar to, but less severe than, animals continuing to perform stereotypical behaviours which developed in a poor environment when rehoused in an enriched environment (Mason, 1991). Conversely, Thodberg *et al.*

(2002a) found increased restlessness during parturition in sows that were previously housed in a free farrowing system. However, in their study, all sows were housed in gestation stalls between the first and second farrowing, therefore sows may have become less reactive to confinement during the second parturition. The effect of the gestation environment has been highlighted in another study, whereby group-housed sows were more restless during parturition in farrowing crates than sows which had been stall housed throughout gestation (Boyle *et al.*, 2002).

The previous farrowing system also affected post-partum nursing behaviours, with a decreased duration of successful nursing bouts and increased incidence of sow-terminated nursing by sows which previously farrowed in the 360s. Sow-terminated nursing bouts are undesirable as they increase the frequency of sow rolling, therefore increasing the risk of piglet crushing, especially in free farrowing systems (Weary *et al.,* 1996a). Sow-terminated nursing bouts also limit the opportunity for piglets to perform post-nursing udder massage as a means of increasing sow milk production (Jensen *et al.*, 1991). It is speculated that previously confined sows may continue to experience increased stress, causing stress-related hormones to interfere with oxytocin expression associated with parturition. Consequently, the oxytocin-induced reduced responsiveness of sows during parturition (Jarvis *et al.*, 1999), and the acceptance of, and bonding with, piglets post-partum may be disrupted by the hormonal modulation of stress (Jarvis *et al.*, 1997), resulting in the increased partum and post-partum restlessness and compromised nursing behaviour of previously confined sows.

Additionally, piglets were found to sleep at the udder more if a sow previously farrowed in the 360s, which may have been a consequence of the poorer nursing behaviour of these sows. A previous study by Weary *et al.* (1996b) found that both individual piglets and entire litters who spent more time active underneath the sow when she was standing or sitting had lower weight gain, whilst the majority of crushed piglets are identified as also being malnourished (Dyck and Swierstra, 1987). Therefore, excessive lying at the udder by piglets may be an indicator that those individual piglets, or the entire litter, are becoming undernourished and may require supplementary feeding to reduce the risk of piglet mortality by starvation or the subsequent increased risk of crushing.

Not only does the current study confirm the effect of prior experience, but the findings also suggest that sows adapt their behaviour depending on the time of year at parturition. One of the primary functions for performing pre-partum nest-building in the wild is to provide a shelter and microclimate for the neonates (Algers and Jensen, 1990), whilst a previous study on sows in a semi-natural environment found sows to adapt their choice of nest site and collection of nesting material across seasons (Jensen, 1989). However, to our knowledge, no previous studies have described seasonal variation in both pre-partum nest-building and post-partum nursing behaviours in a commercial setting. Successful nursing bouts may have been longer in the autumn/winter due to increased demand for milk by the litter, although whether this demand was fulfilled by the sow via increased milk supply cannot be determined. The percentage of nursing bouts ending with piglets asleep at the udder was also increased during the autumn/winter months, as well as with a decreasing frequency of successful nursing bouts, suggesting piglets risked resting at the udder when their nutritional requirements were not being met. However, lying at the udder may also increase during the colder months as the piglets are attracted to the additional warmth radiating from the udder (Weary *et al.,* 1996b).

Furthermore, individual variation in pre-partum nesting behaviour had significant associations with parturient and post-partum behaviours of the sow. As pre-partum nesting behaviour was so strongly affected by the season of farrowing in the current study, these associations may be reflective of sow responsiveness to climatic temperature fluctuations. For example, sows with more observations of pre-partum nesting exhibited increased ventral and reduced lateral lying during parturition, with an increased ratio of ventral to lateral lying previously associated with colder room temperatures amongst gilts (Canaday *et al.*, 2013).

Whilst an increased latency between the last nesting bout and BFP was associated with desirable behaviour during parturition (i.e. increased latency to first posture change), this measure was associated with undesirable post-partum behaviours (increased percentage of time outside of the nest and an increased successful nursing bout interval). Thodberg *et al.* (2002a) found an increased latency between the last nesting bout and BFP to be associated with an escape response during a pre-pubertal human test. Therefore, this nest-building behavioural measure may be associated with a flighty behavioural response to stress, including the post-partum avoidance of the litter indicated in the current study. An increased latency between the peak hour of nesting and BFP was associated with a decreased frequency of posture changes during the early farrowing interval in both Thodberg *et al.* (2002a) and the current study, which could be due to individual differences in the hormonal control of both pre-partum nesting and sow passivity during parturition (Algers and Uvnäs-Moberg, 2007).

In conclusion, sow farrowing behaviour was affected by the previous farrowing system, as confinement during the previous farrowing was associated with increased fragmentation of pre-partum nesting, increased restlessness during parturition and poorer post-partum nursing behaviour. These differences provide further evidence that farrowing behaviour develops with experience, as housing in a restrictive environment at farrowing had a detrimental effect on later farrowing behaviour in a free farrowing system. Domesticated sows also possessed the ability to adapt their nesting and nursing behaviour according to climatic variation.

Chapter 5. Temporary Crate Opening Procedure Affects Immediate Post-Opening Piglet Mortality and Sow Behaviour

5.1. Abstract

Producers are interested in utilising farrowing systems with reduced confinement to improve sow welfare, however concerns of increased mortality may limit commercial uptake. Temporary confinement systems utilise a standard crate which is opened 3-7 days post-partum, providing protection for neonatal piglets at their most vulnerable age and later increased freedom of movement for sows. However, there is anecdotal evidence that piglet mortality increases immediately after the temporary crate is opened. The current study aims were to determine if piglet mortality increases post-opening, to trial different opening techniques to reduce post-opening piglet mortality and to identify how the different opening techniques influence sow behaviour. Three opening treatments were implemented across 416 sows: two involved opening crates individually within each farrowing house when each litter reached seven days of age, in either the morning or afternoon (AM or PM), with a control of the standard method used on the farm to open all crates in each farrowing house simultaneously once the average litter age reached seven days (ALL). Behavioural observations were performed on five sows from each treatment during the six hours after crate opening, and during the same six hour period on the previous and subsequent days. Across all treatments, piglet mortality was significantly higher in the post-opening than pre-opening period ($P < 0.0005$). Between opening treatments, there were significant differences in piglet mortality during the two days after crate opening ($P < 0.05$), whilst piglet mortality also tended to differ from crate opening until weaning ($P = 0.052$), being highest in ALL and lowest in PM. Only sows in the PM treatment showed no increase in standing behaviour but did show an increased number of potentially dangerous posture changes after crate opening ($P = 0.01$), which may be partly attributed to the temporal difference in observation periods. Sow behaviour only differed between AM and ALL on the day before crate opening, suggesting the AM treatment disrupted behaviour pre-opening. Sows in AM and PM treatments showed more sitting behaviour than ALL, and therefore may have been more alert. In conclusion, increases in piglet mortality after crate opening can be reduced by opening crates individually, more so in the afternoon. 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.

5.2. Introduction

The prolonged confinement of sows in crates during farrowing and lactation remains common practice across commercial indoor breeding units. The confinement of sows in crates has severe implications for sow welfare, such as restricting the capacity to turn around, perform pre-partum nesting behaviours and maintain attachment with the litter (Pedersen *et al.*, 2013; Melišová *et al.*, 2011), resulting in increased physiological stress for the sow (Jarvis *et al.*, 2006). However, farrowing crates were primarily introduced to improve piglet welfare by protecting new-born piglets from fatal or injurious crushing. Whilst a greater respect for the biological needs of the sow during farrowing and lactation is required to improve welfare standards (Baxter *et al.*, 2011b), the safety of piglets from injury and death must also be considered. Although more recent studies on commercial farms suggest total piglet mortality can be comparable between confined and unconfined farrowing systems (Weber *et al.,* 2007; KilBride *et al.,* 2012), concerns remain that piglet mortality may worsen in less confined farrowing systems (Farm Animal Welfare Committee, 2015).

Considering that the majority of piglet mortality occurs during the first 48-72 hours post-partum, and over 80% within the first seven days (Marchant *et al.,* 2000; KilBride *et al.,* 2012), confining the sow beyond this period may not be of significant benefit for piglet survival. Therefore temporary confinement systems, consisting of an openable crate within individual farrowing pens, can be used to protect the neonates immediately post-partum. After this period, the crate is opened to provide additional space for the sow, providing a compromise between the needs of the farmer, the sow and her piglets. Whilst temporary confinement systems can reduce early piglet mortality in comparison to no confinement (Moustsen *et al.*, 2013; Hales *et al.*, 2015a, 2015b; Chidgey *et al.*, 2015), anecdotal reports from commercial farms suggest piglet mortality increases during the first 24 hours immediately after crate opening. In order to improve animal welfare, along with the economic viability and commercial uptake of temporary confinement systems, it is necessary to understand if the immediate post-opening period (24-48 hours after crate opening) creates a higher risk of piglet mortality and, if so, to identify suitable interventions to reduce the impact of crate opening.

The way in which crates are opened may cause different amounts of disturbance to the sow and litter, in turn affecting their immediate post-opening behaviour. Increased disturbance from human activity may cause increased restlessness (Chaloupková *et* *al.,* 2008), and therefore increase the incidence of dangerous posture changes and the subsequent risk of accidental piglet crushing. Sows are also responsive to the vocalisations of trapped piglets, especially in less confined systems (Melišová *et al.*, 2014). However, sows which respond excessively to the distress vocalisations of piglets in neighbouring litters risk causing unnecessary injuries within their own litter (Baxter *et al.*, 2011a). Therefore, as we expected crushing incidence to increase post-opening, it was hypothesised that opening crates individually would reduce behavioural disturbance by minimising the peak contagion effect of sow responsiveness to crate opening and piglet vocalisations. It was also hypothesised that opening crates in the afternoon, immediately before stockpersons left for the day, would evoke a shorter sow response period as there would be no subsequent stockperson disturbance, and opening is performed closer to night-time when lights are dimmed and sows perform fewer posture changes (Hales *et al.*, 2016).

The current study aimed to determine a) if piglet mortality increases immediately after, compared to immediately before, crate opening; b) if crate opening procedure affects post-opening piglet mortality; and c) if crate opening procedure affects sow behaviour. Knowledge of these outcomes will enable the most efficient opening procedure within temporary confinement systems to be adopted, and may identify which sow behaviours are associated with increased piglet mortality.

5.3. Material and Methods

5.3.1. Animals and dry sow management

The experiment was conducted on a commercial pig breeding unit in the north east of England. The farm consisted of 1 300 Camborough (Genus PIC, Basingstoke) breeding gilts and sows bred with Hampshire semen. During gestation, all animals were kept in straw pens in groups according to age, for gilts, or by size for multiparous sows. The farm utilised 250 farrowing places; 168 of which were temporary crate accommodation used for this study (360^0 Freedom Farrower™, Midland Pig Producers, Burton-on-Trent). The date of moving into the farrowing accommodation and farrowing date were recorded for inclusion in statistical models.

5.3.2. Farrowing sow housing and management

Each farrowing pen contained a stainless steel crate (closed = 2.55m x 0.90m, open = 2.55m x 1.50m) within a 2.55m x 1.80m pen (Figure 5.1a). Each pen had plastic slatted flooring with a solid sow lying area containing drainage slots plus a 1.80m x

0.40m hot water heat pad along one side of the pen as the piglet resting area. Of the 168 temporary crates, 120 were located in six “Portapig” cabins containing 20 farrowing places each (cabins; Figure 5.1c) and a further 48 were in a converted farrowing house of three rooms containing 16 farrowing places each (rooms; Figure 5.1b), with pen arrangement, and therefore crate opening procedure, differing between cabins and rooms (See Figure 2.3(a,b) for images of each pen arrangement). To open the crate, a lever on one side released the crate side to be manually adjusted vertically, whilst the other side was released to drop open obliquely. In the cabins, one person had to lean over each crate to operate the lever, allowing both persons to push the far side of the crate open before releasing the drop down side closest to the passageway. In the rooms, each crate was opened by two stockpersons, one in the central and one in the side passageway, without the need to lean over each crate.

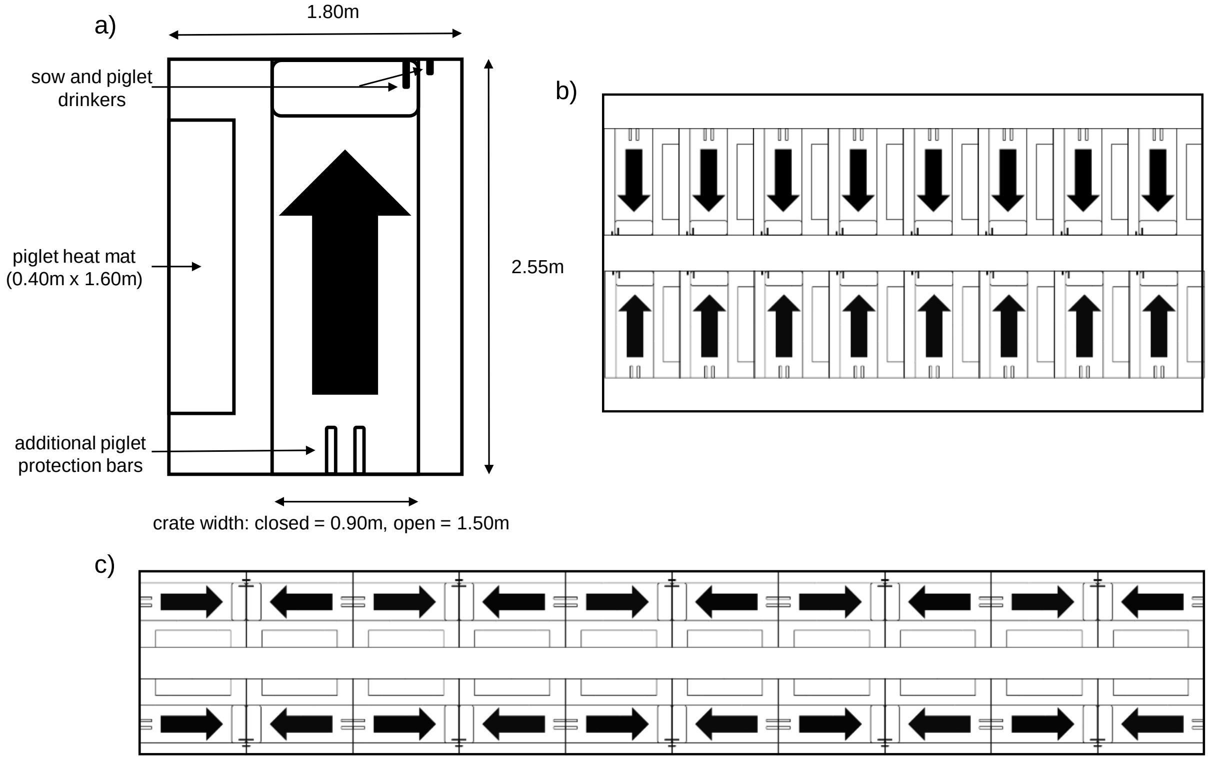


Figure 5.1. Diagram of (a) temporary confinement pen, with (b) arrangement for 16 pens per converted room and (c) 20 pens per new cabin. Arrow indicates sow orientation when crate is closed.

The temporary crates were closed from entry into the farrowing house at approximately 2-5 days pre-partum. No sows had artificial induction of farrowing. Farrowing houses were kept at 22 ± 1°C, with the heat pad kept at 36°C. Farrowing house temperature gradually reduced automatically to 18 ± 1°C by day ten post-partum and to 16 ± 1°C by weaning, whilst heat pad temperature reduced to 30°C by weaning. Farrowing houses were ventilated via a central extractor fan and had full artificial lighting during working hours (05:30-14:30), with dimmed lighting outside of these hours.

Sows were fed once daily in the morning until all sows in the farrowing house had farrowed, after which sows were fed twice a day (commencing 05:30 and 13:30; diet contained 15.98% CP, 13.69 DE MJ/Kg). Cabins were hand fed via a Groba Ad-Lib feeder above the trough (Finrone Systems Ltd, Londonderry), whilst rooms contained a semi-automatic system (www.360farrower.com) feeding all sows simultaneously. Feed was gradually increased from 2kg to 10kg per sow per day during lactation. Sow drinkers were located inside the feed trough, with smaller piglet drinkers provided at the front of the pen on the opposite side to the heat pad (see Figure 5.1a).

5.3.3. Piglet management and procedures

In accordance with veterinary recommendation, piglets were tail docked, teeth clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd, Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24 hours of birth. The placentae and deceased piglets were removed, with live litter size equalised for both piglet number and size by cross-fostering piglets of a similar age.

