The effects of alternative lactation housing on stress and performance in piglets around weaning

By
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Declaration

I declare that this thesis is record of original work and contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and believe, this thesis contains no material previously published or written by another person, except where due reference is made in the text.

Emily Martje de Ruyter

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A number of agonistic behaviours differed between treatments across days. Whilst the frequency of belly nosing was unaffected, the mean duration of a belly nosing event was longer on day one post-weaning in the CON compared to SP piglets (6.3 ± 2.0 versus 2.4 ± 1.3 sec; P < 0.05), but this treatment effect had disappeared by day two (Figure 4).

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LITERATURE ANALYSIS

1. Introduction

The development of housing and management systems which optimise sow and piglet welfare is a high priority for both the Australian and international pig industries. In conjunction with major food retailers and animal welfare groups, the Australian pig industry has developed a strategy to phase out the use of dry sow or gestation stalls, and develop non-confinement, high welfare housing systems. Countries outside Australia, such as Denmark, Sweden and the United Kingdom, are attempting to reduce confinement in other production stages such as during lactation (Baxter *et al.* 2012), with emphasis on reducing sow confinement whilst maintaining sow and piglet performance. During this pivotal shift in housing conditions, practical and commercially viable alternatives to confinement of sows must be obtainable. Opportunities for the re-design of housing may allow for the reduction of sow confinement whilst maintaining piglet productivity. (Hotzel *et al.* 2004). This may also provide the opportunity to allow weaning to occur more gradually and thus provide further benefit the sow, piglet and producer in various ways.

The majority of Australian sows are housed in farrowing crates throughout lactation as the design restricts sow movement which in turn protects newborn piglets from being overlayed (NSW DPI 2006). However, there is evidence that farrowing crates have little benefit to either sows or piglets from mid-late lactation, suggesting that a reduction in sow confinement may not have a significant effect on piglet health or mortalities after this time (Ahmadi *et al.* 2011). In addition to the direct adverse welfare costs of confinement on the sow, the abrupt weaning of piglets at a relatively early age is exacerbated by the confinement of the sow, as the sow is unable to naturally wean her litter. Commercial practice involves an abrupt weaning of piglets and causes a reduction in piglet productivity early-post weaning, intensifying negative behaviours such as aggression and stress responses, implying that welfare may be compromised (Hotzel *et al.* 2011). Alternative lactation housing systems can provide a sow only area which allows for intermittent suckling. Intermittent suckling is a management strategy in which sow and piglets are separated during a fixed period of the day. Intermittent suckling has been associated with a more gradual weaning process and increased consumption of solid feed prior to weaning as opposed to abruptly weaned piglets which have continuous access to the sow (Kuller *et al.* 2004; Gerritsen *et al.* 2008; Tarocco 2008; Berkeveld *et al.* 2009; Kuller *et al.* 2010).

This review will highlight the differences that exist between commercial and 'natural' weaning of piglets, discuss the impact of current commercial weaning practices on the piglet, and lastly, identify how alternative housing and weaning strategies affect piglet behaviour and welfare.

2. The Natural Weaning Process

A natural weaning process is described by Pajor *et al.* (pg 106, 1999) as "a decrease in the amount of contact between the mother and offspring, usually accompanied by declines in the frequency of nursing and in the level of milk production, and by an increase in the offspring's consumption of food". Under semi-natural conditions, sows will lactate for approximately 12-16 weeks (Newberry and Woodgush 1985). Piglets will suck up to 30 times a day during their first week of life. However, after approximately day 10 post-farrowing the sow will spend increasing amounts of time away from her piglets resulting in a steady reduction in nursing frequency (Jensen and Recen 1989). This reduction in nursing frequency stimulates the piglets to seek alternative feed sources, resulting in an increased intake of solid feed. As piglets grow their energy requirements are no longer met by milk alone, stimulating them to seek additional nutrients from solid feed (Boe 1991; Cox and Cooper 2001). Piglets also benefit from the reduction of suckling over time as this encourages piglets to reduce their dependence on the sow and may reduce the negative effects of a separation response following weaning. Additionally, sows may also benefit from the reduction in dependence as energy that would otherwise go to milk production becomes available to improve body condition for future reproductive output (Weary *et al.* 2008).

3. The Conventional Weaning Process

The lactation length in a conventional piggery is considerably shorter than those observed in a natural setting. This shortened lactation of three to four weeks of age was established in the 1970's as the optimal weaning age to gain a profitable outcome (Nielsen *et al.* 1979). Weaning age is also dependent on when piglets are able to develop their own immune systems without the reliance on maternal antibodies. A shorter lactation provides additional benefits in that the sow is able to be mated sooner therefore producing more piglets/sow/year (dos Santos *et al.* 2004). Prolonged lactations of greater than four weeks in farrowing crates also have welfare costs to the sow, as she is confined for the entire period of lactation. When to wean is one of the most contentious topics in the industry as often economics, welfare and health overlap considerably. Whilst production and economic advantages are achieved by weaning piglets early, a reduction in lactation length means that the majority of piglets will have consumed little, if any, solid feed prior to weaning (Boudry *et al.* 2004).

In contrast to natural weaning, abrupt weaning is much more stressful for both the sow and piglet. Changes to the social and physical environments are more prominent in commercial systems than an outdoor system and can result in a pronounced behavioural and physiological response to the weaning process (Weary *et al.* 2008). It is common for piglets to stop growing or even lose weight during the one – three days after weaning, a phenomenon commonly referred to as the post-weaning growth check. Behavioural responses to abrupt weaning result in piglets interacting negatively with their new pen mates, and abnormal behaviours such as belly nosing are often observed (Dybkjaer 1992). Mal-adaptation may create negative behavioural patterns, including belly nosing or chewing on the tails or ears of other pigs (Blackshaw 1981). Dybkjaer (1992) suggested that the previously described behavioural patterns, together with other physiological responses, such as elevated cortisol and intestinal functions, are indicators of poor welfare in weaned piglets.

4. Piglet response to weaning

In addition to nutritional change, weaning involves significant changes in environment and social structure resulting in detrimental welfare outcomes for some individuals. Whilst it is often difficult to understand how an animal 'feels', the combined use of physiological, behavioural and production measures can be used to assess the impacts of weaning on piglet welfare.

4. 1 Nutritional stress at weaning

Morphological and functional adaptations of the gastrointestinal tract are necessary at weaning to enable piglets to acclimatise to the sudden change from a liquid, milk-based to solid, grain dominant diet (Pluske *et al.* 1995). It is common practice to provide piglets with access to solid (creep) feed during lactation. Consumption of creep feed is influenced by digestive maturity and nutritional demand, and is low prior to 18 days of age, both in terms of the quantity consumed and the proportion of the litter consuming the creep feed (Metz and Gonyou 1990; Worobec *et al.* 1999; Sulabo *et al.* 2010).

Cortisol, a physiological measure of the response to stress, is higher in piglets which consume no or little creep feed prior to weaning, suggesting a clear link between changes in diet and stress (Mason *et al.* 2003). There is some evidence that adaptation in intestinal morphology is stimulated by the decrease in cortisol, and suggests piglets which adapt more readily experience a lower amount of cortisol at weaning(Yao *et al.* 2011).

Due to the low consumption of creep feed, an abrupt change from milk to solid feed occurs, leading to atrophy of villi in the small intestine (Hedemann *et al.* 2007; de Souza *et al.* 2012). Pluske *et al.* (1995) demonstrated a positive relationship between the height of the villi in the small intestine at weaning and daily weight gain post-weaning, indicating that atrophy of the villi reduces growth rate. Immediately post-weaning, the intestinal tract does not yet produce all the enzymes necessary to digest solid feed which may also result in malnutrition through impaired absorption and transport of nutrients early post-weaning (de Souza *et al.* 2012).

The mucosal lining is also affected by the atrophy of villi and post-weaning scours is a response to the higher bacterial loads from the compromised mucosal lining (Pluske *et al.* 1996). The presence of feed in the intestinal lumen stimulates intestinal development (Pluske *et al.* 1996), meaning that piglets who continue to eat feed early post-weaning will maintain villus height and crypt depth in the gastrointestinal tract (Pluske *et al.* 1995). As the small intestine goes through a maturation process, where digestive enzymes become of use approximately ten days post-farrowing, piglets should be encouraged to consume creep feed from this age to limit the post-weaning nutritional stress effects on intestinal function (de Souza *et al.* 2012).

When weaning occurs between 20 and 28 days of age, weaning stress is reduced in piglets consuming creep feed prior to weaning and solid feed after weaning (Bruininx *et al.* 2002; Weary *et al.* 2008). Some attempt has been made to associate the post-weaning feed intake to intakes before weaning when associated with age (Gonyou *et al.* 1998; Worobec *et al.* 1999). Feed intake in older piglets is higher than piglets at four weeks of age, as older weaned piglets (six or more weeks of age) will be more likely to consume solid feed than younger weaned piglets (Fraser 1978; Pajor *et al.* 2002).

4.2 Environmental stress at weaning

Weaning commonly involves a dramatic change in environment, with piglets moved into large group pens or eco-shelters and housed with unfamiliar piglets. In conventional lactation housing, a small creep area is provided for the piglets. The creep areas are often heated for the first few weeks after birth to decrease the risk of piglets chilling. Conventional weaner pens provide more space than the creep area of farrowing crates to allow a larger number of piglets to be accommodated. The flooring of the pens is often slatted with a concreted area often near the feeders. Eco shelters provide a very large space, with several hundred piglets per shelter, although the actual space allowance per pig may be no different to weaner pens (Barnett *et al.* 2001). Thermoregulation is more achievable in weaner pens, where sheds are often installed with heating and cooling, whereas eco shelters often rely on natural shading and wind guarding to provide thermoregulation. The benefits of eco shelters are that enrichment is able to be provided through providing a straw base for piglets to lie on and play in.

The new environment provides the piglet with new ways of interacting with its surroundings, and the social interactions between piglets can also change. Arey and Sancha (1996) reported an increased incidence of play behaviours in piglets at weaning which were housed in lactation housing which provided enrichment for the piglets in the form of straw bedding and a communal area for different sows and litters to interact. However, the effects of housing type on play behaviours post-weaning were not investigated.

4.3 Social stress at weaning

Contact between the sow and piglet ceases after abrupt weaning, and the ending of the contact can cause significant distress to both sow and piglet (Barnett *et al.* 2001). Age effects on maternal separation have been difficult to interpret and although many studies have focused on age at weaning in piglets, there is still limited knowledge on the effect of weaning at different ages (Dybkjaer 1992; Gonyou *et al.* 1998; Worobec *et al.* 1999; Mason *et al.* 2003).

In addition to the loss of the sow, piglets can be separated from their litter mates and forced to establish social interactions and hierarchies with unfamiliar, non-litter mate piglets. Negative behaviours are often observed during formation of these new hierarchies and can be interlinked with stress. Aggression towards piglets may also be an indicator that a piglet is not coping with the changes experienced at weaning (Pajor *et al.* 1999; Worobec *et al.* 1999; Hotzel *et al.* 2004; Widowski *et al.* 2008; Hotzel *et al.* 2011).

4.4 Behavioural outcomes of weaning stress

The natural behaviours that occur during late lactation include piglet stimulation of nursing by massaging the sow's udder. The term "belly nosing" describes the distinctive, rhythmic up-and-down movement of one piglet rubbing the belly of another with its snout, and is widely accepted as a re-directed behaviour to nursing stimulation (Fraser 1978). Repetitive belly nosing can result in lesions on the belly and flank of the receiver (Straw and Bartlett 2001) and is suggested to indicate stress due to maternal separation (Jarvis *et al.* 2008). A reduction in the growth of piglets performing and receiving belly nosing has been reported (Fraser, 1978), suggesting that re-directed behaviours can impact negatively upon production. Another agonistic behaviour observed post-weaning is severe fighting between unfamiliar piglets to establish hierarchy (Blackshaw *et al.* 1987; Hotzel *et al.* 2004). Agonistic interactions, such as chasing and displacement, reduce feed consumption when piglets were weaned into a confined setting (Pluske *et al.* 1997; Dybkjaer *et al.* 1998; Gonyou *et al.* 1998; Weary *et al.* 1999). Aggression has been found to decrease food conversion efficiency and weight gain in older pigs and may also affect pigs at weaning (Gonyou *et al.* 1998; Jarvis *et al.* 2008), once again establishing a clear link between behaviour and production.

The behaviours which have been observed as a response to weaning have been limited in respect to their impact on performance (Table 1). There is, however, a clear link in negative behavioural patterns and growth and performance when compared together. These results suggest that positive behavioural patterns such as play behaviours and non-aggressive feeding in piglets have not been used to compare weaning strategies in various studies. Thus, it is still unclear if positive behaviours are observed in piglets which have better performance outcomes.

