Managing the lactating sow to stimulate lactation ovulation

Robyn Terry

Bachelor of Science (Agricultural Science) with First Class Honours

A thesis submitted in total fulfilment of the requirements for the degree of

Doctor of Philosophy

School of Animal and Veterinary Sciences

The University of Adelaide

Roseworthy, South Australia

Australia

July 2015

ABSTRACT

In lactation, sows are typically anoestrus, with ovulation occurring three to seven days after weaning at approximately 24 days post-partum. Increasing piglet age to greater than 28 days improves piglet performance and welfare; however, it also results in reduced sow farrowing frequencies, making the commercial adoption of increasing piglet weaning age unsustainable. Stimulating a sow to ovulate in lactation represents a solution as it enables lactation length to be increased whilst maintaining reproductive efficiencies.

The aims of the research reported in this thesis were to investigate mechanisms to reliably stimulate a lactation oestrus in multiparous and primiparous sows. Secondly, to determine the effect of these strategies on piglet growth, subsequent pregnancy rate, farrowing rate and litter size. The mechanisms investigated were focused on: reducing the suckling input to the sow through split weaning or low-confinement alternative lactation housing; and fence, or full physical, boar exposure.

The importance of a reduced suckling input was demonstrated in Chapter Two. The proportion of sows expressing a lactation oestrus increased as the number of piglets weaned on day 18 of lactation increased from zero, three, five to seven. Additionally, early weaning did not compromise growth of the split weaned piglets, with both early and late weaned piglets experiencing similar body weights by day 40 of age.

Chapter Three evaluated the effect of full physical boar exposure commencing at day 10, 14 or 18 postpartum on the incidence of lactation oestrus in primiparous and multiparous sows. A high proportion of multiparous sows expressed a lactation oestrus in response to boar exposure compared to first parity sows; however, the summer months impacted this expression. No benefits of commencing boar exposure before day 18 post-partum on lactation oestrus expression were observed.

Chapter Four coupled full physical boar exposure with split weaning of piglets at day 18 post-partum within a commercial piggery. Boar exposure was effective at stimulating a lactation oestrus in multiparous sows whereas primiparous sows require, in addition to boar exposure, a reduction in suckled litter size. A high incidence (24%) of lactating multiparous sows that received no stimulation spontaneously ovulated before weaning resulting in a prolonged weaning to oestrus interval. These results suggest that for the modern sow, weaning is not necessary for ovulation. Lastly, Chapter Five demonstrated that low confinement lactation housing from seven days post-partum, in combination with fence line boar exposure, was not sufficient to stimulate a lactation oestrus.

Overall, split weaning to seven piglets in conjunction with physical boar exposure resulted in the highest proportion of lactation oestrus expression with this response greater in multiparous sows than primiparous sows. Season affected the proportion of lactation oestrus expression, and this requires further investigation. Furthermore, the incidence of spontaneous ovulation during lactation suggests that the inhibition of LH release during lactation is less severe in modern genotypes. In conclusion, this thesis has demonstrated that boar exposure effectively stimulates lactation oestrus with a further increase observed when a distinct reduction in the suckling stimulus has occurred, particularly in the multiparous sow.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Robyn Terry

ACKNOWLEDGEMENTS

I decided to undertake my PhD within the pig industry as I saw it as my way into a career in agriculture. Over the course of my PhD I have learnt so much which has transpired into my current position as the Research and Innovation Manager of Production Innovation with Australian Pork Limited. However, I could not have gotten to that point without the continual guidance and support of the Pork Cooperative Research Centre for High Integrity Australian Pork, namely Dr Roger Campbell, and my supervisors Dr Karen Kind and Dr William van Wettere.

Of course you can't complete a PhD without a little help from your friends and family. To Alice Weaver and Michael Wilkes I am truly in your debt for your unwavering support and friendship and for keeping me laughing in the good times and the bad. To my family, thank you for your encouragement and help along the way, especially with the labelling of what seemed like endless amounts of Eppendorf tubes. A special mention to my sister and brother-in-law, Lisa and Daniel, who allowed me to share their house and family whilst on a student budget. A debt that I will never be able to re-pay to you both – unless you're both homeless. To my partner, Ern, you are the best support I could ever hope for. Thank you for pushing me to do things I didn't think I could and, for always believing in me, especially when I didn't.

A PhD was a learning curve from my honours degree, which was a learning curve from my undergraduate degree. So it goes without saying that working at Australian Pork Limited has been another learning curve. So lastly, thank you to Dr Darryl D'Souza, the R&I team and APL for allowing me time to write up my thesis whilst working.

LIST OF PUBLICATIONS ARISING FROM THE THESIS

Refereed scientific journal publications

Terry R, Kind KL, Hughes PE, Kennaway DJ, Herde PJ, van Wettere WHEJ (2013) Split weaning increases the incidence of lactation oestrus in boar-exposed sows. *Animal Reproduction Science* **142**, 48-55.

Terry R, Kind KL, Weaver AC, Hughes PE, van Wettere HEJ (2015) Optimal timing of boar exposure relative to parturition for stimulation of lactation oestrus. *Livestock Science* **177**, 181-188.

Terry R, Kind KL, Lines DS, Kennett TE, Hughes PE, van Wettere WHEJ (2014) Lactation estrus induction in multi- and primiparous sows in an Australian commercial pork production system. *Journal of Animal Science* **92**, 2265-2274.

Refereed conference publications

Terry R, Kind KL, Hughes PE, van Wettere WHEJ (2011) The effect of split weaning on piglet growth. In "Manipulating Pig Production XIII", p. 209, ed. R.J. van Barneveld, (Australian Pig Science Association: Werribee).

Terry R, Kind KL, Hughes PE, van Wettere WHEJ (2011) The effect of split weaning and boar contact on the incidence of sow lactational oestrus. In 'Manipulating Pig Production XIII', p. 210, ed. R.J. van Barneveld, (Australian Pig Science Association: Werribee).

Terry R, Kind K, Weaver A, van Wettere W (2012) Boar contact is an effective stimulant of lactation oestrus. *Reproduction in Domestic Animals Supplement.* **47**, 556-556.

Terry R, Kind KL, Lines DS, Kennett TE, Hughes PE, van Wettere WHEJ (2013) Boar exposure and split weaning used in a commercial herd to induce oestrus in lactation. In 'Manipulating Pig

Production XIV', p. 210, eds. J.R. Pluske and J.M. Pluske, (Australian Pig Science Association: Werribee).

Terry R, Kind KL, Lines DS, Kennett TE, Hughes PE, van Wettere WHEJ. Boar contact, parity and suckled litter size affect lactation oestrus: a commercial study. In *'9th International Conference on Pig Reproduction'*, 2013, Olsztyn, Poland, p. 134.

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CHAPTER ONE

Literature Review

1.1 Introduction

Within pig production, the number of pigs produced per sow per year is the key performance indicator which is why lactation lengths have been reduced to between 21-24 days. However, early weaning of piglets, especially light for age piglets, impedes their growth and development and has welfare implications due to the stressors of maternal separation and changes in nutritional demands (Cabrera et al., 2010). When weaned, piglets switch from a liquid milk based diet to a solid grain based diet resulting in reduced growth post-weaning, reduced feed intake, and diarrhoea thereby reducing piglet welfare (Gerritsen et al., 2008a). The earlier weaning takes place post-parturition (day 21 vs. day 35) the more stressful it is for the piglets and the more susceptible the piglets are to impaired gastrointestinal function (Mason et al., 2003; Moeser et al., 2007).

By increasing weaning age these stressors can be reduced; however, by increasing weaning age, sow production will also be decreased from 2.4 litters per sow per year. One option that could allow both weaning age to be increased and the productivity of the sow to be maintained is to stimulate oestrus during lactation. The objective of stimulating a lactation oestrus is to allow the sow to suckle her piglets for a longer period of time thereby extending the weaning age of the piglet to allow for better growth and development post-weaning. This is particularly true for lighter weight piglets. A lightweight piglet (<5 kg) at weaning will perform worse and have poorer growth post-weaning than a piglet weaned heavier (Cabrera et al., 2010). However, lactation oestrus is restricted in domestic sows as follicle growth and ovulation are prevented by the suckling induced suppression of LH (Soede et al., 2012). This review will focus on the hormonal mechanisms controlling reproduction, the environmental factors contributing to a lactation anoestrus, the effect of the boar on reproductive outcomes and strategies to stimulate the lactating sow to exhibit a fertile oestrus.

1.2 Hormonal control of reproduction during lactation

In the pig, parturition is followed by a period of anovulation which typically lasts until the piglets are weaned, and is commonly referred to as lactation anoestrus. Lactation is one of the main regulators of oestrus and ovulation during this period, primarily due to the stimuli exerted by the piglets when they stimulate and nuzzle the teat for milk letdown. The oestrous cycle of a mature sow occurs at regular 21 day intervals, but can range from 18-22 days in length (Knox and Wilson 2007). The oestrous cycle can be divided into two phases: a luteal phase of 13-15 days and a follicular phase of 5-7 days. The luteal phase begins from day two following the onset of oestrus when progesterone increases and generally lasts until day 15 of the cycle at which point progesterone declines (Knox and Wilson 2007). The follicular phase begins five to six days before oestrus and is characterised by low plasma progesterone and increasing oestrogen (Knox and Wilson 2007).

Factors from the external, as well as the internal environment, can influence the secretion of gonadotrophin releasing hormone (GnRH) and therefore luteinising hormone (LH) and follicle stimulating hormone (FSH; Figure 1). The age of the sow, her metabolic status and health status can all influence the secretion of GnRH (Prunier and Quesnel, 2000). Factors in the external environment such as light, temperature, nutrition, and social and physical environments, can also exert an effect (Prunier and Quesnel, 2000). However, perhaps the strongest external environmental effect is the inhibitory effect of suckling on GnRH secretion, and hence on ovarian cyclicity.

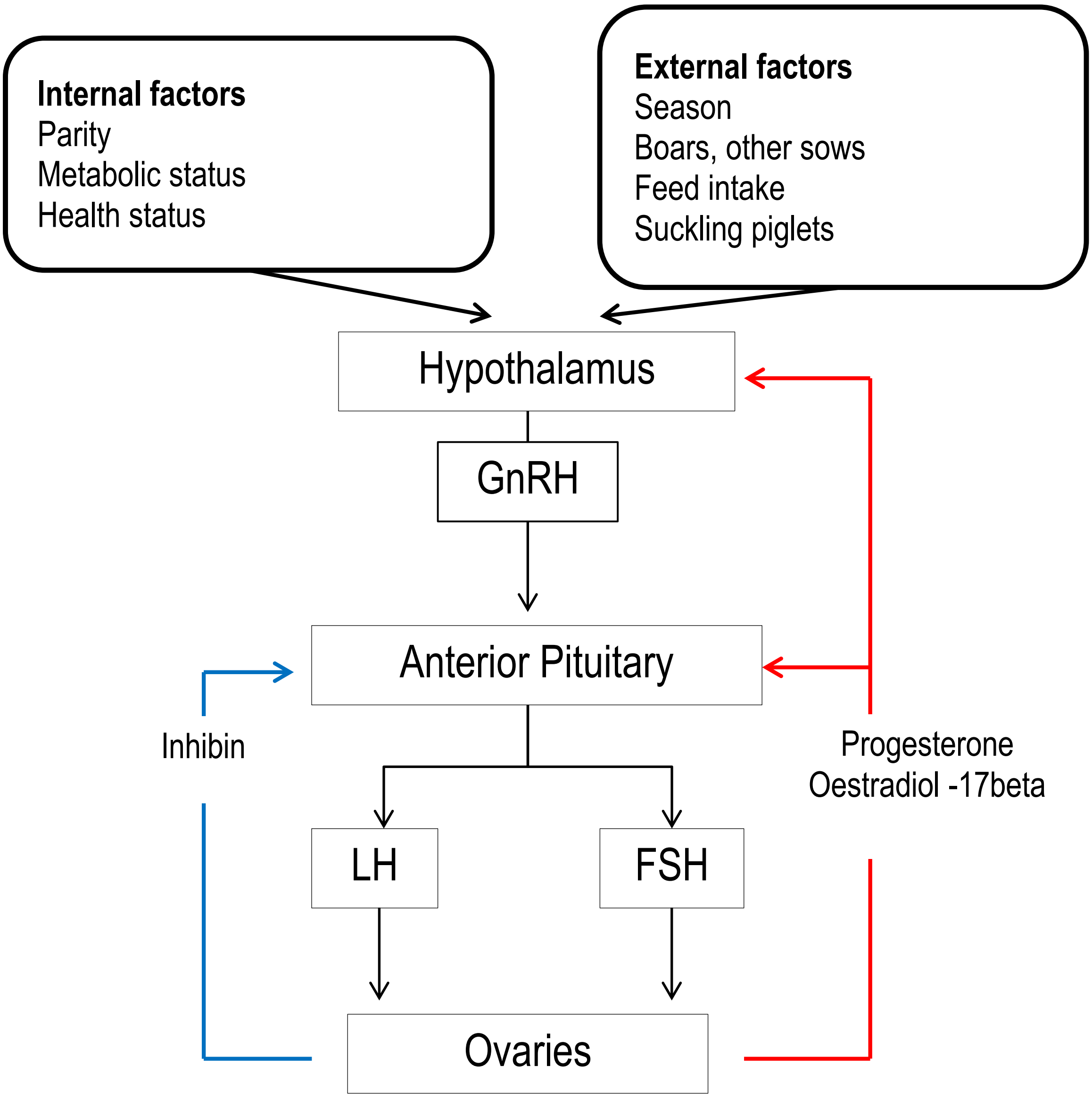

Figure 1.1 Hypothalamic pituitary ovarian axis and the influence of internal and external factors on the release of GnRH, LH and FSH (adapted from Prunier and Quesnel 2000).

1.2.1 Hypothalamic-pituitary-ovarian axis

Luteinising hormone and FSH, both gonadotrophic hormones secreted by the anterior pituitary, are controlled by the hypothalamic release of GnRH and by the positive and negative feedback effects from ovarian steroids and endogenous opioid peptides (Armstrong et al., 1988; Prunier and

Quesnel 2000; Knox and Wilson 2007). Both LH and FSH are important for follicle growth; however, FSH has a greater effect on early follicle growth up to 2-3 mm and LH has a greater effect in the final stages of follicle growth, above 4 mm (Driancourt et al., 1995). Through FSH stimulation the granulosa cells begin to synthesise LH receptors and the follicle then becomes receptive to the stimulatory effects of LH (Zeleznik, et al., 1974). Once the antral follicle has become responsive to LH, FSH secretions are inhibited due to the negative feedback mechanisms of inhibin and oestradiol from follicular origin, with the follicle then continuing on to mature to pre-ovulatory stage (Sullivan et al., 1999; Prunier and Quesnel, 2000; Knox and Wilson 2007). Oestrogens, in particular oestradiol-17beta, synthesised by the follicles are an inhibitor of LH secretion; however, when oestradiol levels are high and reach a threshold it then acts as a positive feedback mechanism on the hypothalamus causing a large surge of GnRH (Prunier and Quesnel 2000; McNeilly 2001; Knox and Wilson, 2007). Each pulse of GnRH released from the hypothalamus stimulates the anterior lobe of the pituitary to secrete preovulatory pulses of LH, which typically occurs 40 hours prior to ovulation (Prunier and Quesnel 2000; Knox and Wilson 2007). Ovulation is then triggered by the pre-ovulatory LH surge (McNeilly 2001; Prunier and Quesnel 2000; Knox and Wilson, 2007). During the luteal phase, progesterone and low levels of oestradiol then exert a negative feedback effect on the hypothalamus causing the release of GnRH to be suppressed (Prunier and Quesnel 2000; Knox and Wilson 2007). As progesterone levels drop, the hypothalamus releases small pulses of GnRH which allows for LH and FSH to be released from the anterior pituitary to allow for the next cycle of follicular development (Prunier and Quesnel 2000).

1.3 Environmental factors that affect reproduction during lactation

1.3.1 Suckling piglets

The process of milk withdrawal from the mammary glands through the neuroendocrine reflex has attracted the interest of researchers for many years (Fraser 1980). Afferent impulses through teat stimulation by the piglets (tactile, auditory and visual) reach the hypothalamus where oxytocin is released into the bloodstream through neural activation of the posterior lobe of the pituitary (Folley and Knaggs 1966; Grant 1989; Figure 2). Once in the bloodstream oxytocin reaches the mammary myoepithelial cells causing them to contract and milk to be released from the alveoli and into larger ducts before reaching the teat (Folley and Knaggs 1966; Grant 1989; Figure 2).

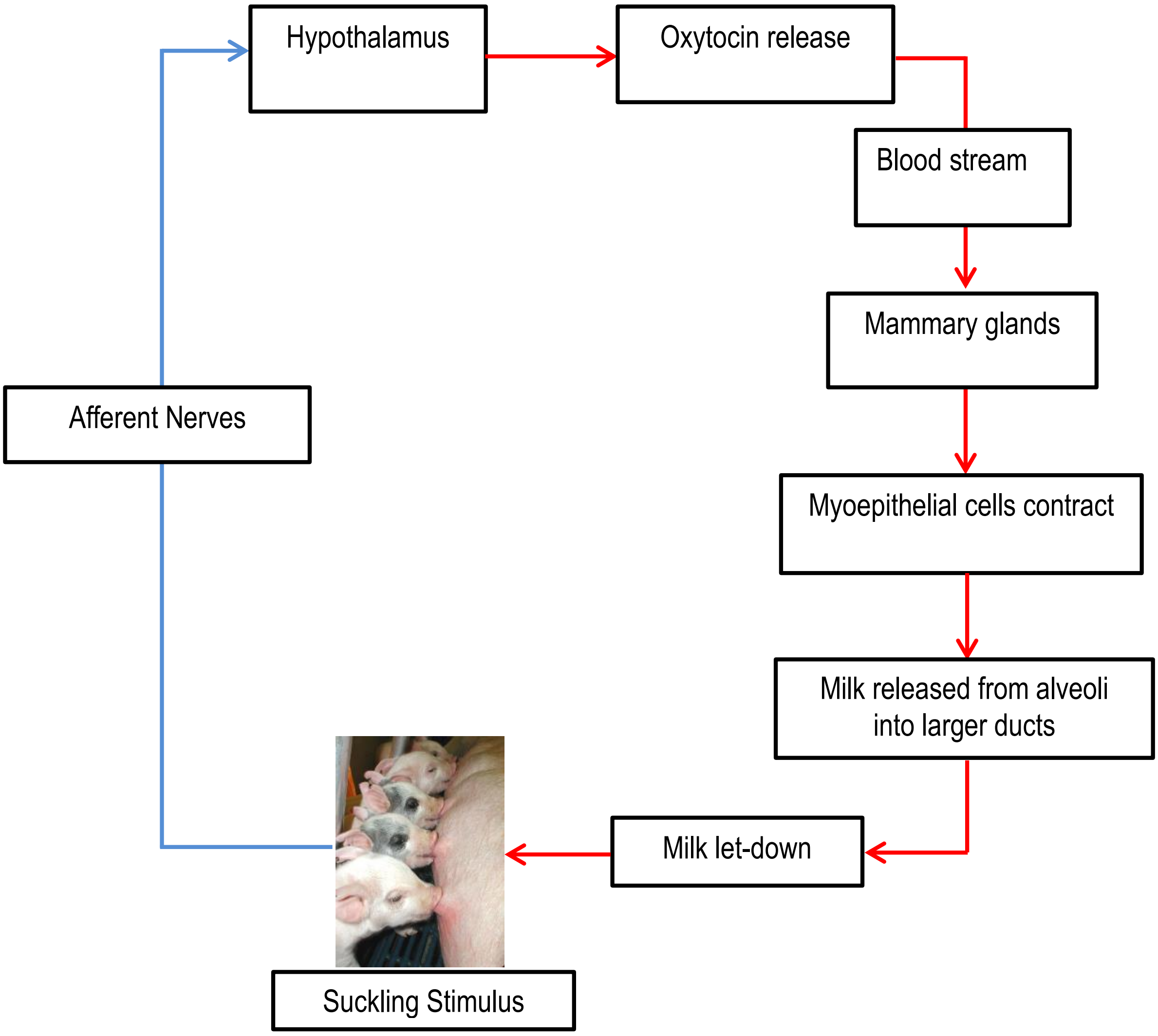

Figure 1.2 The physiology of milk ejection in the sow (adapted from Grant 1989; Senger 2005)

1.3.1.1 Suckling induced suppression of LH during lactation

The release of GnRH and thus LH and FSH release during lactation is suppressed by the suckling induced neuroendocrine reflex, which is the primary cause of lactation anoestrus (Varley and Foxcroft 1990). Suckling piglets inhibit GnRH secretion, ovarian follicular growth, and a behavioural oestrus; however, as lactation progresses the influence of the suckling stimulus diminishes and the GnRH pulse generator becomes less sensitive, possibly due to a reduction of endogenous opioid peptides acting at the hypothalamus, thereby allowing for concentrations of GnRH, LH, and

FSH to slowly rise due to the recovery of the hypothalamic-pituitary-ovarian axis (Stevenson et al., 1981; Varley and Foxcroft, 1990; Quesnel and Prunier 1995; Langendijk et al., 2007; Soede et al., 2011). The opioidergic system plays an important role in lactation anoestrus by inhibiting GnRH secretion at the hypothalamus and thereby the secretion of LH (Barb et al., 1986; Armstrong et al., 1988; Cosgrove et al., 1993). Chronic administration of naloxone from 39 hours postpartum and continuing for 3 hour intervals between 42-78 hours postpartum did not modify LH secretion (De Rensis et al., 1993a). However, treatment with a single injection of the opioid antagonist, naloxone on day 10 of lactation significantly increased LH secretion from day 10 of lactation (De Rensis et al., 1993a). These data indicate that endogenous opioid secretion is absent during the early post-partum period indicating that endogenous opiates do not modulate the initial inhibitory effects of suckling in the early post-partum period but rather exert an effect later in lactation (De Rensis et al., 1993a; De Rensis et al., 1999). By removing all piglets from the sow after parturition mean plasma LH levels are significantly increased 48 hours post-partum with immediate follicular development (De Rensis et al., 1999). Therefore, the ability of naloxone to counteract the suckling induced inhibition of LH at day 10 postpartum highlights the significance of the opioid system to prevent a lactation oestrus in the sow (De Rensis et al., 1993a).

At weaning on day 28 of lactation, an immediate change occurred in the pattern of LH release from a high amplitude and low pulsatility in late lactation to a low amplitude and high pulsatility (Foxcroft et al., 1987). However, if weaning occurs too soon in lactation (day 10 compared to day 35 of lactation) the recovery of LH post-weaning is diminished and there is an increase in the weaning to oestrus interval (Kirkwood et al., 1984). Similarly, sows weaned at day 14 of lactation have a longer weaning to LH peak interval and a longer weaning to oestrus interval, compared to sows conventionally weaned at day 24 of lactation (Willis et al., 2003; Table 1.1). Therefore, to allow for the recovery of the hypothalamic-pituitary-ovarian axis it is practical to increase lactation lengths with the likelihood that LH secretion will improve later in lactation.

Table 1.1 Post-weaning plasma LH characteristics and weaning to oestrus intervals in early weaned and conventionally weaned sows (Willis et al., 2003).

Item	Early weaned[1]	Conventionally weaned[2]
Litter size at weaning	9.5 ± 0.17	9.5 ± 0.16
Litter weight at weaning, kg	40.2 ± 1.2 [a]	66.2 ± 1.8 [b]
Weaning to LH peak interval, hours	129.7 ± 4.8 [a]	113.8 ± 5.4 [b]
Weaning to oestrus interval, hours[3]	120.3 ± 3.3 [c]	112.3 ± 2.6 [d]

[1]Early weaned sows were weaned on day 14 of lactation (n=35); [2]Conventionally weaned sows were weaned on day 22 to 25 of lactation (Mean = 23.7 ± 0.6 days; n=35); [3]Early weaned n=14, conventionally weaned n=11; [ab]Different superscripts indicate significant differences between treatments (P < 0.05). [cd]Different superscripts indicate significant differences between treatments (P < 0.05).

1.3.2 Nutrition

The influence of nutrition on the reproductive performance of sows has been comprehensively reviewed (Foxcroft 1992; Prunier and Quesnel 2000). Through genetic selection for lean and efficient finisher pigs, appetite has decreased leading to complications in balancing reproductive capacity of the sow and uniform finisher growth (Bergsma et al., 2009). The threshold at which body protein and body fat percentage losses start to have detrimental effects on reproductive capacity have been well documented (Clowes et al., 2003a,b). When the demand for milk production cannot be met from feed intake alone, the lactating sow, particularly the lactating gilt, will mobilise body reserves leading to a catabolic state and fertility problems if substantial losses occur, especially in body protein compared to body fat (Whittemore 1996; Quesnel et al., 1998b; Clowes et al., 2003a,b; Kemp et al., 2011; Patterson et al., 2011). By increasing sow lactation feed intake it is possible to prevent excessive losses in body protein and this is also suggested to lead to an increase in litter weight at weaning; however, there is a threshold of energy input where further litter growth was not seen (Bergsma et al., 2009). Sows that mobilise a greater amount of body reserves during lactation have been suggested to prioritise energy for milk production leading to higher litter growth rates, compared to sows that had a lower weight loss during lactation

(Rojkittikhun et al., 1992). Similarly, findings from Pluske et al., (1998) found that primiparous sows which were anabolic at the end of lactation, prioritised nutrients into maternal body tissue rather than milk production. Bergsma et al., (2009) has described this as the lactation efficiency of the sow in terms of energy input to the sow and output to the litter, in terms of growth. More lactation efficient sows were efficient through lower feed intake and lower fat losses with higher litter growth and lower piglet mortality. However, by being less efficient during lactation, sows fed to 90% of their predicted feed intake had greater milk production, measured by litter weight gain, whilst preserving their body tissue and therefore not subjecting the next litter to the damaging effects of sow catabolism (Patterson et al., 2011). However, there is a complexity in the degree of tissue mobilisation used to support the growth of the litter and the impacts on the subsequent litter, with a high degree of variation between sows in how they respond to nutrient restriction and catabolism.