Super Dry Klenz powder (A-One Feed Supplements Ltd, Thirsk) was distributed across each pen daily. Additional dish drinkers with water were provided for smaller or weaker litters, and were removed before crate opening. A handful of creep feed (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed Supplements Ltd, Thirsk) was provided once daily on the heat mat from approx. ten days of age until weaning. The farm's management routines included piglet fostering throughout lactation as necessary to ensure piglet and litter sizes remained similar.

5.3.4. Experimental design

The study compared three different crate opening treatments. The standard procedure on the farm of opening all crates within each house on the same morning when average litter age reached seven days (ALL) remained as a control treatment. Alternatives investigated in the experiment involved crates being opened individually when each litter reached seven days of age, either in the morning (AM) or afternoon (PM). Crate opening occurred at 08:30-09:30 in the AM and ALL treatments, and 13:30-14:30 for the PM treatment. All sows in a farrowing house were allocated the same crate opening treatment, which was alternated per batch, according to a balanced design to control for farrowing house effects. Experiments were approved under the Newcastle University Animal Welfare and Ethics Review Body, Approval 379 on 23rd June 2014.

Due to researcher absence, the final treatment allocations were split across two batches; cabin one, cabin two and cabin three data were collected from batch three whilst data for the remaining locations were collected in batch four. Data from any crates which were not opened within two days of the expected opening date due to poor performing litters deemed at greater risk of crushing (n = 19), crates being opened and subsequently closed due to sow aggression towards stock people (in the cabins only, due to the close proximity of sows to the central passageway; n = 2), and from sows which farrowed later than expected and had to be relocated to a different room to better match litter ages for weaning, were removed from the study.

5.3.5. Piglet mortality study

Sow identity, sow parity, farrowing location, farrowing date and the number of live-born and stillborn piglets were recorded post-partum. Four days later, the frequency and cause of piglet mortality since farrowing, as identified by the stockperson (categorised as crushed, low viability or other), and current litter size were recorded. Recording sheets were attached above each pen specifying the day and time (AM or PM) of crate opening, and for the researcher to record piglet mortality during the five day period around crate opening (two days before crate opening, day of opening and two days following crate opening). After this period, additional piglet mortality, weaning date and litter size at weaning were recorded via stockperson records.

5.3.6. Sow behaviour study

Sow behaviours were investigated for a subset of five sows from each treatment across three batches housed in one of the converted rooms. CCTV cameras (Gamut Professional Sony Effio E Bullet CCTV Camera 700 TV Line, 15m Infrared Night Vision (Gamut, Open24 seven Ltd, Bristol, UK)) were installed above six pens, with the same six crates observed for each batch. Cameras recorded continuously from two days before until two days after temporary crate opening. From the video recordings, time of crate opening was identified and continuous sampling of sow behaviour (Table 5.1) was performed for the subsequent six hours. The same six hour period was then analysed during the day before and day after crate opening. The frequencies, total durations and average durations were calculated for each posture. The incidence and cause of piglet crushing, whereby a piglet became trapped by the sow by any means, was recorded as either fatal or non-fatal.

Table 5.1. Ethogram of sow behaviours recorded for four hours after crate opening, and during the same time period on the previous and subsequent days.

Sow behaviour	Description
Standing	Included standing, walking and kneeling.
Sitting	Dog-sitting, with rear and front hooves on the floor.
Ventral lying	Lying with neither shoulder on the ground.
Lateral lying	Lying with one shoulder on the ground.
Dangerous posture changes	Included all downward posture changes (stand-lie, sit-lie) and rolling (ventral-lateral, lateral-ventral).
Turning	Sow is standing and changes body direction by a minimum of 180º, usually from facing front-to-back or back-to-front of the pen.
Sniffing piglets	Sow moves snout towards one or more piglets.
Use of support	Sow leans on pen fixtures during stand-lie transition.
Riskiness of rolling	
Post-standing	A standing event has occurred since the previous rolling event.
Same side	No standing event has occurred, sow rolls onto the same side of the body as the previous roll.
Opposite side	No standing event has occurred, sow rolls onto the opposite side of the body as the previous roll.

5.3.7. Statistical analysis of results

The time periods of primary interest were the two days before (‘pre-opening’; days 5-7 post-partum) and the two days after (‘post-opening’; days 7-9) temporary crate opening, in order to determine and compare the risk of piglet mortality for these time periods. Analyses were also performed for piglet mortality after the post-opening period until weaning (‘late’; days 10-27), the early post-partum period (‘early’; days 0-4), from parturition until crate opening (‘before’; days 0-7), from crate opening until weaning (‘after’; days 7-27) and the entire lactation (‘total’; days 0-27).

Piglet mortality data were analysed using the GLIMMIX procedure in SAS 9.4. The base model included the variable total born litter size and the fixed effects of treatment, housing type (cabin or room), batch (1-4), sow parity (1, 2, 3, 4, 5, 6+), the number of days between housing and farrowing (0-1, 2-5, 6-7, 8+), litter age at opening (in days; <7, =7, >7), and whether or not a litter had been cross-fostered to consist of all the smallest piglets in that batch (“smalls” based on routine visual inspection and cross-fostering performed by farm staff) were included for all periods of investigation. The variable litter size on day five was included in all models except for the ‘early’ and ‘before’ time periods, whilst the continuous variable of litter age at weaning was only included for ‘late’, ‘after’ and ‘total’ piglet mortality models. Due to a chance uneven distribution of total born litter size across the treatments, the interaction of total born and treatment was included for all time periods to correct for this effect. All models used a Poisson distribution, with explanatory variables eliminated in a step-wise manner to create the final models including all variables with a P value < 0.10.

Sow behaviour data were analysed in SAS 9.4 using the PROC MIXED procedure. Sow was included as a repeated factor whilst pen number and whether a day was on the weekend or not (yes/no; to control for reduced stockperson contact during weekends) were used as random factors. Current litter size was included as a continuous variable, with day, treatment, sow parity (1, 2-5, 6+), treatment*day and parity*day as fixed effects. Explanatory variables were eliminated in a step-wise manner to create the final models including variables with a P value < 0.10, whilst day, treatment and the interaction of treatment and day were forced into all final models.

5.4. Results

5.4.1. Piglet mortality study

Data were included from 416 sows (ALL = 145; AM = 134; PM = 137), with a mean sow parity of 3.48 ± 0.11 (range 1-11; ALL = 3.29 ± 0.19; AM = 3.71 ± 0.18; PM = 3.47 ± 0.18). Mean total born litter size was 14.25 ± 0.14 piglets, consisting of 13.72 ± 0.14 live-born and 0.53 ± 0.05 stillborn piglets. Mean litter age at crate opening was 7.36 ± 0.06 days, whilst some crates were opened later than scheduled due to a reliance on stockperson assistance to open crates (ALL = 7.52 ± 0.16 days, range 4-13 days; AM = 7.41 ± 0.06 days, range 7-9 days; PM = 7.15 ± 0.04 days, range 7-9 days).

Piglet mortality risk throughout lactation

A total live-born piglet mortality of 574 piglets was recorded from 5,708 live-born piglets, with a mean live-born piglet mortality of 1.38 ± 0.08 piglets per litter. Total born piglet mortality to weaning was 13.38%, consisting of 10.06% of live-born and 3.69% of stillborn deaths.

Of the live-born piglet mortality, 60.45% occurred during early lactation (days 0-4), 4.88% during pre-opening (days 5-7), 11.15% during post-opening (days 7-9) and 23.52% during later lactation (day 10 until weaning). In terms of piglet mortality per litter (mortality/litter): early = 0.834 ± 0.062, pre-opening = 0.067 ± 0.014, post-opening = 0.154 ± 0.022 and late = 0.325 ± 0.030. Adjusting these estimates for the number of days per time period, piglet mortality per litter per day (mortality/litter/day) were calculated as 0.167 for early lactation, 0.034 during pre-opening, 0.077 during post-opening and 0.018 during later lactation. Combining all opening treatments, mortality/litter was significantly higher during the post-opening than pre-opening period ($P < 0.0005$; Wilcoxon signed rank test).

Effect of crate opening treatment and housing type

Crate opening treatment had a significant effect on piglet mortality during the post-opening ($P < 0.05$), and therefore the after opening period ($P = 0.052$), being highest for treatment ALL, followed by AM then PM (Figure 5.2a). Piglet mortality was also affected by the housing type, being significantly higher in the rooms than the cabins during pre-opening ($P < 0.01$), late ($P < 0.05$) and therefore the total lactation ($P < 0.05$; Figure 5.2b).

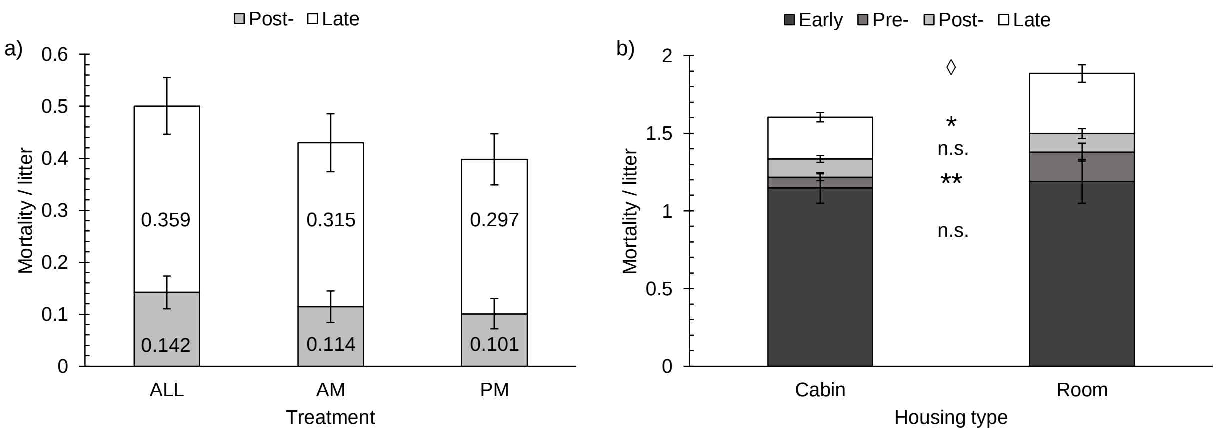


Figure 5.2. Least square means (± s.e.) for piglet mortality. (a) Treatment effects during the post-opening (P < 0.05), late lactation (P > 0.10) and therefore after opening (P = 0.052) periods. (b) Housing type effects indicated between bars for each lactation period (n.s. (P > 0.05), *(P < 0.05), **(P < 0.01)) and total lactation (◊(P < 0.05)).

Effect of days until farrowing and litter age at opening

The number of days between housing and farrowing affected piglet mortality during late lactation (P < 0.05), and therefore after opening (P < 0.05). During late lactation, piglet mortality was significantly higher for sows housed 0-1 days pre-partum (0.45 ± 0.07) than sows housed 2-5 days (0.28 ± 0.06; P < 0.05) or 8+ days (0.22 ± 0.05; P < 0.01), but not 6-7 days pre-partum (0.38 ± 0.06); whilst late piglet mortality was also significantly lower for sows housed 8+ days than 6-7 days pre-partum (P < 0.05).

Effect of litter characteristics and sow parity

Piglet mortality increased with increasing live born litter size during the early (P < 0.0001), before (P < 0.01), late (P < 0.01), after opening (P < 0.001) and total lactation periods (P < 0.0001); however piglet mortality decreased with increasing total born litter size during the post-opening period (P < 0.01). A larger litter size on day five post-partum was associated with lower total piglet mortality (P < 0.001), but tended to result in higher pre-opening (P = 0.058) and post-opening piglet mortality (P = 0.061), whilst litter age at crate opening had no significant effect on piglet mortality during any stage of lactation. Piglet mortality was significantly higher within the cross-fostered litters of ‘small’ piglets during the early (P < 0.0001), before

($P < 0.0001$), pre-opening ($P < 0.05$) and total lactation ($P < 0.0001$). Sow parity affected post-opening piglet mortality ($P < 0.05$), being significantly higher for parity six plus sows (0.26 ± 0.06) than parity one (0.11 ± 0.04; $P < 0.05$), two (0.09 ± 0.03; $P < 0.05$), or four (0.07 ± 0.03; $P < 0.01$), and tending to be higher than parity three (0.13 ± 0.04; $P = 0.067$) and five (0.11 ± 0.05; $P = 0.052$).

5.4.2. Sow behaviour study

Incidence of piglet crushing

There were no incidents of fatal piglet crushing within video-recorded litters, and only seven non-fatal crush incidents (one stand-to-lie, one lateral-to-ventral, two ventral-to-lateral and three standing on piglet), therefore further analyses on piglet crushing could not be performed.

Sow carefulness during stand-to-lie

Although treatment or day had no effect, frequency of sniffing or rooting piglets before lying tended to be higher for parity 2-5 sows (2.02 ± 0.30) than both parity 6+ sows (0.95 ± 0.41, $P = 0.054$) and gilts (1.10 ± 0.40, $P = 0.088$). There were no significant effects of day, treatment or parity on the percentage of sniffing or rooting piglets.

The frequency of using support structures during stand-to-lie was significantly affected by treatment ($P < 0.05$), being lower in PM (1.77 ± 1.08) than both AM (3.94 ± 1.06; $P < 0.01$) and ALL (3.29 ± 1.02; $P < 0.05$). However, the percentage of stand-to-lie posture changes where support was used was unaffected by treatment or day. Moreover, the percentage of lying events using support was lower amongst gilts (33.6% ± 12.8) than parity 2-5 sows (51.0% ± 12.0, $P < 0.05$) and parity 6+ sows (56.5% ± 14.4, $P = 0.061$).

Frequency of dangerous posture changes

The frequency of dangerous posture changes are shown in Figure 5.3a. Treatment tended to affect the frequency of stand-to-lie ($P = 0.084$), and within the treatment x day interaction, frequency of stand-to-lie was significantly higher on the day before crate opening for ALL than AM and PM (both $P < 0.05$). Treatment tended to affect the frequency of sit-to-lie posture changes ($P = 0.069$), and within the treatment x day interaction, frequency of sit-to-lie was significantly higher for PM on the day of crate opening than both AM ($P < 0.05$) and ALL ($P < 0.01$), and remained higher than AM on the following day ($P < 0.05$). Sow parity tended to affect the frequency of stand-to-lie posture changes ($P = 0.070$), being higher amongst parity 2-5 sows (7.39 ± 0.72) than parity 1 sows (5.44 ± 0.84; $P < 0.05$) and parity 6+ sows (5.30 ± 1.00; $P = 0.077$).

Frequency of turning around was significantly higher on the day of crate opening (13.68 ± 1.42) than the day after (7.88 ± 1.42; $P < 0.01$). Frequency of turning tended to differ across treatments ($P = 0.078$), being significantly higher for AM (10.02 ± 1.56) than PM (4.85 ± 1.56; $P < 0.05$), but not ALL (6.65 ± 1.42). Frequency of turning also tended to be affected by sow parity ($P = 0.074$), with parity 6+ sows (4.09 ± 1.69) turning significantly less frequently than parity 1 sows (10.01 ± 1.69; $P < 0.05$), but not parity 2-5 sows (7.42 ± 1.24).

Total duration of postures

The total durations of each posture are displayed in Figure 5.3b. Standing duration was significantly affected by day ($P < 0.0001$), being higher on the day of opening than the day before ($P < 0.0001$) or after ($P = 0.01$). Total standing duration differed between treatments ($P < 0.01$), being significantly higher in AM than PM ($P < 0.001$), whilst total standing duration in ALL tended to be both lower than AM ($P = 0.055$) and higher than PM ($P = 0.068$). Total sitting duration tended to differ across treatments ($P = 0.082$), being lower in ALL than both AM ($P < 0.05$) and PM ($P = 0.088$).

Total duration of lateral lying tended to be affected by treatment ($P = 0.054$), being significantly lower in AM than PM ($P < 0.05$); whilst total duration of ventral lying was not affected by day or treatment. Total duration of lying (ventral + lateral) was affected by day ($P < 0.001$), being lower on the day of opening than both the day before ($P = 0.0001$) and day after ($P < 0.05$), whilst the day before and day after crate opening also tended to differ ($P = 0.055$). Total duration of lying was also affected by treatment ($P < 0.01$), being lower for AM than both PM ($P < 0.01$) and ALL ($P < 0.05$).

Sow parity had a significant effect on the total duration of both ventral and lateral lying (both $P < 0.05$). Parity 2-5 sows had both a lower total duration of lateral lying (211 mins ± 25) and higher total duration of ventral lying (91.4 mins ± 8.5) than parity 1 sows (lateral = 258 mins ± 27; ventral = 53.5mins ± 10.5; both $P < 0.01$), but not parity 6+ sows (lateral = 241 mins ± 27; ventral = 70.9 mins ± 11.4).