Table 1. Behaviours observed alongside performance observations in conventional settings

Reference	Behaviours Observed	Performance measures observed
Blackshaw *et al.* (1987)	Contact agonistic, head-thrusting, biting and pushing, chasing, threat and displacement	Nil
Newberry *et al.* (1988)	Pivot, hop and scamper	Nil/ Low cost of production
Dybkjaer (1992)	Agonistic, chasing and displacement	Poor growth rate
Worobec *et al.* (1999)	Aggression, belly nosing and chewing	Slow growth/ Poor growth rate
Pajor *et al.* (1999)	Standing and biting	Poor growth rate
Widowski *et al.* (2008)	Feeding, belly nosing and other nursing behaviours	Poor growth rate

Whilst it is clear that negative behaviour occurs post-weaning, the effect of lactation housing on the expression of these behaviours is less clear. Alternate lactation housing may provide an environment which allows a piglet that is better able to cope with the stress typically witnessed at weaning and therefore creates a piglet with a temperament which is able to regulate their stress response better (Pajor *et al.* 1999). Play has an important role in the behavioural development of pigs and is an indicator of good health (Fraser 1990). Although play behaviours have been observed in many weaning studies (Blackshaw *et al.* 1987) none to date have recorded and analysed positive behaviours and their differences due to weaning and housing types. Relationships between piglet-directed behaviour and stress responses have not been observed (Pluske and Williams 1996; Widowski *et al.* 2008), however, injury score and performance suggest that this relationship may exist. Widowski *et al.* (2003) considered the piglets well-being to be compromised when aggressive behaviours occurred and that they are, therefore, indicators of poor welfare.

4.5 Physiological outcomes from weaning stress

Basal plasma cortisol levels are correlated to increased behaviours indicative of elevated anxiety in piglets at weaning (Worsaae and Schmidt 1980; Dantzer and Mormede 1981). The adverse experiences associated with weaning result in activation of the hypothalamus-pituitary-adrenal (HPA) axis which is characterised by a rise in cortisol levels and an acute down-regulation of hippocampal glucocorticoid receptors (Kanitz *et al.* 1998; Jarvis *et al.* 2008). The down-regulation of these receptors elevates basal plasma glucocorticoids, namely cortisol, which activates an anti-stress pathway and suppresses the immune system (Young and Vazquez 1996).The suppression of the immune system comes at a time when the piglets are in an immune-compromised state.

Piglets with a high colostrum intake during the first 48 hours after birth will receive maternal antibody protection for between 1-12 weeks dependent on the disease causing organism. However, there is no antibody protection for piglets under 24 hours old and piglets largely rely on the hygienic conditions in the farrowing crates. Through lactation maternal antibody protection is reduced and by weaning does not offer any immune support. Piglets are relatively naïve to new environments they have not been exposed and are susceptible to the new microbial communities and are more likely to become ill due to the naivety (Konstantinov *et al.* 2004). The housing conditions post weaning are often not as hygienic as that of a farrowing crate meaning piglets are more at risk of acquiring disease which they have no immunity. Compromised immunity, along with naivety, can result in piglets becoming ill with high burdens of gastrointestinal diseases, especially when occurring in conjunction with compromised intestinal function (Konstantinov *et al.* 2004; de Souza *et al.* 2012).

4.6 Impact of weaning on performance

The consumption of creep feed before weaning has been shown to impact the gastrointestinal function of piglets at weaning. Kuller *et al.* (2004) found that the net absorption in the small intestine is significantly higher in piglets which consume creep feed during lactation than those who have not consumed creep feed. The slow introduction of creep feed may reduce intestinal disruption and allow villi to adjust to the diet without compromising nutrient intake as milk is still able to be digested (Berkeveld *et al.* 2009). The slow introduction of solid feed may also reduce the energy cost of adaption, thus reducing or even eliminating the post-weaning growth check (Pluske *et al.* 1997; Colson *et al.* 2006; Berkeveld *et al.* 2007; Berkeveld *et al.* 2009).

Correlations between creep feed intake before and after weaning at the conventional weaning age of two to four weeks has shown to reduce the increased behavioural characteristics of weaning stress observed in piglets at this younger weaning age, and provide more relevant data for creep feed intake effects on weaning stress (Weary *et al.* 2008). Feed intake in older piglets weaned after six weeks of age is higher than younger weaned piglets as these piglets are much more readily able to consume solid feed due to their intestinal morphology (Fraser 1990).

Consumption of creep feed directly impacts the second most important trait in a grower herd, growth, with feed efficiency being the first most important. Piglets which consume less feed will grow slower than those that consume feed at a faster rate. Post-weaning performance has been positively correlated with the level of pre-weaning feed intake of gradually weaned piglets in a few studies (Kuller *et al.* 2004; Berkeveld *et al.* 2007). Although intermittent suckling has resulted in lower weaning weights and a lower average daily gain during lactation, the higher average daily gain after weaning typically compensates for these negative effects (Thompson *et al.* 1981; Kuller *et al.* 2004). More specifically, lower weaning weights due to gradual weaning do not negatively affect growth during the first week after weaning, which suggests that growth shortly after weaning is dependent on the adaptation to solid feed rather than weaning weight (Kuller *et al.* 2004). Whilst these findings suggest performance may not be increased overall, welfare may still be improved and a gradual weaning process is still an important factor in piglet management.

5. Inducing gradual weaning in alternative lactation housing

The lactation environment may be especially important for the early stages of growth in pigs and in turn may influence the lifetime productivity of the piglet. Immediate and long term effects on behaviour are also affected through the lactation housing, The complexity of the nursing environment has been shown to influence the learning abilities of piglets and their ability to cope with stressors at weaning (O'Connell and Beattie 1999; Sneddon *et al.* 2000). Applying a gradual weaning strategy in a conventional environment increased the feeding independence of piglets from the sow (Berkeveld *et al.* 2009). The process of gradual weaning involves the separation of the piglets from the sow by encouraging the sow to separate herself or by separating the sow for small periods of time during lactation, which results in an intermittent suckling regime.

Intermittent suckling reduces the opportunity for milk ingestion with the aim that the piglet would then be required to consume more solid feed during lactation in order to meet its energy requirements. This has been shown to be the case as intermittent suckling results in piglets consuming larger amounts of creep feed compared to piglets housed with sows in a conventional farrowing crate for the duration of lactation (Kuller *et al.* 2004; Berkeveld *et al.* 2007; Gerritsen *et al.* 2008; Berkeveld *et al.* 2009). However, gradually weaned piglets are lighter at weaning due to the abrupt start of intermittent suckling, with piglets separated from the sow for six or more hours. Understanding of how piglets respond to different durations of intermittent suckling is limited and it is unclear if a shorter period of time may be more beneficial.

Contrary to the above studies, Millet *et al.* (2008) showed that piglets in the intermittent suckling treatment were able to consume sufficient milk when there is access to the sow, and therefore, creep feed was not consumed and a gradual weaning effect was not observed in relation to the performance of piglets post-weaning. The piglets in Millet's study were separated for seven hours of the day, two weeks before weaning. This period of time provides a separation length which allows the intake of milk not to be reduced and thus, not affect weight gain during lactation and suggests that a longer separation is needed for creep feed consumption and gut development.

Whilst benefits in solid feed ingestion are observed, intermittent suckling still involves the confinement of the sow or the piglet or both which may be detrimental to the welfare of animals involved. However, this may just be due to methods previously tried involving no reduction in confinement at all. Sow controlled housing involves a farrowing environment in which the sow can remove herself from her litter thereby facilitating her own gradual weaning process (Pajor *et al.* 1999; Baxter *et al.* 2012). However, in systems which are sow-controlled there is a large variation in the post-weaning effects due to inconsistent times of separation, with some sows spending most of their time with their litter. As a consequence, the litters of sows who choose not to leave them still spend most of their time feeding on milk and not creep feed (Bruininx *et al.* 2002).

6. Conclusion

The maternal investment which provides adequate nutrition, socialisation and immune protection to piglets is known to gradually decrease throughout lactation in a natural setting. An abrupt weaning strategy does not allow for the gradual weaning process to occur, and has significant early post-weaning health and welfare issues. A gradual weaning strategy can be implemented with the use of alternative lactation housing which may alleviate the problems caused by abrupt weaning. Creep feed intake before weaning and feed intake after weaning has been positively correlated with a daily weight gain seen in piglets which are gradually weaned. A successful and commercially viable lactation housing design would need to take into account a reduction in confinement for the sow, in addition to facilitating intermittent suckling to induce a gradual weaning effect.

It is still unknown if piglets from alternative lactation housing which induces a gradual weaning process experience a reduction of the stress response to weaning. The reduction of stress may explain previously reported increases in post-weaning production. Stress resulting from abrupt weaning can compromise piglet wellbeing and is evident when negative behaviours occur. This indicator of poor welfare may be reduced with alternative lactation housing. However, there is a lack of positive behavioural observation on gradual weaning so the welfare of the piglets is still not well defined.

Therefore, the study to be conducted herein will investigate the effect of gradual weaning in alternative lactation housing on piglet welfare and behaviour. The study will identify if piglets from alternative lactation housing experience a reduction in the stress typically experienced at weaning, and if this has a positive effect on post-weaning performance. This will be determined by the piglets behavioural, physiological and performance response to weaning after sow to piglet contact is gradually reduced during lactation.

7. References

Ahmadi, BV, Stott, AW, Baxter, EM, Lawrence, AB, Edwards, SA (2011) Animal welfare and economic optimisation of farrowing systems. *Animal Welfare* **20**, 57-67.

Barnett, JL, Hemsworth, PH, Cronin, GM, Jongman, EC, Hutson, GD (2001) A review of the welfare issues for sows and piglets in relation to housing. *Australian Journal of Agricultural Research* **52**, 1-28.

Baxter, EM, Lawrence, AB, Edwards, SA (2012) Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. *Animal* **6**, 96-117.

Berkeveld, M, Langendijk, P, Soede, NM, Kemp, B, Taverne, MAM, Verheijden, JHM, Kuijken, N, Koets, AP (2009) Improving adaptation to weaning: Effect of intermittent suckling regimens on piglet feed intake, growth, and gut characteristics. *Journal of Animal Science* **87**, 3156-3166.

Berkeveld, M, Langendijk, P, van Beers-Schreurs, HMG, Koets, AP, Taverne, MAM, Verheijden, JHM (2007) Postweaning growth check in pigs is markedly reduced by intermittent suckling and extended lactation. *Journal of Animal Science* **85**, 258-266.

Blackshaw, JK (1981) Some behavioral-deviations in weaned domestic pigs - persistent inguinal nose thrusting and tail and ear biting. *Animal Production* **33**, 325-332.

Blackshaw, JK, Bodero, DAV, Blackshaw, AW (1987) The effect of group composition on behavior and performance of weaned pigs. *Applied Animal Behaviour Science* **19**, 73-80.

Boe, K (1991) The process of weaning in pigs - When the sow decides. *Applied Animal Behaviour Science* **30**, 47-59.

Boudry, G, Guerin, S, Malbert, CH (2004) Effect of an abrupt switch from a milk-based to a fibre-based diet on gastric emptying rates in pigs: difference between origins of fibre. *British Journal of Nutrition* **92**, 913-920.

Bruininx, E, Binnendijk, GP, van der Peet-Schwering, CMC, Schrama, JW, den Hartog, LA, Everts, H, Beynen, AC (2002) Effect of creep feed consumption on individual feed intake characteristics and performance of group-housed weanling pigs. *Journal of Animal Science* **80**, 1413-1418.

Colson, V, Orgeur, P, Foury, A, Mormede, P (2006) Consequences of weaning piglets at 21 and 28 days on growth, behaviour and hormonal responses. *Applied Animal Behaviour Science* **98**, 70-88.

Cox, LN, Cooper, JJ (2001) Observations on the pre- and post-weaning behaviour of piglets reared in commercial indoor and outdoor environments. *Animal Science* **72**, 75-86.

Dantzer, R, Mormede, P (1981) Influence of weaning time on piglet behavior and pituitary-adrenal reactivity. *Reproduction Nutrition Development* **21**, 661-670.

de Souza, TCR, Landin, GM, Garcia, KE, Barreyro, AA, Barron, AM (2012) Nutritional changes in piglets and morphophysiologic development of their digestive tract. *Veterinaria Mexico* **43**, 155-173.

dos Santos, JMG, Wentz, I, Bortolozzo, FP, Barioni, W (2004) Early-weaned sows: altrenogest therapy, estrus, ovulation, and reproductive performance. *Animal Reproduction Science* **84**, 407-413.

Dybkjaer, L (1992) The identification of behavioral indicators of stress in early weaned piglets. *Applied Animal Behaviour Science* **35**, 135-147.

Dybkjaer, L, Paisley, LG, Vraa-Andersen, L, Christensen, G (1998) Associations between behavioural indicators of 'stress' in weaner pigs and respiratory lesions at slaughter. *Preventive Veterinary Medicine* **34**, 175-190.

Fraser, D (1978) Observations on the behavioral development of suckling and early-weaned piglets during the first six weeks after birth. *Animal Behaviour* **26**, 22-30.

Fraser, D (Eds DJA Cole, GR Foxcroft, BJ Weir (1990) 'Behavioral perspectives on piglet survival.' (Journals Reproduction & Fertility Ltd: Cambridge)

Gerritsen, R, Soede, NM, Langendijk, P, Hazeleger, W, Kemp, B (2008) The Intermittent suckling regimen in pigs: consequences for reproductive performance of sows. *Reproduction in Domestic Animals* **43**, 29-35.

Gonyou, HW, Beltranena, E, Whittington, DL, Patience, JF (1998) The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. *Canadian Journal of Animal Science* **78**, 517-523.

Hedemann, MS, Dybkjaer, L, Jensen, BB (2007) Pre-weaning eating activity and morphological parameters in the small and large intestine of piglets. *Livestock Science* **108**, 128-131.

Hotzel, MJ, de Souza, GPP, Dalla Costa, OA, Machado, LCP (2011) Disentangling the effects of weaning stressors on piglets' behaviour and feed intake: Changing the housing and social environment. *Applied Animal Behaviour Science* **135**, 44-50.