1.3.2.1 Effects of the level of nutrition during lactation on post-weaning reproductive outcomes

Luteinising hormone is a key regulator of ovarian function and the effects of nutrition and the sow's metabolic state on LH secretion have been extensively studied in both primiparous and multiparous sows (Kirkwood et al., 1987; Baidoo et al., 1992; Tokach et al., 1992; Zak et al., 1997a,b; Zak et al., 1998; Koketsu et al., 1998; Quesnel et al., 2007). There is a vast amount of research supporting an effect of nutrition on LH secretion during lactation (Quesnel et al., 1998a; Mao et al., 1999). However, it is difficult to separate the effects of the suckling stimulus from the metabolic demands of the lactating sow on LH release. Therefore, Mullan et al., (1991; Table 1.2) compared the effects of two levels of feed intake (fed to appetite or restricted to 3 kg/day) to two levels of suckling intensity (6 or 12 piglets) on lactation weight loss over a 21 day lactation and LH pulsatility pre and post-weaning. Overall, a reduced energy intake during lactation was related to an increased weaning to oestrus interval and reduced plasma LH concentration post-weaning;

however, suckling intensity appeared to have a greater control over LH concentration pre-weaning (Mullan et al., 1991). Therefore the primary inhibitor of LH secretion in lactating sows is the suckling stimulus; however, the sow's level of nutrition during this period can exacerbate this effect. Potentially, in the circumstance of lowered voluntary lactation feed intake, by lowering the suckling intensity, the sow's post-weaning reproductive capacity could be maintained to an adequate standard. It may therefore be possible, when voluntary lactation feed intake is low, to maintain the sow's post-weaning reproductive capacity by lowering the suckling intensity.

Table 1.2 Live weight loss, weaning to oestrus interval and plasma LH concentrations pre- and post-weaning for sows either fed to appetite or reduced feed intake of 3/kg/day and suckling either 6 or 12 piglets in a 21 day lactation (Mullan et al., 1991).

Item	Feed Intake during lactation[1]				SEM
	Fed to appetite		3 kg/day		
	6 piglets	12 piglets	6 piglets	12 piglets	
Energy intake (MJ ME/day)	62.0 [a]	66.3 [a]	33.1 [b]	35.2 [b]	2.28
Live weight loss during lactation, kg	-0.1[a]	-8.1 [b]	-17.2 [c]	-34.0 [d]	3.03
Weaning to oestrus interval, d	11.2 [a]	8.7 [a]	8.5 [a]	19.2 [b]	4.28
Mean plasma LH, ng/ml					
Pre-weaning	0.30 [a]	0.21 [b]	0.38 [a]	0.20 [b]	0.047
Post-weaning	0.57 [ab]	0.49 [bc]	0.81 [a]	0.28 [c]	0.133

[abcd]Means within a row with different superscripts differ significantly (P<0.05).

In feed restricted sows the inhibition of gonadotrophic hormones is more evident in late lactation and the resumption of follicular development following weaning can be variable (Quesnel et al., 1998a). Mao et al., (1999) demonstrated that the sow's level of nutrition will act directly at the hypothalamus to inhibit LH secretion. Mao et al., (1999) compared primiparous sows fed *ad libitum* throughout lactation to sows that were restrict fed to 50% of *ad libitum* intake between days 22 – 28 (weaning) and sows that were also restrict fed and received 800 ng of GnRH at 6 hourly intervals from day 22 to 28 of lactation. Feed restriction depressed the secretion of LH, but administration of exogenous gonadotrophins to feed restricted sows in the last week of lactation was found to restore the secretion of LH pre-weaning to that of sows which were *ad libitum* fed. However, this response in LH secretion did not carry through to the post-weaning reproductive performance as both feed restricted treatments had a significantly delayed weaning to oestrus interval, indicating that exogenous gonadotrophins will not alleviate the depression in post-weaning performance seen in catabolic sows. Vinsky et al., (2006), found that the weaning to oestrus interval, ovulation rate, and pregnancy rate did not differ in primiparous sows that had their feed intake restricted to 50% of the control sows intake between day 14 - 21 (weaning). The embryo survival rate did, however, decline by more than 10% when sows were restrict fed in the last week of lactation (Vinsky et al., 2006). Similarly, results from Patterson et al., (2011) found that restrict feeding primiparous sows to 60% of their anticipated feed intake in the last week of lactation did not have a detrimental effect on the ovulation rate, embryo survival or the number of embryos at day 29 of gestation despite the sow being catabolic. A potential hypothesis for the lack of an effect on reproductive outcomes of restrict fed sows is that the modern sow may be better able to cope with unfavourable conditions during lactation due to selection against extended weaning to oestrus intervals, sow prolificacy and litter quality (Bergsma et al., 2009; Foxcroft et al., 2006; Patterson et al., 2011; Kemp and Soede 2012a).

Conversely, feeding sows to 125% of *ad libitum* intake did not ameliorate the dominant effect of suckling or improve mean LH, weaning to oestrus interval or ovulation rate following weaning despite making the sows anabolic during lactation, when compared to sows fed *ad libitum* or restrict fed (Zak et al., 1998). Therefore, whilst feeding to 125% of *ad libitum* did create a positive energy balance, these data did demonstrate that the effects of suckling is the primary controller of LH secretion during lactation and that feeding above *ad libitum* will not ameliorate this effect (Zak et al., 1998).

1.3.2.2 Lactation weight loss

First litter sows don't recover from the effects of lactation as well as older parity sows, as they themselves are still maturing and growing (Bračič and Škorjanc, 2008). At the time of first lactation the gilt has reached 30-40% of her target body protein mass and less of her body fat mass and therefore the gilt's post-weaning reproductive capacity may be compromised if there is inadequate nutritional intake (Whittemore 1996). Inadequate nutritional intake during lactation, leading to a catabolic state, can have various effects post-weaning, such as: delayed weaning to oestrus interval, reduced LH concentration, reduced ovulation rate, reduced pregnancy rate and reduced embryonic survival (Cosgrove et al., 1995; Thaker and Bilkei 2005; Quesnel et al., 2007; Kemp and Soede, 2012a).

A body weight loss greater than 10% has been shown to decrease the size of the second litter in first parity sows, thus indicating the importance of adequate body reserves at farrowing and weaning (Schenkel et al., 2010). On average, a sow can achieve a weaning to oestrus interval within seven days of weaning with a lactation weight loss of <15% body weight (Thaker and Bilkei 2005). Thaker and Bilkei (2005) demonstrated the effect of parity and lactation weight loss on the weaning to oestrus interval by categorizing sows according to lactation weight losses of <5%, 5–10%, 11–15%, 16–20%, or >20% (Figure 3). A pronounced effect on the weaning to oestrus interval was observed in first parity sows when lactation weight losses surpassed 5%, however, for multiparous sows this effect was observed only when lactation weight losses were beyond 10% (Thaker and Bilkei 2005).

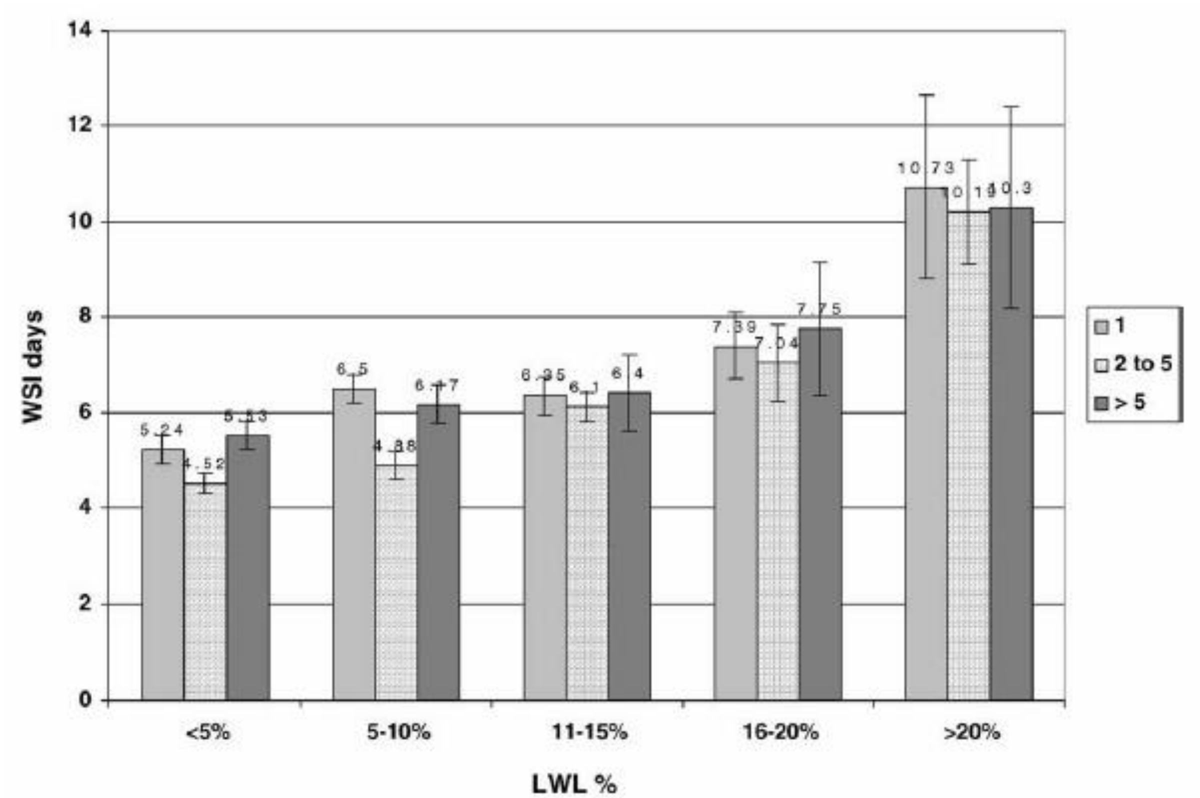

Figure 1.3 Weaning to service intervals (WSI; days ± SEM) of *ad libitum* fed lactating sows of parity 1, parity 2-5 and >5 suffering different lactation weight losses (LWL) evaluated from 1677 sows (Thaker and Bilkei 2005).

1.3.2.3 Sow body protein losses

Sow body weight loss during lactation is inevitable. Even if the lactating sow achieves a high voluntary feed intake, body protein reserves are still mobilised; however, if dietary protein is limited the sow will become increasingly dependent on body protein mobilisation to support lactation (Clowes et al., 2003a). Clowes et al., (2003a) attempted to determine the contribution of high losses in body protein to effects on milk biosynthesis and reproductive function. Their data revealed that the sow can sustain a loss of 9 to 12% of body protein mass at parturition without adversely affecting piglet growth or ovarian function (Clowes et al., 2003a). A high body protein loss of 16% altered milk composition and reduced ovarian function and was associated with a reduction of milk protein concentration on day 20 of lactation and a decrease in litter growth rate from day 20 to weaning (Clowes et al., 2003a). The effect of high body protein loss on ovarian function was more severe as these sows had a lowered follicular fluid volume, fewer follicles over 4 mm in diameter, and a lowered uterine weight (Clowes et al., 2003a).

1.3.3 Parity

The fertility of primiparous sows following their first lactation is considered to be poorer than multiparous sows generally due to a reduced metabolic status (Quesnel et al., 2007). The factors that lead to a decreased reproductive capacity of the primiparous sow are: they are still growing and maturing, and they have a lower feed intake capacity and fewer fat and protein stores to maintain lactation (Bračič and Škorjanc, 2008). The rigours of lactation have a negative effect on primiparous sows, leading to increased weaning to oestrus intervals, and lowered ovulation rates, embryo survival, farrowing rates, and litter sizes (Tokach et al., 1992; Vesseur et al., 1997; Kemp and Soede, 2012a). An option often suggested to improve the metabolic condition of the primiparous sow during lactation is to implement split weaning, removing a portion of the litter, a few days prior to weaning (Vargas et al., 2009). Split weaning primiparous sows between day 18 of lactation and weaning on day 21 increased the number of follicles ≥ 3mm, one day after weaning, when compared to conventionally weaned sows (Zak et al., 2008). This in turn resulted in an earlier post-weaning return to oestrus in split weaned sows, compared to conventionally weaned sows (4.6 vs. 5.7 days, respectively Zak et al., 2008).

1.4 Effect of boar exposure

Boars are used to stimulate follicle development and ovulation post-weaning, facilitate oestrus detection, and to increase fertilisation rates during the artificial insemination process (Kemp et al., 2005). The display of a standing response, when the sow displays a rigid stance, arched back and raised ears, is regarded as the first sign of oestrus (Langendijk et al., 2000c). Exposure to a boar also accelerates the attainment of puberty in gilts, and synchronises the timing of puberty within cohorts of gilts (Brooks and Cole 1970; Pearce 1992). The boar provides stimuli in the form of visual, tactile, olfactory and auditory cues to stimulate an oestrus response in the female (Pearce and Hughes 1987; Langendijk et al., 2006). There are two common ways a boar can be used to stimulate oestrus: fence-line boar exposure or direct physical boar exposure (Patterson et al., 2002; Breen et al., 2005).

1.4.1 Mechanisms of action of boar exposure

The use of the boar for puberty attainment is well accepted within the industry (Brooks and Cole 1970; Soede 1993). Pheromones emitted by the boar can be classified into two categories: either signalling or priming pheromones. The signalling pheromones cause immediate changes in the sow's behaviour causing a standing response and priming pheromones cause slower physiological changes to the endocrine state and thereby stimulate puberty attainment and shorten the period of post-partum anoestrus (Wani et al., 2013). Olfactory stimulation may be largely accounted for by the production of priming pheromones which are released from the boar's salivary glands (Pearce and Hughes 1987; Rekwot et al., 2001). It is well established that the production of the frothy saliva which contains and disperses the pheromones from the boar's submaxillary salivary glands is crucial in the attainment of puberty and oestrus post-weaning (Perry et al., 1980). The pheromones, 5alpha-androstenone and 3alpha-androstenol are both contained in large quantities in the boar's saliva and urine and both have signalling functions whereas the latter also has a priming function (Soede 1993). The production of the priming pheromones secreted by the boar can be dramatically affected by the age of the boar (Kirkwood and Hughes, 1981). Gilts exposed to either a 2 year old boar or a 11 month old boar attained puberty 24 days faster compared to gilts exposed to a boar that was 6.5 months of age or no boar contact at all (Kirkwood and Hughes, 1981). Therefore, it is critical that boars of greater than one year old be used for oestrus stimulation protocols involving boar exposure.

There are two methods of boar exposure commonly used throughout the commercial industry: fence-line contact where the sow and boar can only make nose-to-nose contact and; full physical contact, where the sow and boar are within the same pen for a period of time, usually in a detection mating area. Pearce and Paterson (1992) demonstrated that full physical boar exposure increased the incidence of puberty attainment compared to fence-line boar exposure, most likely because physical contact allowed for the direct transfer of priming pheromones to the snout of the gilt. The importance of nose-to-nose contact in the transfer of priming pheromones was highlighted by Pearce and Paterson (1992) as they compared puberty attainment in gilts with no boar exposure, full physical exposure for 20 minutes per day, and full physical exposure for 20 minutes per day in gilts fitted with a snout mask so that the priming pheromones could not be transferred (Table 1.3). The age at puberty and interval from treatment to puberty was significantly decreased for both groups exposed to the boar, however sows allowed full nose contact reached puberty almost 10 days earlier than was observed in the gilts with masks attached during boar exposure (Pearce and Paterson 1992). These data demonstrated that nose-to-nose contact during full boar exposure is crucial in reducing the age at puberty (Pearce and Paterson 1992).

Table 1.3 The effect of fitting gilts with snout masks on the attainment of puberty in response to full physical boar contact (Pearce and Paterson 1992).

Treatment[1]	Proportion of gilts reaching puberty	Age at puberty	Interval to puberty, days[4]
Control[2]	0.89 (17/19)	202.3 ± 1.04 [a]	30.3 ± 1.28 [a]
Full boar exposure with a mask[3]	1.00 (21/21)	178.6 ± 1.02 [b]	17.4 ± 1.13 [b]
Full boar exposure	1.00 (18/18)	169.0 ± 1.01 [c]	9.1 ± 1.11 [c]

[abc]Different superscripts indicate significant differences between treatments ($P < 0.05$); [1]Treatment was conducted from a mean gilt age of 159.8 ± 1.8 days; [2]Gilts were isolated from the boars; [3]Each gilt was fitted with a snout mask immediately before full physical exposure to a mature boar; [4]Interval was from treatment commencement to puberty.

1.4.2 The effect of boar exposure on oestrus stimulation

The use of the boar to stimulate ovarian activity and oestrus stimulation is crucial in both primiparous and multiparous sows (Langendijk et al., 2000a,b; Breen et al., 2005; Kemp et al., 2005). Whilst the exact mechanisms through which the boar effects oestrus stimulation are unknown, it is known that the olfactory stimuli emitted from the boar are important in triggering the oestrus response (Booth and Baldwin 1983; Pearce and Hughes 1987). Similarly, the mechanism of the 'ram effect' where a sexually active male is introduced to seasonally anoestrus ewes has been shown to cause an immediate increase in short-term LH pulsatility leading to ovulation outside of the breeding season (Martin et al., 1983; Fabre-Nys et al., 2015). The significant role of pheromones in stimulating anoestrus ewes to ovulate was demonstrated by comparing ewes exposed to the wax and wool from recently shorn rams to that of ewes exposed to entire males with their wool removed and ewes isolated from the rams (Knight and Lynch 1980). The result indicated that wool and wax from a ram contains enough pheromones to stimulate anoestrus ewes to ovulate at rates similar to ewes exposed to an entire male (48% compared to 50% ovulation, respectively; 7% ovulation for isolated ewes; Knight and Lynch 1980). Whilst pheromones play a key role, the effects of sight, sound and touch are not eliminated as intensive sexual behaviour of the buck by increased nudging, mounting and ano-genital sniffing was shown to cause a pre-ovulatory LH surge and ovulation in seasonally anovulatory does (Martínez-Alfaro et al., 2014). Physical contact between a buck and a doe for 1 or 2 hours daily has proven to increase LH pulsatility and resulted in 100% and 95%, respectively, of anoestrus does ovulating compared to 5% of does which remained isolated from the buck (Bedos et al., 2014).

The role of the boar in stimulating puberty was established by investigating the hormone profiles of gilts exposed to fence-line exposure of a boar compared to gilts raised without exposure to a boar (Kingsbury and Rawlings 1993). Gilts exposed to the boar expressed their first oestrus 24 days earlier than gilts not exposed to the boar (169 days compared to 193 days of age, respectively; $P < 0.05$; Kingsbury and Rawlings 1993). Most notably, the gilts that expressed an early oestrus had a two-fold increase in LH pulse frequency immediately following the introduction of the boar (Kingsbury and Rawlings 1993). This trend in LH pulse frequency decreased by day 20; however, these transient changes in LH secretion following the induction of a boar could be a sufficient trigger to result in early oestrus (Kingsbury and Rawlings 1993). Post-weaning ovulation of the primiparous sow increased from 30 to 51% with the use of a boar, compared with no boar exposure (Langendijk et al., 2000a). In weaned primiparous sows, boar exposure also decreased the interval from weaning to oestrus from 137 to 128 hours and increased the duration of oestrus from 38 to 56 hours compared to no boar exposure (Langendijk et al., 2000a). Further studies assessed increasing levels of boar stimulus in multiparous sows from parity 2 to 12 (average 6) by comparing the effects of a back pressure test (BPT) in the absence of a boar, the presence of a teaser boar, the presence of a teaser boar with a BPT, and finally a BPT in a detection mating area surrounded by four boars (Langendijk et al., 2000c). As the level of stimulation increased the number of sows exhibiting oestrus behaviours increased, the weaning to oestrus interval decreased and the duration of oestrus increased, thus further demonstrating the importance of the boar (Langendijk et al., 2000c; Table 1.4).

Table 1.4 Number of sows exhibiting oestrus, and means and standard deviation for the interval from weaning to oestrus, and duration of standing oestrus at different stimulus levels (adapted from Langendijk et al., 2000c).

Treatments[1]	Oestrus expression	Weaning to oestrus interval and SD	Duration of oestrus, h
BPT only	46[a]	107 ± 28 [a]	22 ± 14 [a]
Spontaneous oestrus	56[a]	106 ± 23 [a]	29 ± 16 [b]
Boar oestrus	90[b]	98 ± 19 [b]	42 ± 20 [c]
DMA oestrus	97[b]	90 ± 20 [c]	55 ± 18 [d]

[abcd]Different superscripts indicate significant differences between treatments and within column (LSD, P < 0.05); [1]Back pressure test (BPT) was conducted to mimic the stimuli of the boar by rubbing and pushing the sow in the flanks and back to get a standing response; spontaneous oestrus was conducted in the presence of a teaser boar; a boar oestrus was conducted in the presence of a teaser boar and a BPT and; detection mating area (DMA) oestrus was conducted in an area surrounded by four boars to maximise boar stimuli.

It has been shown that daily boar exposure is sufficient to detect sows coming into oestrus and higher frequencies of boar exposure do not increase the percentage of sows coming onto oestrus within eight days post-weaning (Knox et al., 2002). However, in the case of puberty attainment, increasing the frequency of exposure of the gilt to the boar to twice daily increased the efficacy of the boar exposure (Hughes and Thorogood, 1999). Starting from a mean age of 160 days gilts were either: not boar exposed, boar exposed only in the morning, boar exposed only in the afternoon, or boar exposed twice daily in the morning and afternoon for 20 minutes each session (Hughes and Thorogood, 1999). Gilts receiving the twice daily boar exposure attained puberty significantly earlier than either of the daily morning or afternoon treatments and the no boar exposure treatments (176.4 vs. 192.7, 189.2 and 205.0 days of age respectively; P < 0.05).

1.4.3 Effect of the boar during the mating process

The presence of the boar is not only important for oestrus stimulation and detection but is also crucial during the mating process (Soede 1993). The duration of the standing response was shorter when the BPT was applied in the absence as opposed to the presence of a boar (Soede 1993; Langendijk et al., 2000b). Similarly, Patterson et al., (2002) demonstrated that gilts exhibited a stronger reaction to the BPT whilst in the presence of a boar compared to no boar exposure. The presence of a boar during artificial insemination induced a release of oxytocin and stimulated myometrial activity, assisting in the transport of sperm to the oviduct (Claus and Schams 1990; Langendijk et al., 2005). Interestingly, the use of a boar spray and a BPT elicited a standing response from one third of sows and had no effect on the release of oxytocin (Langendijk et al., 2003). These results display the importance of using a mature boar to elicit a fertile oestrus in the sow as the use of a BPT alone is not adequate.

1.5 Strategies to stimulate a lactation oestrus

The period between parturition and weaning is usually considered to be a period of anoestrus in the lactating sow. In order to minimise the interval between successive farrowings, and thus maximise the number of litters produced per sow, lactation lengths have been reduced to between 14 and 28 days, with an Australian industry average of 24 days (Pluske et al., 2003). However, weaning as early as 14 days impairs piglet growth, causing a distinct post-weaning growth check and has welfare implications due to the stress of maternal separation and nutritional demands (Mason et al., 2003; Pluske et al., 2003; Callesen et al., 2007). Increasing lactation lengths to benefit the piglet extends the sow's non-productive days by reducing sow farrowing frequencies, making commercial adoption of extended weaning ages unsustainable (Cabrera et al., 2010; van der Meulen et al., 2010). However, weaning piglets too early generally results in an extended weaning to oestrus interval.

By stimulating a lactation oestrus it would be possible to extend the weaning age, not to increase the number of farrowings per year, but rather to maintain the reproductive capacity of the sow. The concept of stimulating the sow to express a lactation oestrus is not new (Cox and Britt 1982; Duggan et al., 1982; Rowlinson and Bryant 1981; Rowlinson and Bryant 1982; Stevenson and Davis 1984; Britt et al., 1985; Sesti and Britt 1993; Alonso-Spilsbury et al., 2004; Soede et al., 2012) with the most common strategies to stimulate a lactation oestrus being: the use of exogenous hormones, intermittent suckling, split suckling, the use of a boar, and low confinement lactation housing.