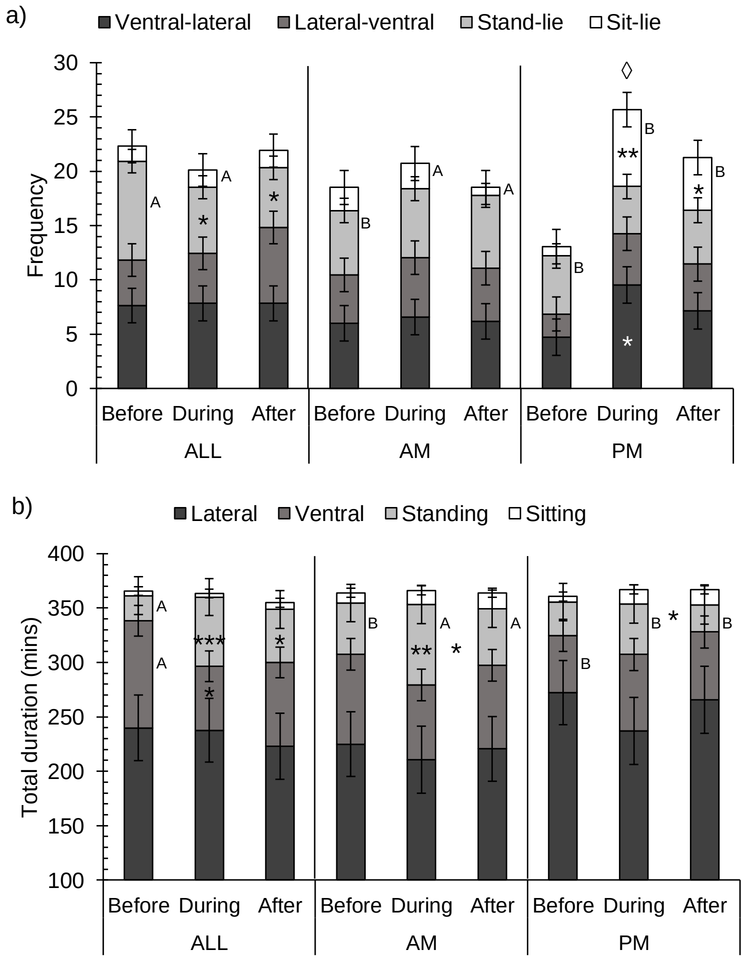


Figure 5.3. Least square means (± s.e.) for (a) frequency of sow dangerous posture changes and (b) total duration of sow postures. Day effects within each treatment between Before-During and Before-After are indicated on the latter day, whilst differences between During-After are indicated between days for each posture (*(P < 0.05), **(P < 0.01), ***(P < 0.001)) and total postures (◊(P < 0.05)). Treatment effects within each day are indicated with different letters (P < 0.05).

Riskiness of rolling behaviour

Across treatments, the frequency of same side and opposite side rolling were affected by day (both: *P* < 0.05), whilst the treatment x day interaction showed a significant increase of same and opposite side rolling on the day of crate opening than the day before within PM only (Figure 5.4). The frequency of standing between rolling was significantly higher in ALL than PM on the day before crate opening (*P* < 0.05; Figure 5.4).

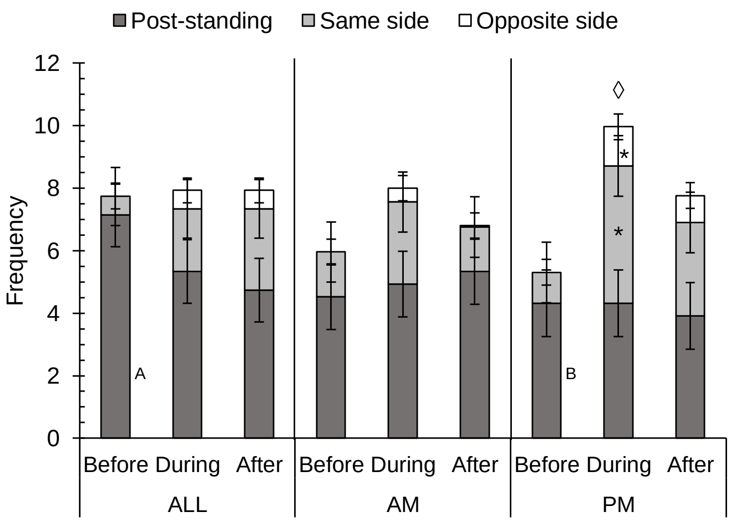


Figure 5.4. Least square means (± s.e.) for frequency of sow rolling by riskiness category. Day effects within each treatment between Before-During and Before-After are indicated on the latter treatment, whilst differences between During-After are indicated between treatments for each rolling category (*(P < 0.05)) and total rolling frequency (◊(P < 0.05)). Treatment effects within each day are indicated with different letters (P < 0.05).

5.5. Discussion

To our knowledge, this is the first study to specifically measure the immediate effect of temporary crate opening on piglet mortality. The results show that piglet mortality was significantly increased after crate opening, confirming our initial hypothesis that the post-opening period is a particularly dangerous time for piglet losses. Consequently, farms may wish to implement additional measures to reduce piglet mortality during the post-opening period, such as increased supervision (Kirkden *et al.*, 2013). Whilst no post-mortem examinations were performed in the current study, it is reasonable to assume that any significant differences in piglet mortality between the pre- and post-opening periods resulted from crushing, as crate opening was the only change to occur within this time period.

There are numerous potential causes for this increase in piglet crushing. Firstly, based on the principle of why confining sows reduces crushing, crate opening eliminated the physical restriction of sow body movements. Subsequently, posture changes may be less controlled and therefore faster (Weary *et al.*, 1996a), increasing the risk of crushing as piglets have less time to escape. Secondly, sows adapt their behaviour to their environment, therefore a sudden change may be stressful and require acclimation (Chidgey *et al.*, 2015). Sow behavioural adaption to farrowing crates and pens has been shown between successive parities (e.g. Jarvis *et al.*, 2001; Thodberg *et al.*, 2002), therefore the sow's ability to adapt and cope may be a gradual process unsuitable for sudden environmental changes occurring mid-lactation. Finally, not only does crate opening increase the proportion of the pen accessible to the sow, but it also decreases the proportion of the pen providing a safe resting area for the piglets. Therefore, piglets may also be required to adapt their behaviour in response to crate opening. Furthermore, as many temporary confinement systems, including the one used in the current study, are designed to use the same floor space as a traditional farrowing crate, there may be minimal safe space available to the piglets after crate opening, especially towards weaning age when piglets are larger.

Despite piglet mortality increasing in response to crate opening, total live-born piglet mortality in the current study was lower than the national average for UK indoor breeding herds (10.1% vs. 11.9% respectively; Agriculture and Horticulture Development Board Pork, 2017), the majority of which use conventional farrowing crates. Some farm surveys have shown that, whilst piglet mortality from crushing may be higher in free farrowing systems, piglet mortality from other causes is higher in crated systems, resulting in no overall difference (Weber *et al.,* 2007; KilBride *et al.,* 2012). In contrast, previous studies comparing free farrowing and temporary confinement within the same farm indicate significantly reduced total piglet mortality in the latter (Hales *et al.*, 2015a, 2015b; Chidgey *et al.*, 2015). However, unconfined farrowing systems were relatively new to both the farm staff and sows in these studies, which is likely to increase piglet mortality as stockpersons develop appropriate management routines. Furthermore, changing the farrowing environment of the sows in successive parities can also increase piglet mortality (Chapter three). In the current study, the temporary confinement system had been in use on the farm for more than one year before the study commenced. However, the farm utilised multiple farrowing systems, therefore the previous farrowing system of individual sows would have differed.

Across all crate opening treatments, sow behaviour changed in response to crate opening. However, behaviour on the following day was more analogous to the day before crate opening, suggesting that the novelty of being released from confinement may have been the predominant cause for post-opening behavioural changes. These acute behavioural changes may also explain why piglet mortality was higher in the post-opening period than later lactation. We also measured the riskiness of sow rolling behaviour, as ventral-to-lateral rolling is an important posture change for piglet crushing in free farrowing systems (Weary *et al.*, 1996a) and previous studies have found piglet crushing in free farrowing systems to be explicitly caused by rolling from one side to the other (Bradshaw and Broom, 1999; Marchant *et al.*, 2001). During observation periods, no opposite side rolling occurred on the day before, whilst eight of the fifteen sows performed opposite side rolling on the day of crate opening.

The different crate opening procedures also resulted in differences in piglet mortality and sow behaviour. Whilst the PM treatment resulted in the lowest piglet mortality, it was also the only treatment with a significant increase in post-opening dangerous posture changes. However, PM posture changes on the pre-opening day were lower than the other treatments, meaning a significant increase was more likely. As behavioural observations were only performed for six hours after crate opening, the different behaviour of PM sows may be due to a temporal difference in observation periods, including the lower level of human disturbance, rather than a temporal difference in crate opening. Increased sitting behaviour is associated with motivational conflict (Jarvis *et al.*, 1997), which in the current study, may indicate PM sows were conflicted between continuing to rest or to actively explore the open pen. This would also explain why the standing duration of PM sows did not significantly increase during the post-opening period, unlike both AM and ALL. The increased sitting behaviour of PM sows may also mean an increased alertness, as sows will often sit when disturbed by external events whilst resting, and increased sow alertness could reduce the risk of piglet crushing. Furthermore, the majority of piglet mortality from crushing is not from the immediate trauma, but rather suffocation, as the risk of a crushing incident being fatal increases with increasing duration of time trapped underneath the sow (Weary *et al.*, 1996a). Therefore, whilst increased posture changes may increase the frequency of crushing, fewer crushing events would have a fatal conclusion.

Piglet mortality was also lower in the AM than ALL treatment, whilst significant differences were also observed between AM and ALL sow behaviour, but only on the day before crate opening. Whilst opening the crates individually may have avoided a simultaneous peak of post-opening sow activity, sows with younger litters could have been disturbed during the pre-opening period. This could have resulted from either the action of stockpersons opening neighbouring crates of older litters, or the subsequent post-opening increased activity of these sows. However, this pre-opening disturbance of AM sows resulted in a less profound change between pre- and post-opening behaviour in comparison to ALL sows. This could explain the reduced post-opening mortality, as piglets may have become more cautious of the restless sow whilst she was still in confinement. The increased pre-opening activity in AM sows could be a sign of stress or frustration (Jarvis *et al.*, 2001), and may have a welfare implication for future investigation. Furthermore, if additional measures to minimise piglet mortality, such as increased supervision, were implemented during the post-opening period; these would be more efficient if all crates were opened on the same day instead of across several days.

Finally, the different housing types used on the farm resulted in different piglet mortality outcomes, being higher in the converted rooms than the cabins during the pre-opening and later lactation periods. Unlike the cabins, pen arrangement in the rooms meant sows had extensive visual contact with other sows in adjacent pens, as well as the opportunity for physical interactions once the crates were opened. This increased sow-sow contact in the rooms may have caused prolonged disturbance, causing increased piglet mortality in later lactation, whilst having no significant effect during the post-opening period as all sows would have been aroused regardless of pen arrangement. Furthermore, as mentioned previously, a change of farrowing system can also increase mortality. The farm in the current study used multiple farrowing systems, however it would have been more likely that sows in the cabins would have farrowed in the cabins previously, due to the larger number of farrowing places in this arrangement (120 in cabins vs. 48 in rooms).

A repeat of the current study in a more controlled environment and with a larger sample size, especially for behavioural observations, would be beneficial for validating the results. In particular, a clearer differentiation between the effects of batch vs single opening, and time of day would be beneficial. It would be recommended for behavioural observations to be performed across the 24-hour period to determine the full extent of behaviours affecting piglet mortality. Future research should determine precisely how many hours or days that piglet mortality is increased, and sow behaviour is altered, after temporary confinement crates are opened. Furthermore, crate opening treatment, including time of day, and pen arrangement should be further explored for their effects on piglet and sow welfare.

In conclusion, the period following crate opening in temporary confinement systems was a high risk time for piglet mortality, presumably due to accidental crushing by the sow. However, opening crates individually, when piglets reached seven days of age, resulted in lower post-opening piglet mortality relative to opening all crates once piglets reached an average age of seven days, particularly individual opening in the afternoon. Increased pre-opening disturbance in the farrowing house from opening crates individually may have increased the activity of the sows before crate opening, habituating sows and piglets to post-opening sow behaviour change.

Chapter 6. Sow Behaviour and Piglet Weight Gain After Late Cross-Fostering in Farrowing Crates and Pens

6.1. Abstract

Determining best practices for managing free farrowing systems is crucial for uptake. Cross-fostering, the exchange of piglets between litters, is routinely performed amongst crate-housed sows. However, cross-fostering can increase fighting amongst the litter, and may be more challenging within free farrowing systems as sows have more freedom to respond to cross-fostered piglets. This study compared the effect of either cross-fostering (FOS), or a control of sham-fostering (CON), of four focal piglets per litter on Day6 post-partum in crates (CRATE) and free farrowing pens (PEN). The post-treatment behavioural responses of sows were recorded (Day6 = 60 mins; Day7 = 300 mins; n = 48), as were the average daily gain (ADG; g/day), total weight gain (TWG; kg) and body lesion scores (BLS) of focal piglets and their littermates throughout lactation (Day6, Day8, Day11 and Day26; n = 539) and the post-weaning period (Day29, Day32 and Day60; n = 108). On Day6, though post-reunion nursing bout latency did not differ, successful nursing bout latency was longer amongst FOS than CON litters ($P < 0.001$), more so amongst CRATE FOS (113 mins ± 10) than PEN FOS (59 mins ± 10; $P < 0.001$). On Day7, PEN FOS sows had fewer successful nursing bouts ($P < 0.05$), and exhibited decreased lateral ($P < 0.05$) and increased ventral lying frequencies ($P < 0.05$) compared to all other housing and treatment combinations. Focal FOS piglet ADG was lower than CON in the CRATE during Day6-Day8 ($P < 0.01$), and lower in the PEN during Day6-Day8 ($P = 0.001$), Day8-Day11 ($P < 0.01$) and Day11-Day26 ($P < 0.05$). The TWG of focal piglets (Day6-Day26) was higher in PEN CON than all other combinations (PEN FOS: $P < 0.01$; CRATE FOS: $P < 0.05$; CRATE CON: $P = 0.07$). Post-weaning, piglet ADG was higher for PEN than CRATE during Day26-Day29 ($P < 0.01$) and higher for FOS than CON during Day26-Day29 ($P = 0.06$), Day29-Day32 ($P < 0.01$) and Day32-Day60 ($P < 0.05$); thus TWG was higher for FOS than CON during the weaner ($P < 0.01$) and the combined lactation and weaner periods ($P < 0.01$). In conclusion, sow behaviour was disrupted by cross-fostering in the crates and pens, and continued to be disturbed on the following day amongst penned sows. FOS piglets exhibited reduced ADG after cross-fostering, which extended throughout lactation in the pens. However, the increased post-weaning weight gain of FOS piglets meant that their TWG was higher than CON piglets, irrespective of the farrowing system used.

6.2. Introduction

Cross-fostering, the exchange of nursing piglets between litters to minimise inter- and intra-litter size variation, is routinely performed on most commercial pig breeding farms. Litter size uniformity is believed to improve the chances of all piglets obtaining sufficient milk from the sow, irrespective of total born litter size or individual birth weight (Baxter *et al.,* 2013). As the teat order begins to become established within 24 hours after birth (McBride, 1963), early cross-fostering within 24 hours has no detrimental effect on piglet weight gain, nor piglet-piglet or sow-piglet aggression (Heim et al., 2012; Pedersen et al., 2008; Robert and Martineau, 2001). However, whilst late cross-fostering, performed after 24 hours since birth, should only be performed when essential for piglet or sow welfare, it remains common practice on many commercial farms (Calderón Díaz et al., 2018; Straw et al., 1998). Furthermore, late cross-fostering is likely to become a more prevalent management strategy as litter sizes continue to increase. For example, the use of nurse sows and shunt-fostering, whereby an entire litter of younger piglets is transferred onto a sow whose litter is weaned, has become an essential part of pig-rearing amongst super-prolific herds (Baxter *et al.,* 2013).

With continued commercial interest in free farrowing and lactation to improve sow welfare, the ease and effectiveness of late cross-fostering in such systems must be considered. Sows are highly protective of their offspring, which can become more apparent when housed in free farrowing systems (Gu *et al.*, 2011). Increased behavioural freedom may also facilitate undesirable sow responsiveness towards cross-fostered piglets, including piglet-directed aggression (Pedersen *et al.,* 2008). Late cross-fostering can also disrupt an established piglet teat order, resulting in increased fighting and reduced weight gain amongst the litter (Horrell and Bennett, 1981; Robert and Martineau, 2001). Increased piglet fighting can disturb the sow during nursing bouts (Horrell, 1982; Pedersen *et al.,* 2008), potentially compromising the welfare of both sows and piglets. However, cross-fostering can also have later benefits of reduced aggression amongst piglets during the post-weaning period (Giroux *et al.*, 2000). Further understanding of the impact of late cross-fostering on sow behaviour and piglet growth, especially amongst free farrowing systems, is required to support their management and successful commercial uptake.