Hotzel, MJ, Machado, LCP, Wolf, FM, Dalla Costa, OA (2004) Behaviour of sows and piglets reared in intensive outdoor or indoor systems. *Applied Animal Behaviour Science* **86**, 27-39.

Jarvis, S, Moinard, C, Robson, SK, Sumner, BEH, Douglas, AJ, Seckl, JR, Russell, JA, Lawrence, AB (2008) Effects of weaning age on the behavioural and neuroendocrine development of piglets. *Applied Animal Behaviour Science* **110**, 166-181.

Jensen, P, Recen, B (1989) When to wean - Observations from free-ranging domestic pigs. *Applied Animal Behaviour Science* **23**, 49-60.

Kanitz, E, Manteuffel, G, Otten, W (1998) Effects of weaning and restraint stress on glucocorticoid receptor binding capacity in limbic areas of domestic pigs. *Brain Research* **804**, 311-315.

Konstantinov, SR, Favier, CF, Zhu, WY, Williams, BA, Kluss, J, Souffrant, WB, de Vos, WM, Akkermans, ADL, Smidt, H (2004) Microbial diversity studies of the porcine gastrointestinal ecosystem during weaning transition. *Animal Research* **53**, 317-324.

Kuller, WI, Soede, NM, Bolhuis, JE, van Beers-Schreurs, HMG, Kemp, B, Verheijden, JHM, Taverne, MAM (2010) Intermittent suckling affects feeder visiting behaviour in litters with low feed intake. *Livestock Science* **127**, 137-143.

Kuller, WI, Soede, NM, van Beers-Schreurs, HMG, Langendijk, P, Taverne, MAM, Verheijden, JHM, Kemp, B (2004) Intermittent suckling: Effects on piglet and sow performance before and after weaning. *Journal of Animal Science* **82**, 405-413.

Mason, SP, Jarvis, S, Lawrence, AB (2003) Individual differences in responses of piglets to weaning at different ages. *Applied Animal Behaviour Science* **80**, 117-132.

Metz, JHM, Gonyou, HW (1990) Effect of age and housing conditions on the behavioral and hemolytic reaction of piglets to weaning. *Applied Animal Behaviour Science* **27**, 299-309.

Millet, S, Aluwe, M, de Brabander, DL, Van Oeckel, MJ (2008) Effect of seven hours intermittent suckling and flavour recognition on piglet performance. *Archives of Animal Nutrition* **62**, 1-9.

Newberry, RC, Woodgush, DGM (1985) The suckling behavior of domestic pigs in a semi-natural environment. *Behaviour* **95**, 11-25.

Newberry, RC, Woodgush, DGM, Hall, JW (1988) Playful behaviour in piglets. *Behavioural Processes* **17**, 205-216.

Nielsen, HE, Danielsen, V, Simesen, MG, Gisselnielsen, G, Hjarde, W, Leth, T, Basse, A (1979) Selenium and vitamin-E deficiency in pigs. 1. Influence on growth and reproduction. *Acta Veterinaria Scandinavica* **20**, 276-288.

NSW DPI (2006) Alternative farrowing accommodation in the pork industry. Available at http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/63840/Alternative-farrowing-accommodation-in-the-pork-industry---Primefact-61-final.pdf

O'Connell, NE, Beattie, VE (1999) Influence of environmental enrichment on aggressive behaviour and dominance relationships in growing pigs. *Animal Welfare* **8**, 269-279.

Pajor, EA, Weary, DM, Caceres, C, Fraser, D, Kramer, DL (2002) Alternative housing for sows and litters Part 3. Effects of piglet diet quality and sow-controlled housing on performance and behaviour. *Applied Animal Behaviour Science* **76**, 267-277.

Pajor, EA, Weary, DM, Fraser, D, Kramer, DL (1999) Alternative housing for sows and litters - 1. Effects of sow-controlled housing on responses to weaning. *Applied Animal Behaviour Science* **65**, 105-121.

Pluske, JR, Hampson, DJ, Williams, IH (1997) Factors influencing the structure and function of the small intestine in the weaned pig: a review. *Livestock Production Science* **51**, 215-236.

Pluske, JR, Williams, IH (1996) Reducing stress in piglets as a means of increasing production after weaning: Administration of amperozide or co-mingling of piglets during lactation? *Animal Science* **62**, 121-130.

Pluske, JR, Williams, IH, Aherne, FX (Ed. MA Varley (1995) 'Nutrition of the neonatal pig.' (CAB International {a}, Wallingford Oxon OX10 8DE, England, UK:

Pluske, JR, Williams, IH, Aherne, FX (1996) Maintenance of villous height and crypt depth in piglets by providing continuous nutrition after weaning. *Animal Science* **62**, 131-144.

Sneddon, IA, Beattie, VE, Dunne, L, Neil, W (2000) The effect of environmental enrichment on learning in pigs. *Animal Welfare* **9**, 373-383.

Straw, BE, Bartlett, P (2001) Flank or belly nosing in weaned pigs. *Journal of Swine Health and Production* **9**, 19-23.

Sulabo, RC, Tokach, MD, Dritz, DD, Goodband, RD, DeRouchey, JM, Nelssen, JL (2010) Effects of varying creep feeding duration on the proportion of pigs consuming creep feed and neonatal pig performance. *Journal of Animal Science* **88**, 3154-3164.

Tarocco, C (2008) Intermittent suckling: the new way of reproduction. *Rivista di Suinicoltura* **49**,

Thompson, LH, Hanford, KJ, Jensen, AH (1981) Estrus and fertility in lactating sows and piglet performance as influenced by limited nursing. *Journal of Animal Science* **53**, 1419-1423.

Weary, DM, Appleby, MC, Fraser, D (1999) Responses of piglets to early separation from the sow. *Applied Animal Behaviour Science* **63**, 289-300.

Weary, DM, Jasper, J, Hotzel, MJ (2008) Understanding weaning distress. *Applied Animal Behaviour Science* **110**, 24-41.

Widowski T M, Cottrell T, Dewey C E, M, FR (2003) Observations of piglet-directed behavior patterns and skin lesions in eleven commercial swine herds *Journal of Swine Health and Production* **11**, 181-185.

Widowski, TM, Torrey, S, Bench, CJ, Gonyou, HW (2008) Development of ingestive behaviour and the relationship to belly nosing in early-weaned piglets. *Applied Animal Behaviour Science* **110**, 109-127.

Worobec, EK, Duncan, IJH, Widowski, TM (1999) The effects of weaning at 7, 14 and 28 days on piglet behaviour. *Applied Animal Behaviour Science* **62**, 173-182.

Worsaae, H, Schmidt, M (1980) Plasma-cortisol and behavior in early weaned piglets. *Acta Veterinaria Scandinavica* **21**, 640-657.

Yao, K, Guan, S, Huang, R, Wu, G, Ruan, Z, Yin, Y (2011) Dietary L-arginine supplementation enhances intestinal development and expression of vascular endothelial growth factor in weanling piglets. *British Journal of Nutrition* **105**, 703-709.

Young, EA, Vazquez, D (1996) Hypercortisolemia, hippocampal glucocorticoid receptors, and fast feedback. *Molecular Psychiatry* **1**, 149-159.

THESIS

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Abstract

A more 'natural' weaning process can occur in 'sow only' farrowing accommodation. It was hypothesised that an incremental reduction in sow contact during lactation, achieved through housing the sow in a 'sow only' area, would reduce piglet stress responses to weaning. Control (CON) treated sows and piglets (n = 20) remained in full contact with one another until weaning, whilst an incremental reduction in sow contact was achieved by the sow being separated from piglets (SP, n = 30) for 5 hrs per day on days 10 to 15, 7 hrs on days 15 to 20, and 9 hrs on days 20 to weaning (day 2 8 ± 1.3). SP piglets were lighter than CON piglets after weaning (CON 7.64 ± 0.16 kg, SP 6.83 ± 0.15 kg), however, a growth check occurred in the CON piglet's thus no difference was identified by day seven post weaning (CON 8.60 ± 0.17 kg, SP 8.35 ± 0.1 5kg, $P > 0.05$). Overall, SP piglets had a tendency to have more piglets consuming creep/solid feed (SP 64 ± 2.0 %, CON 48 ± 2.0% $P = 0.10$). Belly nosing and aggressive events were longer in duration for CON piglets (belly nosing: CON 6.3 ± 2.0 seconds and SP 2.4 ± 1.3 seconds; aggression: CON 6.5 ± 1.1 seconds; SP 4.2 ± 0.8 seconds; $P < 0.05$). Weaning produced an increase in circulating plasma cortisol concentrations in CON piglets (18.7 ± 13.3 nmol/L), and decreased in the SP piglets (-12.3 ± 14.1nmol/L; $P < 0.05$). These findings imply reducing sow contact during lactation lessens the piglet stress response to weaning.

1. Introduction

Optimising sow welfare and productivity throughout lactation is a high priority for both Australian and international pig industries. The majority of Australian sows are housed in farrowing crates throughout farrowing and lactation (Barnett *et al.* 2001). Farrowing crates were originally designed to protect newborn piglets from being crushed or savaged by the sow (Weber *et al.* 2009). However, there is a suggestion that farrowing crates have little benefit to either the sow or piglet from mid to late lactation as piglet mortality from sow crushing is minimal (Marchant *et al.* 2000). A reduction in sow confinement may not have significant implications for piglet health or mortalities after mid-lactation (Ahmadi *et al.* 2011). Farrowing crates may also be restrictive in space for the sow and also for piglets to move in, as the standard size of a farrowing crate is $3.2m^2$ (PISC 2008). Due to these concerns, there is now growing pressure to find practical and commercially viable alternatives to the conventional farrowing crate.

Alternative lactation housing design has largely focused on improving sow welfare through reducing confinement, but now there is increasing concern for how the different housing types affect piglet performance and welfare (Ahmadi *et al.* 2001; Baxter *et al.* 2012). Sows have a natural tendency to spend time away from their piglets as lactation progresses and gradually reduce suckling frequency, effectively creating a gradual weaning process (Pajor *et al.* 1999). In conventional farrowing crates, the ability of the sow to modulate her own suckling frequency is reduced, thus weaning is an abrupt event. Farrowing accommodation that allows for a 'sow only' area has been shown to result in a more 'natural' weaning process, whereby suckling frequency can be reduced as lactation progresses (Pajor *et al.* 1999). This may benefit sow welfare through reducing confinement and allowing respite from piglets, but may also influence the piglet's adaptability to weaning (Berkeveld *et al.* 2009).

Piglets in a conventional setting are often provided solid feed (known as 'creep feed') prior to weaning to assist the transition from a milk to cereal based diet (Pajor *et al.* 1991). However, consumption of creep feed prior to weaning varies enormously between individuals (Bruininx *et al.* (2004), with some piglets consuming very little or even no creep feed and thus, these animals experience an abrupt diet change following weaning (Pluske *et al.* 2007). Abrupt weaning is typically associated with a reduction in growth immediately post-weaning (known as a 'growth check'). Although gradually weaned piglets are often slightly lighter at weaning (Kuller *et al.* 2004), the severity of the post-weaning growth check is reduced. This is thought to occur as creep feed ingestion may be increased by sow separation in lactation (Berkeveld *et al.* 2007; Berkeveld *et al.* 2009; Kuller *et al.* 2010). Growth performance post-weaning may be further affected by elevated cortisol (Barnett *et al.*1983) as the weaning event is thought to be stressful. Cessation of maternal contact, introduction of a new social and physical environment, along with the changes in diet are all thought to contribute to this stress response (Weary *et al.* 2008). Cortisol is elevated in response to stress, however, no studies have compared cortisol post-weaning due to difficulties in acquiring samples (Worsaae and Schmidt 1980; Mason *et al.* 2003; Jarvis *et al.* 2008). It is, therefore, still unknown if cortisol levels are influenced by a gradual weaning in piglets.

Piglets compete with litter mates for access to more productive teats, and teat order is generally established within the first days following birth. Pluske *et al.* (2007) demonstrated that growth rate between parturition and weaning was affected by teat order, and it is therefore, logical to suggest that teat order may also affect performance post-weaning. Larger piglets are often located on anterior teats with higher milk yields, and smaller piglets on posterior teats with lower milk yields (Kim *et al.* 2000; Mason *et al.* 2003). As milk production is lower in posterior teats, the smaller piglets feeding from these teats are often observed to consume more creep feed prior to weaning (Pluske *et. al.,* 2007). Given the already discussed influence of gradual weaning on creep consumption, it may then be suggested that teat order may interact with any gradual weaning treatment when creep feed ingestion is examined.

There have been several studies conducted on the performance of piglets in relation to intermittent suckling (sow removed from piglets for defined proportion of day) which results in a gradual wean, and many have shown a beneficial effect on productivity post-weaning (Kuller *et al.* 2004; Berkeveld *et al.* 2007; Berkeveld *et al.* 2009). These findings warrant further studies into the welfare of piglets in alternative lactation housing that induce gradual weaning. The few investigations of piglet behaviour following weaning have targeted the incidence of negative behaviours thought to be associated with stress (Blackshaw *et al.* 1987; Dybkjaer 1992; Dybkjaer *et al.* 1998; Pajor *et al.* 1999; Weary *et al.* 1999). However, it is not known whether alternate lactation housing and gradual weaning affect the expression of positive behaviours suggestive of improved welfare state (Newberry *et al.* 1988).