1.5.1 *Exogenous hormones*

The use of exogenous gonadotrophins such as 400 IU of pregnant mare serum gonadotrophin (PMSG) combined with 200 IU of human chorionic gonadotrophin (hCG), and commonly known as PG600, for the purpose of oestrus stimulation has been extensively investigated (Hausler et al., 1980; Britt et al., 1985; Kirkwood and Thacker 1998; De Rensis et al., 2003; Downing et al., 2011). However, success with exogenous gonadotrophins can vary greatly as the proportion of sows exhibiting a lactation oestrus varies considerably with the stage of lactation at which exogenous gonadotrophins are administered. Hausler et al., (1980) reported that at 15 days post-partum the ovaries are responsive to exogenous gonadotrophins, however, not at five days postpartum. Similarly, Zemitis et al., (2015) injected 1000IU hCG at either 24 or 48 hours post-partum to stimulate an oestrus immediately post-partum with the expectation that the sow will exhibit a predictable second oestrus 19-21 days subsequently in late lactation. Of the 34 sows injected with hCG at either 24 or 48 hours, only nine sows ovulated within five days of farrowing, however, these sows did not exhibit normal oestrous cyclicity following this induced ovulation and therefore did not ovulate in late lactation as was hypothesised (Zemitis et al., 2015). Therefore, the unpredictability of sows responding to hCG treatment in early lactation indicates that this strategy will not be a practical means to stimulate a lactation oestrus.

The use of exogenous gonadotrophins has also been investigated when coupled with split weaning, intermittent suckling and boar exposure to stimulate a lactation oestrus. Sows injected with PG600 at day 18 of lactation showed a poor lactation oestrus response (9.5% ovulating during lactation) compared to sows split weaned and injected with PG600 (47.6% ovulating during lactation) indicating that the use of gonadotrophins alone does not provide sufficient stimulation and that the use of split weaning is more effective than injectable gonadotrophins (Kirkwood et al., 2013). However, when PG600 was combined with fence-line boar exposure and intermittent suckling in late lactation, between 79-93% of sows were stimulated to exhibit a lactation oestrus (Downing et al., 2012). These findings suggest that when exogenous gonadotrophins are used on their own, the proportion of sows exhibiting a lactation oestrus is quite low and unpredictable, however when used in conjunction with a reduction in suckling intensity and boar exposure, the proportion exhibiting a lactation oestrus is significantly improved.

1.5.2 Intermittent Suckling

Intermittent suckling is a system by which an entire litter is physically separated from the sow for a number of hours per day during lactation, often with separation for 12 consecutive hours or twice per day for 6 hours (Gerritsen et al., 2008c). Intermittent suckling has been investigated as a means to induce lactation oestrus with response rates of 28% (Langendijk et al., 2009), 72% (Grinwich and McKay 1985) and 100% (Newton et al., 1987b). The lactation oestrus response to intermittent suckling is affected by the duration of separation of the sow and litter (6 to 12 hours), the timing relative to parturition, and for how many days it is conducted prior to complete weaning (Gerritsen et al., 2008a). However, the parity and breeding of the sow have also been shown to have a significant impact with a greater percentage of higher parity sows exhibiting lactation oestrus in response to intermittent suckling, compared to first lactation sows (Soede et al., 2012).

1.5.2.1 LH secretion and follicle growth resulting from intermittent suckling

Typically during lactation the sow is anoestrus with low pulsatile release of LH, however, intermittent suckling can cause an immediate increase in the release of LH when the piglets are removed (Langendijk et al., 2007). Prior to the commencement of intermittent suckling Langendijk et al., (2007) observed low frequency (2.8 pulses per 8 hours) high amplitude (0.66 ng/ml) secretion of LH in lactating sows. Immediately following the commencement of intermittent suckling on day 14 post-partum between 0800 and 2000 hours the frequency of the LH pulses increased (5.2 pulses per 8 hours) and the amplitude decreased (0.4 ng/ml; Langendijk et al., 2007). However, LH secretion was inhibited again when piglets were returned to the crate indicating that the suckling intensity has a pronounced effect on LH secretion. In sows that went on to ovulate during lactation, LH pulsatility remained high on the second day of intermittent suckling even when the piglets were returned to the sow, but was reduced in sows which did not ovulate until after weaning (Langendijk et al., 2007). This finding suggests that some sows may be pre-disposed to expression of a lactation oestrus under the correct conditions, such as with the introduction of intermittent suckling.

Coincident with the increases in pulsatile release of LH, follicle diameter has been shown to increase in response to intermittent suckling. It appears from the findings of Gerritsen et al., (2008a) that the stimulation of both follicle growth and ovulation is inversely proportional to the timing of commencement of intermittent suckling post-partum. A greater number of pre-ovulatory follicles were developed in sows commencing IS on day 21 compared to day 14 of lactation (100% vs. 87% respectively) as was the percentage of sows ovulating within 8 days from the commencement of intermittent suckling (day 14, 75% vs. day 21, 94% ovulation; $P < 0.05$; Gerritsen et al., 2008a). Interestingly Langendijk et al., (2009) found no change in concentration of FSH, FSH pulses or the amplitude of FSH between sows that ovulated and sows that did not ovulate, in response to intermittent suckling. However in comparison with Degenstein et al., (2006) FSH concentrations increased in response to split weaning which was expected to have stimulated greater follicle development at weaning. Furthermore, Langendijk et al., (2009) found no change in LH and FSH concentration in response to boar exposure which was not expected; however, these findings suggested that FSH was not limiting follicular development.

Therefore, intermittently suckled sows will show follicular development and ovulate similar to that of a weaned sow as long as intermittent suckling commencement does not occur too early post-farrowing.

Whilst the use of intermittent suckling as a strategy to induce a lactation oestrus has proved to be effective, the feasibility of this approach in a commercial setting may be limited by the high labour input required for its management.

1.5.3 Split weaning

Split weaning is the weaning of a proportion of the piglets, usually the heavier piglets, prior to weaning the entire litter to reduce the suckling input on the sow. The primary objectives of many split weaning investigations is to reduce the weaning to oestrus interval, improve fertility post-weaning and improve the growth of lighter piglets remaining on the sow (Matte et al., 1992; Vesseur et al., 1997; Zak et al., 2008; van Leeuwen et al., 2012). Studies investigating the use of split weaning to elicit an oestrus response in the lactating sow are minimal.

1.5.3.1 LH secretion and follicle growth resulting from split weaning

Split weaning has been shown to cause a marked increase in LH pulsatility and FSH concentration during lactation, possibly leading to improved fertility post-weaning (Degenstein et al., 2006; Zak et al., 2008). Coincident with increased LH pulsatility, increases in follicle growth were observed in response to split weaning (Zak et al., 2008). Split weaned sows possessed a higher number of follicles greater than 3 mm one day after weaning compared to conventionally weaned sows (7.3 vs. 4.0 follicles, respectively); and exhibited a significantly shorter wean to oestrus interval (111 vs. 136 hours, respectively; Zak et al., 2008). Therefore split weaning has the capacity to reduce the suckling induced inhibition of gonadotrophins and potentially accelerate follicular development leading to a lactation oestrus.

In order to demonstrate the effect of the suckling stimulus, Grant (1989) compared control sows that suckled an entire litter throughout the 21 day lactation, sows that were split weaned, by removing the heaviest piglets and leaving the five lightest piglets and, sows that were similarly split weaned down to the five lightest, but only had 3 posterior pairs of teats available due to the addition of a canvas cover. Prior to the sows being split weaned or having their teats covered there were no differences in the mean plasma LH concentration compared to control sows (Grant 1989; Table 1.5). However, in the 12 hours following split weaning and teat covering LH concentrations rose significantly for both split weaned and teat covered sows, indicating that split weaning will stimulate LH release (Grant 1989; Table 1.5). Prolactin concentrations did not differ between controls and split weaned sows, but were significantly lowered in teat covered sows in the first 12 hour period and the following 36 hours (Grant 1989; Table 1.5). Further to this, there was a significant reciprocal correlation between prolactin and LH concentrations in the first 12 hours in teat covered sows only (Grant 1989). Therefore despite the piglets vigorously suckling from the few remaining teats, it is apparent that the visual, auditory and olfactory stimuli of the piglets are not sufficient to maintain the secretion of milk from the covered teats. Therefore, split weaning will reduce the suckling stimulus from the piglet, whilst not impairing milk production, and allowing for an increase in LH concentrations and possibly resulting in a fertile oestrus during lactation.

Table 1.5 Overall mean LH and prolactin concentrations in the 12 hour period before split weaning or teat covering and the 12 hour period following split weaning or teat covering (Grant, 1989).

	Mean LH concentrations (ng/ml)		Mean prolactin concentrations (ng/ml)	
Treatments	12 hours prior to treatment	12 hours post-treatment	12 hours prior to treatment	12 hours post-treatment
Control	0.25 ± 0.04	0.23 ± 0.04	17.50 ± 2.35	18.09 ± 3.01
Split weaned	0.21 ± 0.02 [a]	0.31 ± 0.05 [b]	19.49 ± 3.79	17.33 ± 2.01
Teat covered	0.19 ± 0.02 [a]	0.51 ± 0.06 [b]	23.96 ± 2.79 [c]	15.03 ± 1.82 [d]

[ab]Different superscripts indicate significant differences within row and main effect ($P < 0.05$); [cd]Different superscripts indicate significant differences within row and main effect ($P < 0.01$).

1.5.3.2 Effect of split weaning on the litter

It is important that split weaning does not compromise the growth of both the lighter piglets remaining on the sow and the heavier piglets split weaned. The growth rate of the four remaining suckling piglets after split weaning of the rest of the litter has been shown to significantly improve from days 18 to weaning on day 21 (281 vs. 193 g/day for split weaned and conventionally weaned litters respectively; Zak et al., 2008). Similarly, light piglets that remained on the sow after split weaning grew 61% faster and were one kg heavier at weaning than their counterparts in the control litters (Pluske and Williams 1996). It is probable that allowing the lighter weight piglets to remain on the sow allowed these piglets greater access to the teats and increased their milk intake allowing for a faster growth rate. However, piglets which are classed as ‘heavies’ and removed from the sow at split weaning may experience a drop in growth rate compared to their counterparts that remain on the sow. The five heavy piglets split weaned at 22 days grew 22% slower than their heavy counterparts in control litters which were allowed to remain on the sow between 22-29 days of age (Pluske and Williams 1996). However, these heavier split weaned piglets grew faster between days 29-62 days of age and were heavier at 62 days of age than their lighter counterparts that remained on the sow (22.0 vs.19.3 kg; Pluske and Williams 1996). These data indicate that the weight at weaning is a key determinant of weight throughout life, but split weaning sows and allowing lighter piglets to remain on the sow for a longer lactation can improve the growth of lighter weight piglets. Therefore, split weaning does not significantly compromise the growth of the heavier piglets removed earlier, and will allow the lighter weight piglets to increase in growth.

1.5.4 Boar exposure

The use of boar exposure during lactation oestrus stimulation increases the prolificacy of the oestrus response (Stevenson and Davis, 1984). In group housed sows receiving *ad libitum* access to feed the greatest proportion expressing a lactation oestrus were sows that were housed continuously with a boar (78% compared to 5% of sows with no boar exposure; P < 0.05; Rowlinson and Bryant 1982). Conversely, Gerritsen et al., (2008c) investigated the proportion of intermittently suckled sows exhibiting lactation oestrus, however, with a BPT in the absence of a boar. Of the 27 sows intermittently suckled, 26 exhibited a lactation oestrus indicating that the boar was not necessary for stimulation of a lactation oestrus (Gerritsen et al., 2008c). Soede et al., (2012) hypothesised that with the use of intermittent suckling and a BPT in the absence of a boar, 23% of primiparous sows and 68% of multiparous sows ovulated in lactation due to a heightened level of anticipation from the sows. As the sows were only detected for oestrus with a BPT, they did not anticipate higher levels of stimulation and this may have increased the response to the BPT (Soede et al., 2012). Conversely, van Wettere et al., (2013) recently compared sows receiving a BPT in the absence of a boar to sows receiving 15 minutes of physical boar exposure in a detection mating pen. Boar exposure increased the response of sows ovulating in lactation from 9% to 61%, compared to sows receiving no boar exposure and only a BPT (P < 0.05; van Wettere et al., 2013). These studies indicate that lactation oestrus can be induced with and without boar exposure;

however, there is a great amount of variation between these studies which depend on a range of factors. Therefore, the use of boar exposure will most likely reduce the risk of missing any sows on oestrus during lactation.

1.5.5 Low confinement lactation housing

During lactation most sows are individually confined in a farrowing crate for the length of lactation. The move of the Australian pork industry towards the removal of sow stalls during gestation may result in an increased focus on the reduced confinement of lactating sows. The primary reason for the use of lactation crates is to minimise piglet crushing events and increase piglet survivability. Sows housed in conventional farrowing crates are unable to regulate the frequency of the suckling bouts which does not allow for the resumption of LH release. In contrast, sows housed in low confinement systems may have a greater chance to escape their piglets and reduce the frequency and duration of suckling, thereby decreasing the inhibitory effects of suckling on the frequency of LH pulses and ovarian activity (Bøe 1993; Kemp and Soede 2012b; Thomsson et al., 2015). Sows which had the ability to escape their piglets, nursed their piglets 10% less and their piglets consumed 65% more solid food than sows and piglets housed in conventional farrowing crates (Pajor et al., 2002). By not confining the sow for the entirety of lactation the sow can experience a reduction in social contact and piglet suckling frequency resulting in a lactation oestrus (Stolba et al., 1990).

The occurrence of lactation oestrus from sows housed continuously with a boar in groups of 2 to 7 sows with their litters from 21 days post-farrowing was investigated by Rowlinson et al., (1975). Of the 180 sows group housed in lactation, 100% exhibited a lactation oestrus with a mean grouping to oestrus interval of 11.2 days (Rowlinson et al., 1975). Similarly, Rowlinson and Bryant

(1981) investigated the effect of group housing sows with a mature boar from either 10, 15, 20 or 25 days post-farrowing on the incidence of lactation oestrus. There were no significant differences between treatments; however, of 92 sows, 91 sows exhibited oestrus during lactation (Rowlinson and Bryant 1981). It is likely that the reduced suckling stimulus within group lactation systems together with daily contact with a mature boar allowed the high proportion of sows to ovulate in lactation.

1.6 Conclusions and aims of the thesis

The overall aim of determining the optimal method to stimulate a sow to express a lactation oestrus is to extend weaning ages for the benefit of the piglets whilst maintaining the reproductive capacity of the sow. However, lactation oestrus results can vary significantly and are therefore unreliable leading to a lack of understanding of the optimal method to stimulate a high proportion of sows to express a lactation oestrus. The methods chosen for further study are split weaning, boar exposure and low confinement lactation housing as they represent the best commercially viable options to reduce the suckling stimulus of the lactating sow and induce a high proportion of lactation oestrus. The objectives of the studies within this thesis were to:

1. Determine the effect of split weaning three, five or seven piglets and fence-line boar exposure on the incidence of lactation oestrus and to monitor piglet growth rates.
2. Determine the optimal time during lactation to commence full physical boar exposure (no boar exposure compared to day 10, 14, and 18 of lactation) to stimulate the greatest proportion of primiparous and multiparous sows to ovulate and conceive during lactation.
3. Determine the effect of full physical boar exposure coupled with a reduction in suckled litter size to seven piglets (split weaning) in both multiparous and primiparous sows on the incidence of lactation oestrus, pregnancy rates and litter size, within a commercial setting.

4. Determine if providing sows with the ability or option to escape their piglets through the use of alternative farrowing crates, in combination with fence-line boar exposure promotes the expression of a lactation oestrus.

The hypotheses tested within this thesis were:

1. The incidence of lactation oestrus in multiparous sows will be increased by split weaning of a higher proportion of piglets in conjunction with fence-line boar exposure and secondly; lighter piglets remaining on the sow from days 18-30 of lactation will increase in growth rate due to lower competition for teats.

2. A greater proportion of multiparous and primiparous sows will exhibit a lactation oestrus in response to boar exposure compared to sows receiving no boar exposure and secondly; a greater proportion of sows will exhibit a lactation oestrus the earlier boar exposure commences in lactation due to a greater amount of stimulation.

3. A greater proportion of both multiparous and primiparous sows will exhibit a lactation oestrus in response to split weaning to 7 of the lightest piglets in conjunction with full physical boar exposure and secondly; the pregnancy and farrowing rates of sows mated in lactation and post-weaned will not differ.

4. A greater proportion of multiparous sows will exhibit a lactation oestrus when housed in low confinement lactation crates due to a lower suckling stimulus, without removing a proportion of their piglets, and fence-line exposure to a mature boar.

CHAPTER TWO

Split weaning increases the incidence of lactation oestrus in boar-exposed sows

R Terry[a], KL Kind[a], PE Hughes[b], DJ Kennaway[c], PJ Herde[b], WHEJ van Wettere[a]

[a] School of Animal and Veterinary Sciences, The University of Adelaide, Roseworthy campus, Roseworthy, South Australia, 5371.

[b] South Australian Research and Development Institute, Roseworthy campus, Roseworthy, South Australia, 5371.

[c] Robinson Institute, Research Centre for Reproductive Health, Discipline of Obstetrics and Gynaecology, The University of Adelaide, South Australia, 5005.

Animal Reproduction Science, 2013, 142, 48-55

STATEMENT OF AUTHORSHIP

Title of Paper	Split weaning increases the incidence of lactation oestrus in boar-exposed sows
Publication Status	Published
Publication Details	Terry R, Kind KL, Hughes PE, Kennaway DJ, Herde PJ, van Wettere WHEJ (2013) Split weaning increases the incidence of lactation oestrus in boar-exposed sows. *Animal Reproduction Science* **142**, 48-55.

Principal Author

Name of Principal Author	Robyn Terry		
Contribution to the Paper	Data collection, data analysis, data interpretation, author of manuscript, and corresponding author.		
Overall percentage (%)	85		
Signature		Date	23/07/2015

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate to include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution

Name of Co-Author	Karen Kind		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	05/07/2015

Name of Co-Author	Paul Hughes		
Contribution to the Paper	Scientific contribution		
Signature		Date	14/07/2015

Name of Co-Author	David Kennaway		
Contribution to the Paper	Progesterone assays		
Signature		Date	13/07/2015

Name of Co-Author	Paul Herde		
Contribution to the Paper	Technical Support and data collection		
Signature		Date	21/07/2015

Name of Co-Author	William van Wettere		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	13/07/2015

2.1 Abstract

This study evaluated the effect of split weaning and fence-line boar exposure during lactation on the incidence of lactation oestrus. Large White and Large White x Landrace sows (parity 2.9 ± 0.17; mean ± SEM) were housed in conventional farrowing crates from day -4 to 30 post-parturition. Four treatments (n=18) were used: Control (SPW0): continuous lactation of 10 piglets with all piglets weaned on day 30 of lactation; and three split wean (SPW) treatments with 3 (SPW3), 5 (SPW5) or 7 (SPW7) of the heaviest piglets removed from the sow on day 18 of lactation. From day 18 lactation all sows received 15 minutes of daily, fence-line boar exposure in a detection mating area. Fewer sows in the SPW0 treatment (56% (10/18)) expressed a lactation oestrus compared to the SPW3, SPW5, and SPW7 treatments (83%; 89%; 94%, respectively). SPW0 sows had a lower subsequent total born compared to SPW5 or SPW7 sows (8.9 ± 1.1 vs. 12.5 ± 1.0 and 13.1 ± 1.1, respectively). Between day 18 and 30 of lactation, sows in SPW5 and SPW7 gained weight (4.5 ± 1.4 and 1.9 ± 1.4 kg, respectively) whereas SPW0 and SPW3 sows lost weight (4.9±1.4 and 2.9±1.4 kg, respectively) ($P<0.05$). Split weaned piglets were heavier at day 17 of age by 1.0 kg however by day 40 of age no weight differences were observed between piglets weaned on day 18 compared to day 30 ($P<0.05$). In conclusion, split weaning coupled with fence-line boar exposure in late lactation induced lactation oestrus in a higher proportion of sows compared to those suckling a normal litter size.

2.2 Introduction

In sows, ovarian follicle growth is typically quiescent during lactation resulting in a characteristic period of anoestrus, which is alleviated 3 to 7 days after weaning (De Rensis et al., 2003). To minimise the interval between successive farrowings, and thus maximise the number of litters produced per sow, lactation lengths have been reduced to between 14 and 28 days (Pluske et al., 2003). However, weaning as early as 14 days impairs piglet growth, causing a distinct post-weaning growth check and has welfare implications due to the stress of maternal separation and nutritional demands (Mason et al., 2003; Pluske et al., 2003; Callesen et al., 2007). Increasing piglet weaning age to more than 28 days can improve piglet performance (Mason et al., 2003). However, doing so will result in reduced sow farrowing frequencies, making commercial adoption of extended weaning ages unsustainable. Stimulating sows to ovulate during lactation represents a solution as it enables lactation lengths to be increased, thus improving piglet performance and welfare, whilst also maintaining reproductive efficiency.

During early lactation, pre-ovulatory follicle growth is inhibited primarily by the suckling induced suppression of GnRH, and thus pulsatile LH release (Alonso-Spilsbury et al., 2004; Gerritsen et al., 2008a). During the later stages of lactation, suckling frequency decreases and the negative energy balance typical of lactation becomes a strong inhibitor of pre-ovulatory follicle growth (Zak et al., 1997a; Valros et al., 2002; Clowes et al., 2003b; Alonso-Spilsbury et al., 2004). Decreasing the suckling demand on the sow, by temporary separation of the sow and litter for 6 – 12 hours each day (intermittent suckling), can alleviate lactation anoestrus by increasing LH pulse frequency (Gerritsen et al., 2008a,b; Soede et al., 2012). However, intermittent suckling is considered labour intensive and the proportion of sows expressing lactation oestrus can be low and often variable (Kuller et al., 2004; Gerritsen et al., 2008a; Soede et al., 2012). Permanent removal of a portion of the litter three to seven days prior to complete weaning (split weaning) increased LH pulse frequency and promoted ovarian follicular growth (Grant 1989; Zak et al., 2008). To date, split weaning has primarily been used to reduce the weaning to oestrus interval, and studies on the effects on incidences of lactation oestrus are minimal (Grant 1989; Mahan 1993; Vesseur et al., 1997; Tarocco et al.,2000; Degenstein et al., 2006; Zak et al., 2008). Although boar exposure during lactation is known to decrease the interval from weaning to oestrus (Walton 1986; Zak et al., 2008) there is limited information on the use of boar exposure, without the assistance of gonadotrophin injections, to induce lactation oestrus (Rowlinson et al., 1975; Guthrie et al., 1978; Rowlinson and Bryant 1981). Therefore, the current study investigated the effect of split weaning in combination with boar exposure from day 18 of lactation onwards, on the incidence of lactation oestrus and the subsequent reproductive performance of sows inseminated during lactation. The study was extended further to monitor the changes in the growth rates of the piglets split weaned and the piglets left on the sow, at birth, pre-weaning and post-weaning to determine if either were advantaged or disadvantaged.

2.3 Materials and Methods

This study was conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC 2004). All experimental procedures were conducted at the University of Adelaide's Roseworthy piggery, South Australia, with approval from the Animal Ethics Committee of The University of Adelaide, South Australia.

2.3.1 Animals, management and treatments

The experiment consisted of four replicates conducted between September 2010 and April 2011. Seventy two Large White and Large White x Landrace sows (parity 2 to 6; 2.9 ± 0.17) were individually housed in conventional farrowing crates from 1 week before expected farrowing until day 30 post-parturition (day 0 = first 24 hours post-parturition). Throughout lactation sows received a commercial lactation diet (14.6 MJ DE/kg, 18.7% CP, 1.0% total lysine) fed at increasing amounts from 1 kg on the day of farrowing reaching a maximum of 7 to 8 kg/day fed over three meals by day 7 of lactation. Within 3 days of farrowing, litters were standardised to 10 piglets per sow and maintained at 10 until day 18 of lactation or weaning, depending on treatment. Sows were weighed on days 1, 13, 18 and 30 of lactation. Sows were stratified according to average live weight loss from day 1 to day 13 of lactation (-8.95 ± 0.85 kg) and randomly allocated to one of four treatments, with Large White and Large White x Landrace sows distributed evenly across treatments (n= 18 sows / treatment). Treatments were: (i) Control (SPW0): continuous lactation of 10 piglets, all piglets weaned on day 30 of lactation; and three split wean (SPW) treatments as follows (ii) SPW3: 3 piglets removed from the sow on day 18 of lactation, (iii) SPW5: 5 piglets removed from the sow on day 18 of lactation, (iv) SPW7: 7 piglets removed from the sow on day 18 of lactation. All sows started boar exposure on day 18 of lactation.

Individual piglets were identified for SPW based on their body weight on day 17 of lactation, with the heaviest piglets selected for weaning. Of the piglets selected for weaning, 45% were female and 55% were male. Piglets identified to be split weaned were permanently removed between 08:00 and 09:00 h on day 18. Piglets that were left on the sow from day 18 to day 30 remained in the farrowing crate. From seven days of age piglets had access to a commercial starter diet (15.7 MJ DE/kg, 22% CP, 1.53% total lysine) as was standard practice at the piggery. Following weaning, piglets were housed in a weaner pen (2.3 x 5.4 m) with *ad libitum* access to a commercial weaner diet (14.6 MJ DE/kg, 23% CP, 1.27% total lysine) and water. During the first week post-weaning piglets were given access to a heated creep area.