The current study aimed to determine if sow behaviour and piglet weight gain were disrupted in response to cross-fostering, and if these responses were more detrimental amongst penned than crated sows and litters. Firstly, we hypothesised that sow behaviour would be more disrupted by cross-fostering in the pens due to the increased freedom of sows. Second, we hypothesised that piglet weight gain would decrease and body lesion scores increase amongst foster litters in both housing systems, but more so amongst penned litters; and third, that post-weaning piglet lesion scores would be lower amongst piglets from cross-fostered litters (both fostered and resident piglets) due to the pre-weaning social experience with unfamiliar piglets.

6.3. Materials and Methods

6.3.1. Animals and dry sow management

The experiment was conducted at Newcastle University's pig unit, Cockle Park, Morpeth, UK. The farm consisted of 150 home-bred breeding Large White x Landrace gilts and sows artificially inseminated with Hylean MQM semen (Hermitage Genetics, Kilkenny, Ireland). During gestation, all sows were kept in groups of six according to size within concrete-floored pens including a straw covered lying area.

6.3.2. Farrowing sow housing and management

The farm batch-farrowed every three weeks using 28 farrowing crates and 12 PigSAFE pens (Edwards *et al.*, 2012; Figure 6.1b). The farrowing crates used in the current study were arranged in two adjoining rooms containing 12 crates each. Each 2.40m x 0.60m farrowing crate was contained within a 2.40m x 1.80m pen, with a predominantly solid concrete floor and a metal slatted area along the rear of the pen (Figure 6.1a). A covered piglet creep area of 0.64m^2 was located in one anterior corner of the pen, with a 175W heat lamp and wood shavings covering the creep floor. The PigSAFE pens used in the current study were arranged in two separate rooms containing four pens each. Each 3.35m x 2.36m pen contained an approximately 4m^2 nest area with a solid plastic floor containing drainage slots, whilst the remaining space had fully slatted plastic flooring for the dunging passage and feed crate areas (see Figure 2.2d for image). A covered piglet creep area of 0.65m^2 was located in one anterior corner of the nest, with a 175W heat lamp and rubber matting covering the creep floor. Approximately 2kg of long straw was provided on the floor of the sow nest area once on the day of housing and removed after farrowing had concluded.

Sows were moved into the farrowing accommodation on day 112 of gestation, with farrowing induced using 2ml Planate (MSD Animal Health, Milton Keynes) on day 115 of gestation if farrowing had not already occurred. Farrowing houses were kept at 21 ± 2°C, with artificial lighting during working hours (08:00-15:30) in the crates, with no additional lighting except for the creep lamps in the crates outside of these hours and continuous lighting in the pens. Sows were hand fed a home mixed diet twice daily (18.50% CP, 13.98 MJ DE/Kg) which was gradually increased according to appetite from 1kg to 10kg per sow per day during lactation. Sows had ad libitum access to water via a button drinker in the trough of both the farrowing crates and pens, plus an additional bite drinker in the dunging area of the pens.

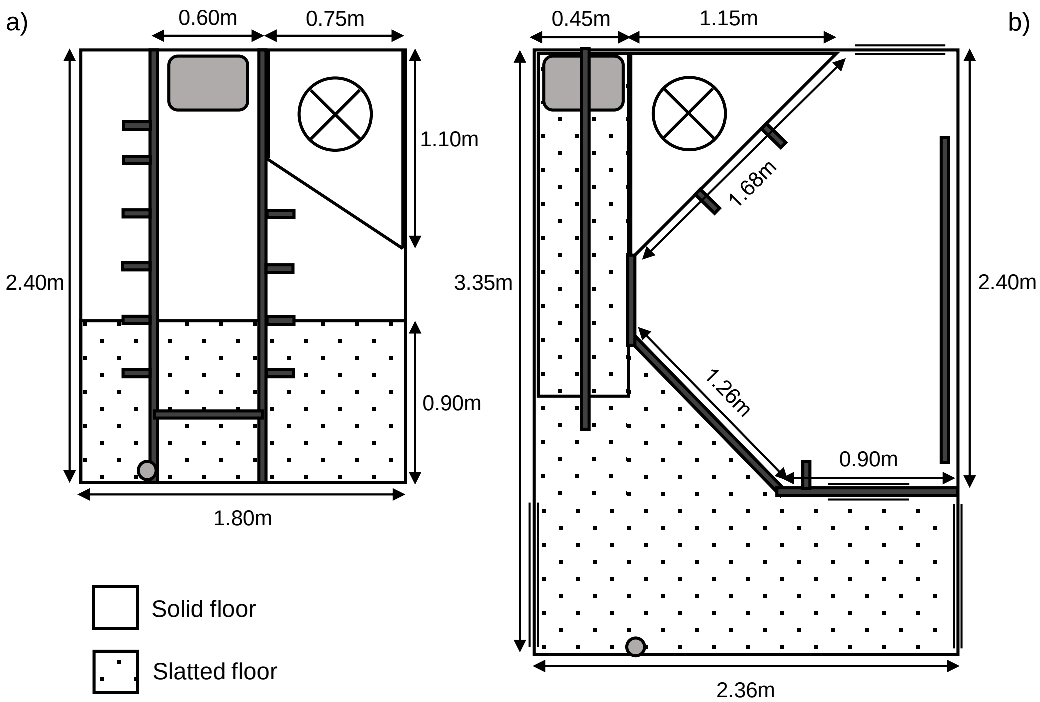


Figure 6.1. To scale diagram of sow farrowing accommodation, comprised of a) farrowing crate and b) PigSAFE free farrowing pen.

6.3.3. Piglet management and procedures

Within 24 hours post-partum, placentae and deceased piglets were removed, with live litter size equalised for both piglet number and size by cross-fostering piglets of a similar age. In accordance with veterinary recommendation, piglets had their needle teeth clipped within 24 hours of birth, and were tail docked and injected with 1ml of Uniferon Iron(III) Dextran (Pharmacosmos UK, Reading) at four days post-partum. Piglets had ad libitum access to water via a bite drinker and bowl, whilst additional dish drinkers of artificial milk were provided for crated litters of smaller piglets. The inclusion of such litters was avoided where possible, with dish drinkers removed at the time of treatment on Day6 and returned after weighing on Day11 if deemed necessary by farm staff. A handful of weaner diet (Flat Deck One, A-One Feed Supplements Ltd, Thirsk) was provided once daily on the piglet creep floor from approximately ten days of age until weaning.

Piglets were weaned on the morning of day 28 post-partum, and were vaccinated by intra-muscular injection with both 2ml M+PAC (MSD Animal Health, Milton Keynes) and 2ml Ingelvac CircoFLEX (Boehringer Ingelheim Ltd., Bracknell). Post-weaning experimental piglets were housed in groups of nine, within a divided (half-sized) standard weaner pen in order to house crate-reared and pen-reared piglets separately (total 18 piglets per batch). Each half-sized weaner pen (1.83m x 1.73m) had a fully slatted plastic floor and contained a feed trough (0.62m x 0.27m) situated at the front of the pen, two bite drinkers along the rear wall and a PVC tube attached to a chain on the pen dividing wall as enrichment. Weaner rooms were set to 26 ± 1°C for the first four days after weaning, and subsequently reduced by 0.2°C per day until rooms reached and were maintained at 22 ± 1°C. Weaned piglets progressed through four diets provided ad libitum, with the first three purchased from the same supplier (A-One Feed Supplements Ltd, Thirsk). The same diet introduced during lactation (Flat Deck One) was provided until 5 weeks of age, followed by Flat Deck 150 until 6 weeks of age, Turbo Wean until 7 weeks of age and a final homemade diet (20.55% CP, 14.82 MJ DE/Kg) until movement into the grower unit at approximately ten weeks of age.

6.3.4. Experimental design

The study included 48 sows across six batches, with two sows of each housing x treatment combination in each batch (CRATE CON, CRATE FOS, PEN CON, PEN FOS). Experiments were approved under the Newcastle University Animal Welfare and Ethics Review Body, Approval 379 on 23rd June 2014. On day six after the expected farrowing date (Day6), both litters within the same housing x treatment were collected simultaneously and all piglets were individually weighed, sexed, body lesion scored and ear-tagged for identification (U-Tag, Dalton Tags, Nottinghamshire). Body lesion scoring, which counted both old and new lesions, involved totalling three scores from 0-4 taken separately for 1) head and ears, 2) neck and shoulders, and 3) main torso and rump. This resulted in a maximum score of 12, and did not assess legs or tails (adapted from Melotti *et al.*, 2011; Table 6.1). Four median sized piglets from each litter, two of each sex, were designated as focal piglets, numbered 1-4 on their back and either exchanged between the two collected litters (FOS) or returned to the same litter (CON), before both litters were returned to their corresponding sow. Cross-fostering was performed in one housing system in the morning and the other in the afternoon, alternating between batches. Individual weight and body lesion scores (BLS; Table 6.1) were recorded for all piglets in experimental litters on subsequent days (Day8 and Day11) and prior to weaning (Day26) at the same time of day their initial treatment was performed.

Table 6.1. Description of piglet body lesion scoring (BLS) method for superficial (reddened skin scratch) and significant lesions (visible scab formation), including both old and new lesions.

Piglet body lesion score	Description
0	No lesions present
1	1-5 superficial lesions
2	6-10 superficial lesions
3	11-15 superficial or 1 significant lesion(s)
4	16+ superficial or 2+ significant lesions

On reuniting litters with their corresponding sow on Day6, sow behavioural observations were performed via CCTV cameras (Sony Effio IP66 infra-red camera, 3.6mm lens, 700 TV Line) for one hour immediately after sow-litter reunion, the maximum period until lights out for afternoon fostering, and when the sow response to foster piglets was expected to be the greatest (Horrell, 1982), and for five hours on the following day to avoid sow feeding times (09:00-14:00). Sow behaviours included the frequency and duration of sow postures, the frequency of nursing behaviours and frequency of sow-piglet sniffing (Table 6.2). Sow sniffing frequency was totalled separately across six ten minute intervals to explore the pattern of sniffing behaviour across the 60 minutes after sow-litter reunion. The number of focal piglets (maximum of four) present at the udder at the start of a nursing bout was also recorded for each observed nursing event.

Table 6.2. Ethogram of sow and litter behaviours recorded for 60 minutes after litter reunion (Day6) and for 300 minutes on following day (Day7).

Sow Behaviour	Description
Sow Postures	
Standing	Included standing, walking and kneeling
Sitting	Dog-sitting, with rear and front hooves on the floor
Ventral lying	Lying with neither shoulder on the floor
Lateral lying	Lying with one shoulder on the floor
Outside nest	Sow has both front feet on the slatted floor outside of the nest area (PEN only)
Sniffing Behaviour	
Sniffing piglets	Sow moves snout towards one or more piglets
Nursing Behaviour	
Start/End of nursing	Over/Under 80% of the litter is active at the udder, whilst sow is in a lateral lying position
Sow-terminated nursing	Sow changes posture whilst over 80% of the litter are active at the udder
Successful nursing	Piglets perform rapid sucking at the udder for over 20 seconds

Before weaning, three fostered piglets (FOS) from each housing system and batch were selected and matched with piglets of a similar weight that were resident piglets from foster litters but were not fostered themselves (RES), and control piglets from undisturbed litters (CON); creating two groups (CRATE, PEN) of nine piglets (3 FOS, 3 RES, 3 CON) per batch. On Day26, selected piglets were re-tagged with a larger ear tag (Suretag ST2 Flag, Dalton Tags, Nottinghamshire) and at weaning on Day28, selected piglets were housed together in groups of nine, separately for each housing system. Weaner piglets were individually weighed and BLS on subsequent days after weaning (Day29 and Day32) and before movement to the grower accommodation (Day60). Pre- and post-weaning piglet weights were used to calculate average daily weight gain (ADG) in each interval, whilst total weight gain (TWG) was calculated for the lactation (Day6-Day26), weaner (Day26-Day60) and combined lactation and weaner periods (Day6-Day60).

6.3.5. Statistical analyses

All analyses were performed in SAS 9.4 using the PROC MIXED function. Sow behaviour models included batch and treatment order (morning or afternoon) as random factors, whilst housing (CRATE, PEN), treatment (CON, FOS), sow parity (Young: parity 2-4, Old: parity 5+) and all two-way interactions (housing x treatment, housing x parity, treatment x parity) were included as fixed effects. Non-significant fixed effects were excluded in a step-wise manner to produce the final models including variables of $P < 0.10$.

Models were created for pre-wean focal, pre-wean resident and post-weaning piglets separately. Piglet weight and lesion score models included batch, treatment order and nurse sow ID as random factors. Piglet weight was forced into all models as a continuous variable to control for its anticipated effect (weight on Day6 for pre-weaning models, weight on Day6 and Day26 for post-weaning models). Additional variables included as fixed effects for investigation were piglet sex (female; male), sow parity (young = 2-4, old = 5+), housing type (CRATE, PEN) treatment (pre-weaning: CON, FOS; post-weaning: CON, FOS, RES) and the housing x treatment interaction. Non-significant fixed effects were excluded in a step-wise manner to produce the final models including variables of $P < 0.10$.

6.4. Results

A technical problem with recording equipment meant the behaviour of all sows in batch one was not recorded on Day7. Piglet data were recorded from 192 focal and 347 non-focal piglets, plus 108 post-weaning piglets. Piglets whose weight gain was determined as too poor by observation of farm staff were removed from experimental litters after Day11 on welfare grounds and replaced with another non-experimental piglet (n = 10; 3 CRATE FOS, 2 CRATE RES, 1 PEN FOS, 2 PEN RES, 2 PEN CON). A further two piglets (1 PEN CON, 1 CRATE FOS) were euthanised between Day11 and Day26 due to serious leg injuries. One PEN CON sow died suddenly on

Day24 of lactation, therefore her piglets were not included on Day26 or for post-weaning analyses.

Whilst an equal number of sows were categorised as young or old across the housing x treatment combinations (six young sows, six old sows per combination), actual sow parity was greater amongst penned (6.04 ± 0.57) than crated sows (4.29 ± 0.57; $P < 0.05$). However, within the parity categories, young sow parity did not differ between the pens (3.64 ± 0.59) and crates (2.93 ± 0.50; $P > 0.10$), whilst old sow parity only tended to be higher in the pens (8.08 ± 0.54) than crates (6.56 ± 0.65; $P = 0.078$). At the sow level, there was no significant difference ($P > 0.10$) between housing systems or treatments for live born litter size (13.15 ± 0.50 piglets), the incidence of stillbirths (0.46 ± 0.13 piglets), litter size (11.25 ± 0.11 piglets) or litter age at the beginning of the study (6.27 ± 0.11 days).

6.4.1. Sow behaviour

Frequency of sniffing piglets

*The frequency of sniffing piglets (*recorded Day6 only) was lower amongst CRATE than PEN sows during all time periods after fostering (0-10 mins, $P < 0.001$; 10-20 mins, $P < 0.001$; 20-30 mins, $P < 0.01$; 30-40 mins, $P = 0.001$; 40-50 mins, $P < 0.05$; 50-60 mins, $P < 0.05$; Figure 6.2), and therefore the total period of observation (0-60 mins; $P < 0.001$). Sniffing frequency was higher amongst FOS sows during 0-10 mins ($P < 0.001$), 10-20 mins ($P < 0.001$) and tended to be higher during 20-30 mins ($P = 0.054$), and therefore the total period of observation (0-60 mins; $P < 0.01$). Sniffing frequency was also affected by a housing x treatment interaction during 10-20 mins ($P < 0.01$) and 50-60 mins (P< 0.05), being highest amongst PEN FOS or PEN CON sows, respectively. During 30-40 mins, sniffing frequency was affected by a housing x parity interaction ($P < 0.05$), being higher amongst older PEN sows (11.47 ± 2.39) than all other parity and housing combinations (younger PEN: 4.18 ± 2.50, $P < 0.01$; younger CRATE: 2.12 ± 2.33, $P < 0.001$; older CRATE: 0.84 ± 2.71, $P < 0.001$).