Piglets typically exhibit a variety of behavioural responses to weaning. Turner *et al.* (2006) showed that aggressive behaviours decrease food conversion efficiency and weight gain in older pigs, thus aggression post-weaning in addition to pre-weaning creep consumption may help to explain the decrease in productivity of abruptly weaned piglets. Negative piglet-directed behaviours are indicators of stress (Dybkjaer 1992) and increased incidences of these behaviours (belly nosing, chewing, aggression, and escape attempts from pen) have been reported in abruptly weaned piglets when compared with those that experienced a more gradual wean (Newberry *et al.* 1988; Dybkjær 1992; Worobec *et al.* 1999). When piglets have satisfied their primary needs, such as food, rest, and comfort, an increase in play behaviours can be observed. Play behaviours are, therefore, a good indicator of a positive welfare state (Newberry *et al.* 1988). However, previous studies have failed to measure play behaviours as an indicator of reduced stress at weaning.

The aim of this study is to determine whether piglets gradually weaned from the sow, facilitated by alternate farrowing accommodation, experience a reduction in the stress response typically experienced at weaning, and if this has a positive effect on post-weaning performance and behaviour. It is hypothesised that if sow-piglet contact is reduced gradually during lactation, an improvement in the piglets behavioural, physiological and performance response to weaning will be observed.

2. Materials and Methods

This study was approved by The University of Adelaide Animal Ethics Committee (Animal Ethics Number: S-2013-081) and was conducted in accordance with the 'Code of Practice for the Care and Use of Animals for Scientific Purposes' (NHMRC 2004). All animal work was conducted at an Australian Pork Farms Group (APFG) commercial piggery over two block replicates and included 50 mixed parity Large White x Landrace sows and their offspring. In total, 469 piglets were used throughout the trial. Three sows were excluded as offspring were breeder replacements and one sow was replaced with a foster mother due to agalactia. A total of 14 piglets were removed from the trial due to morbidity or death.

2.1 Experimental Design

2.1.1 Treatment Allocation

Sows were randomly allocated at farrowing to one of two treatments; ten sows per replicate (total n = 20) were allocated to the control (CON) treatment and 15 sows per replicate (total n = 30) to separation pen (SP) treatment. The control treatment experienced no separation, with sows remaining in the farrowing crate in constant contact with piglets throughout lactation resulting in an abrupt wean. In the SP treatment, sows were placed in a pen at the rear of the farrowing crate in isolation from piglets from day -17 relative to weaning to replicate a gradual weaning process. The separation regime for the SP treatment involved a gradual increase in the time in which the sow was isolated from piglets (Figure 1).

Table 1. Separation regime imposed on the SP (separation pen) treatment which involved sows being housed in a pen at the rear of the farrowing crate in isolation from piglets for the specified length of time per day.

Day relative to weaning	**Sow separation for SP treatment**
Birth to -17	0 hrs
-17 to -12	5 hrs
-12 to -7	7 hrs
-7-weaning	9 hrs

2.1.2 Weaning

For both treatment groups, weaning occurred at day zero, with piglet age being 28 ± 1.3 days old (mean ± SD). Piglets were transferred from the farrowing house to a conventional weaner facility where they were sorted according to sex and size, and housed in group pens measuring 3.4 m long by 1.64 m wide (Figure 1). The flooring of each pen consisted of a partially slatted area and a solid concrete area. Wood shavings were provided on the concrete area, and sprayers were present at one end of the slatted area of flooring. Water was provided in each pen by a nipple drinker and feed via one *ad libitum* feeder. Each pen housed 15 to 20 piglets (dependent on piglet size) of the same treatment.

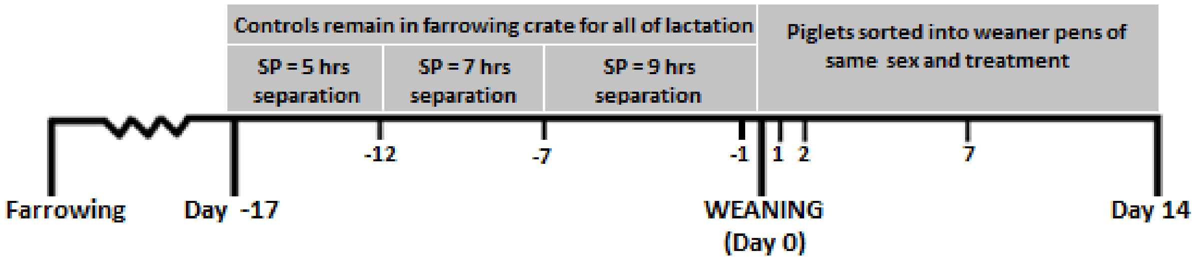

Figure 1. The timing of sow separation relative to farrowing for the SP treatment. Treatments were managed relative to weaning, commencing at day -17 of weaning and concluding on day 14 post weaning. The SP treatment followed the intermittent suckling protocol from day -17 to weaning. The post-weaning measurements were collected from piglets until 14 days following the weaning event.

2.1.3 Housing Design

Lactation housing used in the SP treatment consisted of a conventional farrowing crate (1.7 m x 2.4 m) with a covered creep area, and a 3 m x 1.7 m pen at the rear of the crate (Figure 2). The pen consisted of plastic slatted flooring, contained one drinker nipple and allowed fence-line social contact with sows in neighbouring pens. A gate at the rear of the crate which opened into the rear pen was kept closed for the CON sows, ensuring the sows remained in the farrowing crate in constant piglet contact for the duration of lactation. For the SP treatment, the gate was opened and the sow was confined to the rear pen for the designated separation period per day (Table 1). Piglets from both treatments remained within the farrowing crate for the duration of lactation.

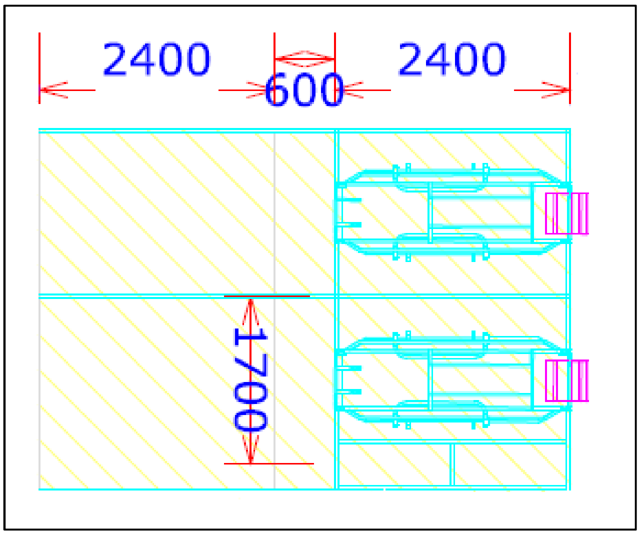

Figure 2. Design of the lactation housing system utilised. The separation pen used included a crate (2.4 m x 1.7 m) and a pen that housed only the sow measuring 3.0 m x 1.7 m.

2.1.4 Feeding

Sows were fed a standard lactation diet (min 14.2 MJ/kg DE) twice daily. The feeding regime was controlled by the SP treatment, and as such, sows were fed at 07:00 (before SP treated sows were moved to the pen) and again at 17:00 (after SP treated sows had been returned to the farrowing crate). In both treatments, piglets had *ad libitum* access to creep feed from day -17 relative to weaning and *ad libitum* access to weaner feed post weaning. The creep and weaner diets were both "starter" diets of 15.5MJ/kg DE dyed at 5 kg per tonne with indigo carmine in order to estimate creep feed consumption (Table 2).

Table 2. Ingredient and nutrient specifications of the piglet starter diet used for both creep and weaner feed.

Ingredient Name	%	Nutrient Name	Amount	Unit
Wheat 12%	25.42	Dry Matter	91.20	%
Ext.Wheat+3.5%Oil	5	D.E. Pigs	15.51	MJ/KG
Peas	7.75	Net Energy Pigs	10.39	MJ/KG
Biscuit Meal -6%	15	Protein	21.27	%
Dextrose	3	Fat	8.07	%
Canola 34 exp. Millicent	2.5	Fibre	2.40	%
Soyabean meal 46%	8	Ash	4.95	%
Soycomil	1.25	Lysine	1.57	%
Nu-pro Yeast Extract	2.5	Methionine	0.50	%
PP-Meatmeal-57%	4	Methionine + Cysteine	0.86	%
Fishmeal 60%	4	Threonine	1.00	%
Blood meal	0.5	Isoleucine	0.89	%
Buttermilk -30P/12F	5	Tryptophan	0.28	%
Whey Powder	10	Calcium	0.9	%
Feed Oil 80:20	3.625	Total Phosphorus	0.72	%
Salt	0.1	Available Phosphorus	0.66	%
Lysine-HCL	0.382	Sodium	2.87	%
Methionine LIQ-80	0.177	Acid Binding Capacity	661.73	MEQ/KG
Threonine	0.157	Choline	2358.74	MG/KG
Tryptophan	0.048	Available Lysine	1.40	%
Zinc Oxide	0.3	Phytate P	0.14	%
Oxicap E2	0.02	Salt	0.71	%
Fysal Fit-4	0.3	Total Legumes	7.75	%
Flavour LQ.VE/VS	0.5	Bulk Density	60.62	KG/HL
Betaine	0.1			
Lysoforte	0.12			
L/A 9854 Creep PMX	0.25			

2.2 Animal Measures

2.2.1 Weights

Individual piglet weights were collected on days -17, -12, -7,-1, 1, 2, 7 and 14 relative to weaning (Figure 1). Weighing commenced after SP sows had finished their time in the sow only area for the day.

2.2.2 Creep feed consumption

Creep and weaner feed was dyed using indigo carmine (5 kg per tonne of dry feed). Faeces were assessed for colour by an anal swab using cotton buds on days -17, -12, -7, -1, 1, 2, 7 and 14. Piglets were given a yes or no status upon successful indication of cyan staining of faeces from the indigo carmine (Pluske *et al.* 2007). Amount of creep feed consumed was recorded but not analysed due to a high wastage level of the feed.

2.2.3 Injury scores

An injury score was collected from each individual piglet in order to subjectively estimate level of aggression. The injury scoring system was adapted from Widowski *et al.* (2003) and consisted of a four point scale for scratches and redness around the head and ears of each piglet (Table 3). This injury score was collected on days -1, 1, 2, 7 and 14 relative to weaning.

Table 3. Injury scoring system using scratches and redness adapted from Widowski *et al.* (2003).

Score:	0	1 (Mild)	2 (Moderate)	3 (Severe)
Redness	No redness, swelling, or hair loss is evident	Reddening, swelling, or hair loss is barely detectable	Swelling, redness, or hair loss is obvious	Irritation easily observed as darker reddening, swelling, and patches of hair loss
Scratches	No scratches or skin loss were evident on face and body	one to three small (≤ 2 cm) scratches or areas of abraded skin is evident, or scratches on face only or back only	one to three larger (>2 cm) scratches or areas of abraded skin is observed on back and/or face	More than three scratches (usually >2 cm) or larger areas of superficial skin loss. Scratches on both face and back

2.2.4 Blood Samples & Teat Order

Piglets were observed during a suckling event between days five and ten to determine teat order (with one being at the anterior end of the sow and four being posterior). Once teat order was recorded, one piglet from the front teat, one piglet from the rear teat and two from the middle teats were chosen as 'focus piglets' to give a total of four piglets per litter. Blood samples were collected from the focus piglets on days -1 and +1 relative to weaning via jugular venepuncture using a 21 gauge needle into a 4 ml heparinised blood tubes (BD Vacutainer®, BD Australia). The time of each bleed and order in which piglets was bled within a crate or pen was also recorded. Care was taken to ensure blood sample collection occurred within a two minute period from animal restraint. After collection, blood samples were spun for 20 min at 3000 rpm and plasma was pipetted into 2ml tubes (Axygen®), where it was frozen and stored at -20°C. Samples were analysed using radio-immunoassay for free cortisol by the Animal Biology department at the University of Western Australia. The limit of detection for cortisol was 3.5 nmol/L and the mean inter-assay co-efficient of variation was 3.5%.

2.2.5 Video Recording for Behaviour

On days one and two post-weaning, two female piglet pens and two male piglet pens from each treatment per replicate, giving a total of eight pens per treatment, were recorded using video cameras (Legria HFR26, Canon Australia) from 07:00 until 13:00. Recordings were then analysed for neutral, negative or positive behaviours (Table 4) using Observer XT v11.5 software (Noldus Inc, The Netherlands). Field of vision did not show access to the drinker, therefore prevented drinking from being recorded as a behaviour.

Table 4. Description of behaviours listed as neutral, positive or negative when examined as a welfare indicator combined from Newberry *et al.*(1988) and Dybkjær (1992) Worobec *et al.* (1999).

Type of Behaviour	**Behaviour**	**Description**
Neutral	Laying	Weight of body not supported by legs.
Neutral	Feeding	Head in feeder.
Negative	Belly-nosing	A piglet rubs a pen-mate's belly with rhythmic, up and down movements of its snout.
Negative	Nosing/chewing pen-mates	Oral-nasal contact with the body of a pen-mate (distinct from belly-nosing).
Negative	Aggression	Pushing, head-thrusting against, biting and chasing pen-mates.
Negative	Aggression at feeder	Aggression (see above) connected with gaining access to the feeder or drinker.
Negative	Mounting	A piglet jumps on the back of another piglet for a prolonged time.
Positive	Playful gestures	Head toss, nudging.
Positive	Hop	Jump up and down on the spot while facing in one direction.
Positive	Scamper	Run slowly with vertical and horizontal bouncy movements.
Positive	Pivot	Jump or whirl around to face in a different direction.
Positive	Toss head	Perform vigorous latero-rotationary movements of the head and neck.