2.3.2 Sow and piglet measures

Sow body weight, P2 backfat and eye muscle depth were measured on days 1, 13 and 18 of lactation and at weaning (day 30). P2 backfat and eye muscle depth were measured over the last rib, 65 mm from the vertebrae, using a 5MHz linear probe (Aquila Vet, Pie Medical Equipment).

At 2 days of age, piglets were tagged and individual piglet weights were recorded at 2, 17, 30 and 40 days of age.

2.3.3 Reproduction

2.3.3.1 Boar exposure and oestrus detection

Beginning on day 18 of lactation sows were taken daily from the farrowing crate to a detection mating area and given fence-line exposure with multiple mature boars for 20 minutes. The detection mating area was located in a separate building and was a 50 metre walk for the sows. Sows were checked for oestrus using the back pressure test within the first 3 minutes of entering the pen, with a standing reflex defined as the first sign of oestrus. At first detection of oestrus sows were artificially inseminated (AI) and again every 24 hours until the end of behavioural oestrus or when the sow had received a total of four inseminations, whichever came first. Inseminations were performed as per standard commercial practice using a disposable spirette catheter with each insemination containing an 80 ml dose of fresh, extended semen (3 x 10^9 spematozoa per inseminate; < 4 days old). Semen was purchased from a commercial artificial insemination collection centre (SABOR Pty. Ltd, Clare, South Australia) and was collected from Large White, Landrace, or Duroc boars. Boar genetics were split equally across treatments. The interval from the start of treatment (day 18) to the first expression of a standing oestrus during lactation was recorded. The duration of oestrus expression (days) was also recorded.

2.3.3.2 Pregnancy status and farrowing rates

Pregnancy status was determined in all sows by transabdominal ultrasound, 28-35 days post AI. The number of piglets born alive, stillborns, and mummies were recorded from the subsequent litter of the sows that were inseminated during lactation.

2.3.4 Blood progesterone concentrations

A pre-prandial blood sample was taken 10 days after the first detection of oestrus for progesterone analysis to confirm the occurrence of lactation ovulation and to determine any concentration differences amongst the treatment groups. Blood samples were taken by jugular venepuncture into a 9 ml Heparin-Lithium coated collection tube (Vacuette, Greiner Labortechnik, Austria) and immediately placed into ice following collection and processed within an hour of collection. Blood samples were centrifuged at 1500g for 15 minutes and plasma then stored at -20°C, until assayed for progesterone concentration.

Blood samples were analysed for progesterone concentration in 50 µl of plasma, in duplicate using a coated tube radio immunoassay (RIA), according to the manufacturer's instructions (IM1188; Beckman Coulter, Brea, CA, USA). Authors, Athorn et al., (2013) and Foisnet et al., (2010) have previously used an identical kit for the analyses of plasma progesterone in porcine. The lowest detectable concentration was 0.1 ng per ml. The intra assay coefficient of variation was less than 10%. The inter assay coefficient of variation was less than 15%. Cross reactivity with related steroids was low (17alpha-Hydroxyprogesterone; 1.15%, Pregnenolone; <0.01%, Manufacturer's information).

2.3.5 Sow body composition and energy and lysine

Sow and P2 backfat depth were measured at different time points in lactation to indirectly determine body protein loss and body fat loss by using the equations set out by (Whittemore and Yang 1989).

Sow body fat (kg) = -20.4 + (0.21 x live weight (kg)) + (1.5 x P2 backfat (mm))

Sow body protein (kg) = -2.3 + (0.19 x live weight (kg)) - (0.22 x P2 backfat (mm))

Milk production was estimated based on piglet live weight gain, with the assumption being that piglets consumed 3.7 g of milk for every g of weight gain (Noblet and Etienne 1986). The equations of Noblet and Etienne (1989) and Pettigrew (1993) respectively, were used to estimate the ME requirement (ME_{milk}) and lysine requirement ($Lysine_{milk}$) for milk production:

ME_{milk} (kJ ME/day) = [4.92 x litter gain, g/day) – 90 x No. pigs)]/0.72] x 4.184)

$Lysine_{milk}$ (g / day) = 26 x litter gain (kg/day)

2.3.6 Statistical Analysis

Unless otherwise stated, data are expressed as mean ± standard error of the mean (SEM). The sow was used as the experimental unit in all analyses. A general analysis of variance (ANOVA), with experimental replicate built in and sow parity as a co-variate, was used to determine treatment effects on sow body condition measures. Sow body condition change was included in the ANOVA model as a covariate when determining treatment effects on days to oestrus, duration of oestrus and subsequent litter size. The cumulative proportion of sows expressing oestrus during lactation was analysed as χ^2. The effects of treatment and weaning age (day 18 vs. day 30) on piglet body weight and body weight gain were analysed with the sow as the experimental unit and using a general ANOVA, with experimental replicate included in the model and piglet body weight on day 2 used as a co-variate.

All analysis, excluding treatment effects on the cumulative proportion of sows expressing oestrus, was done using Genstat, 10th Edition (Rothamsted Experimental Station, Harpenden). Analysis of treatment effects on the cumulative proportion of sows expressing oestrus was conducted using Microsoft Office Excel® 2007. Probability values < 0.05 were described as significant.

2.4 Results

2.4.1 Sow body condition throughout lactation

Sow body tissue loss was similar for all treatments between days 1 and 18 of lactation (Table 2.1). Total weight loss and protein loss during lactation (days 1-30) were lower ($P < 0.05$) for sows suckling 5 and 3 piglets compared to those suckling 10 or 7 piglets. Between days 18 and 30, sows with a suckling load of 3 and 5 gained weight and calculated body protein. Backfat loss during lactation did not differ between groups. There was no difference between treatments for energy and lysine output in milk between days 3 and 18 of lactation. In late lactation, between days 18 and 30, energy and lysine output in milk decreased with decreasing suckled litter size ($P<0.05$; Table 2.1).

Table 2.1 Sow body weight and change, backfat and change, sow body protein change and sow body fat change at farrowing, day 18 of lactation and day 30 of lactation (Mean ± SEM).

	Treatment			
Item	SPW 0	SPW 3	SPW 5	SPW7
Number of sows	18	18	18	18
Piglets suckling: d 18-30 post-partum	10	7	5	3
Parity	2.8 ± 0.2	3.0 ± 0.2	2.6 ± 0.2	3.1 ± 0.2
Sow body weight, kg				
Day 1, post-partum	265.3 ± 6.0	270.1 ± 6.0	268.1 ± 6.0	270.5 ± 6.0
Day 18, post-partum	251.3 ± 6.1	256.8 ± 6.1	258.0 ± 6.0	258.2 ± 6.1
Day 30, post-partum	244.5 ± 6.2	253.4 ± 5.9	261.8 ± 5.9	259.6 ± 6.1
Sow body weight change, kg				
Days 1-18	-12.9 ± 2.0	-14.2 ± 2.0	-10.9 ± 2.0	-11.5 ± 2.0
Days 18-30	-5.4 ± 1.4 [a]	-2.9 ± 1.4 [a]	4.6 ± 1.3 [b]	2.0 ± 1.4 [b]
Days 1-30	-18.8 ± 2.2 [a]	-16.7 ± 2.1 [a]	-6.4 ± 2.1 [b]	-9.4 ± 2.2 [b]
Sow backfat change, mm				
Days 1-18	-1.3 ± 1.0	-2.8 ± 1.0	-1.7 ± 1.0	-3.1 ± 1.1
Days 18-30	-1.4 ± 0.9	0.9 ± 0.9	0.6 ± 0.9	0.8 ± 0.9
Days 1-30	-2.9 ± 1.1	-1.8 ± 0.9	-1.0 ± 0.9	-2.8 ± 1.0
Sow body protein change[1], %				
Days d1-18	-4.9 ± 0.8	-4.9 ± 0.9	-3.9 ± 0.9	-3.1 ± 0.9
Days d18-30	-2.0 ± 0.7 [a]	-1.6 ± 0.7 [ab]	1.9 ± 0.7 [c]	0.3 ± 0.76 [bc]
Days d1-30	-6.9 ± 0.8 [a]	-6.3 ± 0.8 [a]	-2.2 ± 0.8 [b]	-2.9 ± 0.9 [b]
Sow body fat change[1], %				
Days d1-18	-6.7 ± 1.7	-7.2 ± 1.8	-6.6 ± 1.7	-10.3 ± 1.8
Days d18-30	-4.8 ± 1.8 [a]	-0.8 ± 1.8 [ab]	3.4 ± 1.7 [b]	2.5 ±1.8 [b]
Days d1-30	-11.7 ± 2.2	-7.7 ± 2.2	-3.7 ± 2.2	-8.2 ±2.3
Energy output in milk[2], MJ/d				
Days 3 – 18	72.1 ± 3.25	70.3 ± 3.25	67.6 ± 3.15	65.9 ± 3.02
Days 18 – 30	79.2 ± 2.35 [a]	61.4 ± 2.30 [b]	44.7 ± 2.28 [c]	24.4 ± 2.18 [d]
Lysine output in milk[3], kg/d				
Days 3- 18	70.3 ± 2.96	68.6 ± 2.90	66.3 ± 2.87	64.7 ± 2.75
Days 18 - 30	76.8 ± 2.14 [a]	59.2 ± 2.09 [b]	43.1 ± 2.07 [c]	23.6 ± 1.98 [d]

[abcd]Means within a row with different superscripts differ significantly ($P<0.05$); [1]Sow body protein and body fat were calculated using the equations set out by Whittemore and Yang (1989) and the change between days (%) subsequently calculated; [2]Energy output in milk calculated using the equation set out by Noblet and Etienne (1989); [3]Lysine output in milk calculated using the equation set out by Pettigrew (1993).

2.4.2 *Oestrus data*

Compared to sows suckling 10 piglets from day 18 to 30 of lactation, split weaning, regardless of the number of piglets removed, resulted in more sows exhibiting a lactation oestrus (90% vs. 56%; $\chi^2 = 9.58$, $P < 0.01$). The incidence of lactation oestrus was higher between days 0 – 6 after the start of boar exposure than days 7 – 12 (90% vs. 10%; $\chi^2 = 72.97$, $P < 0.01$; Figure 1). The interval from day 18 of lactation to lactation oestrus was similar across all treatments, as was the duration of oestrus (Table 2.2). There was no treatment effect on progesterone concentration 10 days after the first detection of lactation oestrus, (SPW0 20.2 ±1.5; SPW3 17.1 ± 1.8; SPW5 18.0 ± 2.1; SPW7 17.3 ± 1.0 ng/ml).

Two sows not exhibiting a lactation oestrus from treatment groups SPW5 and SPW7 were culled from the herd post-weaning due to lameness. Of the sows which didn't show an oestrus during lactation (n=14) the interval from weaning to the first post-weaning oestrus was 3.8 ± 0.3 days (range 1 – 5 days; n=12).

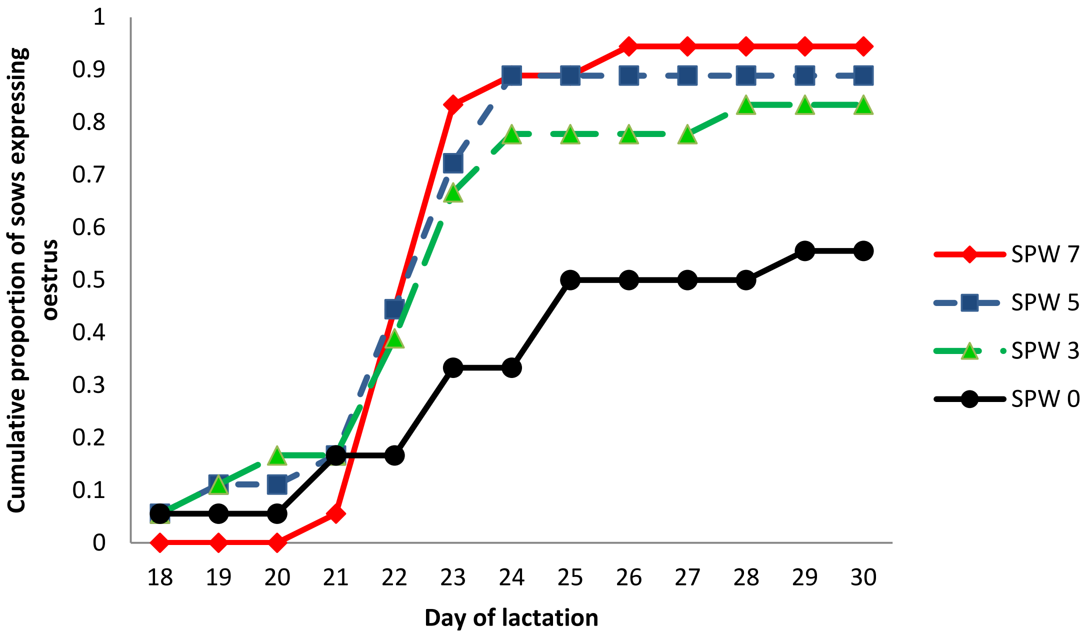

Figure 2.1 Cumulative proportion of sows expressing oestrus relative to the day post-partum, for treatments SPW7, SPW5, SPW3 and SPW0, (n= 17, 16, 15, 10 respectively) beginning on day 18 and finishing on day 30 post-partum

Table 2.2 Cumulative percentage of sows expressing oestrus during lactation and pregnancy rate of sows mated

	Cumulative % of sows expressing lactation oestrus		*n* of sows expressing lactation oestrus	Pregnancy rate[1]	Farrow rate	Days to oestrus[2]	Duration of oestrus
	Day 18-24	Day 18-30					
SPW0	33.3[a]	55.6[a]	10/18	100%[a]	100%	5.4 ± 0.6	2.5 ± 0.2
SPW3	77.8[b]	83.3[b]	15/18	67%[b]	100%	4.5 ± 0.5	3.0 ± 0.2
SPW5	88.9[b]	88.9[b]	16/18	81%[ab]	92%	4.0 ± 0.4	3.1 ± 0.2
SPW7	88.9[b]	94.4[b]	17/18	100%[a]	94%	4.7 ± 0.4	3.1 ± 0.2

[ab]Means within a column with different superscripts differ significantly (P<0.05); [1]Only sows expressing oestrus during lactation; [2]Number of days from the start of treatment (day 18) to expression of oestrus.

2.4.3 Pregnancy and farrowing rates and subsequent reproductive performance of sows mated during lactation

Of the sows mated during lactation, a lower proportion of sows in the SPW3 group were pregnant on day 28 post-mating compared to those in the SPW0 and SPW7 treatments (P<0.05; Table 2.2). There was no effect of treatment (P>0.05; Table 2.2) on the proportion of sows that were pregnant on day 28 post-mating that farrowed.

At their subsequent farrowing, sows that had suckled 10 piglets during lactation gave birth to fewer (P < 0.05) piglets (total born) when compared to sows that had suckled 7 or 5 piglets (Table 2.3). Although SPW3 sows had the lowest pregnancy rate they had the highest total born and born alive of all the treatments. All other parameters were comparable across groups.

Table 2.3 Subsequent reproductive performance of sows mated during lactation

	n	Total born	Born alive	Still born	Mummified foetuses
SPW0	10	8.9 ± 1.1 [a]	8.9 ± 1.1	0.04 ± 0.3	0.19 ± 0.2
SPW3	10	13.1 ± 1.1 [b]	12.3 ± 1.1	0.79 ± 0.3	0.28 ± 0.2
SPW5	12	12.5 ± 1.0 [b]	11.7 ± 1.0	0.83 ± 0.3	0.17 ± 0.1
SPW7	16	11.6 ± 0.9 [ab]	10.8 ± 0.9	0.80 ± 0.2	0.45 ± 0.1

[ab]Means within a column with different superscripts differ significantly ($P<0.05$).

2.4.4 Piglet BW pre-weaning and post-weaning

As intended, piglets weaned on day 18 were 1.0 kg heavier ($P<0.05$) compared to those left on the sow (Table 2.4). Piglets in the SPW0 treatment gained more weight between day 17 and 30 than the other suckled litter sizes ($P>0.05$). Weaning at 18 compared to 30 days of age resulted in a 2.5 kg decrease ($P < 0.05$) in body weight gain between day 17 and 30, but a 1.9 kg increase ($P<0.05$) in body weight gain between day 30 and 40 (Table 2.4). Piglets which were heavier on day 18 of age and consequently weaned were lighter on day 30 compared to piglets weaned on day 30 (Table 2.4). Body weight at day 40 of age and body weight gain between day 2 and 40 post-partum was unaffected by age at weaning.

Table 2.4 Average body weight (BW) and body weight gain of piglets throughout lactation for piglets split weaned at 18 days of age or late weaned at 30 days of age

Treatment	SPW0	SPW3	SPW5	SPW7	Pooled SEM	Weaning age		Pooled SEM
						d 18	d 30	
n	18	36	36	36		54	72	
Suckled litter size[1]	10	7	5	3				
BW, kg								
Day 2	2.0	2.1	2.0	2.0	0.1	2.2 [c]	1.9 [d]	0.04
Day 17	5.8	6.0	5.8	5.5	0.2	6.3 [c]	5.3 [d]	0.1
Day 30	9.6 [a]	9.0 [ab]	8.9 [ab]	8.6 [b]	0.3	8.1 [c]	9.6 [d]	0.2
Day 40	11.1	11.2	11.1	10.9	0.3	11.2	11.0	0.2
BW gain, kg								
Days 2-17	3.8	3.9	3.8	3.4	0.2	4.3 [c]	3.3 [d]	0.1
Days 2-30	7.6 [a]	7.0 [ab]	6.9 [ab]	6.5 [b]	0.3	6.0 [c]	7.6 [d]	0.2
Days 17-30	3.8 [a]	2.9 [b]	3.1 [b]	3.1 [b]	0.2	1.7 [c]	4.2 [d]	0.1
Days 17-40	5.2	5.2	5.3	5.4	0.3	4.9 [c]	5.6 [d]	0.2
Days 30-40	1.5 [a]	2.3 [a]	2.2 [a]	2.5 [b]	0.3	3.3 [c]	1.4 [d]	0.2
Days 2-40	9.1	9.1	9.1	8.7	0.4	9.1	8.9	0.2

[1]Suckled litter size between day 18-30; n=number of litters; [ab]Means within a row with different superscripts differ significantly (P<0.05); [cd]Means within a row for weaning age with different superscripts differ significantly (P<0.05).

2.5 Discussion

Overall, the current data demonstrated that split weaning in combination with fence-line boar exposure is an effective stimulant of lactation oestrus in individually housed sows, with the incidence of lactation oestrus further improved when a greater number of piglets are removed. Previously, less than 14% of sows exhibited lactation oestrus in response to boar exposure, with or without split weaning (Rowlinson and Bryant 1982; Walton 1986; Newton et al.,1987a). Therefore, to the best of our knowledge, the current data provide the first evidence that a high proportion of lactating sows can respond to split weaning and boar exposure with the sequence of endocrine and ovarian changes necessary for ovulation. Split weaning increased the number of piglets born at the subsequent farrowing, extending previous data that split weaning increased follicle growth prior to weaning and embryo number in sows mated after weaning (Grant 1989; Zak et al., 2008). Notably, no long term effects on piglet growth were observed when weaning occurred at 18 compared to 30 days of age.

It is evident from the current data that boar stimulation can overcome lactation anoestrus in a large proportion of sows. Providing lactating sows with boar exposure previously resulted in few sows exhibiting oestrus prior to weaning (0 - 13%) Compared to animals used in studies conducted in the 1990's (reviewed by (Whittemore 1996; Kemp et al., 2006)), modern genotypes exhibit an increased propensity to return to oestrus rapidly after weaning, despite nutritional restriction (Vinsky et al., 2006; Patterson et al., 2010, 2011) or high levels of tissue mobilization (Schenkel et al., 2010). Short weaning to oestrus intervals occur when follicle growth and LH pulse frequency during lactation are higher (Shaw and Foxcroft 1985; Tokach et al., 1992; Van den Brand et al., 2000; Bracken et al., 2006), suggesting the inhibitory effects of lactation on LH release and thus follicle growth may be less severe in modern genotypes. Further to this the prevalence of sows spontaneously ovulating during lactation is markedly higher in recent (Gerritsen et al., 2009) compared to early studies (Thompson et al., 1981; Grinwich and McKay 1985; Newton et al., 1987a, b). A low percentage of sows, 5%, in the current study exhibited a spontaneous and ovulatory oestrus on the first day of treatment suggesting the level of LH release during lactation was increasing prior to day 18. These data are supported by the work of van Wettere et al., (2013) where only 9% of non-boar exposed sows ovulated during lactation by day 21 in response to being removed from their lactation crates daily for 5 minutes and testing for a standing oestrus in a pen where no boars were present. As a consequence, the increase in LH release during lactation, believed responsible for boar-induced follicle growth (reviewed by (Langendijk et al., 2006; van Wettere and Hughes 2008) is more likely to occur and result in a lactation ovulation.

The efficacy of boar exposure as a stimulus of oestrus in weaned sows and pre-pubertal gilts is well accepted (Pearce and Hughes 1987; Hughes et al., 1990; Knox et al.,2002; Zak et al., 2008). Follicle growth and ovulation in response to the boar is attributed to an increase in LH pulses and amplitude (Kingsbury and Rawlings 1993). The increased capacity of sows in the current study to ovulate during lactation in response to a reduction in piglet numbers and boar exposure compared to boar exposure alone could be explained by a reduction in the intensity of lactation anoestrus experienced by modern genotypes and a more developed hypothalamic pituitary ovarian axis (discussed by van Wettere et al., 2013). Certainly, the ability of the majority of sows in this study to express a fertile oestrus by day 24 of lactation indicated that not only can follicular growth and maturation resume in the lactating sow after the second week of lactation but that these follicles can reach ovulatory sizes by the third week of lactation.

As suckled litter size was reduced from 10 there was an increase in the expression of oestrus. A reduction in suckling frequency or intensity can result in high incidences of lactation oestrus likely due to the immediate increase in LH pulse frequency that follows litter removal (Thompson et al., 1981; Rowlinson and Bryant 1982; Grinwich and McKay 1985; Armstrong et al., 1988; Grant 1989; Hultén et al., 2006; Langendijk et al., 2007; Gerritsen et al., 2008b, c; Zak et al., 2008; Soede et al., 2012). An increased metabolic demand during lactation has been linked to decreased LH release and ovarian development (Auldist et al., 1998; Kim and Easter 2001; Quesnel et al., 2007). Improved metabolic status during lactation may therefore promote LH release and, concomitantly with reduced suckling, influence the sow's ability to express a lactation oestrus (Quesnel et al., 2007). However, the effects of live weight losses during lactation on subsequent reproductive performance of multiparous sows are only evident when weight loss exceeds 10% (Thaker and Bilkei 2005; Schenkel et al., 2010). In the current study, the increase in lactation oestrus expression that occurred as litter size was reduced from 10 to 7 occurred in the absence of an appreciable loss in live weight, and may, therefore, be attributed to a reduction in suckling intensity rather than metabolic demand. Support for a relationship between suckling intensity and ovarian development is provided by the study of Grant (1989), in which the positive effects of split weaning on LH pulsing and follicle growth were enhanced when the numbers of teats available for sucking were restricted. Further, Zak et al., (2008) demonstrated that decreasing suckled litter size prior to weaning increased LH pulse frequency despite sow intake being reduced to ensure a similar metabolic status to sows experiencing no change in suckled litter size.

The positive effects of reducing suckled litter size on lactation oestrus expression were also associated with an increase in the total number of piglets born at the subsequent farrowing. It is therefore reasonable to suggest that not only does a reduction in suckled litter size increase the capacity of sows to ovulate in response to boar stimulation it may also increase the number and quality of embryos shed. However the small number of animals that farrowed makes it difficult to draw firm conclusions on the effects of suckled litter size on subsequent litter size. Reasons as to why the SPW3 treatment had a lowered farrowing rate but high litter sizes are difficult to ascertain as numbers are too small and it's not possible to differentiate if it was an early or late pregnancy loss. It is worth noting that the litter size of multiparous sows mated at their first post-weaning oestrus during the same period, and within the same environment, had a subsequent total born litter size and a born alive rate (n=238, 11.7 ± 0.2 and 10.9 ± 0.2, respectively) similar to the sows mated during lactation. These data suggest that mating sows in the fourth week of their lactation, as opposed to after weaning, did not negatively affect subsequent litter size. Previous research suggests the subsequent litter size of sows mated during lactation is affected by the timing of mating relative to parturition and whether lactation is maintained post-insemination (Gaustad-Aas et al., 2004). It has been suggested that the best reproductive outcomes occur when lactating sows are mated after day 21 post-partum and sows are weaned within 7 days of mating (Gaustad-Aas et al., 2004; Soede et al., 2012), therefore given the majority of sows in the current study were mated between days 22 and 25 (n = 45/58) post-partum and with lactation continuing for an average of 7.4 days post-mating, the current study is consistent with these recommendations.