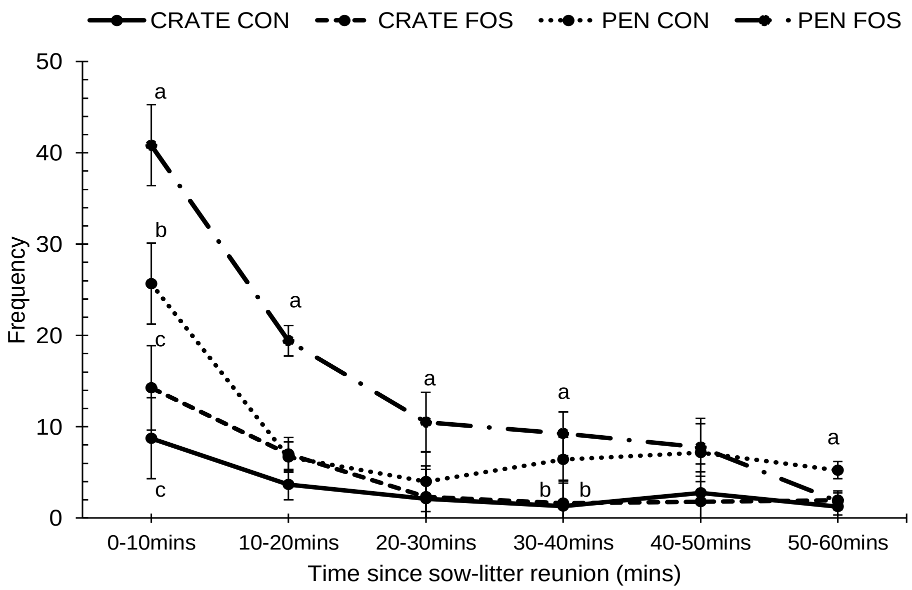


Figure 6.2. Sow sniffing frequency per 10 minute interval during the 60 minute post-reunion period on Day6, according to housing and treatment combination. Significant differences between groups indicated with different letters, or with one letter if only one group differed from all others (*P* < 0.05).

Frequency of postures

On Day6, CRATE sows exhibited fewer frequencies of standing (*P* < 0.001), ventral lying (*P* < 0.001), lateral lying (*P* = 0.001) and therefore total posture changes than PEN sows (*P* = 0.001; Figure 6.3a). On Day6, treatment had no effect on posture frequencies, whereas a housing x treatment interaction affected sitting frequency (*P* < 0.05), and tended to affect ventral lying frequency (*P* = 0.054) and therefore total posture change frequency (*P* < 0.05). Day6 sitting frequency was also affected by a treatment x parity interaction (*P* < 0.01), being lower amongst older FOS sows (2.03 ± 0.63) than younger FOS (5.23 ± 0.68; *P* < 0.01) and older CON sows (4.33 ± 0.77; *P* < 0.05); whilst younger FOS sows also tended to be higher than younger CON sows (3.47 ± 0.59; *P* = 0.058).

Day6 total posture change frequency during 0 to 30 minutes post-treatment was lower amongst CRATE (5.33 ± 1.14) than PEN sows (9.88 ± 1.14; *P* < 0.001). Total posture change frequency during 30 to 60 minutes post-treatment remained lower amongst CRATE than PEN sows (*P* < 0.01), however a housing x treatment interaction meant posture change frequency was higher amongst PEN CON sows

(11.25 ± 1.33) than all other combinations (PEN FOS = 7.08 ± 1.33, $P < 0.05$; CRATE FOS = 6.25 ± 1.33, $P < 0.05$; CRATE CON = 3.08 ± 1.33, $P < 0.001$), whilst PEN FOS and CRATE CON sows also differed ($P < 0.05$). Within PEN sows only, Day6 frequency of leaving the nest area was higher amongst FOS (7.17 ± 1.76) than CON sows (3.33 ± 1.76; $P < 0.05$), but unaffected by treatment or parity on Day7.

On Day7, CRATE sows tended to exhibit a higher frequency of sitting ($P = 0.056$) and fewer frequencies of ventral ($P = 0.057$) and lateral lying ($P = 0.072$; Figure 6.3b) than PEN sows. On Day7, FOS sows tended to exhibit a higher frequency of both ventral ($P = 0.091$) and lateral lying ($P = 0.056$), whilst a housing x treatment interaction tended to affect the frequency of both ventral ($P = 0.081$) and lateral lying ($P < 0.05$).

Duration of postures

Total posture durations were also affected. On Day6, CRATE sows exhibited less standing ($P < 0.01$), more sitting ($P < 0.01$) and more lying than PEN sows ($P < 0.05$; Figure 6.3c). On Day6, FOS sows exhibited more standing ($P < 0.01$) and less lying than CON sows ($P < 0.01$). On Day7, CRATE sows continued to exhibit less standing ($P < 0.05$), more sitting ($P < 0.01$) and a tendency for more ventral lying ($P = 0.084$) than PEN sows. On Day7, a housing x treatment interaction affected the time spent in ventral ($P < 0.05$) and lateral lying ($P < 0.05$; Figure 6.3d). Amongst PEN sows, the duration of time outside of the nest area was unaffected by treatment or parity on Day6 and Day7.

Nursing behaviour

*O*n Day6, whilst there were no effects of housing, treatment or parity on the first nursing bout latency, the first successful nursing bout latency was shorter amongst PEN than CRATE sows ($P < 0.05$), amongst CON than FOS sows ($P < 0.001$) and was affected by a housing x treatment interaction ($P < 0.01$; Table 6.3). Total nursing frequency tended to be lower amongst CRATE than PEN sows on Day6 ($P = 0.060$) and was significantly lower on Day7 ($P < 0.05$). On Day6, the frequency of sow-terminated nursing bouts was lower amongst CRATE than PEN sows ($P < 0.05$); whilst on Day7 there were no effects of housing, treatment or parity. However, Day7 frequency of successful nursing bouts was lower amongst PEN FOS sows than the other housing and treatment combinations ($P < 0.05$).

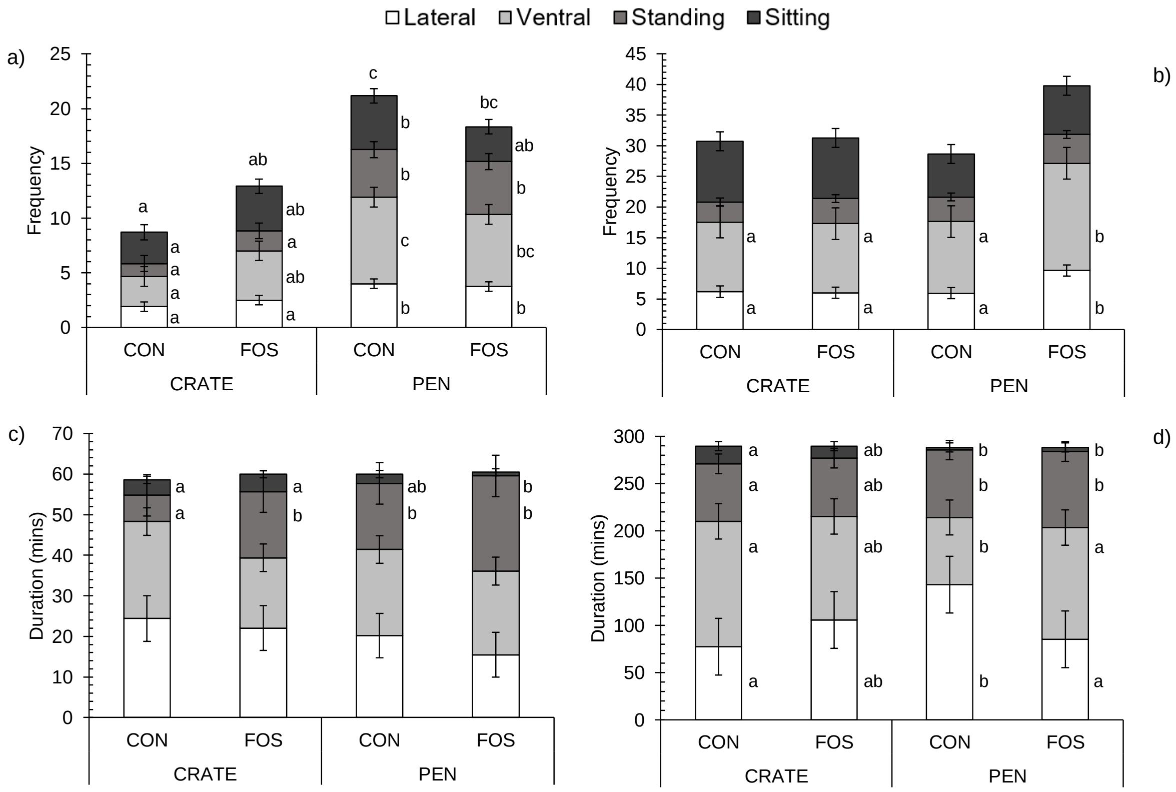


Figure 6.3. Least square means (± s.e.) of sow postures on Day6 (60 mins) and Day7 (300 mins) for each housing and treatment combination: a) Day6 frequencies, b) Day7 frequencies, c) Day6 durations, d) Day7 durations. Significant differences between bars are indicated with different letters (P < 0.05).

Day6 average focal piglet nursing attendance (out of a possible 4) was higher amongst CRATE than PEN litters (P < 0.01) and CON than FOS litters (P < 0.05; Table 6.3). Day7 average focal piglet nursing attendance was higher amongst FOS than CON litters (P < 0.001) and did not differ between CRATE and PEN. Paired t-tests between the average focal piglet nursing attendance on Day6 and Day7 within each housing x treatment combination found attendance to be lower on Day6 for PEN FOS (P < 0.001), PEN CON (P < 0.001) and CRATE FOS (P < 0.05), but not CRATE CON piglets.

Table 6.3. Least square means (± s.e.) of sow and litter nursing behaviours for each housing system and treatment combination during 60 minutes after litter reunion (Day6) and 300 minutes on the following day (Day7).

	Housing (H) and Treatment (T) combination (H*T)					*P* value		
Nursing observation	CRATE CON	CRATE FOS	PEN CON	PEN FOS	s.e.	H	T	H*T
Day6 (60 mins)								
First nursing latency (min)	5.26	11.51	7.74	8.57	3.01	-	-	-
Successful nursing latency[†] (min)	9.19^{a}	113.14^{b}	19.74^{a}	59.08^{c}	10.29	0.05	0.001	0.01
Nursing frequency	2.17	2.08	2.83	2.67	0.38	-	-	-
Sow-terminated frequency	1.50^{a}	1.50^{a}	2.33	2.58^{b}	0.40	0.05	-	-
Average focal piglets present	2.92^{a}	2.34	2.18^{b}	1.63^{b}	0.25	0.01	0.05	-
Day7 (300 mins)								
Nursing frequency	6.90	6.70^{a}	7.90	8.70^{b}	0.66	0.05	-	-
Sow-terminated frequency	5.84	5.44^{a}	5.84	8.34^{b}	1.34	-	-	-
Successful nursing frequency	4.48^{a}	4.48^{a}	4.58^{a}	3.18^{b}	0.64	-	-	-
Average focal piglets present	2.99^{ab}	3.36^{bc}	2.90^{a}	3.63^{c}	0.13 – 0.16	-	0.001	-

† observation period extended if required only to record successful nursing latency

a,b Values within a row with different superscripts differ significantly at $P < 0.05$

6.4.2. Pre-weaning piglets

Day6 piglet weight was balanced across housing systems and treatments ($P > 0.10$). However, male piglets were heavier than female piglets (2.79kg ± 0.11 vs. 2.73kg ± 0.11; $P < 0.05$), whilst piglets on older sows tended to be heavier than piglets on younger sows (2.83kg ± 0.11 vs. 2.69kg ± 0.11; $P = 0.063$).

Average daily gain

Focal piglet Day6-Day8 ADG (g/day) was significantly lower for FOS than CON ($P < 0.001$; Figure 6.4a). Focal piglet Day6-Day8 ADG tended to be lower amongst litters with older (0.20g/day ± 0.02) than younger parity sows (0.24g/day ± 0.01; $P = 0.068$). Focal piglet ADG continued to be lower for FOS than CON during Day8-Day11 ($P < 0.01$), whilst focal piglet Day11-Day26 ADG only differed between PEN FOS and PEN CON ($P < 0.05$). Focal piglet TWG (Day6-Day26) was higher for CON than FOS ($P = 0.01$), being higher for PEN CON focal piglets (5.54kg ± 0.32) than all other housing x treatment combinations (PEN FOS: 4.56kg ± 0.31, $P < 0.01$; CRATE FOS: 4.87kg ± 0.31, $P < 0.05$; CRATE CON: 5.14kg ± 0.31, $P = 0.070$). Non-focal piglet Day6-Day8 ADG tended to be lower for FOS than CON ($P = 0.062$), and influenced by a treatment x housing interaction ($P = 0.052$), being lower amongst PEN FOS than PEN CON ($P < 0.01$; Figure 6.4b). Non-focal piglet Day6-Day8 ADG was also lower for litters on older (0.23g/day ± 0.01) than younger parity sows (0.27g/day ± 0.01; $P < 0.05$). Non-focal piglet Day8-Day11 ADG was influenced by a treatment x housing interaction ($P = 0.079$), remaining lower amongst PEN FOS than PEN CON ($P < 0.05$). Non-focal piglet Day11-Day26 ADG and TWG (Day6-Day26) were not affected by housing or treatment.

Body lesion scores

Day6 (before cross-fostering), piglet BLS (0-12 scale) were all low, but were higher amongst PEN than CRATE for both focal ($P < 0.001$; Figure 6.4c) and non-focal piglets ($P < 0.001$; Figure 6.4d). Focal piglet Day11 BLS were lower for FOS than CON ($P < 0.01$) and tended to be higher amongst female than male piglets (1.95 ± 0.14 vs. 1.61 ± 0.14; $P = 0.059$), whilst non-focal piglet BLS tended to be higher for PEN than CRATE on Day11 ($P = 0.063$) and Day26 ($P = 0.099$; Figure 6.4d). Non-focal piglet Day26 BLS tended to be higher for FOS than CON (2.72 ± 0.18 vs 2.24 ± 0.19, $P = 0.071$). Moreover, focal piglet Day26 BLS were affected by a housing x treatment interaction ($P < 0.05$). Amongst non-focal piglets, BLS were higher for female than male piglets on Day8 (1.59 ± 0.20 vs 1.35 ± 0.20, $P = 0.094$), Day11

(2.04 ± 0.27 vs 1.69 ± 0.27, $P < 0.05$) and Day26 (2.67 ± 0.47 vs 2.29 ± 0.47, P = 0.065).