2.3 Statistical Analysis

The following analyses were performed using SPSS 20.0 (IBM, Chicago USA). The model used to analyse piglet weight and injury score was a linear mixed model with piglet ID as the random effect. The model included fixed effects of replicate (one or two), sow ID, sow parity (two to seven), litter size (seven to 12), weaning pen (one to 14), teat order (front, middle or rear located), day (-17 to 14), treatment (CON or SP), and a day by treatment interaction, a day by teat order interaction, and a day by treatment by teat order interaction, and lactation length was fitted as a covariate. Cortisol was transformed using $\log^{10}$ transformation and analysed using a general linear model with lactation length and weight as the covariates and fixed effects as replicate, pen, litter size, parity, sex, teat order, sampling order, treatment. Creep feed intake was analysed in ASReml 3.0 (Gilmour *et al.* 2009) using a binomial regression analysis with a logit function. Weaning pen, farrowing crate, piglet ID were fitted as random effects and fixed effects included replicate, piglet grade (small, medium or large), sow parity, litter size, sex, teat order, day, treatment, day by treatment interaction and day by teat order interaction. Behaviours were transformed using log transformation and analysed using a linear mixed model. The model included weaning pen as the random effect, number of piglets in a pen (14-20) as the covariate and fixed effects of replicate, sex, grade, treatment, day, and a day by treatment interaction. Data are expressed as means ± standard error of the mean (SEM). Results were considered significant at $P < 0.05$.

3. Results

3.1 Piglet weights

At the commencement of the trial, piglets in the separation pen (SP) treatment weighed the same as the control (CON) treatment. CON piglets were heavier than SP piglets on the day prior to weaning and on days one and two post-weaning ($P<0.001$, Table 5). However, on days seven and 14 post-weaning the live weight was similar for CON and SP piglets.

A significant interaction between teat order and day was identified (Table 6). On the days around weaning, piglets from anterior teats weighed significantly more than those from middle and posterior teats. On days seven and 14, anterior piglets were 1.5 kg heavier than the lightest piglets which were from posterior teats, with middle order piglets being intermediate with almost a kilogram difference to the anterior piglets, and half a kilogram heavier than the posterior piglets.

Table 5. Average weight of piglets (mean ± SEM kg) in separation pen (SP and control (CON) treatment groups for days -17, -12,-7, -1, 1, 2, 7 with day 0 representing the day of weaning.

	Day relative to weaning							
	-17	**-12**	**-7**	**-1**	**1**	**2**	**7**	**14**
Treatment								
CON	3.40 ± 0.16	4.67 ± 0.16	6.00 ± 0.16	7.64 ± 0.16^{a}	7.64 ± 0.16^{a}	7.91 ± 0.16^{a}	8.60 ± 0.17	10.81 ± 0.17
SP	3.42 ± 0.15	4.64 ± 0.15	5.75 ± 0.15	6.83 ± 0.15^{b}	7.27 ± 0.15^{b}	7.42 ± 0.15^{b}	8.35 ± 0.15	10.61 ± 0.15

$^{a\text{-}b}$ Means within same column not sharing a common superscript differ significantly (P < 0.001).

Table 6. Influence of teat order on weight (mean ± SEM kg) of piglets on days -17, -12,-7, -1, 1, 2, 7 with day 0 representing the day of weaning.

	Day relative to weaning							
	-17	**-12**	**-7**	**-1**	**1**	**2**	**7**	**14**
Teat order								
Front	3.63 ± 0.16	5.08 ± 0.16^{a}	6.46 ± 0.16^{a}	7.95 ± 0.16^{a}	8.03 ± 0.17^{a}	8.35 ± 0.17^{a}	9.14 ± 0.17^{a}	11.26 ± 0.17^{a}
Middle	3.42 ±0.18	4.58 ± 0.18^{b}	5.69 ± 0.18^{b}	7.01 ± 0.18^{b}	7.17 ± 0.18^{b}	7.50 ± 0.18^{b}	8.21 ± 0.18^{b}	10.36 ± 0.18^{b}
Rear	3.32 ± 0.26	4.30 ± 0.26^{b}	5.22 ± 0.26^{c}	6.52 ± 0.26^{c}	6.88 ± 0.26^{c}	6.96 ± 0.26^{c}	7.64 ± 0.26^{c}	9.68 ± 0.26^{c}

$^{a\text{-}c}$ Means within same column not sharing a common superscript differ significantly (P < 0.001).

3.2 Creep feed

There was a tendency for a higher percentage of SP piglets to consume creep feed than the CON piglets (64 ± 32.0 versus 48 ± 2.1%; P = 0.10). There was also an effect of day on creep consumption, in that more piglets were eating creep feed as lactation progressed (Figure 3). On the day preceding and following weaning, there was no difference in the percentage of piglets eating creep feed (day -1: 28.5 ± 2.4%, day 1: 31.3 ± 2.9%). By day 2, 55.1 ± 3.0% of piglets were consuming feed. By day seven post-weaning, 100.0 ± 2.9% of piglets were consuming solid feed (Figure 3). There was no day by treatment interaction observed for creep consumption.

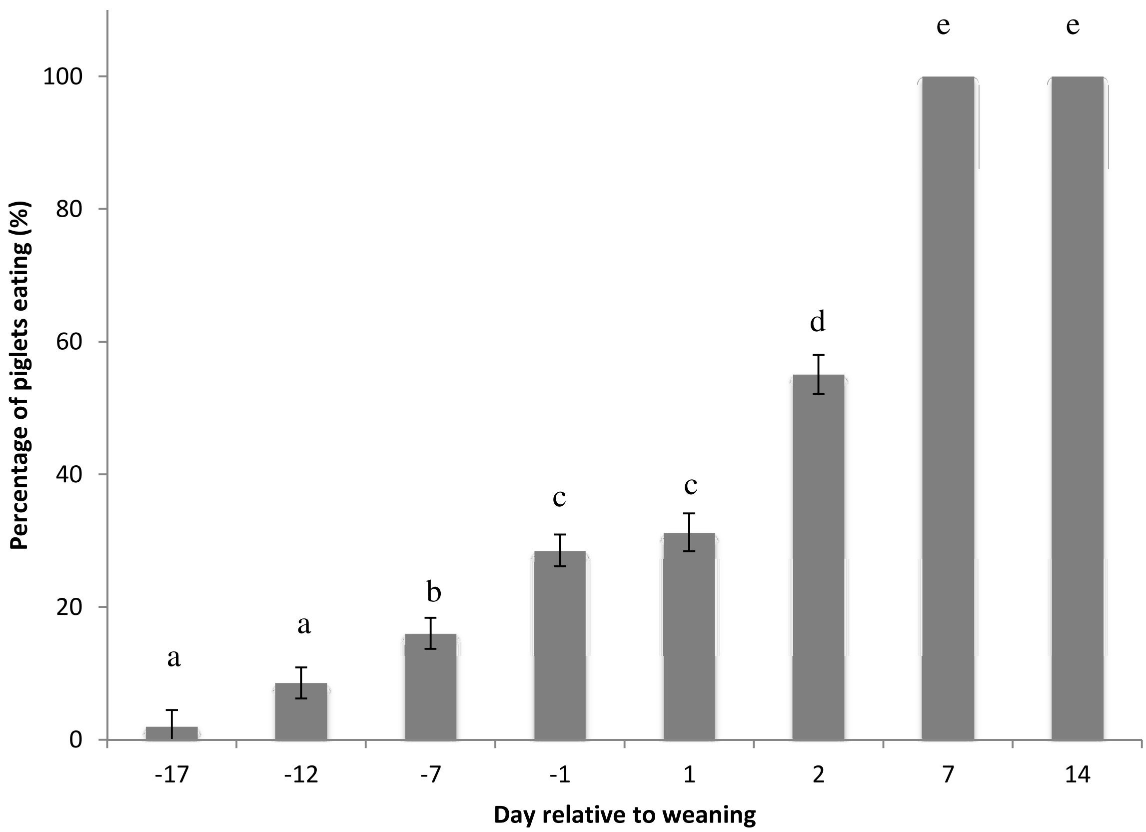

Figure 3. The percentage of piglets consuming creep feed on days -17, -12, -7 and -1, and solid feed on days 1, 2, 7 and 14 with day 0 representing the day of weaning. [a-e] Means not sharing a common superscript differ significantly (P < 0.001)

3.3 Behaviour of piglets on days following weaning

3.3.1 Effect of day on behaviour

The number of times a particular behaviour was observed within a pen differed across days (Table 7). Piglets lay three times more often on day one when compared with day two relative to weaning ($P < 0.01$). Piglets also had 31 more feeding events per pen on day one than on day two ($P < 0.05$). Some play behaviours differed between days and were performed more often on day one than day two (Table 7). Both pivot and scampering was performed twice as much on day one than on day two, and head tossing occurred over twice as much on day one. There was no difference in any of negative behaviours scored over days.

Table 7. Number (mean ± SEM) of times a particular behaviour was performed within a pen on days one and two post-weaning

Behaviour (number of times an event occurred)	**Day 1**	**Day 2**	**P-value[1]**
Laying	21.5 ± 3.9	6.9 ± 3.9	**
Feeding	146.0 ± 14.8	115.0 ± 14.8	*
Active	11.9 ± 2.3	12.6 ± 2.3	ns
Belly nosing	1.9 ± 0.9	1.3 ± 0.9	ns
Nosing/chewing pen-mates	28.6 ± 5.2	28.4 ± 5.2	ns
Aggression	254.8 ± 30.1	195.5 ± 30.1	ns
Aggression at feeder	2.8 ± 1.3	1.6 ± 1.3	ns
Playful gestures	10.8 ± 1.7	8.0 ± 1.7	ns
Scamper	42.5 ± 8.5	21.7 ± 8.5	**
Mounting	39.4 ± 14.5	50.7 ± 14.5	ns
Hop	40.4 ± 6.7	28.2 ± 6.7	ns
Pivot	40.0 ± 5.2	19.6 ± 5.2	**
Toss head	22.4 ± 3.1	10.5 ± 3.1	***

[1] ns = not statistically significant, * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$

In addition to the number of times a behaviour was performed, the average length of time a behaviour was performed differed across days. The mean duration of an aggressive event was longer on day one (5.3 ± 0.7 seconds) when compared with day two (4.0 ± 0.7 seconds; $P < 0.05$) (Table 8). The mean duration of an aggressive event at the feeder was also longer on day one (2.3 ± 0.5 seconds) than on day two (0.8 ± 0.5 seconds; $P < 0.05$). The mean duration of all other behaviours did not differ in duration across days ($P > 0.05$.)

Table 8. Average length of time (seconds) a behaviour was performed (mean ± SEM) on days one and two post-weaning

Behaviour (seconds)	**Day 1**	**Day 2**	**P-value**[1]
Laying	1796.5 ± 1442.1	4657.9 ± 1442.1	ns
Feeding	56.8 ± 38.5	67.3 ± 38.5	ns
Active	2075.9 ± 395.9	1458.0 ± 395.9	ns
Belly nosing	4.4 ± 1.2	3.2 ± 1.2	ns
Nosing/chewing pen-mates	6.8 ± 4.9	14.8 ± 4.9	ns
Aggression	5.4 ± 0.7	4.0 ± 0.7	*
Aggression at feeder	2.3 ± 0.5	0.8 ± 0.5	*
Playful gestures	4.0 ± 0.8	4.4 ± 0.8	ns
Scamper	3.0 ± 0.4	3.2 ± 0.4	ns
Mounting	10.0 ± 2.0	7.8 ± 2.0	ns
Hop	-	-	-
Pivot	-	-	-
Toss head	-	-	-

[1] ns = not statistically significant, * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$

The total length of time piglets spent performing a given behaviour within a pen differed across days (Table 9). The total time piglets spent laying was significantly higher on day two than on day one post weaning. The total duration of piglets being active was longer on day one than on day two post-weaning ($P<0.05$). The total time piglets spent performing aggressive behaviours was higher on day one than on day two. Piglets also spent a higher amount of time scampering on day one.

Table 9. Total duration (minutes) of a given behaviour (mean ± SEM) observed within a pen on days one or two post weaning[1]

Behaviour (minutes)	Day 1	Day 2	P-value
Laying	290.2 ± 20.4	324.4 ± 20.4	**
Feeding	107.0 ± 13.4	125.3 ± 13.4	ns
Active	310.6 ± 12.9	272.8 ± 12.9	*
Belly nosing	4.36 ± 1.27	3.15 ± 1.27	ns
Nosing/chewing pen-mates	3.58 ± 1.0	5.4 ± 1.0	ns
Aggression	21.0 ± 2.7	13.7 ± 2.7	*
Aggression at feeder	0.2 ± 0.1	0.0 ± 0.1	ns
Playful gestures	0.7 ± 0.2	0.7 ± 0.2	ns
Scamper	2.0 ± 0.4	1.2 ± 0.4	*
Mounting	9.0 ± 3.9	11.2 ± 3.9	ns
Hop	-	-	-
Pivot	-	-	-
Toss head	-	-	-

[1] ns = not statistically significant, * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$

3.3.2 Day by treatment interactions for piglet behaviour following weaning

A number of agonistic behaviours differed between treatments across days. Whilst the frequency of belly nosing was unaffected, the mean duration of a belly nosing event was longer on day one post-weaning in the CON compared to SP piglets (6.3 ± 2.0 versus 2.4 ± 1.3 sec; $P < 0.05$), but this treatment effect had disappeared by day two (Figure 4).