In the current study, piglets allowed to suckle for 30 days gained 2.5 kg more weight from day 18-30 than piglets which were weaned at 18 days old. However, between days 30-40 early weaned piglets gained 1.9 kg more than the day 30 weaned piglets indicating that all piglets experienced a post-weaning growth check regardless of their age at weaning. Despite the split weaned piglets being 1.0kg heavier at day 17 of age, there were no observed weight differences between piglets weaned at day 18 of age and their later weaned counterparts between days 2-40 and at 40 days of age suggesting that apart from the initial decline in growth of the split-weaned piglets, there were no long term effects on growth. The current findings were, therefore, in agreement with previous conclusions from Mahan and Lepine (1991) and Pluske and Williams (1996) that piglet weight at weaning, regardless of weaning age, is a major determinant of subsequent growth.

In conclusion, split weaning combined with fence-line boar exposure resulted in a high proportion of sows expressing a lactation oestrus. The reduced suckling input and effect of the boar likely promoted LH release thereby enabling ovarian follicle growth and a higher expression of lactation oestrus. Additionally, piglet growth was not compromised by early weaning, with both early and late weaned piglets experiencing similar body weight gains by day 40 of age. For these reasons it is evident that split weaning is a practical and commercially relevant method of altering the suckling stimulus to induce a lactation oestrus. By uncoupling weaning from ovulation and the resumption of oestrous cyclicity it is possible to extend the suckling period for the benefit of the piglet, whilst maintaining sow productivity.

CHAPTER THREE

Optimal timing of boar exposure relative to parturition for stimulation of lactation oestrus

R Terry[a*], Karen L Kind[a], Alice C Weaver[a], Paul E Hughes[b], William HEJ van Wettere[a]

[a]School of Animal and Veterinary Sciences, The University of Adelaide, Roseworthy Campus, Roseworthy, South Australia 5371, Australia

[b]Pig and Poultry Production Institute, Roseworthy Campus, Roseworthy, SA 5371, Australia

Livestock Science, 2015, 177, 181-188.

STATEMENT OF AUTHORSHIP

Title of Paper	Optimal timing of boar exposure relative to parturition for stimulation of lactation oestrus
Publication Status	Published
Publication Details	Terry R, Kind KL, Weaver AC, Hughes PE, van Wettere HEJ (2015) Optimal timing of boar exposure relative to parturition for stimulation of lactation oestrus. *Livestock Science* **177**, 181-188.

Principal Author

Name of Principal Author	Robyn Terry		
Contribution to the Paper	Data collection, data analysis, data interpretation, author of manuscript, and corresponding author.		
Overall percentage (%)	85		
Signature		Date	23/07/2015

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

iv. the candidate's stated contribution to the publication is accurate (as detailed above);
v. permission is granted for the candidate to include the publication in the thesis; and
vi. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution

Name of Co-Author	Karen Kind		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	5/07/2015

Name of Co-Author	Alice Weaver		
Contribution to the Paper	Technical Support		
Signature		Date	10/07/2015

Name of Co-Author	Paul Hughes		
Contribution to the Paper	Scientific contribution		
Signature		Date	14/07/2015

Name of Co-Author	William van Wettere		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	13/07/2015

3.1 Abstract

This study evaluated the effect of full physical boar exposure at different stages of lactation on the incidence of lactation oestrus in both primiparous and multiparous sows. A total of 38 primiparous and 80 multiparous sows (parity 2 to 6; 3.1 ± 0.18) of Large White x Landrace genetics were individually housed in conventional farrowing crates from 1 week before expected farrowing until weaning on day 27.5 ± 0.08 post-parturition. The experiment was designed as a 2 x 4 factorial, incorporating the two sow parity groups, and boar exposure commencing on one of four days post-farrowing (days 10, 14 and 18 of lactation and weaning). The eight treatments were as follows: primiparous sows, boar exposure starting on day 10 (n = 10), day 14 (n = 9), day 18 (n = 9) and weaning (n = 10); multiparous sows boar exposure starting on day 10 (n = 20), day 14 (n =20), day 18 (n = 20) and weaning (n = 20). According to treatment, sows were taken daily to a detection mating area where they received 20 minutes of boar exposure and were artificially inseminated at the first observed oestrus. A significant effect of replicate on the incidence of lactation oestrus was found; specifically, the proportion of sows expressing a lactation oestrus was lower in replicate 4 (autumn) than in the other three replicates (winter / spring; 0.15 vs. 0.51; $P < 0.01$). In replicate 1 – 3, a significantly higher proportion of multiparous compared to primiparous sows experienced a lactation oestrus (0.63 vs. 0.36; $P < 0.05$). Lactation oestrus expression was lower for multiparous sows starting boar exposure on day 14 compared to day 18 post-partum (0.38 vs. 0.79, respectively; $P < 0.05$), but was similar for days 10 and 18 of lactation (0.69 vs. 0.79, respectively; $P > 0.05$). Commencing boar exposure on day 18 as opposed to day 10 post-partum significantly reduced the interval from boar exposure to lactation oestrus expression (4.5 ± 0.8 vs. 7.7 ± 0.8 days, respectively; $P < 0.05$). Therefore, full physical boar exposure stimulated a high proportion of lactation oestrus in multiparous sows; however, season impacted this expression, and first parity sows are less likely than multiparous sows to express a lactation oestrus. In conclusion, there

appears to be no benefit in commencing boar exposure before day 18 post-partum to stimulate a lactation oestrus.

3.2 Introduction

Early weaning strategies are used to maximize the number of litters per sow per year, and often result in poor post-weaning performance of light weight piglets (Cabrera et al., 2010). One solution to this problem would be the development of alternative management practices which extend lactation for the benefit of the light weight piglet without impairing sow productivity. This could be achieved by stimulating sows to ovulate and conceive within 30 days of farrowing whilst maintaining lactation, thus enabling piglet weaning age to be increased. After weaning, suckling induced inhibition of LH and FSH release is removed, and typically culminates in oestrus and ovulation within 5-7 days of weaning. However, suckling induced inhibition of gonadotrophins is reduced as lactation progresses making it possible for sows to be mated prior to weaning, as long as a positive stimulus for LH release is provided (Rowlinson and Bryant 1982; Varley and Foxcroft 1990). A number of studies have reported lactation oestrus in the sow in response to boar exposure, split weaning, intermittent suckling, and exogenous gonadotrophins (Guthrie et al., 1978; Newton et al., 1987a, b; Gerritsen et al., 2008a; Zak et al., 2008). It has recently been demonstrated that providing lactating sows with fence-line exposure with a mature boar, coupled with split weaning, from day 18 of lactation onwards will stimulate a high proportion of sows to express oestrus, and ovulate during lactation (Chapter Two). Boars are used widely throughout the pig industry to stimulate oestrus in pre-pubertal gilts and weaned sows, with boar-component stimuli known to stimulate an increase in circulating LH release and the proportion of sows exhibiting oestrus post-weaning (Kingsbury and Rawlings 1993; Langendijk et al., 2000; Rekwot et al., 2001; Patterson et al., 2002). Fence-line boar exposure commencing on day 1 post-partum increased the proportion of multiparous sows demonstrating a lactation oestrus by 52%, compared to sows not receiving boar exposure (van Wettere et al., 2013). First lactation sows are less likely to exhibit a lactation oestrus compared to multiparous sows. Using intermittent suckling, Soede et al., (2012) observed lactation oestrus in 23% of primiparous sows compared with 68% of multiparous sows. Typically, first parity sows have a poorer reproductive performance than older parity sows in terms of weaning to oestrus intervals, litter sizes and weaning weights which is often impacted further due to high weight losses during lactation (Koketsu and Dial 1997; Clowes et al., 2003b). A greater proportion of sows may respond to boar exposure commencing later in lactation due to higher LH levels, greater follicle development and reduced suckling in late lactation (Britt et al., 1985). Sows are characteristically anoestrus during lactation; however, in the later stages of lactation LH pulsatility is restored in both primiparous (van den Brand et al., 2000) and multiparous sows (Kemp et al., 1995) most likely due to the decrease in suckling intensity during this time (Valros et al., 2002; Alonso-Spilsbury et al., 2004). However, sows may respond to boar exposure commencing earlier in lactation giving them a greater amount of stimulation to achieve higher rates of lactation oestrus. Chapter Two showed a low percentage (5%) of multiparous sows exhibited a spontaneous oestrus on day 18 of lactation, indicating that LH levels may be increasing prior to day 18 in high performing sows. Therefore, the primary objective of the current study was to determine the optimal time during lactation to commence full physical boar exposure to stimulate the greatest proportion of primiparous and multiparous sows to ovulate and conceive during lactation.

3.3 Materials and Methods

This study was conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC 2004). All experimental procedures were conducted at the University of Adelaide's Roseworthy piggery, South Australia, with approval from the Animal Ethics Committee of The University of Adelaide, South Australia.

3.3.1 Animals, management and treatments

The experiment consisted of four replicates; replicates 1-3 were conducted between August 2011 and November 2011 and replicate 4 was conducted in March 2012. A total of 38 primiparous and 80 multiparous (parity 2 to 6; 3.1 ± 0.18) Large White x Landrace sows were individually housed in conventional farrowing crates from 1 week before expected farrowing until weaning. Piglets were weaned on day 27.5 ± 0.08 post-parturition (day 0 = first 24 hours post-parturition). Throughout lactation sows received a commercial lactation diet (14.6 MJ DE/kg, 18.7% CP, 1.0% total lysine) fed at increasing amounts from 1 kg on the day of farrowing to a maximum of 7 to 8 kg/day, fed over three meals, by day 7 of lactation. The facility used in the study is a high health status herd and there were no threats of any infectious diseases on the reproductive outcomes of the sows used. To ensure no effect of disease on the reproductive outcomes all sows were vaccinated against porcine parvovirus.

The experiment was designed as a 2 x 4 factorial, incorporating two sow parity groups (primiparous vs. multiparous) and boar exposure commencing on one of four days post-farrowing (days 10, 14 and 18 of lactation and weaning). The eight treatments were as follows: primiparous sows, boar exposure starting on day 10 (n = 10), day 14 (n = 9), day 18 (n = 9) and weaning (n = 10);

multiparous sows, boar exposure starting on day 10 (n = 20), day 14 (n =20), day 18 (n = 20) and weaning (n = 20). Average parity did not differ across treatment groups for multiparous sows. Allocations were conducted at farrowing shed entry to ensure sows in different treatments were housed in different farrowing rooms to avoid boar pheromones being transferred (note, rooms were alternated between replicates). A reduced number of primiparous sows, compared to multiparous sows, were available for use in the study and due to these issues with availability no primiparous sows were included in replicate four.

Within 72 hours of farrowing, litter size was standardized to 11 piglets. Boar exposure consisted of 20 minutes of full, physical exposure with a mature boar (> 12 months of age) with up to three sows in a detection mating area. Four mature boars were used throughout each replicate. Sows were artificially inseminated at first detection of oestrus and every 24 hours thereafter until a standing reflex was no longer observed or they had been inseminated a total of four times, whichever came first. Sows receiving boar exposure during lactation were weaned on day 28 post-parturition (day 0 = first 24 hours post-parturition), with those commencing boar exposure at weaning weaned on day 26 post-parturition. Sows commencing boar exposure at weaning were removed from their farrowing crate for 5 minutes each day from day 10 post-parturition to weaning to check for oestrus behaviours by testing for a standing reflex and a reddened vulva. They were taken to a designated area away from their piglets and in the absence of any boar pheromones. Post-weaning, and regardless of treatment, sows that failed to display oestrus during lactation continued to receive 15 minutes of daily boar exposure until first expression of oestrus or day 14 post-weaning. Sows failing to express oestrus within 14 days of weaning were described as anoestrus.

3.3.2 *Sow and piglet measures*

Sow live weight and P2 backfat were measured on day 1 of lactation and at weaning. P2 backfat was measured over the last rib, 65 mm from the vertebrae, using a 5 MHz linear probe (Aquila Vet, Pie Medical Equipment).

Whole litter weights and piglet numbers were recorded on day 3 of lactation and weaning. The interval from start of boar exposure to first detection of oestrus was recorded. The proportions of sows experiencing a lactation oestrus, a post-weaning oestrus, and an oestrus by day 14 post-weaning were recorded. Subsequent reproductive performance, including pregnancy rates and litter size were recorded.

3.3.3 *Blood progesterone concentrations*

A pre-prandial blood sample was taken by jugular venipuncture into a 9 ml Heparin-Lithium coated collection tube (Vacuette, Greiner Labortechnik, Austria) at the commencement of lactation boar exposure, at weaning, and 10 days after the first detection of oestrus to confirm the occurrence of lactation ovulation and to compare progesterone concentration between treatment groups. Blood samples were maintained on ice and were centrifuged at 1500g for 15 minutes and plasma was stored at -20°C.

Blood samples were analysed for progesterone (P4) concentration in 50 µl of plasma, in duplicate using a coated tube radio immunoassay, according to the manufacturer's instructions (M118; Beckman Coulter, Brea, CA, USA). The lowest detectable concentration was 0.1 ng per ml. The intra assay coefficient of variation was less than 10%. The inter assay coefficient of variation was less than 15%. One QC was used at a concentration of 1.2 ng/ml, the intra assay CV of the QC sample was 6.2% and the inter assay CV was 6.8% across 5 assays.

3.3.4 Pregnancy status and farrowing rates

Pregnancy status was determined in all sows by transabdominal ultrasound at approximately 28 days post insemination. The number of piglets born alive, stillborns, and mummies were recorded in the subsequent litter of the sows that were inseminated during lactation.

3.3.5 Statistical Analysis

Unless otherwise stated, data are expressed as mean ± standard error of the mean (SEM). In all analyses the sow was the experimental unit. A general analysis of variance (ANOVA), with experimental replicate built in, was used to determine treatment effects on sow body condition measures with sow parity and sow live weight on day 1 included as covariates. Sow live weight loss was included in the ANOVA model when determining treatment effects on days to oestrus and duration of oestrus. An ANOVA, with experimental replicate built in, was used to determine whether lactation oestrus or lactation anoestrus sows differed with respect to live weight and P2 during lactation or litter performance. The cumulative proportion of sows expressing oestrus during lactation and farrowing rate were analysed as χ^2. Effects of treatment and parity on litter weight and litter weight gain were analysed using an ANOVA, with experimental replicate included in the model. Subsequent reproduction including total born, born alive, stillborns and mummies were analysed using an ANOVA with experimental replicate built in and sow parity and sow live weight loss between day of lactation and weaning used as a covariate. An ANOVA was used to determine treatment and parity effects on P4 levels ten days after first oestrus detection for sows expressing oestrus during lactation.

All analysis, excluding the cumulative proportion expressing oestrus, was performed using Genstat, 10th Edition (Rothamsted Experimental Station, Harpenden). Probability values less than 0.05 were described as significant.

3.4 Results

3.4.1 Sow body condition

Multiparous sows were heavier than primiparous sows on day 1 of lactation and at weaning ($P < 0.05$; Table 3.1), however, the percentage of live weight loss over lactation was not significantly different between parity groups ($P>0.05$; Table 3.1). The live weight at day 1 of lactation and weaning and live weight loss did not differ between treatments ($P > 0.05$; Table 3.1). Despite having similar P2 backfat on day 1 of lactation, multiparous sows had greater P2 backfat at weaning, and lost less P2 backfat over the course of lactation than primiparous sows ($P < 0.05$; Table 3.1). Sows which expressed a lactation oestrus were heavier on days 1 and 28 of lactation compared to sows which remained anoestrus during lactation (259.1 ± 6.70 vs. 237.8 ± 5.70 kg ($P < 0.05$) and 240.8 ± 6.63 vs. 223.9 ± 5.72 kg ($P = 0.063$), respectively). However, there was no difference in the percentage of live weight lost over lactation between sows which were anovulatory or ovulatory during lactation (6.3 ± 1.3 vs. 7.0 ± 1.8, respectively; $P = 0.763$). There was no difference in P2 or P2 change during lactation or litter performance between lactation oestrus or anoestrous sows. There was an interaction between treatment and parity for P2 backfat loss, with primiparous sows starting boar exposure at weaning losing less P2 backfat than those starting boar exposure during lactation (3.0 ± 1.2 vs. 7.2 ± 1.2 mm respectively; $P<0.05$).

Table 3.1 Live weight (kg), live weight change and P2 backfat (P2) for primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 post-partum (pp) or at weaning.

Item	Start BE[1]				Parity	
	Day 10	Day 14	Day 18	Wean	PP	MP
n	30	29	29	30	38	80
LW, kg						
Day 1, pp	256.1 ± 6.2	237.4 ± 6.3	246.3 ± 6.3	247.7 ± 6.2	213.3 ± 5.9 [a]	262.9 ± 3.9 [b]
Wean, pp	236.9 ± 5.6	223.9 ± 5.8	230.8± 5.7	236.9 ± 5.6	196.4 ± 5.3 [a]	249.5 ± 3.6 [b]
LW loss, kg						
Days 1-wean	19.1 ± 2.9	13.7 ± 3.0	15.4 ± 2.9	10.8 ± 2.9	17.0 ± 2.7	13.7 ± 1.8
% LW loss, kg						
Days 1-wean	7.4 ± 2.0	8.9 ± 2.1	6.0 ± 2.1	3.9 ± 2.0	6.5 ± 1.9	6.6 ± 1.3
P2, mm						
Day 1, pp	23.3 ± 1.0	22.8 ± 1.0	23.8 ± 1.0	24.6 ± 1.0	24.6 ± 0.9	23.2 ± 0.6
Wean, pp	20.1 ± 0.9	20.0 ± 0.9	20.0 ± 0.9	21.4 ± 0.9	18.9 ± 0.8 [a]	21.1 ± 0.6 [b]
P2 loss, mm						
Days 1-wean	3.2 ± 0.7	3.0 ± 0.7	3.8 ± 0.7	3.1 ± 0.7	5.8 ± 0.7 [a]	2.1 ± 0.4 [b]

[ab]Within a row means with different superscripts differ (P<0.05); [1]Day post-partum that boar exposure was started with parity combined.

3.4.2 Oestrus expression

Due to matters beyond our control, the weaning to oestrus data for replicate four is unavailable. One multiparous sow in replicate one which was not to receive boar exposure until weaning (control group), ovulated spontaneously during lactation on day 21 post-partum and weaned 11 piglets. She was weaned on day 26 of lactation confirmed to be pregnant and farrowed 13 born alive and 2 still born piglets. This sow has been removed from the analyses of timing of oestrus during lactation.

There was a significant effect of replicate on the incidence of lactation oestrus ($P < 0.01$; Table 3.2). Specifically, regardless of the day of boar exposure commencement the incidence of lactation oestrus was significantly lower in replicate 4 (autumn) than in the other three replicates (winter / spring; 0.15 vs. 0.51; $P < 0.01$; Table 3.2).

In replicates 1 – 3, regardless of when boar exposure started, a significantly higher proportion of multiparous compared to primiparous sows experienced a lactation oestrus (0.63 vs. 0.36; $P < 0.05$). For multiparous sows only, lactation oestrus expression was lower for sows starting boar exposure on day 14 compared to day 18 post-partum (0.38 vs. 0.79; $P < 0.05$), but was similar for sows starting boar exposure on days 10 and 18 of lactation. There was no effect of treatment on the proportion of multiparous or primiparous sows expressing oestrus within 14 days of weaning ($P > 0.05$; Table 3.2). There was a significant effect ($P < 0.05$) of parity on the duration of lactation oestrus, with the mean oestrus length longer in multiparous (2.89 ± 0.14 days; range 2 – 4 days) compared to primiparous sows (1.97 ± 0.24 days; range 1 – 3 days).

Table 3.2 Incidence of oestrus for primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 of lactation or at weaning

Parity	Start BE[1]	n[2]	Replicates 1 – 3 (spring / winter) Proportion of sows oestrus		Replicate 4 (summer / autumn) Proportion of sows oestrus		
			During lactation	Post weaning	n[3]	During lactation	Post weaning[4]
PP	Day 10	10	0.40 (4/10) ^{a}	0.50 (5/10) ^{a}	-	-	-
PP	Day 14	9	0.33 (3/9) ^{a}	0.44 (4/9) ^{a}	-	-	-
PP	Day 18	9	0.33 (3/9) ^{a}	0.67 (6/9) ^{a}	-	-	-
PP	Weaning	10	0.00 (0/10) ^{b}	1.00 (10/10) ^{b}	-	-	-
MP	Day 10	13	0.69 (9/13) ^{xy}	0.31 (4/13) ^{y}	7	0.29 (2/7)	0.71 (5/7)
MP	Day 14	13	0.38 (5/13) ^{xz}	0.62 (8/13) ^{yz}	7	0.00 (0/7)	0.86 (6/7)
MP	Day 18	14	0.79 (11/14) ^{y}	0.21 (3/14) ^{y}	6	0.17 (1/6)	0.67 (4/6)
MP	Weaning	13	0.08 (1/13) ^{z}	0.85 (11/13) ^{z}	7	0.00 (0/7)	1.00 (7/7)

^{ab}Within a column and within primiparous sows, means without a common superscript differ (P<0.05); ^{xyz}Within a column and within multiparous sows, means without a common superscript differ (P<0.05); [1]Day post-partum that boar exposure was started; [2]number of primiparous and multiparous sows in replicates 1, 2 and 3; [3]number of multiparous sows in replicate 4 (NB no primiparous sows were able to be included in replicate 4); [4]As no post-weaning dates are available these results are based on sows which farrowed on an average of 116 days post-weaning.

There was no effect of replicate on the timing of lactation oestrus, and therefore the data for all replicates were analysed together ($P > 0.05$; Table 3.3). Commencing boar exposure on day 18 as opposed to day 10 post-partum significantly reduced the interval from boar exposure to lactation oestrus expression ($P < 0.05$; Table 3.3). However, lactation oestrus expression did occur sooner relative to parturition for sows starting boar exposure on day 10 as opposed to day 18 of lactation ($P < 0.05$; Table 3.3). The boar exposure to lactation oestrus interval was significantly longer in sows commencing boar exposure on day 10, compared to day 14 or 18 ($P < 0.05$; Table 3.3). Although not significant, regardless of boar exposure treatment, the interval from the start of boar exposure to lactation oestrus expression was shorter for multiparous compared to primiparous sows (Table 3.3; $P = 0.07$). For sows which did not exhibit a lactation oestrus, the interval from weaning to oestrus was not different between treatments or parity (Table 3.3; $P > 0.05$).

Table 3.3 Timing of oestrus for primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 of lactation or at weaning (All blocks).

Parity	Start BE[1]	BE to lactation oestrus	Weaning to oestrus interval	Farrow to lactation oestrus	Farrow to oestrus
All	Day 10	7.7 ± 0.8[a]	4.9 ± 0.8	17.9 ± 0.9[a]	23.8 ± 2.2
	Day 14	5.9 ± 1.2[b]	4.0 ± 0.7	19.2 ± 1.2[a]	29.6 ± 2.2
	Day 18	4.5 ± 0.8[b]	4.0 ± 0.9	22.6 ± 0.9[b]	29.5 ± 2.1
	Weaning	-	5.5 ± 0.5	-	31.1 ± 2.2
PP	All	8.1 ± 1.1	4.9 ± 0.5	21.4 ± 1.1	31.3 ± 1.7 [a]
MP	All	5.4 ± 0.6	4.8 ± 0.5	19.6 ± 0.6	26.5 ± 1.4 [b]

[cd]Within a column, means with different a common superscripts differ (P<0.05); [1]Day post-partum that boar exposure was started; [ab]Within a column, means with different superscripts differ (P<0.05).

3.4.3 Subsequent reproductive performance

There was no effect of the interaction between the timing of boar exposure and parity on subsequent farrowing rate (Table 3.4; P > 0.05). Farrowing rate was lower for multiparous compared to primiparous sows inseminated during lactation (Table 3.4; P < 0.05). The farrowing rates were higher for multiparous sows inseminated post-weaning compared to during lactation (Table 3.4; P < 0.05).

Table 3.4 Farrow rates for primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 of lactation or at weaning.

Parity	Start BE[1]	Farrow rate[2]	
		AI in lactation, %	AI Post-weaning, %
PP	Day 10	100 (4/4)	80 (4/5)
	Day 14	100 (3/3)	100 (4/4)
	Day 18	100 (3/3)	50 (3/6)
	Weaning	-	90 (9/10)
MP	Day 10	55 (6/11)	89 (8/9)
	Day 14	60 (3/5)	93 (13/14)
	Day 18	58 (7/12)	86 (6/7)
	Weaning	100 (1/1)	100 (18/18)
PP	All	100 (10/10)[a]	80 (20/25)
MP	All	59 (17/29)[b y]	94 (45/48) [z]

[ab]Within a column, means with different superscripts differ (P<0.05); [yz]Within a row, means with different superscripts differ (P<0.05); [1]Day post-partum that boar exposure was started; [2]For multiparous sows, all four replicates have been combined.

There was no effect of the timing of boar exposure on subsequent litter size (Table 3.5; P > 0.05). Multiparous sows had a higher subsequent total born and born alive than primiparous sows (Table 3.5; P <0.05). Multiparous sows tended to have a higher stillborn rate than primiparous sows (Table

3.5; P = 0.09). There was no main effect of insemination during lactation or post-weaning on subsequent litter size for total born, born alive, and mummies; however, sows inseminated during lactation had a higher stillborn rate (Table 3.5; P = 0.02).