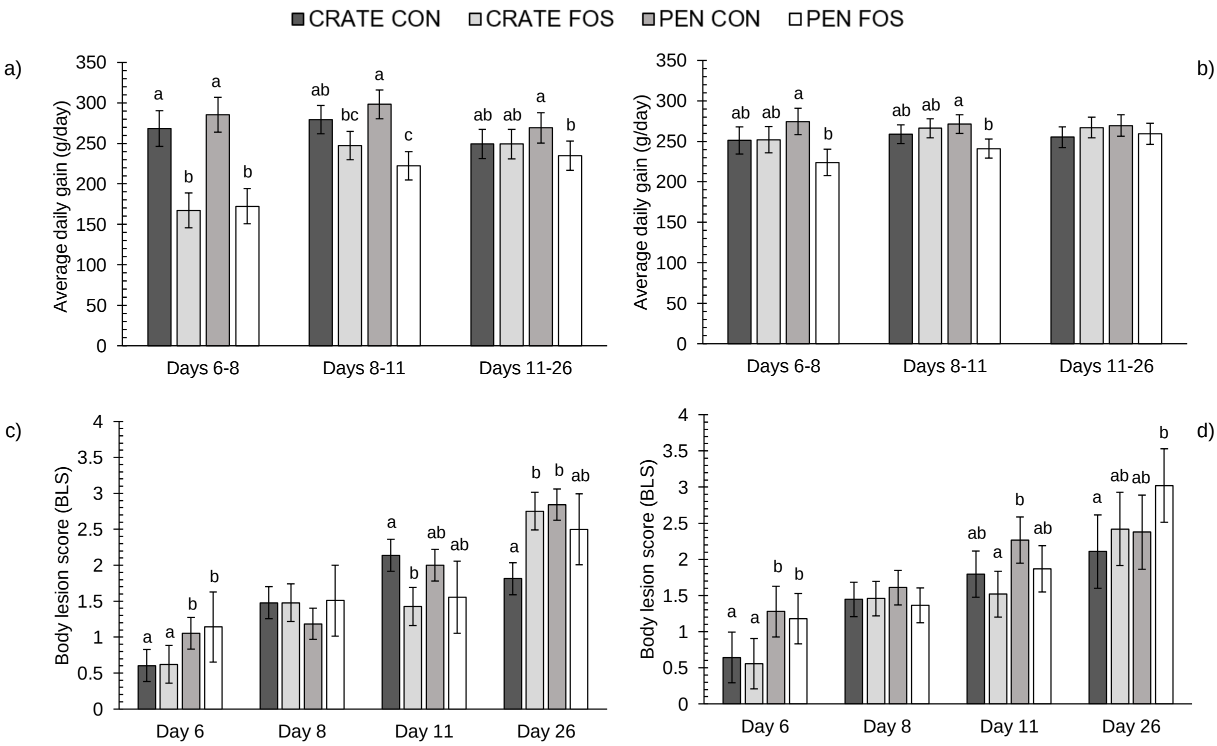


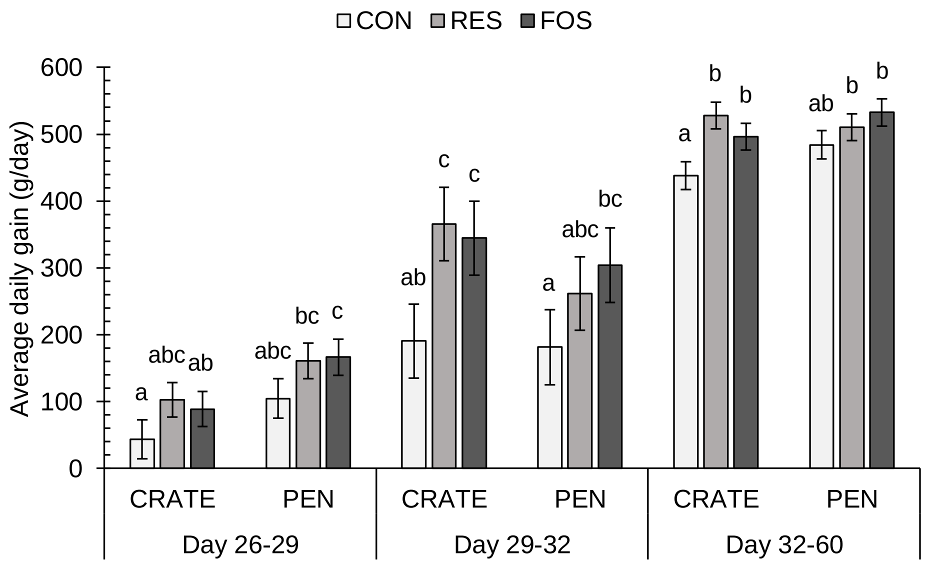
Figure 6.4. Least square means (± s.e.) of pre-weaning piglet outcomes for each housing and treatment combination: a) focal piglet ADG, b) non-focal piglet ADG, c) focal piglet BLS, d) non-focal piglet BLS. Significant differences between bars are indicated with different letters (P < 0.05).

6.4.3. Post-weaning piglets

Post-weaning, Day26-Day29 ADG was lower for CRATE than PEN ($P < 0.01$; Figure 6.5). Moreover, piglet ADG was lower for CON than both RES and FOS during Day26-Day29 (RES: $P < 0.05$; FOS = 0.061), Day29-Day32 (RES: $P < 0.01$; FOS: $P < 0.01$) and Day32-Day60 (RES: $P < 0.01$; FOS: $P < 0.05$). This resulted in TWG during the weaner period (Day26-Day60) being lower for CON (13.70kg ± 0.48) than both RES (15.87kg ± 0.46; $P < 0.01$) and FOS piglets (15.77kg ± 0.47; P < 0.01). Consequently, TWG throughout the combined lactation and weaner periods (Day6-Day60) was lower for CON (18.77kg ± 0.48) than both RES (20.95kg ± 0.46; P <

0.01) and FOS piglets (20.84kg ± 0.47; $P < 0.01$). Day29 BLS were higher amongst male (5.39 ± 0.65) than female piglets (4.35 ± 0.64; $P < 0.01$), whilst BLS were higher amongst pen-reared than crate-reared piglets on both Day32 (4.67 ± 0.68 vs. 3.83 ± 0.68; $P < 0.05$) and Day60 (3.51 ± 0.30 vs. 2.85 ± 0.30; $P < 0.05$).

Figure 6.5. Least square means (± s.e.) of post-weaning piglet weight gain for each housing and treatment combination. Significant differences between bars within each time period are indicated with different letters (P < 0.05).



6.5. Discussion

This is the first paper to investigate the effects of housing type on the responses of sows and piglets to cross-fostering, showing an influence on both maternal behaviour and piglet performance. The farrowing systems were in separate buildings, therefore sows and piglets were isolated from any secondary environmental effects of the other farrowing system, such as olfactory or auditory differences. Whilst this means the results are more applicable to commercial settings that would not usually utilise different farrowing systems in the same building, it also meant that building effects could not be controlled for. The biggest limitation of the current study was the high average parity of study sows, especially penned sows, which should be mitigated in future studies.

6.5.1. Sow behaviour

As hypothesised, cross-fostering had a more profound effect on the behaviour of the dam amongst penned than crated sows. Most notably, whilst nursing bout latency was unaffected, successful nursing bout latency was increased amongst foster sows in both housing systems. This finding has been observed previously amongst crated sows (Horrell, 1982), indicating that the sow's willingness to begin nursing is unaffected, but she is perturbed from nursing successfully when cross-fostered piglets are present. Furthermore, Amdi et al. (2017) found no significant effect of cross-fostering new-born piglets to a nurse sow seven days post-partum on the frequency of successful nursing bouts, suggesting that the behaviour of older, but not new-born, piglets may be disruptive to nursing success. Sows may be disturbed and change posture, thus terminating a nursing bout, by piglets in teat disputes at the udder during pre-nursing massage or by the presence of unknown piglets in the pen (Horrell, 1982; Pedersen et al., 2008), especially when a cross-fostered piglet wanders close to the sow's head (Horrell, 1982). Whilst not explicitly recorded, the latter was also observed in the current study as a cause of sows terminating a nursing bout before milk ejection. The successful nursing bout latency after cross-fostering was more prolonged amongst crated sows; these sows also exhibited an increased standing duration, whilst the frequency of sniffing piglets was unaffected. As sniffing contact between the sow and piglets is primarily instigated by the sow (Chidgey *et al.*, 2016), these behavioural changes suggest that confinement impeded the sows' attempts to sniff and identify unknown piglets in the litter, thus prolonging the time taken for the sow to settle and nurse successfully.

Conversely, amongst penned sows, the increased freedom facilitated increased sniffing amongst foster sows for 30 minutes after litter reunion, whilst sniffing was highest amongst penned control sows by the end of the 60 minute observation. Sow contact with the litter is higher amongst penned sows (Chidgey *et al.*, 2016), and may facilitate a stronger bond between the sow and piglets. Penned control sows also exhibited increased posture changes during 30-60 minutes post-reunion, suggesting that they were either distressed by separation from their own litter or by the disruption caused amongst neighbouring cross-foster litters. Alternatively, the olfactory changes arising from the use of marker pen to number focal piglets may have disrupted both penned and crated control sow behaviour, which was less pronounced amongst crated control sows due to the restriction of confinement.

During the day following cross-fostering, only the nursing and lying behaviour of penned foster sows continued to be affected. Whilst the durations of ventral and lateral lying differed between penned foster and control sows, penned foster sow lying behaviour was more comparable to both crated sow treatment groups than penned control sows. The increased lateral lying duration of penned control sows - if reflective of lying behaviour throughout lactation - would have permitted the increased performance of udder massage by the litter. An increased performance of post-nursing udder massage has been previously reported amongst penned litters (Pedersen *et al.*, 2011), and results in an increased milk yield of the sow (Algers and Jensen, 1991), which may contribute to the higher weight gain of penned control piglets at weaning. Although penned foster sow nursing behaviour differed from other housing and treatment combinations, the total frequency of nursing bouts remained unaffected. This finding was previously reported by Pedersen *et al.* (2008), and provides further evidence that penned cross-foster sows are willing to initiate nursing bouts, but that they are somehow prevented from performing milk let-down successfully. Conversely, cross-fostering had no significant effect on the nursing frequency of crated sows in the current or a previous study by Amdi *et al.* (2017).

The nursing bout success of 37% amongst penned foster sows in the current study is comparable to the 35% nursing success of crated foster sows reported by Horrell (1982), but considerably lower than the 76% nursing success of penned foster sows reported by Pedersen *et al.* (2008). The nursing success of control sows in the current study was also lower than that found by Pedersen et al. (2011) amongst both penned (65% vs. 76%) and crated (58% vs. 78%) sows and litters. This could be due to Pedersen *et al.* (2011) observing nursing behaviour later in lactation than the current study, as the definition of successful and unsuccessful nursing bouts is similar between the two studies. However, the seemingly low nursing success rate of control sows – 58% and 65% amongst penned and crated sows, respectively – may have been due to the strict definition of a successful nursing bout used in the current study. Further research is needed to ascertain how long sow behaviour, particularly nursing success, is disrupted after cross-fostering amongst penned sows, whilst nursing success amongst crated cross-foster sows appeared to normalise by the following day.

6.5.2. Pre-weaning piglets

Also as hypothesised, cross-fostering had a greater detrimental effect on piglet weight gain amongst penned than crated litters. However, cross-fostered piglets housed in crates did exhibit a short-term reduction in weight gain during the two days after cross-fostering. Foster piglet weaning weights that are 76-79% of resident piglet weaning weights have been reported previously (Giroux *et al.*, 2000; Horrell and Bennett, 1981), whilst crated and penned foster piglets in the current study weighed 96% and 93% of resident piglet weaning weights, respectively. Amongst crated cross-foster litters, the weight gain of resident piglets remained unaffected, suggesting that this initial reduction in cross-foster piglet weight gain resulted from piglet-centric, rather than sow-centric, behavioural changes. Previous studies have described the immediate behavioural responses of cross-fostered piglets, such as increased vocalisations, increased ambulation and repeated escape attempts from the new pen (Horrell and Bennett, 1981; Price *et al.*, 1994). Therefore, cross-fostered piglet weight gain may be reduced due to the increased energy expenditure from performing these behaviours and the subsequent increased likelihood of missing nursing bouts within the new litter (Horrell, 1982; Pedersen *et al.,* 2008), with the latter also recorded in the current study amongst both crated and penned cross-fostered piglets. However, in the current study, attendance of cross-fostered piglets at nursing bouts was higher on the following day, indicating that the piglets quickly adapted to seeking milk from the foster sow.

Amongst penned cross-foster litters, the weight gain of cross-fostered piglets remained lower throughout lactation, whilst resident piglet weight gain also decreased during the five days after cross-fostering. As the weight gain of the entire litter was affected, this suggests that sow-centric behavioural changes may be responsible, which is supported by our behavioural observations of prolonged disruption to penned foster sow nursing behaviour. Sow nursing behaviour is disturbed by excessive piglet fighting at the udder, which occurs after cross-fostering due to a disruption of an established teat order (Horrell and Bennett, 1981; Pedersen *et al.,* 2008). Whilst the formation of a teat order begins within hours of birth (McBride, 1963), peak stability occurs between 7-14 days postpartum (Hemsworth *et al.*, 1976; Straw *et al.*, 1998). The higher lesion scores of penned piglets on day six, before cross-fostering had occurred, indicate that the teat order may have been less established amongst penned than crated litters by this age. Indeed, Pedersen *et al.*

(2011) reported lower teat affinity amongst penned than crated litters at 14 days of age. The early teat order takes longer to establish with increasing sow changes of lying side, resulting in increased fighting amongst piglets (McBride, 1963). Therefore, a stable teat order may take longer to establish amongst penned litters as the sow is permitted to lie in different locations and directions within the pen.

However, an increased teat order stability is associated with an increased sow milk yield (McBride, 1963) and increased piglet growth (Hemsworth *et al.*, 1976). As both sow milk yield and piglet weight gain are reportedly greater in free farrowing systems (Pedersen *et al.*, 2011; Yun and Valros, 2015), the latter also being observed in the current study, it would be expected that the teat order is also more established amongst penned litters. Furthermore, cross-fostering is more disruptive if a foster piglet's preferred teat is already taken, leading to reduced presence at nursing bouts, increased fighting and increased failed nursing attempts (Horrell, 1982; Price *et al.*, 1994). The increased disruption to piglet weight gain amongst penned foster litters might be indicative of a more established teat order, as cross-fostered piglets would be less flexible to change from their preferred teat if it were already occupied by a resident piglet on the foster sow. This may cause a positive feedback loop, with increased piglet fighting, resulting in more failed nursing bouts, leading to further fighting.

If disruption to sow nursing behaviour were persistent, or foster piglets remain fixed on an unavailable teat, unused teats would regress and become dysfunctional (Farmer, 2013; Straw *et al.*, 1998). It was noted in the current study that penned foster sow udders appeared to show gland regression, which would explain the reduced weight gain of foster piglets throughout lactation, and warrants future investigation. However, in the current study, if a longer teat order re-establishment was responsible for the longer disruption to piglet growth, this problem may be lessened or absent when cross-fostering is performed with the smallest or largest piglets in a litter, or indeed the entire litter, as is standard practice commercially.

6.5.3. Post-weaning piglets

Contrary to our initial hypothesis and previous work (Giroux *et al.*, 2000), post-weaning piglet body lesion scores were not higher amongst control than foster and resident piglets. However, piglet lesion scores were higher amongst pen-reared than crate-reared piglets at 32 and 60 days of age. Previous studies have also found an effect of the lactation environment on lesion scores at weaning, being reportedly higher amongst both pen-reared (Melotti *et al.*, 2011) and crate-reared piglets (Kutzer *et al.*, 2009). The post-weaning environment - or rather, a poor post-weaning environment – may lead to increased aggression, especially if the piglets experienced a more enriched environment previously (Melotti *et al.*, 2011). Thus, the relatively barren and small post-weaning pens used in the current study may have been more detrimental for pen-reared than crate-reared piglets. This highlights the need for consistency in animal housing throughout life to improve welfare, therefore farms considering a transition to higher welfare farrowing systems may also benefit from changing their weaner and grower accommodation to ensure continuity.

Post-weaning piglet weight gain was higher amongst both foster and resident piglets than controls, from both housing systems, throughout the weaner period. Reduced piglet growth from increased competition for milk during lactation increases the pre-weaning solid feed intake of piglets (Huting *et al.*, 2017), whilst pre-weaning solid feed intake is highly correlated with post-weaning feed intake and growth (Berkeveld *et al.*, 2007). However, if this were the predominant cause of increased weight gain in the current study, pen-reared foster and resident piglet growth would be greatest, whilst crate-reared resident piglet growth would be unaffected. Alternatively, permitting litters to mix before weaning leads to reduced fighting and improved growth after weaning (Kutzer *et al.*, 2009). Therefore, our third hypothesis of reduced lesion scores amongst piglets from cross-foster litters may be correct, but the effects were masked by the larger effect of increased lesion scores amongst pen-reared piglets. Consequently, the feed intake of pen-reared piglets may indeed have been greater throughout the post-weaning period, but this additional energy was utilised in fighting. This meant that no increased growth was observed in the current study, which may have occurred if piglets were housed in a more enriched post-weaning environment to facilitate reduced fighting amongst pen-reared piglets.

In conclusion, late cross-fostering was more disruptive to sow behaviour amongst penned than crated sows, including reduced nursing success throughout the following day. Although focal piglet weight gain exhibited an acute reduction after cross-fostering in both housing systems, the effect remained throughout lactation amongst pen-reared foster piglets and reduced the weight gain of residents. However, after weaning, weight gain was increased amongst foster and resident piglets from both housing systems, which may be attributable to increased socialisation before weaning.

Chapter 7. General Discussion

7.1. Thesis Overview

The primary aim of this thesis was to facilitate the commercial uptake of free farrowing systems by providing management recommendations based on scientific evidence. The included management strategies were designed to be implemented easily and to have tangible benefits for piglet survival and performance.

All known establishments in the UK which currently use both conventional farrowing crates and less confined farrowing systems - both in industry and research - do so within the same herd and interchange sows between the confined and unconfined farrowing systems. Chapter three is the first published research to present the role of the previous farrowing system on piglet mortality, and confirmed the hypothesis that piglet mortality can be reduced by returning sows to the same farrowing system amongst both conventional farrowing crates and free farrowing pens (but not temporary crates). Piglet mortality was highest amongst sows which were interchanged between conventional and temporary crates, whilst sows which farrowed in free farrowing pens had a larger subsequent litter size and lower pre-processing crushing mortality in their second parity. Parity effects were also observed, with only pre-processing or post-processing mortality affected by the current farrowing system in the first or second parity, respectively. Individual differences in mortality were consistent throughout the first but not second parity.