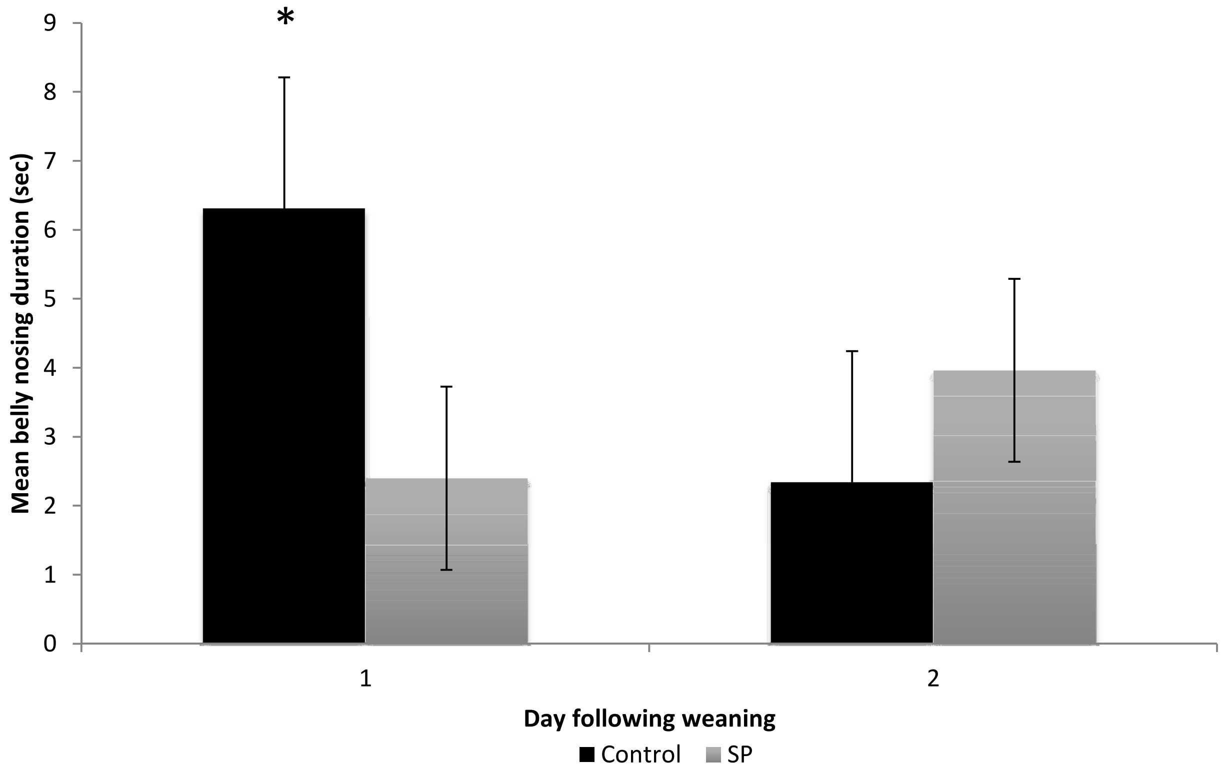

Figure 4. Mean length of time belly nosing event was performed (mean ± SEM) on days one and two post weaning for both control (CON) and separation pen (SP) treatments. * represents significant effect of treatment within day ($P < 0.05$).

Similarly, the frequency of aggressive events was unaffected by treatment across days, however, the mean duration of an aggressive event was longer on day one in the CON compared to SP piglets (6.5 ± 1.1 versus 4.2 ± 0.8 seconds; $P < 0.05$), but this treatment effect had disappeared by day two (Figure 5). There were no further treatment effects across days for any of the other behaviours examined.

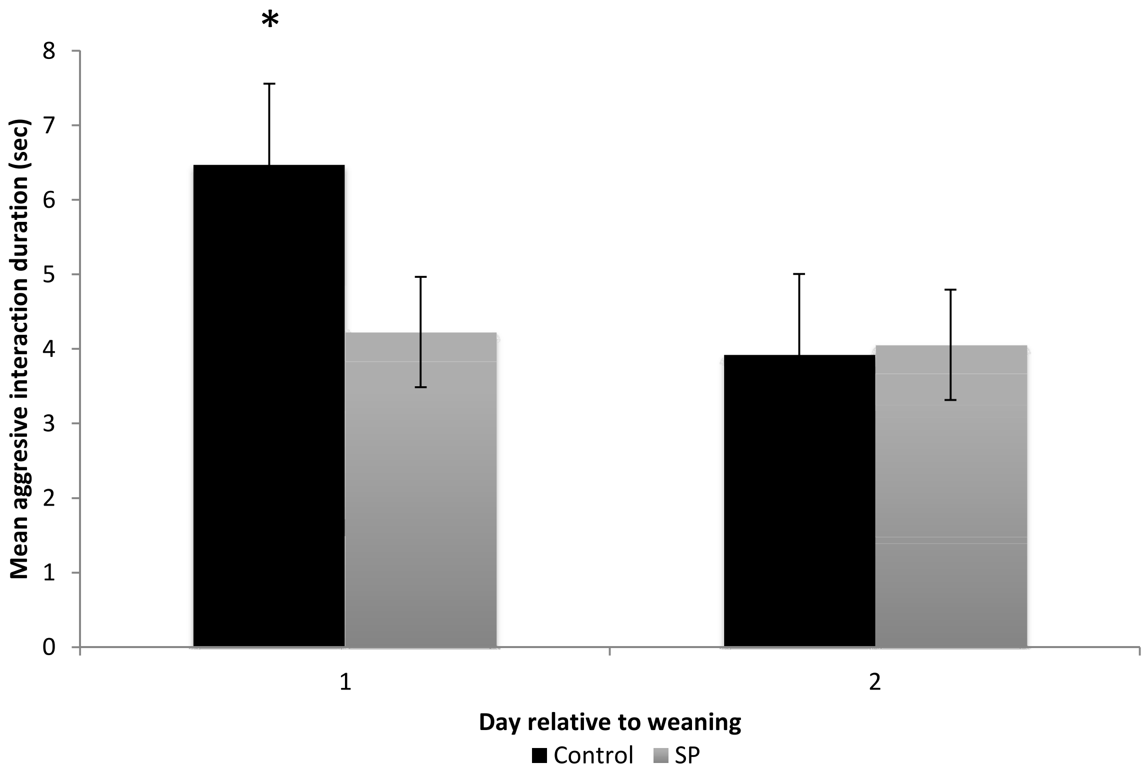

Figure 5. The mean length of time an aggressive event was performed (mean ± SEM) on days one and two post weaning for both control (CON) and separation pen (SP) treatments. * represents significant effect of treatment within day ($P < 0.05$).

3.4 Injury Score

The scores used to subjectively quantify the level of aggression in piglets differed between treatments across days. Scratch score was significantly lower in SP piglets (Figure 6; P < 0.001) on all days, with the exception of day 14 (day -1 0.32 ± 0.06, day one 0.78 ± 0.06, day two 0.95 ± 0.06, day seven 0.48 ± 0.06) when compared with CON (day -1 0.52 ± 0.06, day one 0.99 ± 0.06, day two 1.30 ± 0.07, day seven 0.87 ± 0.07). By day 14, there was no longer a treatment effect for scratch score.

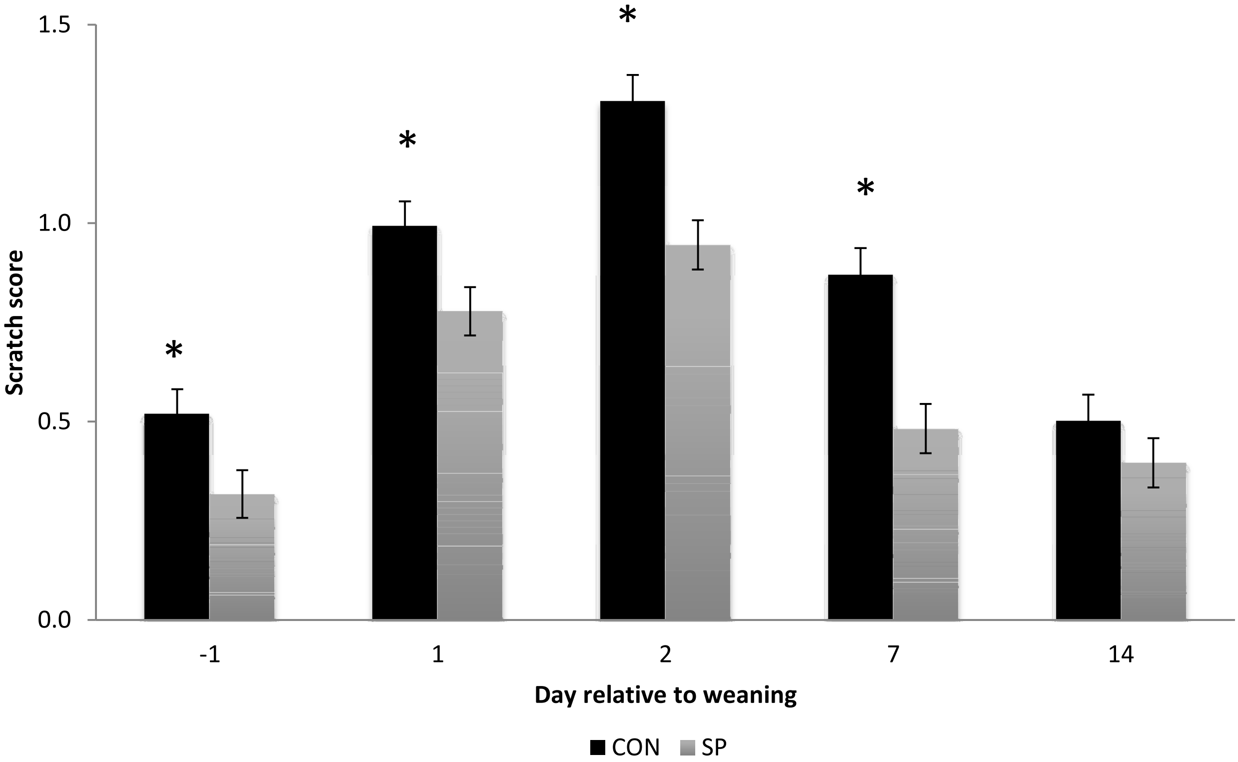

Figure 6. Scratch score (mean ± SEM) for control (CON) and separation pen (SP) treatments on days -1, 1, 2, 7 and 14 relative to weaning. * represents significant effect of treatment within day (P < 0.05).

Similarly, redness score was influenced by treatment across observation days (Figure 7). Redness score was significantly lower in SP piglets (Figure 7; P < 0.001) on all days with the exception of day -1 (day -1 0.14 ± 0.06, day 11.22 ± 0.06, day two 1.53 ± 0.07, day seven 1.11 ± 0.07 and day 14 0.55 ± 0.06) when compared with CON piglets (day -10.22 ± 0.0.62, day one 1.07 ± 0.06, day two 1.08 ± 0.06, day seven 0.82 ± 0.64 and day 14 0.85 ± 0.07).

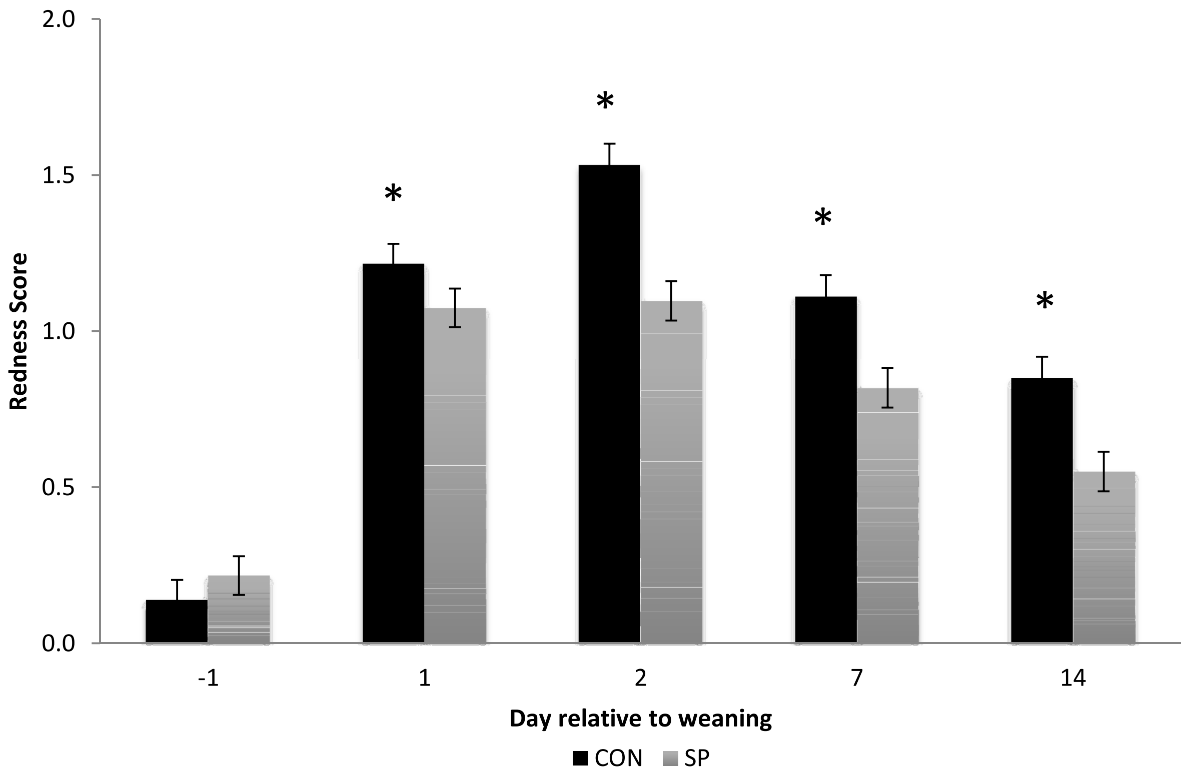

Figure 7. Redness score (mean ± SEM) for control (CON) and separation pen (SP) treatments on days -1, 1, 2, 7 and 14 relative to weaning. * represents significant effect (P < 0.05) of treatment within day.