Table 3.5 Subsequent litter size for primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 of lactation or at weaning.

	Subsequent reproductive performance			
	Total born	Born alive	Still born	Mummies
Start of BE[1]				
Day 10	12.3 ± 0.6	11.3 ± 0.5	0.7 ± 0.2	0.3 ± 0.2
Day 14	11.9 ± 0.6	10.7 ± 0.5	0.9 ± 0.2	0.4 ± 0.2
Day 18	11.3 ± 0.6	10.6 ± 0.6	0.4 ± 0.2	0.3 ± 0.2
Weaning	12.6 ± 0.5	11.7 ± 0.5	0.6 ± 0.2	0.3 ± 0.1
Parity				
PP	11.2 ± 0.5 [a]	10.3 ± 0.4 [a]	0.4 ± 0.2	0.4 ± 0.1
MP	12.5 ± 0.3 [b]	11.5 ± 0.3 [b]	0.7 ± 0.1	0.3 ± 0.1
Timing of mating				
Post-weaning	12.1 ± 0.4	11.3 ± 0.3	0.5 ± 0.1[a]	0.4 ± 0.1
Lactation	13.0 ± 0.9	11.7 ± 0.8	1.3 ± 0.3[b]	0.1 ± 0.3
P-value				
Start of BE	0.41	0.37	0.34	1.00
Parity	0.02	0.03	0.09	0.35
Timing of mating	0.85	0.64	0.02	0.44

[ab]Within a column, means with different a superscripts differ ($P<0.05$); [1]Day post-partum that boar exposure was started.

3.4.4 Progesterone concentration

For sows expressing oestrus during lactation, P4 levels ten days after first oestrus detection were 11.7 ± 2.40, 22.5 ± 3.23 and 16.5 ± 2.51 ng/ml for sows commencing boar exposure on days 10, 14 and 18 post-partum, respectively. Progesterone levels were higher ($P < 0.05$) for sows commencing boar exposure on day 14 compared to day 10. Sows determined to be not in pig at 28 days post first lactation insemination had significantly lower progesterone concentration at 10 day post first lactation insemination than sows determined to be pregnant (8.53 ± 2.7 vs. 19.36 ± 1.8 ng/ml; $P < 0.001$).

3.4.5 Piglet growth

The average number of piglets suckling remained constant across treatments at day 3 of lactation and weaning. There was no effect of timing of boar exposure relative to parturition on litter weight at weaning ($P > 0.05$; Table 3.6). Primiparous sows had lower litter weights and piglet weights on day 3 and at weaning and lower litter and piglet growth rates between days 3 and weaning, compared to multiparous sows ($P < 0.05$; Table 3.6).

Table 3.6 Piglet and litter weight and weight change during lactation for litters suckling primiparous (PP) and multiparous (MP) sows commencing daily boar exposure (BE) on day 10, 14 or 18 post-partum or at weaning.

Item	Treatment				Parity	
	Day 10	Day 14	Day 18	Weaning	PP	MP
Average n piglets, day 3	10.7 ± 0.1	10.4 ± 0.1	10.7 ± 0.1	10.7 ± 0.1	10.5 ± 0.1	10.7 ± 0.1
Average n piglets, weaning	10.1 ± 0.2	9.7 ± 0.2	10.3 ± 0.2	10.0 ± 0.2	9.8 ± 0.2	10.1 ± 0.1
Average litter weight, kg						
Day 3, pp	20.9 ± 0.8	20.4 ± 0.8	19.1 ± 0.8	21.1 ± 0.7	18.7 ± 0.7 [a]	21.2 ± 0.5 [b]
Weaning, pp	90.1 ± 3.7	82.4 ± 3.5	81.9 ± 3.4	78.8 ± 3.9	75.9 ± 3.3 [a]	87.1 ± 2.3 [b]
Average piglet weight, kg						
Day 3, pp	2.0 ± 0.1	2.0 ± 0.1	1.8 ± 0.1	2.0 ± 0.1	1.8 ± 0.1 [a]	2.0 ± 0.1 [b]
Weaning, pp	8.9 ± 0.3	8.5 ± 0.3	7.9 ± 0.3	7.9 ± 0.3	7.6 ± 0.3 [a]	8.6 ± 0.2 [b]
Average litter growth rate, kg						
Days 3-wn	2.6 ± 0.1	2.3 ± 0.1	2.3 ± 0.1	2.3 ± 0.1	2.1 ± 0.1 [a]	2.5 ± 0.1 [b]
Average piglet growth rate, kg						
Days 1-wean	0.25 ± 0.01	0.23 ± 0.01	0.22 ± 0.01	0.23 ± 0.01	0.21 ± 0.01 [a]	0.24 ± 0.01 [b]

[ab] Within a row means without a common superscript differ (P<0.05).

3.5 Discussion

Overall, our data demonstrated that multiparous sows have a greater propensity to ovulate during lactation in response to boar exposure than primiparous sows. The incidence of lactation oestrus expression was similar for primiparous sows regardless of when boar exposure commenced during lactation. Multiparous sows starting boar exposure on day 10 and 18 exhibited the highest proportion of lactation oestrus. The expectation was that sows commencing boar exposure on day 18 of lactation would express a higher proportion of lactation oestrus than sows commencing boar exposure earlier due to higher LH levels, greater follicle development and reduced suckling in late lactation. However, sows starting boar exposure earlier in lactation may also exhibit a higher proportion of lactation oestrus compared to sows beginning boar exposure later in lactation simply due to a more prolonged period of exposure to the boar stimuli.

In conventionally weaned animals, the metabolic demands of lactation exert a greater negative impact on ovarian activity and the subsequent reproductive performance of primiparous compared to multiparous sows (Quesnel and Prunier., 1995; Thaker and Bilkei, 2005). It is, therefore, unsurprising that our data demonstrated a lower incidence of lactation oestrus in primi- compared to multi-parous sows (36 vs. 63%). This finding is supported by the previous study of Soede et al., (2012) in which the incidence of lactation oestrus in response to intermittent suckling was lower for primi- compared to multi- parous sows (23 vs. 68%; Soede et al., 2012). A larger body mass at parturition and decreased protein mobilization during lactation has been associated with improved ovarian activity and follicle development in weaned first lactation sows (Clowes et al., 2003b). It is noteworthy, that sows which expressed oestrus during lactation were heavier at the start of lactation than their anoestrus counterparts. A lactation weight loss greater than 5% has been reported to impair weaning to service interval and total born litter size in first parity sows, whereas a loss of greater than 10% is required for the induction of similar effects in multiparous sows (Thaker and Bilkei, 2005). Lactation weight losses for primiparous sows in the current study were on average 6.5%, which is above the threshold specified by Thaker and Bilkei (2005), suggesting that the metabolic condition of the primiparous sow may be influencing the ovarian response to boar exposure.

During lactation, piglet suckling suppresses the release of gonadotrophin releasing hormone, LH and FSH, and thus prevents ovulation. A gradual decline in the strength of this suppression is evident after the third week of lactation, with a complete cessation occurring at weaning (Varley and Foxcroft 1990; Foxcroft 1992; De Rensis et al., 1993b). In the current study, the majority of primiparous and multiparous sows expressed a lactation oestrus when boar exposure started on day 10 and 18. However, sows which commenced boar exposure on day 18, compared to day 10, exhibited a lactation oestrus within a similar timeframe to a weaned sow (average 4.5 ± 0.8 d vs. average 7.7 ± 0.8 d respectively; $P < 0.05$). This therefore indicates that the expression of a lactation oestrus is not improved by commencing boar exposure earlier in lactation. These data suggest the timing of the sequence of physiological events required for sows to ovulate in response to boar exposure is similar in lactating and weaned sows, as long as boar exposure does not commence too early post-farrowing; a theory supported by Gerritsen et al., (2008a). We would, therefore, recommend that lactation oestrus stimulation should occur at 18 days post-partum, thereby allowing for an interval of 4-5 days between stimulation and insemination.

The stimulatory effect of boar exposure on ovulation and oestrus expression is due to the provision of olfactory, auditory, visual and tactile cues (Booth and Baldwin 1983; van Wettere et al., 2006). Boar exposure stimulates LH release and ovarian follicle growth, and is most commonly used to reduce gilt age at puberty, and post-weaning to facilitate oestrus detection and reduce the interval from weaning to ovulation (Brooks and Cole 1970; Dyck 1988; Soede 1993; Langendijk et al., 2000). The current study provides further evidence that the use of a boar is essential in overcoming a lactation anoestrus (Chapter Two; van Wettere et al., 2013). The capacity of multiparous sows to ovulate in response to boar exposure was lowest when stimulation commenced on day 14 compared to days 10 and 18 which potentially could be related to differences in ovarian maturity at this stage of lactation (Langendijk et al., 2009). For sows that did not express a lactation oestrus in response to the boar, their ability to express a normal post-weaning oestrus was not compromised. This indicates that the hypothalamic-pituitary-ovarian axis was not compromised in these lactation anoestrus sows and their failure to exhibit lactation oestrus may be due to a dichotomous distribution whereby some sows are inherently more responsive to lactation oestrus stimulation; a theory supported by Gerritsen et al., (2008a) and Soede et al., (2012).

The incidence of lactation oestrus was significantly reduced in the fourth replicate which occurred during summer / early autumn, and is when conventionally weaned sows typically experience a seasonally induced reduction in fertility (Paterson et al., 1991; Hughes, 1994; Prunier et al., 1996; Lopes et al., 2014). Seasonal infertility is caused by a decrease in melatonin and elevated temperatures that occur during summer and thereby inducing a suppression of lactation feed intake, LH release and ovarian follicle growth (Peltoniemi et al., 1999; Ramírez et al., 2009). It is, therefore, reasonable to suggest that the lack of lactation oestrus expression in the fourth replicate was due to seasonally induced suppression of LH release and ovarian follicle growth, as well as a reduced capacity to produce the endocrine response to boar stimuli required for ovulation; a theory supported by Newton et al., (1987b). The reduced capacity of sows to express a lactation oestrus during the seasonal infertility period emphasizes the need to conduct further work in this area to develop strategies to overcome this issue if lactation oestrus management systems are to be commercially viable. This work should focus on strategies which increase stimulation of gonadotrophin hormone release, such as more intense or more frequent boar stimulation or exogenous gonadotrophin hormones, or a reduction in the strength or duration of suckling, such as reduced litter sizes or periods of sow and piglet separation.

Overall, mating sows in lactation compared to post-weaning had no effect on the total born alive of the subsequent litter size which is promising for the commercial adoption of this management strategy. However, farrowing rate decreased and stillbirths increased in the multiparous sow, when mating occurred in lactation. It is possible that incomplete uterine involution and a hormonal imbalance may be affecting the sow's follicular development, ovulation rate and embryo survival (Gaustad-Aas et al., 2004). Conception of the subsequent litter should not take place before 21 days post-partum as it is known to reduce the farrowing rate and subsequent litter size (Belstra et al., 2002; Gaustad-Aas et al., 2004; Gerritsen et al., 2008b; Soede et al., 2012). However, on average all sows both primiparous and multiparous, which commenced boar exposure on day 10 or 14, expressed an oestrus before day 21 post-partum with no significant differences in their farrowing rate or subsequent litter size, suggesting the involution of the uterus did not have an impact.

From the current data there is no indication that exposing sows to boar exposure during lactation negatively affected piglet growth rate. These results are consistent with previous findings that no effect was found on piglet growth when these results are compared to sows nursing complete litters (Chapter Two). Piglets suckling primiparous as opposed to multiparous sows were lighter and grew more slowly during lactation, consistent with previous reports in the literature (Mahan, 1998; Carney-Hinkle et al., 2013). These data demonstrate that the stimulation of a lactation oestrus by way of full physical boar exposure can allow for the weaning age of all piglets to be determined on their requirements, rather than the need to reduce the farrowing to re-mating interval.

In conclusion, the current data demonstrates that full physical boar exposure can be used to stimulate a high proportion of multiparous sows to exhibit an oestrus and ovulation during lactation. However primiparous sows are less likely to ovulate during lactation than are higher parity animals. The capacity of multiparous sows to exhibit a lactation oestrus was impaired when boar exposure commenced on day 14 as opposed to day 10 or 18 of lactation however, commencing boar exposure on day 18 as opposed to day 10 post-partum significantly reduced the interval from boar exposure to lactation oestrus expression. The data indicate a possible seasonal variation in the expression of a lactation oestrus which needs to be further investigated across years and genetics and management strategies to overcome this need to be elucidated. Therefore it is recommended that full physical boar exposure is required to stimulate a lactation oestrus; however, commencing boar exposure before day 18 post-partum may not be required.

CHAPTER FOUR

Lactation oestrus induction in multi- and primi-parous sows in an Australian commercial pork production system[1]

R. Terry[a], K.L. Kind[a], D.S. Lines[b], T.E. Kennett[b], P.E. Hughes[c], and W.H.E.J. van Wettere[a]

[a]School of Animal and Veterinary Sciences, The University of Adelaide, Roseworthy Campus, Roseworthy, South Australia 5371, Australia

[b]Australian Pork Farms Group, Stirling, South Australia 5152, Australia

[c]Pig and Poultry Production Institute, South Australian Research and Development Institute, Roseworthy Campus, Roseworthy, SA 5371, Australia

[1]This research was funded by the CRC for High Integrity Australian Pork. We also express our gratitude to the staff of Australian Pork Farms Group for their assistance in the development and technical assistance in the animal phase of this study.

Journal of Animal Science, 2014, 92, 2265-2274.

STATEMENT OF AUTHORSHIP

Title of Paper	Lactation oestrus induction in multi- and primiparous sows in an Australian commercial pork production system
Publication Status	Published
Publication Details	Terry R, Kind KL, Lines DS, Kennett TE, Hughes PE, van Wettere WHEJ (2014) Lactation estrus induction in multi- and primiparous sows in an Australian commercial pork production system. *Journal of Animal Science* **92**, 2265-2274.

Principal Author

Name of Principal Author	Robyn Terry		
Contribution to the Paper	Data collection, data analysis, data interpretation, author of manuscript, and corresponding author.		
Overall percentage (%)	80		
Signature		Date	23/07/2015

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate to include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution

Name of Co-Author	Karen Kind		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	05/07/2015

Name of Co-Author	David Lines		
Contribution to the Paper	Scientific contribution, data collection and technical support		
Signature		Date	14/07/2015

Name of Co-Author	Tracy Kennett		
Contribution to the Paper	Technical Support		
Signature	This person has since left the employment of APFG and is uncontactable. I, Karen Kind as Principal Supervisor, verify that the proportion of contribution to the publication is accurate	Date	22/07/2015

Name of Co-Author	Paul Hughes		
Contribution to the Paper	Scientific contribution		
Signature		Date	14/07/2015

Name of Co-Author	William van Wettere		
Contribution to the Paper	Supervised development of the work, data interpretation and manuscript evaluation		
Signature		Date	13/07/2015

4.1 Abstract

This study evaluated the effect of full physical boar exposure and split weaning on the incidence of lactation oestrus within a large commercial piggery. A total of 299 multiparous (parity 2.5 ± 0.03) and 303 primiparous sows of Large White x Duroc x Landrace genetics were individually housed in conventional farrowing crates from one week before expected farrowing until weaning on day 30.7 ± 0.05 post-parturition. Before shed entry, sows were allocated randomly within parity to receive either boar exposure (BE; n = 454) or no BE (No BE; n = 149). Sows assigned to receive boar exposure were then allocated to one of two litter size treatments: litter size unchanged (BE; n = 302) or litter size split weaned to the seven lightest piglets (BESPW7; n = 152) on day 18 of lactation. From day 18 of lactation until weaning, sows in both boar exposure treatments were taken daily to a detection mating area where they received 15 minutes of full physical boar exposure and were artificially inseminated at the first observed oestrus. Providing sows with boar exposure increased the incidence of lactation oestrus, with a further increase observed when litter size was reduced to seven piglets (16% No BE vs. 62% BE and 75% BESPW7; $P < 0.05$). Multiparous sows exhibited a greater incidence of lactation oestrus than primiparous sows irrespective of treatment (81% compared to 52%, respectively; $P < 0.05$). Both multiparous and primiparous sows exhibited an increased incidence of lactation oestrus when a portion of the litter was removed (multiparous: 76% vs. 89% and primiparous, 47% vs. 61%; $P < 0.05$). Farrowing rates were higher in BE multiparous sows mated post-weaning, and all BESPW7 sows mated post-weaning when compared to their counterparts mated in lactation ($P < 0.05$). Percentage live weight loss over the course of lactation was greatest for sows in the No BE compared to the BE and BESPW7 treatments (7.7% ± 0.5 vs. 5.4% ± 0.3 and 4.5% ± 0.4, respectively; $P < 0.05$). Between day 17 and weaning, piglets suckling sows in the BESPW7 treatment had a higher average weight gain than piglets suckling sows with a full litter (3.5 ± 0.06 vs. 3.1 ± 0.05 kg, $P < 0.05$). In conclusion these data suggest that providing multiparous sows with boar exposure is effective at stimulating

a synchronous lactation oestrus whilst primiparous sows require, in addition to boar exposure, a reduction in suckled litter size to seven piglets.

4.2 Introduction

Lactation anoestrus is common in domestic sows, as follicle growth and ovulation is prevented by the suckling induced inhibition of LH and lactation induced catabolism (Foxcroft, 1992; Soede et al., 2012). Increasing lactation lengths to benefit the piglet extends the sow's non-productive days (Cabrera et al., 2010; van der Meulen et al., 2010). A possible solution is to stimulate sows to ovulate and conceive whilst lactating as this will enable lactation lengths to be optimized for piglet performance and welfare without impairing sow reproductive output or increasing non-productive days.

In order for lactating sows to ovulate during lactation, LH release and ovarian follicle growth need to be stimulated. Techniques such as split weaning and intermittent suckling have been used with varying rates of success to reduce the duration or severity of suckling and allow for the inhibition of LH to be lifted (Matte et al., 1992; Kemp and Soede, 2012; Chapter Two). Stimulating primiparous sows to exhibit a lactation oestrus can be more challenging than stimulating multiparous sows. Using intermittent suckling, Soede et al., (2012) achieved a rate of 23% of primiparous sows exhibiting a lactation oestrus compared to 68% of multiparous sows. In order to overcome these difficulties, primiparous sows may require a greater amount of stimulation during lactation to achieve higher rates of lactation oestrus. Exposing multiparous sows to boar exposure during lactation has been shown to increase the expression of oestrus (61% vs. 9%; van Wettere et al., 2013) with a further increase shown when boar exposure is coupled with split weaning (56% vs. 89%; Chapter Two).

The current study tested two hypotheses; first, that the use of full daily boar exposure coupled with split weaning, in a commercial setting, will increase the incidence of lactation oestrus; second, that the incidence of lactation oestrus will be lower for first parity sows compared to multiparous sows.

4.3 Materials and Methods

This study was conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC, 2004). All experimental procedures were conducted at a large commercial breeding unit in South Australia, with approval from the Animal Ethics Committee of The University of Adelaide, South Australia.

4.3.1 Animals, housing and diet

The experiment consisted of 13 replicates conducted between June 2012 and October 2012. A total of 603 Large White x Duroc x Landrace primiparous sows (n = 303) and multiparous sows (n = 300; parity 2 to 3; 2.5 ± 0.03) were individually housed in conventional farrowing crates from one week before expected farrowing until weaning. Piglets were weaned on day 30.7 ± 0.05 post-parturition (day 0 = first 24 hours post-parturition). On the day of farrowing (day 0) sows were fed 1 kg of a lactation diet (14.0 MJ/kg DE, 17.1% protein, and 0.872% available lysine). On day 1 post-partum this was increased to 2.5 kg of the same lactation diet; by day 5 of lactation sows were receiving 4 kg, and thereafter sows were fed ad libitum to a maximum of 9 kg through to weaning. On day 1 of lactation, litters were standardised to 11 piglets per sow.

4.3.2 Treatments

Before shed entry multiparous (n = 300) and primiparous (n = 303) sows were allocated randomly based on parity to either the control (a conventional lactation with no boar exposure; No BE; n = 149) or to a boar exposure (BE; n = 454) in lactation treatment.

4.3.2.1 Conventional lactation treatment (No BE).

Sows not receiving boar exposure (No BE; n = 149) were housed separately from sows receiving boar exposure during lactation to ensure they were not exposed to any boar pheromones that may be present on sows after full physical boar exposure. Sow live weight and P2 backfat were measured at the start of lactation (1.8 ± 0.1 days post-farrowing; range: 1 – 3) and again on the day of weaning (29.9 ± 0.9 days post-farrowing; range: 28 – 32). A pre-prandial blood sample was taken by jugular venipuncture into a 9 ml heparin-lithium coated collection tube (Vacuette, Greiner Labortechnik, Austria) two days post-weaning between 0700 and 0800 h to measure progesterone (P4) concentration to be able to determine if ovulation had occurred during lactation. Blood samples were maintained on ice and were centrifuged at 1500 x *g* for 15 minutes at 0 degrees. The centrifuge used was not refrigerated and plasma was then stored at -20°C, until assayed for P4.

Blood samples from the No BE sows were analysed for P4 concentration in 50 µl of plasma, in duplicate using a coated tube radio immunoassay, according to the manufacturer's instructions (M118; Beckman Coulter, Brea, CA, USA). The lowest detectable concentration was 0.1 ng per ml. The intra assay coefficient of variation was less than 10%. The inter assay coefficient of variation was less than 15%. Sows with a P4 concentration ≥4 ng/ml on day 2 post-weaning were defined as expressing a spontaneous lactation oestrus.

4.3.2.2 Boar exposure treatments

Sow live weight and P2 backfat were measured at the start of lactation (2.0 ± 0.04 days post-farrowing; range 1 – 4), on day 17 of lactation and again on the day of weaning (30.8 ± 0.05 days post-farrowing; range 29 – 34). On day 17 of lactation, sows were stratified within parity group, according to their average live weight loss (5.7 ± 0.58 kg) between days 1 and 17 of lactation and suckled litter size and allocated to one of the two boar exposure treatments: boar exposure with an unchanged litter size (BE, n = 302) or boar exposure and the litter permanently reduced (split weaned) to 7 piglets (BESPW7, n = 152). Increased numbers of sows were allocated to the boar exposure treatments to ensure that there were adequate numbers of sows with a litter size of 9 or more piglets at weaning, in each parity group, to allow comparison to the split weaned group (BESPW7). All sows started full physical boar exposure on day 18 of lactation and were artificially inseminated at the first detection of a standing oestrus.

4.3.2.3 BE (unchanged litter size)

Sows not receiving a change in litter size at day 18 (BE; n = 302; multiparous n = 151; primiparous n = 151) had their litter weighed on day 17 of lactation and no piglets were removed from the litter (average number of piglets suckling, 9.5 ± 0.01).

4.3.2.4 BESPW7 Boar exposure and the litter permanently reduced (split weaned) to 7 piglets

Only sows with 9 or more piglets suckling (average 10.2 ± 0.06; range 9-11) on day 17 were eligible for allocation to the BESPW7 (n = 152; multiparous: n = 75; primiparous: n = 77) treatment. On day 17 of lactation litters were weighed and the heaviest piglets were identified for split weaning and were then removed from the lactation crate between 0700 and 0800 h on day 18 of lactation.

4.3.3 Boar exposure and oestrus detection

Beginning on day 18 of lactation sows were taken daily from the farrowing crate to a detection mating area and given full physical boar exposure with a mature boar for 15 minutes. The detection mating area was separate from the lactation shed and involved a maximum of a five minute walk for the sows. Within the first three minutes of entering the pen, sows were checked for oestrus using the back pressure test, with the display of a standing reflex defined as the first sign of oestrus. Sows were artificially inseminated at the first detection of oestrus and again every 24 hours until the end of behavioural oestrus or when the sow had received a total of three inseminations, whichever came first. Cervical inseminations were performed using a sponge-tipped disposable catheter with each insemination containing an 80 ml dose of fresh, extended semen (3×10^9 spermatozoa per inseminate; < 4 days old). Semen was purchased from a commercial artificial insemination collection centre. The interval from the start of treatment (day 18) to the first expression of a standing oestrus during lactation was recorded. The duration of oestrus expression (days) was also recorded.

4.3.4 Post-weaning housing of all sows, and boar exposure and artificial insemination of sows not mated during lactation

At weaning, sows mated in lactation were removed from their lactation crates and placed into group housing pens for the remainder of gestation. Multiparous sows were housed in separate group pens to primiparous sows.

At weaning, sows which did not exhibit a lactation oestrus, including sows from the No BE treatment, were removed from their lactation crates and placed into group pens, with primiparous and multiparous sows separated. From weaning they received daily nose to nose boar exposure with a mature boar in a detection mating area. When sows first exhibited an oestrus post-weaning they were artificially inseminated in an "AI station" by first detecting oestrus by fence line contact with a mature boar. Sows were inseminated at the first detection of oestrus and again every 24 hours until the end of behavioural oestrus or when the sow had received a total of two inseminations, whichever came first. Cervical inseminations were performed using a sponge-tipped disposable catheter with each insemination containing an 80 ml dose of fresh, extended semen (3 x 10^9 spermatozoa per inseminate; < 4 days old). Semen was purchased from a commercial artificial insemination collection centre. Sows were mixed back into group housing accommodation two hours after their final insemination. Within the group pens, sows were given 2 m^2 of floor space at all times.