Additionally, to further research the role of previous farrowing experience, Chapter four compared the farrowing behaviour of second parity sows whilst housed in free farrowing pens, who had previously farrowed in either a free farrowing pen or temporary confinement crate. Differences were observed between sows with different prior farrowing experience, confirming the hypothesis that sows which previously farrowed in a free farrowing pen would exhibit better farrowing behaviour, and expanding upon findings from previous studies (Jarvis *et al.*, 2001; Thodberg *et al.*, 2002a, 2002b). During parturition, sows with prior free farrowing pen experience exhibited increased lateral lying and decreased ventral lying, sitting and dangerous posture changes during parturition. Postpartum, the average duration of nursing bouts was increased, whilst the percentage of nursing bouts that were successful increased and those that were sow-terminated decreased amongst these sows. The study also found associations between nesting, partum and postpartum behaviours similar to previous studies (Thodberg *et al.*, 2002a, 2002b). Finally, sow behaviour also showed seasonal variation, with the frequency of nesting, intensity of peak nesting and successful nursing bout duration all increased in the autumn/winter than the spring/summer.

Temporary confinement crates are often considered a more reasonable compromise to free farrowing for commercial use, as sows are confined during the first few days postpartum when piglet mortality is greatest. However, the abrupt environmental change that occurs when temporary confinement crates are opened may cause piglet mortality to increase as sows are required to adapt their behaviours mid-lactation. Chapter five is the first published research to confirm that piglet mortality risk increases after the opening of temporary confinement crates. The study also trialled different crate opening strategies, which had different short-term effects on sow behaviour, and identified a strategy which successfully reduced piglet mortality during the post-opening period.

Commercial farms regularly perform cross-fostering to equalise piglet number and size across litters. Moreover, late cross-fostering, performed after 24 hours postpartum, is likely to become more prevalent with increasing live born litter sizes and the subsequent reliance on foster and nurse sows. Because sows are highly maternal and protective of their offspring, late cross-fostering was hypothesised to be more disruptive amongst penned sows, which have greater freedom to interact with unknown piglets. Chapter six will be the first published study to compare the effects of late cross-fostering on sow behaviour and piglet weight gain amongst both penned and crated animals, which confirmed the hypothesis that sow behaviour would be more disrupted, and piglet weight gain more reduced, after late cross-fostering in free farrowing pens. Specifically, it was found that penned foster sows exhibited increased ventral lying, decreased lateral lying and decreased nursing bout frequency on the day following cross-fostering. This was associated with the reduced weight gain of both resident and foster piglets immediately after cross-fostering and a continued reduction of weight gain for foster piglets throughout lactation and of resident piglets.

The thesis focussed on management alterations, rather than management additions. Stockperson time is already limited, therefore alterations to existing routines are more likely to remain implemented in the long-term instead of recommending additional practices, such as increased supervision of farrowings or drying of new-born piglets (Kirkden *et al.*, 2013; Rosvold *et al.*, 2017), which may be both unrealistic to perform consistently and unsustainable in a commercial setting. The thesis also aimed to highlight the imperative need to work with, and not against, the natural behaviour of sows in order to manage free farrowing systems successfully. Farrowing crates facilitate various management practices designed to promote piglet survival – such as split suckling, cross-fostering and supplementary feeding of piglets (Baxter and Edwards, 2018) – by protecting the piglets, giving stockpeople safe and easy access to assist piglets and limiting the possible behavioural responses of the sow. Therefore, stockperson routines whose effects may not be very noticeable on the behaviour of confined sows can have a significant impact on the behaviour of sows in unconfined farrowing systems. Ensuring systematic practices which support the correct performance and development of sow maternal behaviours throughout their reproductive life should reap returns in improved sow productivity and piglet survival. This style of management is arguably of vital importance for the commercial success of free farrowing systems, where sow farrowing and maternal behaviour has a more tangible effect on piglet survival and performance than when housed in the behaviourally restrictive conventional farrowing crate.

7.2. Piglet Performance in Higher Welfare Farrowing Systems

Whilst not a primary aim of the current thesis, the recording of piglet performance across the studies - such as mortality and weight gain – permits a comparative overview of piglet performance between the included farrowing systems.

7.2.1. Sow and piglet productivity

In addition to achieving comparable piglet mortality to more confined farrowing systems, and the financial incentives currently available in the market for adopting true free farrowing systems, productivity also appeared to be greater in the two studied free farrowing systems than both the conventional and temporary confinement systems.

In Chapter three, second parity sows had a larger total born litter size if they were housed in free farrowing pens during their first parity. This additional productivity benefit from free farrowing pens most probably resulted from an increased voluntary feed take by sows, as several previous studies have indicated an increased feed intake amongst unconfined in comparison to confined sows during lactation (Cronin *et al.*, 2000) and a negative association between sow weight loss during the first lactation and total born litter size in the second parity (Schenkel *et al.*, 2010; Thaker and Bilkei, 2005). However, improved second parity litter sizes could also have resulted from differences in the maternal behaviour of gilts housed in free farrowing pens. Evidence exists for increased control of nursing amongst unconfined sows (Thodberg *et al.*, 2002b), and increased pen size also provided the opportunity for sows to avoid piglet demands in later lactation. A longer wean-to-serve interval (Segura Correa *et al.*, 2013), or a longer lactation before weaning (Hidalgo *et al.*, 2014), both result in improved total born litter sizes at the subsequent farrowing, with the latter effect also observed in Chapter three. Thus, gilts in farrowing pens may have been better enabled to begin weaning their piglets before the abrupt weaning at separation occurred, resulting in the subsequent improvement in second parity total born litter size.

Increasing total born litter sizes in second parity sows may be of particular interest for producers, as second parity sows often experience the ‘second litter syndrome’, whereby total born litter sizes are similar to, or small than, those in the first parity (Correa 2013; Tummaruk, 2001). The second litter syndrome was also observed amongst sows in Chapter three, with an average total born litter size of 13.7 piglets/litter and 12.9 piglets/litter amongst first and second parity sows, respectively. However, when considering second parity litter size individually for each first parity farrowing system, gilts housed in farrowing pens did not exhibit a reduced second parity litter size (13.7 piglets/litter), whilst gilts from both farrowing crates (12.7 piglets/litter) and temporary crates (12.7 piglets/litter) exhibited the second parity syndrome. The only other study highlighted from the literature review which compared the farrowing system effects on subsequent reproductive performance found no differences between sows housed in either temporary confinement or conventional farrowing crates (Chidgey *et al.*, 2015), a finding that is in agreement with the results from Chapter three.

Furthermore, in Chapter six, there was some evidence for higher piglet weight gain amongst penned than crated litters, however this only occurred when comparing the weight gain of focal piglets from control litters in both housing systems. Previous studies have indicated higher piglet weight gain in both free farrowing pens (Pedersen *et al.*, 2011) and temporary confinement crates (Chidgey *et al.*, 2015) in comparison to conventionally crated litters. This production benefit could further support the commercial viability of less confined farrowing systems. However, both of these studies also reported increased piglet mortality or removal in the less confined farrowing systems, resulting in smaller litter sizes during lactation which could have contributed to the increased weight gain of individual piglets. This may explain why a less significant effect of farrowing system on piglet weight gain was found in Chapter six, where litter sizes were equal between sows housed in crates and free farrowing pens.

Piglet average daily gain (g/day; ADG) of control litters in both the crates and pens from one week post-partum until weaning varied between 250-300g per day. This weight gain was similar to previous studies involving farrowing crates (Kuller *et al.*, 2004) and farrowing pens (Valros *et al.*, 2002), yet higher than a previous study by Pedersen *et al.* (2011) involving both farrowing systems. However, in Chapter six, there was significant variation between piglets, with total weight gain amongst control litters varying between 2.05kg – 7.72kg and 2.52kg – 8.05kg in the crates and pens, respectively. This range was further increased amongst litters where cross-fostering was performed, between 1.56kg – 8.80kg and 0.81kg – 8.28kg in the crates and pens, respectively, resulting in both lower and higher individual weight gains throughout lactation. This may have occurred due to the selection of median-sized piglets for cross-fostering. This methodology was chosen as the movement of small piglets was deemed an unnecessary risk for their welfare, whilst the movement of large piglets risked causing unnecessary detriment to the weight gain of resident piglets. However, the weights of median-sized piglets chosen from one litter were not always comparable to median-sized piglets chosen from another litter, and therefore this methodology was not always successful in its aim of minimising disruption to the dynamics of the litter. Furthermore, in a commercial setting, cross-fostering is usually performed by exchanging the largest piglets from one litter with the smallest piglets from another litter, which may have resulted in significantly different weight gain outcomes for cross-fostered piglets than the methodology used in Chapter six.

Finally, free farrowing pens also presented some drawbacks for piglet performance. Whilst the weight gain of cross-fostered piglets was compromised in both farrowing systems, this was more evident in the farrowing pens. As farrowing pens provide greater freedom to sows, management routines which disrupt maternal behaviours – such as cross-fostering – will pose a greater challenge in these less confined farrowing systems. Stockpersons may need to perform careful selection of nurse sows for late fostering to be successful in free farrowing systems, similar to outdoor herds (Cox, 2006), which poses as an important area for future research to support the commercial viability of indoor free farrowing systems.

7.2.2. Piglet mortality

Piglet mortality continues to be a significant problem for both animal welfare and farm productivity across all types of farrowing systems. However, concerns about higher piglet mortality remain the predominant barrier for the widespread commercial uptake of free farrowing systems. As piglet mortality is dependent on numerous inter-relating factors, comparisons between different farms or studies should be made with caution. For example, it is well understood that total piglet mortality increases with an increasing total born litter size, which was also highlighted in Chapter three and Chapter five. Therefore, whilst the average total born litter size of the farm in Chapter five (14.3 pigs/litter) is comparable to the UK average for indoor breeding herds (14.4 pigs/litter; AHDB, 2018), the average total born litter size of the farm in Chapter six was lower (13.6 pigs/litter), and so it would be expected that piglet mortality would also be lower than the UK average on this farm.

Moreover, average pre-weaning live-born piglet mortality amongst indoor farrowing systems in the UK is currently 11.7% (AHDB, 2018), almost all of which are sows housed in conventional farrowing crates. In Chapter three, average total live-born piglet mortality in farrowing crates equated to 14.1%, which is considerably higher than the UK average. This figure is also higher than recent previous studies, including a cross-farm study of farms in the UK which found live-born piglet mortality rates of 11.7% in farrowing crates (KilBride *et al.*, 2012), and recent studies in other countries such as Denmark (7.9%-11.5%; Hales *et al.*, 2014) and New Zealand (6.1%; Chidgey *et al.*, 2015). A likely explanation for higher piglet mortality in Chapter three than previous studies is due to the inclusion of only first and second parity sow data. Specifically, Chapter three piglet mortality in farrowing crates was both higher (16.2%) and lower (9.9%) than the UK average in the first and second parity, respectively. Similar results were obtained for piglet mortality being higher in the first but not second parity amongst sows housed in temporary confinement crates (14.3% vs. 11.4%) and free farrowing pens (13.9% vs. 9.3%). Thus, sow parity must also be considered when comparing piglet mortality rates obtained in Chapter three across all farrowing systems with previous studies that include a greater range of sow parities.

The average live-born piglet mortality in free farrowing pens in Chapter three across both the first and second parity (11.5%) is comparable to the UK average for indoor farrowing sows. This figure is also comparable to KilBride *et al.* (2012), who reported mortality amongst UK indoor free farrowing herds as 10.9%. In a study by Hales *et al.* (2014) across three commercial farms, whilst one farm reported similar piglet mortality of 10.1%, the other two farms reported piglet mortality as significantly higher (17.2% and 21.3%). Piglet mortality in the pens used in Chapter three may be lower than some other studies involving free farrowing pens due to the kennel-and-run design, which is rarely seen in other modern research studies and therefore not easily comparable. Nonetheless, the farm with the lowest piglet mortality in farrowing pens in the Hales *et al.* (2014) study was also using the largest farrowing pen size, which may be important for ensuring the sow has sufficient space to perform maternal behaviours successfully. However, piglet mortality can also increase if the nest area of the farrowing pen is too large (Baxter *et al.*, 2015), meaning careful consideration is required when implementing free farrowing pens. Thus, deviations in pen size from the specific free farrowing pen design should be avoided, which could easily occur if existing farrowing buildings are being retrofitted to convert to a free farrowing pen system.

The average live-born piglet mortality in temporary confinement crates was 12.6% in Chapter three across both the first and second parity, but 10.1% in Chapter five across all sow parities. Chidgey *et al.* (2015) reported similar piglet mortality of 10.2% amongst sows in temporary confinement crates, whilst KilBride *et al.* (2012) reported a slightly higher rate of 11.4% across UK farms using temporary confinement. Furthermore, whilst temporary crates in Chapter five were closed from entry into the farrowing house until approximately seven days post-partum, piglet mortality in temporary crate systems may be similar between sows that are confined for either four or seven days post-partum (Moustsen *et al.*, 2013). However, pre-processing piglet mortality is increased when sows are loose housed on entry into the farrowing house and then confined at farrowing, in comparison to sows that are confined throughout this period (Hales *et al.*, 2015a, 2015b; Moustsen *et al.*, 2013); so much so that total piglet mortality amongst sows that are only confined from farrowing until four days post-partum have the same total live-born piglet mortality as sows that are loose housed throughout farrowing and lactation (Hales *et al.*, 2015a). The period immediately after temporary confinement crates are opened was also determined as a sensitive period for increased piglet mortality risk in Chapter five.

Overall, the current studies found no indication for higher piglet mortality in free farrowing systems. Not only was this true for the farm involved in the studies for

Chapter three, Chapter four and Chapter five; but also anecdotally for the farm in Chapter six, where there was no observable difference in piglet mortality amongst penned and crated litters from day six postpartum until weaning. Conversely, amongst first parity sows in Chapter three, total piglet mortality was significantly higher amongst conventionally crated than temporarily confined or free farrowing gilts. Furthermore, as Chapter three demonstrates, the best farrowing system in respect of the lowest total piglet mortality is not fixed, even when comparing the same animals across successive parities within the same farrowing systems.

The direct comparison of piglet mortality outcomes from different farms proves difficult and can even be counter-productive. As highlighted in the literature review and in the results of the studies in the current thesis, there are an extensive number of factors known to affect piglet mortality, including total born litter size and sow parity. Whilst within-farm comparisons of piglet mortality in different farrowing systems are more useful, as they inherently control for many contributory factors, the management practices of these farms are generally tailored to suit one farrowing system over another, such as the most familiar or preferred farrowing system. This would mean the other farrowing systems will look worse in comparison, but they are actually just being managed inappropriately. This indicates that the debate should not be about which farrowing system produces the lowest piglet mortality, but which management routines produce the lowest piglet mortality for each farrowing system respectively.

7.3. Sow Behaviour in Higher Welfare Farrowing Systems

The studies in this thesis provide evidence for how sow management and the farrowing system interact to affect both the development and performance of sow peri-parturient behaviours. The studies also enhance previous scientific knowledge on the direct association between sow peri-parturient behaviour and piglet performance outcomes.

7.3.1. Piglet productivity

The studies in the current thesis, which include results from both piglet performance and sow peri-parturient behaviour, can provide insight into the relationship between them. In Chapter six, the greater reduction in piglet weight gain after cross-fostering amongst penned litters corresponded to greater differences in the maternal behaviour of penned cross-foster sows. Sow nursing behaviour was significantly different, with penned cross-foster sows exhibiting more sow-terminated nursing bouts and fewer successful nursing bouts. Furthermore, these sows spent more time lying ventrally and less time lying laterally, with an increased performance of rolling behaviour. It could be inferred that adapting sow management and housing to discourage these behaviours may lead to improved sow maternal behaviours and subsequent piglet performance. For example, providing warm ambient room temperatures increases the duration of sow lateral lying (Canaday *et al.*, 2013), which consequently may lead to improved nursing behaviour. However, cause and effect between sow posture and nursing behaviour cannot be determined from the current studies, as decreased nursing behaviour could cause decreased lateral lying instead of vice versa. Furthermore, the greater maternal control of nursing behaviour observed amongst penned sows in Chapter six may be beneficial if performed in later lactation for encouraging the piglets to supplement their milk intake with solid feed at an earlier age, thus easing the transition to a completely solid feed diet at weaning.

Furthermore, sow nursing behaviour is not only affected by the current environmental conditions, but also from sow experience in the previous farrowing system. A change of farrowing system in Chapter four resulted in similar behavioural outcomes to cross-fostering in Chapter six, including more ventral lying, less lateral lying and more rolling during parturition, as well as more sow-terminated nursing bouts and fewer successful nursing bouts during the early post-partum period. Whilst these behavioural differences may be indicative of a prior adaption of sow farrowing behaviour during confinement in Chapter four, when viewed in combination with the same behavioural disturbances occurring after cross-fostering in Chapter six, they suggest that disturbances to sow nursing and lying behaviours may actually be behavioural indications of stress amongst the sows in response to a change of farrowing system or the presence of unfamiliar piglets in Chapter four and Chapter six, respectively.