3.5 Cortisol

The order of blood sample collection had no effect on circulating plasma cortisol concentration. However, cortisol concentrations were lower on day -1 for CON compared to SP piglets (44.7 ± 5.0 versus 66.8 ± 5.1 nmol/L; P < 0.05). This treatment effect had disappeared by day one (Figure 8).

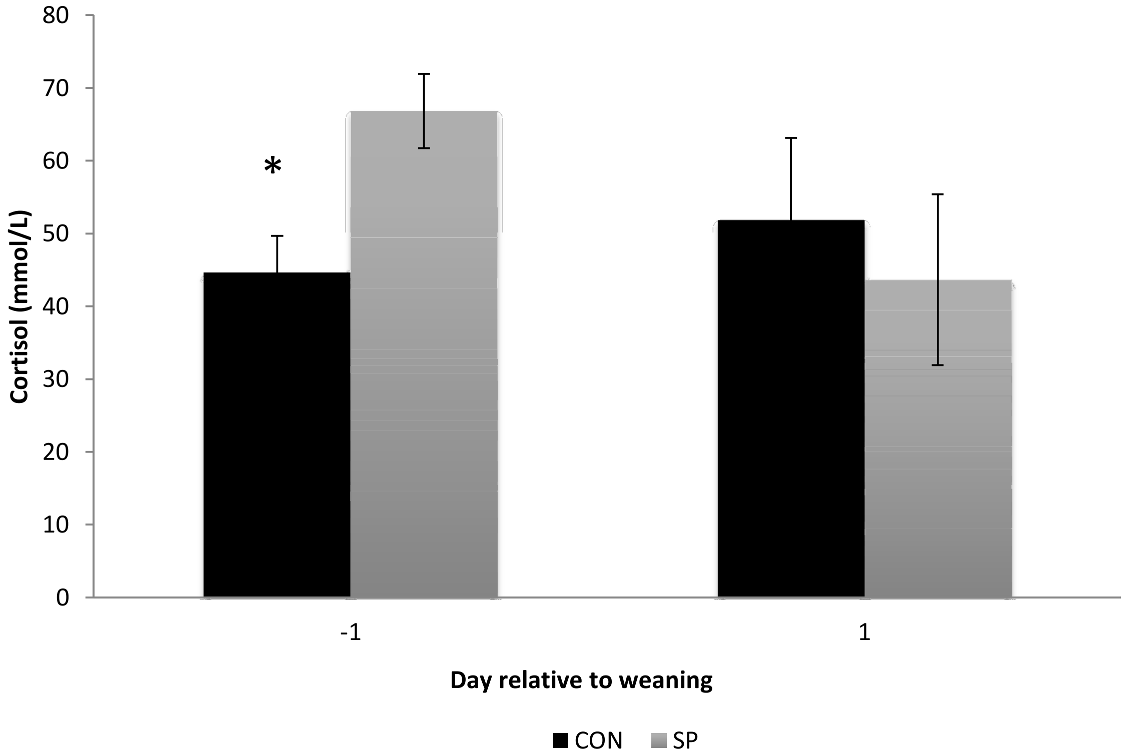

Figure 8. Cortisol (nmol/L; mean ± SEM) for control (CON) and separation pen (SP) treatments on days -1, and one relative to weaning. * represents significant effect (P < 0.05) of treatment within day.

Change in plasma cortisol concentration from day -1 to day one relative to weaning also differed across treatment (Figure 9; P<0.05). Cortisol increased in CON piglets post-weaning (18.7 ± 13.3 nmol/L), whilst the weaning event induced a decrease in cortisol in the SP piglets (-12.3 ± 14.1 nmol/L).

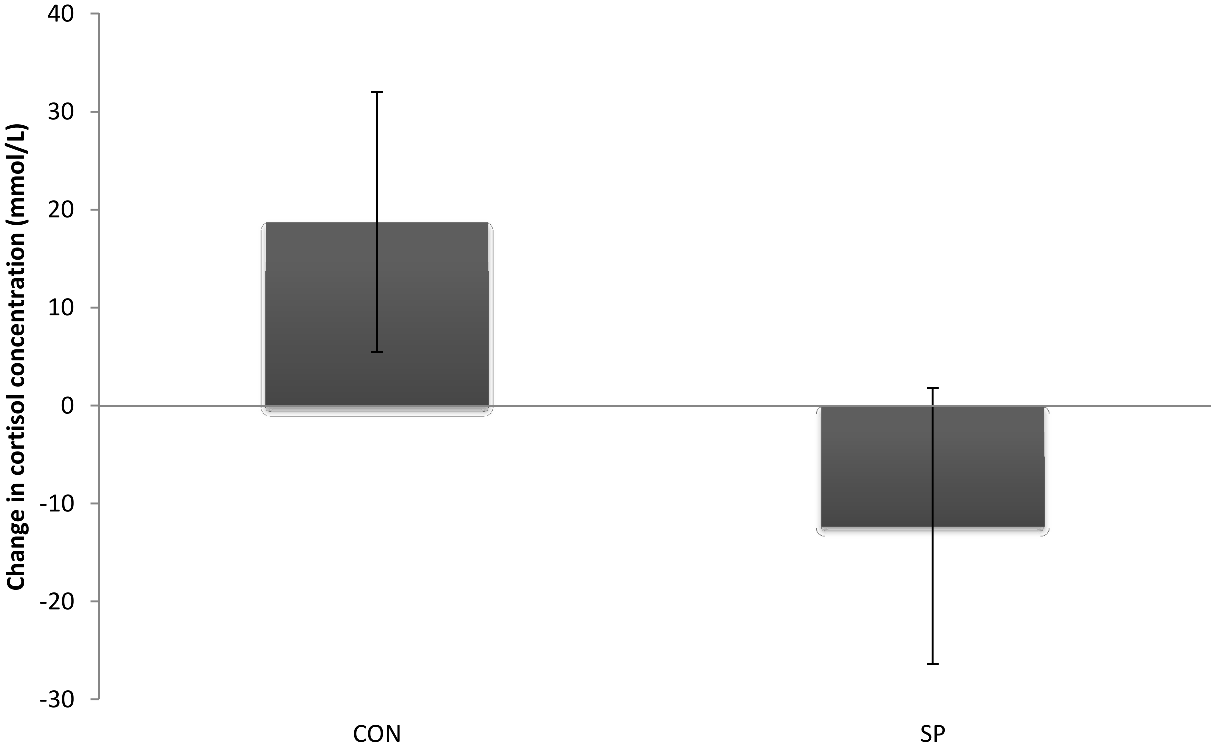

Figure 9. Change in plasma cortisol concentration (mean ± SEM; nmol/L) over weaning (day -1 to day 1) for both the control (CON) and separation (SP) treatments, P < 0.05.

4. Discussion

This investigation has identified that piglets experiencing a gradual increase in sow separation show a reduction in the post-weaning growth check and increased creep feed ingestion which supports previous findings. It was also shown that gradually weaned piglets exhibit fewer negative behaviours and a decreased cortisol response to weaning when compared to those piglets that are abruptly weaned. These novel findings suggest that in addition to previously reported increases in creep consumption, a reduction in the level of stress may help to explain differences in the performance of gradually weaned piglets.

4.1 Piglet liveweight and growth performance pre- and post- weaning

Consistent with previous studies (Pajor *et al.* 1999; Weary *et al.* 2002), the current data demonstrated that sow-piglet separation pre-weaning reduced piglet weight at weaning. SP piglets weighed less before weaning and this is most likely due to reduced suckling opportunities caused by sow separation. This has been shown to be the case previously, where decreased milk intake can cause reduction in weight gain in gradually weaned piglets (Kuller *et al.* 2004). Although creep feed was provided, Kuller *et al.* (2004) also suggested that if piglets separated from the sow still hear suckling vocalisation (such as the CON sows), it may cause distress to the separated piglets leading to lower consumption of creep feed. Thus, the reduced suckling opportunities combined with distractions inhibited creep consumption and may explain the slower growth in the gradually weaned piglets during lactation.

CON piglets experienced a 'growth check' whilst SP piglets continued to grow post weaning. This could be due to the increased pre-weaning creep consumption that gradually weaned often experience during lactation. As Kuller *et al.* (2004) explained, gradually weaned piglets experience hunger after several hours of separation and will turn to alternative sources for energy, in this case, creep feed. There was a tendency for more SP piglets to consume creep feed pre-weaning leading to digestion of the creep feed more readily. As gastrointestinal function can be disrupted during an abrupt wean, CON piglets may have not been able to digest the creep feed as readily as the SP piglets and thus experienced a growth check after weaning (Berkeveld *et al.* 2009). As CON piglets did not experience a gradual wean, they may have not adjusted to the cereal based diet and thus experienced a growth check after weaning. The continued growth of the SP piglets after weaning meant that there were no treatment effects evident by the end of the study. So whilst gradual weaning hinders piglet growth before weaning, an improvement in growth post-weaning means that there are no adverse outcomes of gradual weaning for long term piglet performance.

It was anticipated that teat order may interact with the gradual weaning treatment with regards to piglet creep consumption and thus, weight. Although there were no effects of the separation treatment on piglet weight relative to teat position, middle and posterior sucking piglets were identified to be at a significant disadvantage to anterior sucking piglets when it comes to growth post-weaning. Previous studies have reported that piglets on anterior teats grow faster post-weaning (Kim *et al.* 2000; Mason *et al.* 2003), although the effect of teat order was not as severe as in the present investigation. There are significant implications in this growth difference post-weaning, as posterior located piglets failed to gain enough weight to be on par with the other teat orders by day 14 post-weaning. The difference between the teat orders may continue through to slaughter, resulting in an older slaughter age. Research into increasing the milk production from posterior teats may be a possible way to improve performance and limit the teat order effects.

4.2 Creep feed

As expected, more piglets consumed creep feed as lactation progressed. Multiple studies have shown that gradually weaned piglets consume more solid feed early post-weaning (Berkeveld *et al.* 2007; Pluske *et al.* 2007; Kuller *et al.* 2010; Yan *et al.* 2011). Contrary to these studies, there was no day by treatment effect observed in this study, thus gradually weaned piglets failed to consume a greater amount creep feed before weaning. Kuller *et al.* (2004) showed that gradually weaned piglets can be more restless as they may hear sows which are not separated from their piglets giving nursing vocalisations. This may lead to piglets visiting the creep feeder less during this time of restlessness. This may be one reason why the SP piglets in this study did not eat more creep feed than the CON piglets as was expected. Whilst there was no treatment effect on specific days, creep consumption overall tended to be higher in the SP piglets than CON. This is most likely due to an increased statistical power when creep consumption measures were combined across all measurement days. This suggests that an insufficient number of piglets were measured in order to detect treatment effects on creep consumption.

There is limited knowledge on how teat order may effect creep consumption in gradually weaned piglets. This study identified no effect of treatment on creep feed over days, and thus, creep consumption by teat order was also unaffected. Pluske *et al.* (2007) found that the effectiveness of gradual weaning may be limited by teat order, as piglets suckling from anterior teats may meet all their nutritional needs via milk where posterior located piglets consume more creep feed due to the lower milk yield. Pluske *et al.* (2007) suggested that posterior located piglets may benefit the most from gradual weaning and provision of creep feed. The fact that current findings disagree with this previous suggestion is intriguing, and further investigation of the effects of piglet teat order within gradual weaning treatments is warranted.

4.3 Behaviour and injury scores

The increased incidence of certain behaviours, or the performance of a behaviour when unexpected, can often be an indicator of the animal's inability to cope with the situation. Although many behaviours analysed in this study were unaffected by treatment, two important behaviours often cited as occurring more frequently under times of stress in piglets, belly nosing and aggression, showed a significant difference between treatments. Belly nosing and aggressive interactions were both significantly longer in the CON group when compared to SP group. Belly nosing has long been described as a key indicator for piglets experiencing maladaptation to weaning (Cox and Cooper 2001; Straw and Bartlett 2001; Jarvis *et al.* 2008; Widowski *et al.* 2008). The repetitive nosing of another piglet's abdomen may suggest that piglets are still attempting nursing behaviours and not attempting to consume solid feeds early post weaning (Widowski *et al.* 2008). The CON piglets in the study wherein spent a longer length of time performing belly nosing, suggesting they did not adapt well to weaning compared to those gradually weaned. The receiver of a belly nosing event may also experience increased stress by being the target of the event. Aggression is another typical behavioural indicator of weaning stress (Worbec *et al.* 1999). The length of time CON piglets performed each aggressive event was longer that SP piglets. The longer duration of a single aggressive interaction in the CON piglets may indicate that the CON piglets were failing to cope with the mixing of unfamiliar pen-mates after weaning. Piglets often exhibit skin damage as a result of being the recipient of piglet directed behaviours. Olesen *et al.* (1996) showed there was a positive correlation between duration of fighting and injury scores, where piglets exhibit skin damage as a result of being the recipient of piglet directed behaviours (Widowski *et al.* 2003). McGlone and Curtis (1985) found that bites and other damaging behaviours occur more frequently later in a fight and may be indicative of the greater injury scores in CON piglets of this study.