4.3.5 Pregnancy status and farrowing rates

Pregnancy status was determined in all sows by transabdominal ultrasound at approximately 28 ± 4 days post AI. The number of piglets born alive, stillborns, and mummies were recorded from the subsequent litter of the sows that were inseminated during lactation.

4.3.6 Statistics

Data are expressed as mean ± standard error of the mean (SEM). In all analyses the sow was the experimental unit. A general analysis of variance (ANOVA) with experimental replicate built in with sow parity and live weight on day 1 of lactation as a covariate was used to determine the treatment effects on sow body condition. Data for effects of parity on sow body condition were analysed using an ANOVA with experimental replicate built in and with live weight on day 1 of lactation as a covariate. The cumulative proportion of sows expressing oestrus and farrowing rate were analysed as χ^2. The effects of treatment and parity on average piglet weight, average piglet weight gain and average daily piglet growth rate were analysed by averaging the litter weight data with the sow as the experimental unit, using an unbalanced ANOVA and with experimental replicate built in to the model and with piglet weight on day 4, sow live weight loss from day 1 to weaning, and lactation length used as covariates. Subsequent reproduction including total born, born alive, stillborns and mummies were analysed using an ANOVA with experimental replicate built in and sow parity and sow live weight loss between first day of lactation and weaning used as a covariate.

All analyses, except for the χ^2 analyses, were performed using Genstat, 10th Edition (Rothamsted Experimental Station, Harpenden). Probability values stated as being $P < 0.05$ were described as significant.

4.4 Results

4.4.1 Sow body condition throughout lactation

Sow live weight on day 1 of lactation did not differ between treatments (Table 4.1). At weaning, the No BE sows had lower live weight and a greater percentage of live weight loss over the course of lactation than both the boar exposure treatments. From day 1 and throughout lactation, primiparous sows consistently had a lower live weight than multiparous sows. Sow P2 backfat measurements at day 1 and weaning were similar across all treatments. Sow P2 backfat was consistently lower in primiparous compared to multiparous sows throughout lactation.

Table 4.1 Sow live weight (LW), live weight loss, and P2 backfat at day 1 and 17 post-partum (pp) and weaning

Item	Treatment[1]			Parity[2]	
	No BE	BE	BESPW7	PP	MP
n	149	302	152	303	300
LW, kg					
Day 1, pp	232.9 ± 2.0	237.6 ± 1.4	237.0 ± 1.9	202.4 ± 1.4 [c]	270.3 ± 1.4 [d]
Day 17, pp	NA[3]	231.9 ± 1.4	230.4 ± 1.9	195.6 ± 1.6 [c]	267.3 ± 1.6 [d]
Weaning, pp	214.5 ± 1.9 [a]	224.7 ± 1.4 [b]	225.9 ± 1.9 [b]	189.2 ± 1.4 [c]	256.3 ± 1.4 [d]
LW loss, kg					
Days 1-17	NA [3]	5.7 ± 0.6	6.6 ± 0.8	7.3 ± 0.6 [c]	4.7 ± 0.6 [d]
Days 17-wean	NA[3]	7.2 ± 0.5	4.0 ± 0.7	4.3 ± 0.6	8.0 ± 0.6
Days 1-wn	18.0 ± 1.1[a]	13.0 ± 0.7 [b]	10.8 ± 1.0 [b]	13.2 ± 0.7	14.0 ± 0.7
% LW loss, kg					
Days 1-17	NA[3]	2.5 ± 0.2	2.8 ± 0.3	3.6 ± 0.3 [c]	1.6 ± 0.3 [d]
Days 17-wean	NA[3]	3.0 ± 0.2 [a]	1.6 ± 0.3 [b]	2.1 ± 0.3 [c]	2.9 ± 0.3 [d]
Days 1-wean	7.7 ± 0.5 [a]	5.4 ± 0.3 [b]	4.5 ± 0.4 [b]	6.5 ± 0.3 [c]	5.0 ± 0.3 [d]
P2, mm					
Day 1, pp	16.0 ± 0.3	15.6 ± 0.2	15.1 ± 0.3	14.8 ± 0.2 [c]	16.3 ± 0.2 [d]
Day 17, pp	NA[3]	14.6 ± 0.2	14.4 ± 0.3	13.5 ± 0.2 [c]	15.5 ± 0.2 [d]
Weaning, pp	13.9 ± 0.2	13.8 ± 0.2	14.1 ± 0.2	12.7 ± 0.2 [c]	15.1 ±0.2 [d]
P2 loss, mm					
Days 1-17	NA[3]	0.8 ± 0.2	0.5 ± 0.2	1.0 ± 0.2 [c]	0.4 ± 0.2 [d]
Days 17-wean	NA[3]	0.9 ± 0.1 [a]	0.3 ± 0.2 [b]	0.9 ± 0.1 [c]	0.5 ± 0.1 [d]
Days 1-wean	1.9 ± 0.3 [a]	1.7 ± 0.2 [a]	0.9 ± 0.2 [b]	2.0 ± 0.2 [c]	1.1 ± 0.2 [d]

[ab]For treatment effects, means within a row without a common superscript differ ($P < 0.05$); [cd]For parity effects, means within a row without a common superscript differ ($P < 0.05$); [1]Weaning and wean refers to when the piglets are removed from the sow at the end of lactation; [2]MP = Multiparous sow; PP = Primiparous sow; [3] NA= Not applicable. Sows in the No BE treatment were not weighed on Day 17.

4.4.2 *Expression of oestrus*

There was an effect of parity on the cumulative proportion of multiparous and primiparous sows expressing oestrus by day 26 post-partum in the BESPW7 (89% vs. 63% respectively; $P < 0.01$) and BE (73% vs. 47% respectively; $P < 0.01$) with a higher proportion of multiparous sows from both treatments expressing oestrus by this stage (Figure 4.1). A greater proportion of oestrus was exhibited between day zero and seven after the start of boar exposure from sows mated in lactation as opposed to sows mated post-weaning in the No BE treatment indicating that an oestrus during lactation is as synchronous as mating post-weaning (Table 4.2). Providing both multiparous and primiparous sows with boar exposure significantly increased the incidence of lactation oestrus, with a further increase observed when litter size was reduced to seven piglets (Table 4.2). A total of 24% of multiparous sows and 8% of primiparous sows in the No BE treatment ovulated spontaneously during lactation based on the progesterone levels post-weaning. In all treatments the incidence of lactation oestrus was higher for multiparous sows than primiparous sows (Table 4.2). When treatments were pooled together, multiparous sows exhibited a 29% higher incidence of lactation oestrus than primiparous sows (81% compared to 52%, respectively; $P < 0.05$). Parity or treatment did not affect the incidence of post-weaning oestrus expression or the weaning to oestrus interval ($P > 0.05$).

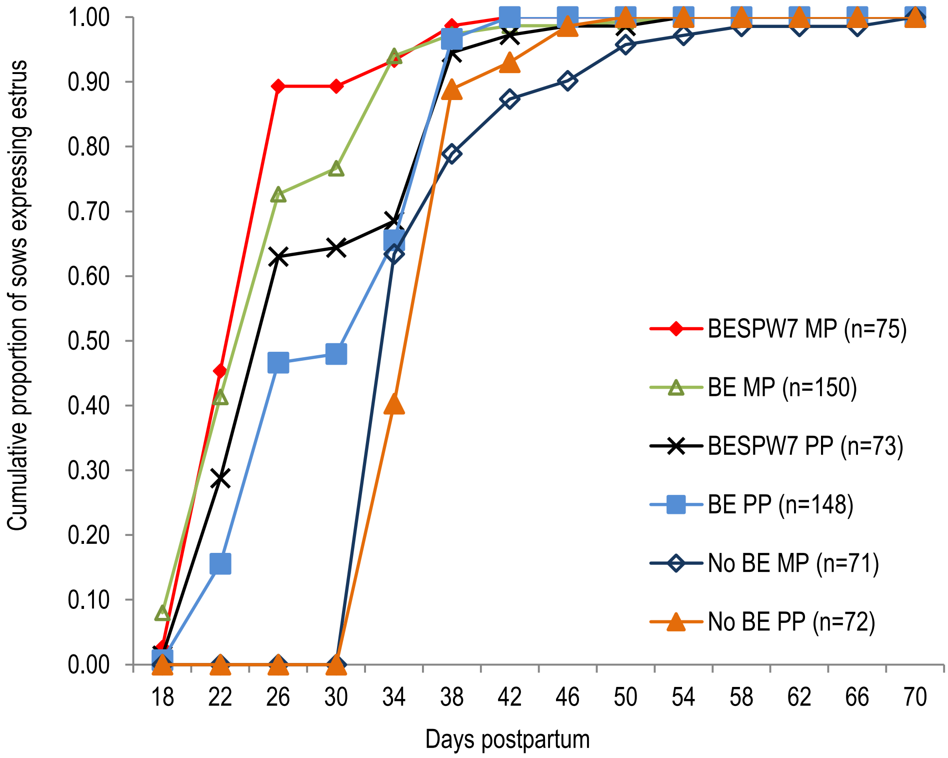

Figure 4.1 Cumulative proportion of primiparous and multiparous sows expressing oestrus relative to the day post-partum beginning on day 18, for treatments BESPW7 MP, BE MP, BESPW7 PP, BE PP, No BE MP , No BE PP, (n = 75, 150, 73, 148, 71, 72, respectively), with weaning on day 30.7 ± 0.05 and finishing on day 70 post-partum for treatments

Table 4.2 Lactation and post-weaning oestrus expression and the weaning to oestrus interval (WOI)

Item	Treatment[1]						Treatment[2]		
	No BE		BE		BESPW7		No BE	BE	BESPW7
	MP	PP	MP	PP	MP	PP			
n	74	75	151	151	75	77	149	302	152
Lactation Oestrus[3], %	24^{a}	8^{b}	76^{c}	47^{d}	89^{e}	61^{f}	16^{g}	62^{h}	75^{i}
Expression of oestrus between days 0-7 of stimulation[4], %	76^{a}	88^{ab}	91^{bc}	92^{bc}	99^{c}	98^{c}	82^{g}	91^{h}	98^{i}
Post-weaning oestrus[5]	72/74[6]	73/75[6]	35/36	78/80	8/8	27/30	145/149	113/116	35/38
WOI[7], d	5.2±1.1	4.9±1.1	4.4±1.1	4.5±1.0	5.4±1.2	4.5±1.1	5.0±1.0	4.4±1.0	4.8±1.1

[abcdef]Within a row, means without a common superscript differ ($P < 0.05$); [ghi]Within a row, means without a common superscript differ ($P < 0.05$); [1]MP = Multiparous sow; PP = Primiparous sow; [2]Both primiparous and multiparous sows are combined for this analysis; [3]Percentage of sows in the No BE treatment suspected of ovulating during lactation is based on P4 analysis ≥4 ng/ml on day 2 post-weaning; [4]Lactation oestrus expression within 0 days and 7 days from the onset of stimulation, where stimulation being boar exposure begun on day 18 of lactation for BE and BESPW7 treatments and from weaning for the No BE treatment; [5]The fraction of sows anoestrus at weaning that expressed oestrus post-weaning; [6]Sows regarded as ovulating during lactation are included in this fraction, as they were regarded at weaning as anoestrus and expressed a post-weaning oestrus; [7]Weaning to oestrus interval of sows anoestrus during lactation.

Boar exposure to lactation oestrus interval was similar among treatment; however, when treatment groups were combined, primiparous sows took slightly longer than multiparous sows to exhibit a lactation oestrus (Table 4.3). The oestrus to weaning interval was similar between treatments and parity (Table 4.3). When treatment groups were combined, multiparous sows had a longer duration of lactation oestrus than primiparous sows.

Table 4.3 Boar exposure (BE) to lactation oestrus interval and the duration of lactation oestrus

Item	Treatment		Parity[1]	
	BE	BESPW7	PP	MP
n	302	152	228	226
BE to lactation oestrus interval[2], d	4.6 ± 0.1	4.5 ± 0.2	4.9 ± 0.2 [a]	4.4 ± 0.1 [b]
Oestrus to weaning interval[2], d	8.4 ± 0.2	8.3 ± 0.2	8.2 ± 0.2	8.4 ± 0.2
Duration of lactation oestrus[2], d	2.8 ± 0.1	2.9 ± 0.1	2.6 ± 0.1 [a]	3.1 ± 0.1 [b]

[ab]Within a row, means without a common superscript differ ($P < 0.05$); [1]MP = Multiparous sow; PP = Primiparous sow; [2]Only including sows that had a lactation oestrus.

4.4.3 Subsequent reproductive performance

The subsequent number of piglets born alive was highest for sows in the No BE and the BESPW7 treatment (Table 4.4). Parity did not affect the total numbers of piglets born, the number born alive or mummified; however, stillborn numbers were increased for multiparous sows. Mating sows pre-weaning resulted in a lower total born and born alive, compared to sows mated post-weaning ($P < 0.05$). There was no interaction between treatment and the timing of mating for sows and gilts. Compared to their counterparts mated during lactation, farrowing rates were higher for BE multiparous sows and all BESPW7 sows mated post-weaning (Table 4.5). There was no effect of treatment or parity on the pooled farrowing rate.

Table 4.4 Effect of treatment, parity and the timing of artificial insemination (AI) on the total born (TB), born alive (BA), still born (SB) and mummified fetus (Mum) at the subsequent litter

Item	n	Parity[1]	TB	BA	SB	Mum
Treatment						
No BE	115	Both	12.0 ± 0.3	11.2 ± 0.3[a]	0.9 ± 0.1	0.1 ± 0.03
BE	223	Both	11.3 ± 0.2	10.4 ± 0.2[b]	0.9 ± 0.1	0.1 ± 0.04
BESPW7	114	Both	11.9 ± 0.3	11.0 ± 0.3[ab]	0.9 ± 0.1	0.2 ± 0.05
Parity						
Primiparous	223	N/A[2]	11.4 ± 0.2	10.8 ± 0.2	0.7 ± 0.04[a]	0.1 ± 0.1
Multiparous	219	N/A[2]	11.9 ± 0.2	10.8 ± 0.2	1.1 ± 0.04[b]	0.2 ± 0.1
Timing of AI[3]						
Pre-weaning	216	Both	11.3 ± 0.2[a]	10.4 ± 0.2[a]	0.9 ± 0.1	0.2 ± 0.04
Post-weaning	236	Both	12.0 ± 0.2[b]	11.1 ± 0.2[b]	0.9 ± 0.1	0.1 ± 0.04
Treatment x Timing of AI x parity						
No BE[3]						
Post-weaning	57	PP	11.6 ± 0.4	10.9 ± 0.4	0.7 ± 0.2	0.1 ± 0.1
Post-weaning	58	MP	12.7 ± 0.4	11.5 ± 0.4	1.2 ± 0.2	0.1 ± 0.1
BE[3]						
Pre-weaning	54	PP	11.1 ± 0.4	10.3 ± 0.4	0.8 ± 0.2	0.1 ± 0.1
Pre-weaning	80	MP	10.8 ± 0.3	9.6 ± 0.3	1.2 ± 0.1	0.3 ± 0.1
Post-weaning	61	PP	11.6 ± 0.4	11.1 ± 0.4	0.5 ± 0.2	0.1 ± 0.1
Post-weaning	28	MP	12.0 ± 0.6	10.9 ± 0.6	1.1 ± 0.3	0.03 ± 0.1
BESPW7[3]						
Pre-weaning	36	PP	11.7 ± 0.5	11.2 ± 0.5	0.5 ± 0.2	0.1 ± 0.1
Pre-weaning	46	MP	11.8 ± 0.5	10.9 ± 0.4	1.0 ± 0.2	0.3 ± 0.1
Post-weaning	25	PP	11.0 ± 0.6	10.1 ± 0.6	0.9 ± 0.3	0.1 ± 0.1
Post-weaning	7	MP	14.1 ± 1.2	13.0 ± 1.2	1.1 ± 0.5	0.1 ± 0.2

[ab]Within a column and main effect, means without a common superscript differ ($P < 0.05$); [1]MP = Multiparous sow; PP = Primiparous sow; Both = Multiparous and Primiparous sows combined in analysis; [2]NA = Not applicable; [4]Pre-weaning relates to the subsequent born from sows mated pre-weaning, in lactation (does not include No BE sows as no sows were mated pre-weaning); Post-weaning relates to the subsequent born from sows mated post-weaning (anoestrus in lactation).

Table 4.5 Subsequent farrowing rate for sows artificially inseminated (AI) in lactation or post-weaning

Item	Treatment[1]								
	No BE			BE			BESPW7		
	MP	PP	Both	MP	PP	Both	MP	PP	Both
n	74	75	149	151	151	302	75	77	152
Farrow rate, AI in lactation, %	NA[2]	NA[2]	NA[2]	73[a]	82	77	73[a]	77[a]	75[a]
Farrow rate, AI post-weaning, %	83	83	83	83[b]	81	82	88[b]	96[b]	94[b]
Pooled farrow rate, %[3]	83	83	83	76	82	79	75	84	79

[ab] Within a column and between farrow rate for AI in lactation and AI post-weaning, means within a treatment and parity group without a common superscript differ ($P < 0.05$); [1]MP = Multiparous sow; PP = Primiparous sow; Both = Multiparous and Primiparous sows combined in analysis; [2]NA = Not applicable. Sows in the No BE treatment weren't artificially inseminated whilst lactating; [3]Pooled farrow rate of sows mated in lactation and post-weaning.

4.4.4 Progesterone concentrations of sows in the conventional lactation treatment (no boar exposure)

A higher proportion of multiparous sows were suspected of ovulating than primiparous sows. The average P4 concentration was highest for all sows, multiparous and primiparous, which were suspected of ovulating during lactation (Table 4.6). The weaning to oestrus interval was highest for all sows that were suspected of ovulating during lactation (Table 4.6). The litter size weaned did not differ between sows suspected or not suspected of ovulating during lactation.

Table 4.6 Average progesterone concentration and weaning to oestrus interval of primiparous (PP) and multiparous (MP) sows suspected of ovulating during lactation within the no boar exposure treatment

Item	Parity[1]					
	PP		MP		Both	
	Anoestrus[2]	Ovulated[3]	Anoestrus[2]	Ovulated[3]	Anoestrus[2]	Ovulated[3]
No. (%) sows	69 (92%)	6 (8%)	55 (76%)	17 (24%)	124 (84%)	23 (16%)
Average P4 concentration, ng/ml	0.4±0.3 [a]	11.7±0.9 [b]	0.6±0.3 [a]	10.8±0.6 [b]	0.5±0.2 [c]	11.0±0.5 [d]
Weaning to oestrus interval, d	5.0±0.5 [a]	11.2±1.5 [b]	4.5±0.5 [a]	14.3±0.9 [b]	4.8±0.3 [c]	13.5±0.8 [d]
Litter size weaned	9.3±0.2	9.3±0.6	9.3±0.2	9.4±0.4	9.3±0.1	9.3±0.3

[ab]Within a row and main effect, means without a common superscript differ ($P < 0.05$); [cd]Within a row and main effect of parity, means without a common superscript differ ($P < 0.05$); [1]MP = Multiparous sow; PP = Primiparous sow; Both = Multiparous and Primiparous sows combined in analysis; [2]Sows in the No BE treatment suspected of being anoestrus during lactation based on progesterone concentration less than 4 ng/ml, 2 days post-weaning; [3]Sows in the No BE treatment suspected of ovulating during lactation based on progesterone concentration greater than 4 ng/ml, 2 days post-weaning.

4.4.5 Piglet growth

Piglet weight on day four was slightly higher for sows in the BESPW7 treatment; however, there was no difference in weight at day 17 between treatments. Consistently throughout lactation piglets from multiparous sows had higher average weights compared to those from primiparous sows (Table 4.7). Growth rate and piglet weight gain throughout lactation was greater for piglets from multiparous sows than from primiparous sows. Piglet weight gain from day 17 to weaning was greatest after a reduction in litter size in the BESPW7 treatment. Sows not receiving boar exposure had lower average piglet weights on the day of weaning compared to both treatments receiving boar exposure.

Table 4.7 Average piglet weight and daily piglet growth rate on days 4 and 17 of lactation and weaning

Item	Treatment[1]			Parity[2]	
	No BE	BE	BESPW7	PP	MP
Average n piglets, day 4	10.2 ± 0.1 [a]	9.9 ± 0.1 [b]	10.5 ± 0.1 [a]	10.3 ± 0.1 [c]	10.0 ± 0.1 [d]
Average n piglets, day 17	na[3]	9.5 ± 0.1	10.2 ± 0.1	10.0 ± 0.1	9.5± 0.1
Average n piglets weaned	9.3 ± 0.1 [a]	9.3 ± 0.1 [a]	6.9 ± 0.1 [b]	8.8 ± 0.1	8.6 ± 0.1
Average lactation length, d	29.9 ± 0.1 [a]	30.9 ± 0.1 [b]	30.9 ± 0.1 [b]	30.9 ± 0.1 [a]	30.5 ± 0.1 [b]
Average piglet weight, kg					
Day 4	2.1 ± 0.02 [a]	2.1 ± 0.01 [a]	2.2 ± 0.02 [b]	2.0 ± 0.01 [c]	2.3 ± 0.01 [d]
Day 17	na[3]	5.5 ± 0.03	5.5 ± 0.04	5.1 ± 0.04 [c]	5.9 ± 0.04 [d]
Day of weaning	8.2 ± 0.09 [a]	8.6 ± 0.06 [b]	8.6 ± 0.08 [b]	7.9 ± 0.06 [c]	9.1 ± 0.06 [d]
Average piglet weight gain, kg					
Day 4 - 17	na[3]	3.3 ± 0.03	3.3 ± 0.04	3.0 ± 0.03 [c]	3.6 ± 0.03 [d]
Day 17 – weaning	na[3]	3.1 ± 0.05 [a]	3.5 ± 0.06 [b]	3.0 ± 0.05 [c]	3.5 ± 0.05 [d]
Average piglet growth rate, kg					
Day 4 - 17	na[3]	0.3 ± 0.01	0.3 ± 0.05	0.2 ± 0.01 [c]	0.3 ± 0.01 [d]
Day 17 – weaning	na[3]	0.2 ± 0.01 [a]	0.3 ± 0.01 [b]	0.2 ± 0.01 [c]	0.3 ± 0.01 [d]

[ab] For treatment effects, means within a row without a common superscript differ ($P < 0.05$); [cd] For parity effects, means within a row without a common superscript differ ($P < 0.05$); [1]No BE = Conventional lactation (didn't receive boar exposure (BE) in lactation); BE = received boar exposure (BE) during lactation and no litter reduction; BESPW7 = received boar exposure (BE) during lactation and litter size split weaned (SPW) to seven piglets on day 18 of lactation; [2]MP = Multiparous sow; PP = Primiparous sow; [3]NA=Not Applicable, Piglets in the No BE treatment weren't weighed on day 17 of lactation.

4.5 Discussion

Overall, the current data demonstrate that daily full boar exposure is an effective stimulant of lactation oestrus in primiparous and multiparous sows within a commercial setting. Multiparous sows had a greater incidence of lactation oestrus, compared to primiparous sows, with oestrus expression further enhanced in both multiparous and primiparous sows when litter sizes were reduced to 7 piglets. The current data support previous findings from this group where a combination of boar exposure and split weaning was used to bring about a lactation oestrus in a high proportion of multiparous sows (Chapter Two). Reducing the litter size to seven piglets also allowed daily piglet growth to be increased between day 17 and weaning. Notably there were differences between the subsequent litter size (total born) of sows mated pre and post-weaning when parity and treatment were pooled.

The use of the boar for puberty attainment and reducing the weaning to oestrus interval is well accepted within the pig industry (Brooks and Cole 1970; Rowlinson and Bryant, 1982; Pearce and Paterson 1992; Hughes 1998; van Wettere et al., 2006). The current study provided further evidence that the use of a boar is essential in overcoming a lactation anoestrus (Chapter Two; Chapter Three). Chapter Two demonstrated that 56% of multiparous Large White and Large White x Landrace sows, with no litter modification, ovulated in response to fence-line boar exposure. The current study demonstrated that the use of full physical boar exposure, with no litter modification, increased the multiparous sow's propensity to express a lactation oestrus by 20%. Although a direct comparison with Chapter Two is not possible, due to differences in genetics, these results suggest that full physical boar exposure could be more effective than fence-line boar exposure at stimulating a lactation oestrus. Similarly, Patterson et al., (2002) considered daily full physical boar exposure to be more effective than fence-line exposure when stimulating puberty in gilts.