Whilst parturition itself causes some physiological stress (Lawrence *et al.,* 1994), previous studies have highlighted the detrimental effects of excessive stress on the hormonal modulation of sow farrowing and maternal behaviour – namely the inhibition of oxytocin (Lawrence *et al.,* 1992). Elevated oxytocin during the peri-parturient period is associated with piglet expulsion and sow passivity during parturition (Gilbert *et al.,* 1994; Jarvis *et al.,* 2004), a shorter total farrowing duration (Castrén *et al.,* 1993), the performance of maternal behaviours (Yun *et al.,* 2013) and successful milk let-down (Valros *et al.,* 2004). Thus, elevated stress can result in increased farrowing durations (Oliviero *et al.,* 2008) and may be responsible for the increased restlessness and reduced ability to perform milk let-down successfully that was observed amongst sows in Chapter four and Chapter six. The previous farrowing system may have had no observable effect on the total farrowing duration of sows in Chapter four as previously penned sows had larger mean litter sizes, thus confounding with their potentially shorter inter-birth intervals due to their lower levels of stress. Furthermore, physiological indicators of stress are often (e.g. Lawrence *et al.,* 1994; Jarvis *et al.,* 1997; Oliviero *et al.,* 2008), but not always (Hales *et al.,* 2016), higher in farrowing crates than less confined farrowing systems. Stress can also increase the risk of several different causes of piglet mortality. Increased farrowing durations often result in an increased incidence of stillborn piglets (Oliviero *et al.,* 2010), more responsive sows perform more piglet savaging behaviour (Jarvis *et al.,* 2004), whilst the increased restlessness and reduced successful nursing behaviour of stressed sows may increase the risk of piglet crushing and starvation. Thus, ensuring stressors are kept to a minimum during the peri-parturient period results in improved welfare for the sow and piglets, and consequently improved productivity for the producer.

7.3.2. Piglet mortality

The results of Chapter three demonstrated that consistently returning sows to the same farrowing system may be more important for reducing piglet mortality than the specific farrowing system used. Supporting this, Chapter four showed improved peri-parturient behaviour amongst sows in free farrowing pens when the sow had previous experience of farrowing in that system instead of a more confined system. It is proposed that sow farrowing behaviour becomes shaped to the farrowing system throughout lactation, therefore returning sows to the same system will mean that peri-parturient behaviour is already immediately adapted to the farrowing system in the successive parity, in contrast to a sow which changes farrowing system, whose behaviour may now be maladaptive for the current farrowing system.

Furthermore, in Chapter three, pre-processing piglet mortality in the second parity was more affected by the previous than current farrowing system. This finding suggests that the behaviour of experienced sows during farrowing and the early post-partum period remains adapted to the previous farrowing system. As the sow adapts to the current farrowing system, post-processing piglet mortality is more affected by the current than previous farrowing system. This theory is further supported by the extensive differences in sow peri-parturient behaviour observed in Chapter four, where sows with different previous farrowing experience were housed in the same free farrowing system. As Chapter four only investigated sow behaviour until 24 hours after parturition, it remains unknown whether maternal behaviour in later lactation would remain more reflective of the previous farrowing system or indeed adapt to the prevailing farrowing system.

However, Chapter three and Chapter four only involved young sows, and therefore the behavioural responsiveness of older sows to a change of farrowing system may differ. Previous studies suggest that gilts show greater environmental sensitivity to their farrowing environment (Baxter *et al.*, 2011a; Jarvis *et al.*, 2001), whilst the behaviour of older sows is less responsive to environmental changes (Cronin *et al.*, 1993). The reduced responsiveness of older sows was also highlighted in Chapter five, as sows of parity six or older exhibited no increase in standing and less turning around in response to crate opening, whilst this reduced responsiveness may have also contributed to the higher post-opening piglet mortality seen amongst parity six or older sows. Furthermore, these studies only used sows housed in group pens throughout gestation. A repeat of the current study using sows that are confined throughout gestation, or loose housed without straw, may have an additional interactive effect of the previous environmental experiences of the sow on subsequent pre-partum, farrowing and maternal behaviours.

Whilst nest-building and maternal behaviours are innate and unlearned, the behavioural measures of nest-building used in Chapter four indicated an adaptive response to both climatic variation and previous nest-building experience. However, the highly controlled farrowing environment in nucleus and multiplier herds, and most commercial farms, may mean that sows are being increasingly selected to perform well in one specific environment and subsequently less adapted to performing well in alternative farrowing environments. All breeding sows on nucleus and multiplier herds are housed in farrowing crates. Alternatively, housing these sows in the farrowing system for which their offspring will later be housed in for farrowing could facilitate the genetic selection of sow lineages with the best piglet survival outcomes for each farrowing system independently.

These findings could potentially have a massive impact on how piglet mortality in free farrowing systems should be interpreted, by both researchers and producers that are trialling or transitioning to less confined farrowing systems. Part of the stigma for higher piglet mortality in free farrowing systems may be due to research and commercial practices which involve housing multiparous sows in a less confined farrowing system for one farrowing and lactation to determine the performance of that system. In light of the findings from the current thesis, these practices would make piglet mortality appear worse than it could be if sows were given the opportunity to adapt to the farrowing system. Furthermore, the stress of repeatedly changing the farrowing system may in fact worsen instead of improve sow welfare, in direct contradiction to what free farrowing sets out to achieve.

7.4. Necessity of Temporary Confinement?

The increasing commercial interest in, and use of, temporary confinement is arguably counter-productive for sow welfare, piglet performance and the commercial progression of higher welfare farrowing systems. Temporary confinement is often seen as a better compromise for commercial viability than true free farrowing systems for several reasons, which will be discussed later. However, the primary reason is the facility to confine sows during the early postpartum period when the majority of piglet mortality occurs.

However, many commercial users of temporary confinement systems routinely confine sows from entry into the farrowing accommodation, including throughout the prepartum nest-building phase of parturition. Sow confinement and the subsequent prevention of prepartum nesting behaviours is already known to result in increased behavioural and physiological indicators of stress (Jarvis *et al.*, 1997; Yun *et al.*, 2015). Whilst the provision of nesting materials amongst temporary confinement crates may have alleviated some stress of confinement (evidenced by lower first parity pre-processing mortality than conventionally crated sows in Chapter three), all higher welfare systems should prioritise both the space and materials needed for sows to perform as much of their natural prepartum nest-building behaviours as practically possible to optimise sow welfare (Baxter *et al.*, 2011b). A further sow welfare problem associated with temporary confinement crates may arise when sows are released from confinement. As already discussed in Chapter five, the disruption caused by opening crates may be distressing for sows, especially when the farrowing room layout facilitates increased visual and physical contact between neighbouring sows; a finding which could be explored further in future research. Furthermore, the risk of piglet mortality increases in response to temporary crate opening, and therefore temporary confinement crates may in fact incorporate the drawbacks of both farrowing crates (reduced sow welfare) and free farrowing pens (increased piglet mortality from crushing) without incorporating any of the benefits.

Temporary confinement is often considered as an intermediate step for farmers converting from conventional farrowing crates to true free farrowing systems (Moustsen, 2018). However, once farms have invested in temporary crating, it seems unlikely that individual farmers would subsequently re-invest in yet another farrowing system. This would be especially the case if the first transition from conventional to temporary crates led to increased piglet mortality, as would be expected from the results in Chapter three. Finally, because of the aforementioned similarities between temporary and conventional crates, current public perception of temporary confinement systems is that they do not provide a significant improvement for sow welfare. It therefore seems unlikely that customers would be willing to pay a premium for pork products produced from a temporary crate system. This is further reflected in amendments to the RSPCA Assured farm assurance standards (RSPCA, 2016), which specify that indoor farrowing systems must provide a minimum pen size of 5m^2 and have no potential to confine sows, thus excluding the certification of temporary confinement systems.

If temporary confinement systems are to be used, they must be carefully designed for their intended purpose as a loose lactation system, instead of being adapted from a conventional farrowing crate (V.A. Moustsen, personal communication). For example, another finding from the use of temporary confinement housing in Chapter five was the significant unintended effect of pen layout on piglet mortality. As temporary confinement systems are very similar to conventional farrowing crates, pens are located alongside one another with low walls to provide easier visual and physical accessibility for stockpersons. A consequence of this is that when the temporary crates are opened, the sows also have greater visual and physical accessibility to other neighbouring sows. This may have been distressing for sows which may be nudged or bitten by their neighbours when turning around, due to the small pen size designed to fit into the same footprint as a farrowing crate. This design provided minimal room for sows to turn around unimpeded, whilst some larger sows may have been unable to turn around at all.

7.5. Barriers for the Commercial Uptake of Free Farrowing

Whilst there is mounting scientific evidence that total piglet mortality is not significantly higher in well-designed free farrowing systems, including the studies in the current thesis, there are further barriers for the widespread commercial uptake of free farrowing systems.

Besides piglet mortality, arguably one of the most important barriers for commercial viability is the increased financial cost of free farrowing systems. Modern farrowing systems must be cheap to construct and economical with space, unlike the design of the long-standing free farrowing pen used in Chapter three and Chapter four, which would not be economically viable to build today. Moreover, even modern higher welfare farrowing systems, such as the temporary confinement crate used in Chapter three and Chapter five, and the designed free farrowing pen in Chapter six, have greater capital costs of £500 and £1,218 per place above the capital cost of a standard farrowing crate (Guy *et al.*, 2012). Part of this increased cost is the increased floor space required per sow with unconfined farrowing systems. Although some temporary confinement systems, such as the one used in Chapter three and Chapter five, fit within the same footprint as a conventional farrowing crate, the majority of true free farrowing systems require a significantly larger floor space per pen, such as the true free farrowing systems used in Chapter three, Chapter four and Chapter six. Furthermore, piglet mortality is increased in free farrowing systems which are smaller than 5m² (Weber *et al.*, 2009). Higher welfare farrowing systems should provide enough space for sows to achieve their basic behavioural needs, including pre-partum nest-building behaviours, as well as sufficient space for the safety of the piglets, which may not be true for the temporary confinement system used in Chapter three and Chapter five. Therefore, whilst the increased floor space requirements of free farrowing systems is an expensive outlay, it should be considered a necessity to ensure the system is able to provide for the needs of both the sow and her piglets.

For example, although the straw pen system used in Chapter three and Chapter four was not modern, it facilitated many of the sow's natural farrowing behaviours – such as visual isolation from other sows, space for locomotor nest-site seeking, a small, dark nest area that was enclosed on three sides and sufficient nest-building materials. As such, sows were often observed performing a large repertoire of nest-building behaviours in the straw pen system, and piglet mortality rates that were comparable to farrowing crates. The free farrowing system used in Chapter six also facilitated the above behaviours, being designed with significant insight of sow peri-partum behaviour to ensure the behavioural needs of the sow and piglets were met in a more cost-effective system for the producer (Edwards *et al.*, 2012). Conversely, the temporary confinement system provided no visual isolation, no space for locomotor nest-site seeking, no high walls to provide an enclosed nest area and a poorer quality nest-building substrate. Furthermore, as sows were confined throughout the pre-partum period, rooting and pawing of the nest-building substrate meant that it was often pushed outside of the crate, therefore becoming out of reach and possibly even more frustrating for the sow than having no nest-building materials. Thus, whilst larger and more complex free farrowing systems may be more costly to commission, they should result in more contented – and more productive – sows.

In addition to the higher capital costs of free farrowing systems, the running costs are also often higher than conventional farrowing crates. The additional provision of manipulable materials to facilitate sow nest-building behaviour, such as straw or shredded paper, can prove costly in the long-term and they are often subject to fluctuating prices when sourced externally to the farm. Furthermore, the use of manipulable materials increases the associated labour costs in disposing of and replenishing these materials. The two farms in the current studies performed this management routine differently, with the farm using the older farrowing pens providing a large amount of straw which was replenished weekly, whilst the farm using the designed farrowing pen provided a small amount of straw which was replenished daily. Differences in this routine can have further implications, as Westin *et al.* (2015a, 2015b) found the provision of a large amount of straw before farrowing, instead of several smaller amounts of straw, increased sow nest-building behaviour and reduced the incidence of stillborn piglets. However, anecdotally, stockpersons on the former farm reported the additional labour of mucking out free farrowing pens as a significant drawback, which was probably highlighted by the comparative ease of maintaining the conventional and temporary crate farrowing systems.

An additional barrier for free farrowing systems is ensuring that stockpeople are both capable and willing to handle free farrowing sows. Highly maternal sows can be dangerous and unpredictable, and will attack stockpersons and their own offspring if they are perceived as a threat, which was seen in all of the farrowing systems used in the current studies. The collection of piglets to perform routine health procedures often took longer within the free farrowing pens on both of the experimental farms, as stockpersons had to navigate the responsiveness of the sow whilst catching the piglets. Farmers must find the right balance in working calmly yet quickly when handling sows and piglets soon after birth to avoid unnecessary disruption. Furthermore, in free farrowing systems, it was sometimes more beneficial for overall litter survival to not intervene to save a crushed or hypothermic piglet, as the intervention resulted in other piglets becoming savaged or crushed instead. These problems may be farm-specific, with stockperson management improving with continued trial-and-error and learning from experience (E M Baxter, personal communication). However, providing opportunities for farmers to share and discuss their experiences and successes of managing free farrowing systems could facilitate a grass-roots initiative of optimising unconfined farrowing sow management which would be more effective than trial-and-error or research alone.

Finally, the current economic and political climate may prevent British farmers from investing in free farrowing systems. Current uncertainties around Brexit – including the prospect of cheaper, lower-welfare meat imports – means that many farmers are unsure about the future viability of their business, irrespective of any potential investment in higher welfare systems. However, public awareness and demand for higher welfare farming systems looks to increase year-on-year, both in the UK and other countries such as the US (Animal Welfare Institute, 2018), and therefore Brexit may provide the opportunity for additional trade deals with other countries outside of the EU that also show increasing interest in higher welfare meat products.

7.6. Thesis Limitations and Implications for Future Research

Whilst the current research has contributed significant advances to the field of sow behaviour and piglet mortality within free farrowing research, and poses additional questions for future research, these studies also have significant limitations.

One perceived drawback may be that individual studies were performed within individual farms, meaning that their findings may not be repeatable on, or even relevant to, other commercial farms. For example, whilst both of the included farms did exchange sows between confined and unconfined farrowing systems on a parity-by-parity basis, not many commercial farms currently utilise multiple farrowing systems simultaneously within the same herd. However, whilst the research findings may not be relevant to many commercial farms at the present time, the findings can be used to better inform the many more farmers currently considering higher welfare farrowing systems; they need to be aware that using multiple systems interchangeably may increase piglet mortality and therefore any future transitions to free farrowing should be performed promptly. As mentioned previously, performing within-farm comparisons of free farrowing systems should be considered advantageous for optimising management practices, as multiple other underlying factors are inherently controlled for.

However, whilst performing commercially-relevant research on a commercial farm has benefits for the applicability of the research, it also created limitations for research logistics. Data collection had to be performed around 'business-as-usual' routines, or even in direct conflict with them, such as limiting the amount of cross-fostering or changing when temporary crates were opened. Furthermore, due to how sows were housed on the commercial farm with no extra farrowing places available, data collection across the different farrowing systems was skewed as there were more farrowing places for some systems than others, and therefore also a greater probability of sows returning to the same farrowing system in the next parity for some farrowing systems more than others. A future replication of the study in Chapter three would be beneficial to correct the uneven sample sizes collected across the different farrowing system combinations.

Similarly, the sample sizes used across all the studies were relatively small in comparison to some other previously published studies. This is an additional drawback of performing studies within individual farms, as it takes a long time to acquire large sample sizes. Finally, as Chapter three and Chapter four only involved a reduced selection of sow parities, this must be taken into consideration when comparing the results to previous studies involving a wider range of sow parities, since the behavioural and piglet mortality effects from a change of farrowing system may be less pronounced amongst older, more experienced sows.

Future research should continue to explore the interactive role of management routines and farrowing systems to further improve and optimise sow management in free farrowing systems.

7.7. Conclusions

In conclusion, this thesis has shown that improving management routines can successfully increase the commercial viability of free farrowing systems. Returning sows to the same farrowing system improves piglet survival and sow maternal behaviour. The opening of temporary confinement crates results in increased piglet mortality, which can be mitigated by opening the crates individually. Piglet cross-fostering is more disruptive to sow behaviour and piglet weight gain in farrowing pens, therefore free farrowing sows may need to be managed more similarly to outdoor than crated sows. These studies show that when management is optimised, piglet survival rates that are similar – if not better – are achievable amongst higher welfare farrowing systems than conventional farrowing crates. The studies also highlighted additional production benefits of free farrowing, such as increased subsequent litter sizes and potentially improved piglet weight gain throughout lactation, which may help to offset the increased capital and running costs of free farrowing systems and further improve their commercial viability.

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