Scratch and redness scores were higher on almost every day after weaning. Injury scores are a useful subjective estimator of aggression as damage often results from piglet directed behaviours (Widowski *et al.* 2003). The increased length of aggression, therefore, helps to explain why there was a higher scratch and redness score in CON than SP piglets. These results may provide evidence that these subjective scores are adequate to detect changes in aggression levels and may be used when video recording cannot occur.

Interestingly, the scratch score was higher the day before weaning in the CON piglets. It can be suggested that piglets may have had an increased injury amount before weaning due to the limited space within the farrowing crate, were SP piglets had a greater area of space whilst the sow was in the separation pen. It has been shown that sows, when given greater space allowance, will be able to avoid aggressive interactions more readily (Salak-Johnson *et al.* 2012). This may be the same in piglets. Injury score may also have been reduced in the SP treatment as gradually weaned piglets have decreased suckling events during lactation and therefore, do no compete to get to a teat as often (Kuller *et al.* 2010). This may result in reduced injury due to nursing aggression compared to CON piglets that have more frequent nursing events.

The occurrence of some positive play behaviours changed over days, with scampering being performed longer and more often on day one. Play behaviours are thought to occur in the absence of stress and when all need of the animal are met (Newberry *et al.* 1988), thus the decrease in these behaviours may be due to the incidence of aggression and post-weaning anorexia. There are minimal studies on how play behaviours are affected in gradual weaned piglets making it hard to determine the cause of this decrease over the two days. It is a possibility that play behaviours could be misleading, with a startled run being classed as scampering. Considerations for this should be taken when analysing behaviours and more studies should be conducted to define if each behaviour is truly associated with stress or not.

4.4 Cortisol

Previous investigations have failed to measure plasma cortisol in piglets and cite that this as being due to the high risk of diurnal variation and effect of sampling itself on cortisol secretion. Early work by Worsaae and Schmidt (1980) analysed cortisol levels in early weaned piglets, but failed to examine or report the effects of sampling order. The present results have highlighted that there was no effect of sampling order in which piglets were bled on cortisol concentrations due to careful time management, and more than one team bleeding piglets at a given time, and thus we could establish accurate results could be established as a response to weaning.

Cortisol levels were significantly higher in SP piglets prior to weaning. Weary et al. (2008) discussed how different biological indicators underlie maternal attachment. Cortisol may be one indicator which can demonstrate an acute response to maternal separation. It may be that the SP piglets in this study experienced an acute response to maternal separation as bleeding occurred during the separation period when the sow was located in the rear pen. Diurnal rhythm may also have been shifted by the separation regime leading to the increased cortisol, however, as piglets were only bled once before weaning it is impossible to detect if this is so. A reduction in cortisol in the SP piglets over weaning does, however, suggest piglets showed a reduced stress response to the weaning event. The CON piglets exhibited increased stress response to weaning, which was evidenced by the significant increase in cortisol concentration from pre- to post- weaning. Future research should be conducted to detect whether the alternative lactation housing had an effect on the gradually weaned piglets cortisol response during lactation to help explain the high levels witnessed in this study.

Elevated plasma cortisol concentration in the CON piglets may be due to separation anxiety. Minimal studies have been done in piglets to explain this cortisol effect in gradual weaning experiments, however, it has been demonstrated in calves. Flower and Weary (2001) showed that social group disruption can have a profound influence on cortisol and may be an indicator of separation anxiety. When the age of the animal increases, this influence becomes more pronounced, suggesting that as CON piglets experienced sow separation at an older age than the SP piglets, a more pronounced response to this separation occurred. Research into the effects of gradual weaning on cortisol response is limited and more investigation is needed to clarify the results of this study.

5. Conclusion

In conclusion, performance results from this investigation support others in that weight gain after weaning is improved by sow separation in lactation inducing a gradual wean. Importantly, SP piglets displayed a reduction in cortisol concentrations as a response to the weaning event and showed less maladaptive behaviours, suggesting there was a reduction in weaning stress. This unique finding of a reduced stress response in gradually weaned piglets may help to explain the difference in post-weaning performance. The importance of clarifying that cortisol sampling was unaffected by the order of which samples were collected will encourage future studies to incorporate piglet cortisol measurement when investigating welfare. Overall, this study was able to provide interesting results on the impacts of weaning stress and how alternative lactation housing may be beneficial in alleviating some of these stressors.

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7. References

Ahmadi, BV, Stott, AW, Baxter, EM, Lawrence, AB, Edwards, SA (2011) Animal welfare and economic optimisation of farrowing systems. *Animal Welfare* **20**, 57-67.

Barnett, JL, Hemsworth, PH, Cronin, GM, Jongman, EC, Hutson, GD (2001) A review of the welfare issues for sows and piglets in relation to housing. *Australian Journal of Agricultural Research* **52**, 1-28.

Baxter, EM, Lawrence, AB, Edwards, SA (2012) Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. *Animal* **6**, 96-117.

Berkeveld, M, Langendijk, P, Soede, NM, Kemp, B, Taverne, MAM, Verheijden, JHM, Kuijken, N, Koets, AP (2009) Improving adaptation to weaning: Effect of intermittent suckling regimens on piglet feed intake, growth, and gut characteristics. *Journal of Animal Science* **87**, 3156-3166.

Berkeveld, M, Langendijk, P, van Beers-Schreurs, HMG, Koets, AP, Taverne, MAM, Verheijden, JHM (2007) Postweaning growth check in pigs is markedly reduced by intermittent suckling and extended lactation. *Journal of animal science* **85**, 258-266.

Blackshaw, JK, Bodero, DAV, Blackshaw, AW (1987) The effect of group composition on behavior and performance of weaned pigs. *Applied Animal Behaviour Science* **19**, 73-80.

Bruininx, E, Schellingerhout, AB, Binnendijk, GP, van der Peet-Schwering, CMC, Schrama, JW, den Hartog, LA, Everts, H, Beynen, AC (2004) Individually assessed creep food consumption by suckled piglets: influence on post-weaning food intake characteristics and indicators of gut structure and hind-gut fermentation. *Animal Science* **78**, 67-75.

Cox, LN, Cooper, JJ (2001) Observations on the pre- and post weaning behaviour of piglets reared in commercial indoor and outdoor environments. *Animal Science* **72**, 75-86.

Dybkjær, L (1992) The identification of behavioural indicators of 'stress' in early weaned piglets. *Applied Animal Behaviour Science* **35**, 135-147.

Dybkjaer, L, Paisley, LG, Vraa-Andersen, L, Christensen, G (1998) Associations between behavioural indicators of 'stress' in weaner pigs and respiratory lesions at slaughter. *Pareventive Veterinary Medicine* **34**, 175-190.

Flower, FC, Weary, DM (2001) Effects of early separation on the dairy cow and calf: 2. Separation at one day and two weeks after birth. *Applied Animal Behaviour Science* 70, 275-284.

Gilmour AR, Gogel BJ, Cullis BR, Thompson R (2009)'ASREML Users Guide Release 3'. (VSN International: Hemel Hempstead, UK)

Jarvis, S, Moinard, C, Robson, SK, Sumner, BEH, Douglas, AJ, Seckl, JR, Russell, JA, Lawrence, AB (2008) Effects of weaning age on the behavioural and neuroendocrine development of piglets. *Applied Animal Behaviour Science* **110**, 166-181.

Kim, SW, Hurley, WL, Han, IK, Easter, RA (2000) Growth of nursing pigs related to the charcteristics of nursed mammary glands. *Journal of Animal Science* **78**, 1313-1318.

Kuller, WI, Soede, NM, Bolhuis, JE, van Beers-Schreurs, HMG, Kemp, B, Verheijden, JHM, Taverne, MAM (2010) Intermittent suckling affects feeder visiting behaviour in litters with low feed intake. *Livestock science* **127**, 137-143.

Kuller, WI, Soede, NM, van Beers-Schreurs, HMG, Langendijk, P, Taverne, MAM, Verheijden, JHM, Kemp, B (2004) Intermittent suckling: Effects on piglet and sow performance before and after weaning. *Journal of Animal Science* **82**, 405-413.

Lawrence, A (1987) Consumer demand theory and the assessment of animal welfare. *Animal Behaviour* **35**, 293-295.

Marchant, JN, Mendl, MT, Broom, DM, Meredith MJ, Corning S, Simmins PH (2000)

Timing and causes of piglet mortality in alternative and conventional farrowing systems. *Veterinary Record* **147**, 209-214

Mason, SP, Jarvis, S, Lawrence, AB (2003) Individual differences in responses of piglets to weaning at different ages. *Applied Animal Behaviour Science* **80**, 117-132.

McGlone, JJ, Curtis, SE (1985) Behavior and performance of weanling pigs in pens equipped with hide areas. *Journal of Animal Science* **60**, 20-24.

National Health and Medical Research Council of Australia (NHMRC) (2004) Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, 7th Ed. (the Code of Practice), *Commonwealth of Australia,* Canberra

Newberry, RC, Wood-Gush, DGM, Hall, JW (1988) Playful behaviour of piglets. *Behavioural Processes* **17**, 205-216.

Olesen, LS, Nygaard, CM, Friend, TH, Bushong, D, Knabe, DA, Vestergaard, KS, Vaughan, RK (1996) Effect of partitioning pens on aggressive behavior of pigs regrouped at weaning. *Applied Animal Behaviour Science* **46**, 167-174.

Pajor, EA, Fraser, D, Kramer, DL (1991) Consumption of solid food by suckling pigs: individual variation and relation to weight gain. *Applied Animal Behaviour Science* **32**, 139-155.

Pajor, EA, Weary, DM, Fraser, D, Kramer, DL (1999) Alternative housing for sows and litters - 1. Effects of sow-controlled housing on responses to weaning. *Applied Animal Behaviour Science* **65**, 105-121.

Pluske, JR, Jae-Cheol, K, Hansen, CF, Mullan, BP, Payne, HG, Hampson, DJ, Callesen, J, Wilson, RH (2007) Piglet growth before and after weaning in relation to a qualitative estimate of solid (creep) feed intake during lactation: A pilot study*. *Archives of Animal Nutrition* **61**, 469-480.

Primary Industries Standing Committee (PISC) (2008) Model code of practice for the welfare of animals: Pigs, 3rd Ed. (the Code of Practice), *CSIRO Publishing*, Australia

Salak-Johnson, JL, DeDecker, AE, Horsman, MJ, Rodriguez-Zas, SL (2012) Space allowance for gestating sows in pens: behaviour and immunity. *Journal of Animal Science* **90**, 3232-3242.

Straw, BE, Bartlett, P (2001) Flank or belly nosing in weaned pigs. *Journal of Swine Health and Production* **9**, 19-23.

Turner, SP, Farnworth, MJ, White, IMS, Brotherstone, S, Mendl, M, Knap, P, Penny, P, Lawrence, AB (2006) The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. *Applied Animal Behaviour Science* **96**, 245-259.

Weary, DM, Appleby, MC, Fraser, D (1999) Responses of piglets to early separation from the sow. *Applied Animal Behaviour Science* **63**, 289-300.

Weary, DM, Pajor, EA, Bonenfant, M, Fraser, D, Kramer, DL (2002) Alternative housing for sows and litters.: Part 4. Effects of sow-controlled housing combined with a communal piglet area on pre- and post weaning behaviour and performance. *Applied Animal Behaviour Science* **76**, 279-290.

Weary, DM, Jasper, J, Hötzel, MJ (2008) Understanding weaning distress. *Applied Animal Behaviour Science* **110**, 24-41.

Weber, R, Keil, NM, Fehr, M, Horat, R (2009) Factors affecting piglet mortality in loose farrowing systems on commercial farms. *Livestock Science* **124**, 216-222.

Widowski TM, Cottrell T, Dewey CE, Friendship RM (2003) Observations of piglet-directed behaviour patterns and skin lesions in eleven commercial swine herds. *Journal of Swine Health Production* **11**(4), 181-185

Widowski, TM, Torrey, S, Bench, CJ, Gonyou, HW (2008) Development of ingestive behaviour and the relationship to belly nosing in early-weaned piglets. *Applied Animal Behaviour Science* **110**, 109-127.

Worobec, EK, Duncan, IJH, Widowski, TM (1999) The effects of weaning at 7, 14 and 28 days on piglet behaviour. *Applied Animal Behaviour Science* **62**, 173-182.

Worsaae, H, Schmidt, M (1980) Plasma-cortisol and behavior in early weaned piglets. *Acta Veterinaria Scandinavica* **21**, 640-657.

Yan, L, Jang, HD, Kim, IH (2011) Effects of varying creep feed duration on pre-weaning and post weaning performance and behavior of piglet and sow. *Asian-Australasian journal of animal sciences* **24**, 1601-1606.