A reduced metabolic status of a first parity sow during lactation is often described as the first-limiting factor of the post-weaning reproductive capacity (Quesnel et al., 2007). The rigours of lactation have a negative effect on the body condition of primiparous sows leading to increased weaning to oestrus intervals (Vesseur et al., 1997). Primiparous sows don't recover from the effects of lactation as well as older parity sows, as they themselves are still maturing and growing (Bračič and Škorjanc, 2008). Further to this, primiparous sows have a lowered feed intake capacity thereby causing them to mobilise greater amounts of body tissue reserves and creating a more acute catabolic state (Kemp et al., 2011). In the current study, primiparous sows lost a greater percentage of live weight throughout lactation than the multiparous sows (6.5% vs. 5.0%, respectively) and this may have altered the primiparous sows' ability to express a lactation oestrus. Significant losses in live weight over the course of lactation not only compromise the weaning to oestrus interval, but also ovulation rates and embryo survival (Tokach et al., 1992; Kemp and Soede, 2012). This is most likely due to a decrease in LH concentration over the course of lactation thereby affecting the primiparous sow's ability to express a lactation oestrus (Tokach et al., 1992). A significant reduction in the subsequent born has been shown when the sow's lactation weight loss is greater than 10-12% of her total body weight (Thaker and Bilkei 2005). Therefore the live weight loss during lactation of the primiparous sows may not be substantial enough to contribute to the differences seen between parities for lactation oestrus expression.

Reducing the suckling stimulus by split weaning or intermittent suckling has been demonstrated in a number of studies to increase follicle sizes, improve ovarian development and increase LH concentrations, resulting in either the occurrence of a lactation oestrus or an improvement in the weaning to oestrus interval (Grant 1989; Degenstein et al., 2006; Langendijk et al., 2007; Quesnel et al., 2007; Gerritsen et al., 2008a; Zak et al., 2008; van Leeuwen et al., 2012). However, in the current study a greater percentage of multiparous sows exhibited a lactation oestrus than primiparous sows in both the BE and BESPW7 treatments (76% vs. 47% and 89% vs. 61%, respectively). While split weaning the litters of primiparous sows to seven piglets in late lactation significantly increased lactation oestrus expression, this increase was not to the same extent as the high proportion of lactation oestrus expressed by multiparous sows. It is generally accepted that primiparous sows experience a diminished reproductive capacity post-weaning compared to multiparous sows; however, the cause of the reduced expression of lactation oestrus in primiparous sows in the current study isn't clear. However, blood samples for analysis of progesterone levels were collected only from non-boar exposed sows. Therefore, the possibility of silent oestrus in boar exposed sows that did not exhibit a lactation oestrus cannot be excluded. Recently, Soede et al., (2012) observed lactation oestrus in only 23% of first parity sows compared to 68% of multiparous sows in response to intermittent suckling, supporting our current evidence that first parity sows are less likely than older sows to ovulate during lactation. However, it is noteworthy that the incidence of lactation oestrus amongst parity one sows in the currently study was approximately 2 fold and 3 fold higher, depending on the treatment, compared to the response reported by Soede et al., (2012).

The suckling stimulus exerted on the lactating sow is often regarded as the primary cause of inhibited ovarian activity during lactation. The increased capacity of both multiparous and primiparous sows in the current study to exhibit a lactation oestrus by day 22 of lactation in response to full boar exposure and a reduction in litter size, compared with boar exposure alone, suggests suckling intensity is a major contributing factor to a lactation anoestrus. Lessening the suckling stimulus by split weaning or intermittent suckling has been associated with increased LH concentrations and pulse frequency (Newton 1987a, b; Grant 1989; Zak et al., 2008). However, the expression of oestrus in response to split weaning, intermittent suckling or the presence of a boar during lactation can vary considerably. The success of lactation oestrus expression prior to the year 2000 ranged from 0-13% (Rowlinson and Bryant 1982; Walton 1986; Mahan et al., 1993; Costa and Varley 1995). More recent studies, however, have reported a higher success rate of 22-100% (Kuller et al., 2004; Gerritsen et al., 2008; Gerritsen et al., 2009; Langendijk et al., 2009; van Wettere et al., 2013). It is likely, that the modern sow is more prolific compared to earlier studies in the 1980-90's and selection against extended weaning to oestrus intervals has contributed to the modern sow being more receptive to stimulation for a lactation oestrus (Kemp and Soede 2012; van Wettere et al., 2013). Furthermore, the cumulative proportions of multiparous sows mated pre-weaning (BE and BESPW7) compared to post-weaning (No BE) after eight days of boar exposure were almost identical suggesting the synchrony of lactation oestrus expression is comparable to the average weaning to oestrus interval. The suggestion that the inhibition of LH release during lactation is less severe in modern genotypes is supported by the high incidence of sows spontaneously ovulating before weaning. In the current study, 24% of multiparous sows spontaneously ovulated during lactation in the absence of a boar; consequently prolonging the weaning to oestrus interval and decreasing the sow's reproductive capacity. A further 5% of sows receiving boar exposure ovulated on or before day 18 suggesting that circulating LH is increasing before day 18. These results and the results of Gerritsen et al., (2009), and van Wettere et al., (2013) support the belief that the modern sow is predisposed to ovulating during lactation. Providing sows with boar exposure and split weaning significantly increased the lactation oestrus response rate and therefore may be the best strategy to induce a lactation oestrus in sows which are predisposed to ovulating in lactation.

In the current study, in sows with a reduced litter size, mating during lactation resulted in a decreased farrowing rate compared to sows mated post-weaning. Further to this, when parity and treatment were pooled, mating in lactation decreased the subsequent total born and born alive. Previously, mating in lactation after day 21 post-partum and weaning within 7 days of mating did not negatively affect the subsequent reproduction (Gaustad-Aas et al., 2004; Soede et al., 2012). However, although not significant, multiparous sows which were split weaned and mated post-weaning had 2.1 more total born piglets at the subsequent litter than multiparous sows that had no litter reduction. These results suggest follicular growth is improved in sows which are split weaned and mated post-weaning (van Leeuwen et al., 2012). Therefore it is possible that split weaning the sows in the current study may have resulted in improved follicle growth also leading to the improved farrowing rate for the sows anoestrus during lactation.

Differences in metabolic and endocrine support for ovarian follicle growth are the most likely causes of the lower reproductive performance of sows mated during, as opposed to, after lactation. However, the negative effect on reproductive function of mixing sows mated during lactation into groups at weaning cannot be discounted. It is well established that grouping sows immediately post-mating as well as before, and during, implantation (e.g. between day 1 and 18 post-mating) can be detrimental to the establishment of pregnancy, farrowing rates and litter size (Spoolder et al., 2009; Kemp and Soede 2012). In the current study, all sows were housed in groups at weaning, with primiparous sows housed in separate groups to the multiparous animals. As a consequence, sows mated during lactation were exposed to the stress associated with group formation, hierarchy establishment and competition for resources on average 8 to 9 days post-mating. It is, therefore, suggested that these stressors could have caused, or at least contributed, to the poorer reproductive function of sows mated during lactation. In apparent support of this, mating during lactation appeared to have little effect on the reproductive output of primiparous sows, a group of animals which are most at risk of reproductive failure due to the metabolic demands of lactation but that are also thought to fight less when housed in groups (Strawford et al., 2008).

In the current study, lighter piglets remaining on the sow following split weaning grew faster between day 17 and weaning compared to piglets from sows with a complete litter. This finding is in agreement with the outcomes reported by Cabrera et al., (2010) and Mahan (1993) where piglets which nursed for a longer duration performed better post-weaning and reached market weight sooner than piglets weaned earlier. However, it is important to note that split weaning the heavier piglets earlier in lactation has been found to have no adverse or long term effects and allows the lighter piglets remaining on the sow to increase in growth (Pluske and Williams 1996; Chapter Two).

In conclusion, full physical boar exposure is an effective stimulus of lactation oestrus with a further increase in lactation oestrus expression observed when boar exposure was combined with split weaning. It is likely that the boar induced follicle growth is assisted by removing some of the suckling stimulus, thereby encouraging LH release and ovarian follicle growth allowing for a higher expression of oestrus. Multiparous sows are more likely to exhibit a lactation oestrus than primiparous sows. Farrowing rate was increased for sows mated post-weaning for both multiparous and primiparous sows in the BESPW7 treatment. Additionally the growth of the lighter weight piglets was improved following litter removal. This study provides further evidence that the modern sow, in particular the multiparous sow, has a higher propensity to ovulate during lactation and by providing split weaning and boar exposure this ability can be utilised effectively.

CHAPTER FIVE

Incidence of lactation oestrus in multiparous sows housed in low confinement systems

This research was kindly funded by the Australian Animal Welfare Strategy as the award sponsors of the 2012 Science and Innovation Award.

5.1 Abstract

This study evaluated the effect of two alternative low confinement crates, a step-in step-out (SISO) and a Swing-sided farrowing crate, on the expression of a lactation oestrus, compared to conventional lactation housing where the sow was confined for the entirety of lactation. A total of 85 Large White x Duroc x Landrace multiparous sows (parity 2 to 7; 3.4 ± 0.14) were individually housed according to treatment from 1 week before expected farrowing until weaning. Sows were allocated randomly to a housing treatment at shed entry. Sows were weaned on day 25.8 ± 0.1 of lactation. Three different lactation housing systems were assessed: a conventional crate (CC; n = 18); a swing-sided farrowing crate (Swing; n = 38), and a conventional crate with an adjacent pen which the sow could reverse into should she choose to, known as a “step-in, step-out” (SISO; n = 29). On day 1 of lactation, litter size was standardised to 11-13 piglets per sow. From shed entry to day 7 post-farrow sows were confined as they would be in a conventional crate. On day 7 post-farrow, the swing-sided crates were opened and the sows in the SISO pens were able to access the adjacent pen. Sow live weight was measured on days 1 and 7 of lactation (day 0 = day of farrowing) and again on the day of weaning. Sows received five minutes of fence-line boar exposure beginning on day 16 post-partum until weaning. The boar was housed in a boar crate to allow nose-to-nose contact between the boar and the sow. Sows were checked for oestrus using a back pressure test, with the display of a standing reflex defined as the first sign of oestrus. Sows were artificially inseminated at the first detection of oestrus and again 24 hours later. Whole litters were weighed on day 2 and 16 of lactation and at weaning. Lactation housing treatment had no significant effect on the incidence of lactation oestrus (0% CC vs. 0% SISO vs. 5% Swing). Average piglet weight gain from day 2 to weaning was greatest for piglets housed in the SISO and Swing crates compared to the conventional crate (5.1 ± 0.3 vs. 5.9 ± 0.2 and 6.2 ± 0.2 kg, respectively; $P < 0.05$). Overall, the current data demonstrated that providing sows with low confinement

housing, from day 7 after parturition, and boar exposure using a boar crate, did not provide a sufficient stimulus to bring about a lactation oestrus response.

5.2 Introduction

The use of confined housing during lactation is controversial due to the lack of social contact, inability to exercise, restriction of stimuli and inability of the sow to exhibit natural behaviours, such as nest-building, development of maternal-progeny bond and the capacity to self-regulate lactation (Barnett et al., 2001). There is significant pressure on the Australian pork industry to improve the welfare of its breeding herd and consequently in 2010 the Australian pork industry voluntarily committed to a phase out of gestation stalls by 2017. Consumer pressure is now leading to a focus on the development of low confinement lactation housing systems that maintain commercial production levels. To achieve this, lactation housing systems need to be designed to maintain both piglet and sow performance, without compromising piglet welfare, and ideally to allow construction within existing building footprints with minimal infrastructure costs. Confined housing was largely developed to reduce piglet deaths due to crushing. Blackshaw et al., (1994) reported a piglet mortality rate of 32% when piglets were housed in a farrowing pen, compared to 14% when housed in a conventional farrowing crate. Currently lactating sows are housed in conventional farrowing crates for an average of 24 days; however, approximately 80% of piglet crushing occurs within the first 72 hours of life (Weary et al., 1998). This suggests that confinement aimed at reducing piglet mortality could be restricted to parturition and the early lactation period.

Lactation anoestrus is common in domestic sows, as follicle growth and ovulation is prevented by the suckling induced inhibition of LH and lactation induced catabolism (Foxcroft, 1992; Soede et al., 2012). Sows housed in conventional farrowing crates are unable to regulate the frequency of suckling bouts which prevents expression of a lactation oestrus. In both conventional farrowing crates and loose pens, the frequency of suckling bouts peaks approximately nine to thirteen days post-partum, and gradually decreases thereafter (Puppe and Tuchscherer, 2000; Valros et al., 2002). However, regardless of the stage of lactation, the time spent suckling is reduced in farrowing pens compared to farrowing crates (Stolba et al., 1990). Sows enter a catabolic state during lactation due to mobilisation of body reserves to fulfil their nutrient requirements for maintenance and milk yield (Thaker and Bilkei 2005). Confinement of the sow during lactation can exacerbate this catabolic state. Pajor et al., (2002) demonstrated that sows that were allowed to escape their piglets consumed 18% more food during lactation and lost less weight over lactation, compared to sows unable to escape their piglets, thereby reducing the demands of lactation. Modification of the lactation housing system also enabled sows to reduce their suckling frequency by 10%, thereby potentially improving the metabolic state of the sow (Pajor et al., 2002), which could potentially assist lactation oestrus attainment. A study from Rowlinson and Bryant (1982) described an additive effect on the occurrence of lactation oestrus when sows were not confined during lactation and received boar exposure. It is, therefore, proposed that the use of low confinement housing of sows, in combination with daily boar exposure, will be an effective method of stimulating oestrus in lactating sows, potentially due to a reduced suckling intensity.

The current study, therefore, aimed to determine whether providing sows with the ability, or option, to regulate their own lactation through low confinement housing, in combination with fence-line boar exposure, promotes the expression of a lactation ovulation. The effects of two alternative low confinement crates, a step-in step-out (SISO) and a Swing-sided farrowing crate, on expression of a lactation oestrus, were compared to conventional lactation housing, which confined the sow for the entirety of lactation.

5.3 Materials and Methods

This study was conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC, 2004). All experimental procedures were conducted at a large commercial breeding unit in South Australia, with approval from the Animal Ethics Committee of The University of Adelaide, South Australia.

5.3.1 Animals, housing and diet

The experiment consisted of two replicates conducted between January and March 2013. A total of 85 Large White x Duroc x Landrace multiparous sows (parity 2 to 7; 3.4 ± 0.14) were individually housed according to treatment from 1 week before expected farrowing until weaning. Sows were weaned on day 25.8 ± 0.1 of lactation. On the day of farrowing (day 0) sows were fed 1 kg of a lactation diet (14.0 MJ/kg DE, 17.1% protein, and 0.872% available lysine). On day 1 post-partum this was increased to 2.5 kg of the same lactation diet; by day 5 of lactation sows were receiving 4 kg, and thereafter sows were fed *ad libitum* to a maximum of 9 kg through to weaning.

5.3.2 Treatments

Three different lactation housing systems were assessed: a conventional crate (CC; n = 18); a swing-sided farrowing crate (Swing; n = 38), and a conventional crate with an adjacent pen which the sow could reverse into should she choose to, known as a “step-in, step-out” (SISO; n = 29) (See Appendix 1). The conventional crates used were closed SISO pens that remained closed throughout lactation, to allow all treatments to be located within one farrowing shed. The design of all crates allowed the sow to be confined if required. For this study, the three farrowing accommodation types were fitted into an existing farrowing shed, which resulted in differences in the numbers of crates, and hence sows, within each treatment. It is important to note that, prior to this study being conducted it was determined that a small wall (20 cm in height) at the rear of the sow in the SISO crate would not allow the sow to enter and exit the pen as she wished. It was thought that this was due to the sow not being able to turn around first and that her back hoof was hitting the small wall and therefore not allowing her to exit the crate. Therefore it was decided to remove the small wall for the study which, unfortunately, also allowed the piglets to leave the farrowing crate area.

Sows were allocated randomly to a housing treatment at shed entry. On day 1 of lactation litter size was standardised to 11-13 piglets per sow. From shed entry to day 7 post-farrow sows were confined as they would be in a conventional crate. At 8:00 am on day 7 post-farrow, the swing-sided crates were opened and the sows in the SISO pens were able to access the adjacent pen. Sow live weight was measured on days 1 and 7 of lactation (day 0 = day of farrowing) and again on the day of weaning.

5.3.3 Blood progesterone concentrations

A pre-prandial blood sample was taken by jugular venipuncture into a 9 ml Heparin-Lithium coated collection tube (Vacuette, Greiner Labortechnik, Austria) on day 16 and 20 post-weaning and again on the day of weaning to measure progesterone concentration to determine if ovulation had occurred during lactation. Blood samples were maintained on ice and were centrifuged at 1500 x *g* for 15 minutes and plasma was then stored at -20°C, until assayed for progesterone.

Blood samples were analysed for progesterone (P4) concentration in 50 µl of plasma, in duplicate using a coated tube radio immunoassay, according to the manufacturer's instructions (M118;

Beckman Coulter, Brea, CA, USA). The lowest detectable concentration was 0.1 ng per ml. The intra assay coefficient of variation was less than 10%. The inter assay coefficient of variation was less than 15%.

5.3.4 Boar exposure and oestrus detection

Beginning on day 16 post-partum until weaning sows received five minutes of fence-line contact with a mature boar. Specifically, the boar was placed in front of each pen in a boar crate to allow nose-to-nose contact between the boar and the sow, should the sow wish it. Two mature boars were rotated between replicates. Within the first few minutes of boar exposure, sows were checked for oestrus using a back pressure test, with the display of a standing reflex defined as the first sign of oestrus. Sows were artificially inseminated (AI) at the first detection of oestrus and again every 24 hours until the end of behavioural oestrus or when the sow had received a total of three inseminations, whichever came first. Cervical inseminations were performed using a sponge-tipped disposable catheter with each insemination containing an 80 ml dose of fresh, extended semen (3×10^9 spermatozoa per inseminate; < 3 days old). Semen was purchased from a commercial artificial insemination collection centre.

5.3.5 Piglet Growth

Whole litter weights and piglet numbers were recorded on day 2 and 16 of lactation and at weaning.

5.3.6 *Post-weaning housing of all sows, and boar exposure and artificial insemination of sows not mated during lactation*

At weaning, sows mated in lactation were removed from their lactation crates and placed into group housing pens for the remainder of gestation. At weaning, sows that did not exhibit a lactation oestrus were removed from their lactation accommodation and placed into group pens. From weaning, they received daily fence-line boar exposure with a mature boar in a boar crate. When sows first exhibited an oestrus post-weaning they were artificially inseminated in an "AI station" by first detecting oestrus by fence line exposure with a mature boar. Sows were inseminated at the first detection of oestrus and again every 24 hours until the end of behavioural oestrus or when the sow had received a total of two inseminations, whichever came first. Cervical inseminations were performed as described above. Sows were mixed back into group housing accommodation two hours after their final insemination. Within the group pens, sows were given 2 m^2 of floor space at all times.

5.3.7 *Subsequent reproduction*

The number of piglets born alive, stillborns, and mummies were recorded from the subsequent litter of the sows that were inseminated during lactation.

5.3.8 *Statistics*

Data are expressed as mean ± standard error of the mean (SEM). In all analyses the sow was the experimental unit. A general analysis of variance (ANOVA) with experimental replicate built-in with sow parity and live weight on day 1 of lactation as a covariate was used to determine the treatment effects on sow body condition. The effects of housing treatment on average piglet weight, average piglet weight gain and average daily piglet growth rate were analysed by averaging the litter weight data with the sow as the experimental unit, using an unbalanced ANOVA and with experimental replicate built-in to the model and with piglet weight on day 2, and sow parity used as covariates. Sow progesterone concentration and weaning to oestrus interval was analysed using an unbalanced ANOVA and with experimental replicate built-in to the model and with sow parity as a covariate. The cumulative proportion of sows expressing oestrus and farrowing rate were analysed as χ^2.

All analyses, except for the Chi-squared analyses, were performed using Genstat, 10th Edition (Rothamsted Experimental Station, Harpenden). Probability values stated as being $P < 0.05$ were described as significant.

5.4 Results

5.4.1 Sow body condition

Sow live weight on days 1 and 7 of lactation was greatest for sows housed in the swing-sided farrowing crate; however, at weaning, live weight did not differ between treatments (Table 5.1). Over the course of lactation the percentage of live weight loss did not differ between lactation accommodations (Table 5.1).

Table 5.1 Sow live weight (LW), and percentage live weight loss, at day 1 and 7 post-partum (pp) and weaning

Item	Treatment		
	CC	SISO	Swing
n	18	29	38
Parity	3.6 ± 0.3	3.7 ± 0.3	3.0 ± 0.2
Average lactation length, d	25.7 ± 0.2	26.1 ± 0.2	25.7 ± 0.2
LW, kg			
Day 1, pp	258.1 ± 5.5 ^{a}	253.8 ± 4.6 ^{a}	277.6 ± 4.0 ^{b}
Day 7, pp	252.6 ± 4.9 ^{a}	249.4 ± 3.9 ^{a}	265.7 ± 3.3 ^{b}
Weaning, pp	244.8 ± 5.9	247.9 ± 4.7	252.6 ± 4.2
% LW loss			
Days 1-7	2.7 ± 0.9	2.2 ± 0.7	2.4 ± 0.7
Days 7-wean	2.7 ± 1.1	2.5 ± 0.9	4.8 ± 0.7
Days 1-wean	5.5 ± 1.2	4.7 ± 1.0	7.1 ± 0.9

^{ab}Within a row, means without a common superscript differ ($P < 0.05$).

5.4.2 Lactation oestrus expression

There was no effect of lactation housing treatment on the incidence of lactation oestrus (Table 5.2). Two sows housed in swing-sided crates exhibited a lactation oestrus on days 27 and 24 post-parturition. Both sows were inseminated at the first detection of oestrus and again 24 hours later, and received a total of two doses each. The sow inseminated on day 27 post-parturition was coincident with the day of weaning and therefore received her second dose the day following weaning. Both sows were determined to be pregnant by trans-abdominal ultrasound approximately 28 days following artificial insemination. The subsequent litter size was a total born of 17 and 18, and born alive of 14 and 18, for sows showing oestrus on days 27 and 24 respectively. There was no difference in the incidence of a post-weaning oestrus or the weaning to oestrus interval between housing treatments (Table 5.2).

Table 5.2 Lactation and post-weaning oestrus expression and the weaning to oestrus interval (WOI)

Item	Treatment		
	CC	SISO	Swing
n	18	29	38
Lactation Oestrus, %	0	0	5 (2/38)
Post-weaning oestrus	16/18	23/26 [1]	30/32 [2]
WOI, d	6.0 ± 0.5	6.9 ± 0.4	6.2 ± 0.4

[1]Three sows were culled at weaning either for age or lameness; [2]Four sows were culled at weaning either for age or lameness.

5.4.3 Progesterone concentration during lactation

The progesterone concentration of sows that exhibited a lactation oestrus on days 27 and 24 post-parturition was 0.11 and 4.01 ng/ml, respectively. There was no difference in progesterone concentrations between sows housed in any lactation housing treatment at day 16 or 20 of parturition, or at weaning (Table 5.3). These results indicate that no undetected lactation ovulation occurred.

Table 5.3 Average progesterone concentration on days 16 and 20 post-partum, and weaning

Item	Treatment		
	CC	SISO	Swing
n	18	29	38
Average P4[1] concentration, d 16, ng/ml	0.26 ± 0.03	0.26 ± 0.03	0.3 ± 0.02
Average P4[1] concentration, d 20, ng/ml	0.25 ± 0.03	0.28 ± 0.03	0.29 ± 0.02
Average P4[1] concentration, weaning, ng/ml	0.27 ± 0.01	0.26 ± 0.08	0.37 ± 0.07

[1]Sows suspected of ovulating during lactation was based on a progesterone concentration greater than 4 ng/ml.

5.4.4 Piglet growth

Average piglet growth rate and average weight gain from day 2 to weaning was greatest for piglets housed in the SISO and Swing crates compared to the conventional crate (Table 5.4). There was no difference in average piglet weight at day 2 or 16 of lactation, or weaning when housed in different systems (Table 5.4). Sows housed in the conventional crates weaned a greater number of piglets than sows housed in the SISO and Swing crates; however, at day 2 sows housed in conventional crates also had a greater number of piglets (Table 5.4).

Table 5.4 Average piglet weight, weight gain and piglet growth rate between days 2 of lactation and weaning

Item	Treatment		
	CC	SISO	Swing
Average piglet numbers, d2	12.2 ± 0.2 [a]	11.4 ± 0.2 [b]	11.5 ± 0.2 [b]
Average piglet numbers, d16	11.3 ± 0.3 [a]	10.4 ± 0.2[b]	10.2 ± 0.2 [b]
Average piglet numbers, wean	11.1 ± 0.3 [a]	10.1 ± 0.3 [b]	10.0 ± 0.2 [b]
Average piglet weight, kg			
Day 2	1.8 ± 0.1	1.7 ± 0.1	1.6 ± 0.1
Day 16	4.8 ± 0.1	4.9 ± 0.1	5.1 ± 0.1
Weaning	6.8 ± 0.3	7.7 ± 0.2	7.8 ± 0.2
Average piglet weight gain, kg			
Day 2 – weaning	5.1 ± 0.3 [a]	5.9 ± 0.2 [b]	6.2 ± 0.2 [b]
Average piglet growth rate, kg			
Day 2 – weaning	0.21 ± 0.01 [a]	0.24 ± 0.01 [b]	0.26 ± 0.01 [b]

[ab]Within a row, means without a common superscript differ ($P < 0.05$).

5.5 Discussion

Overall, the current data demonstrated that providing sows with lactation accommodation that did not confine them from day 7 post-partum, in combination with fence-line boar exposure, does not effectively stimulate a lactation oestrus. The concentration of progesterone during lactation and at weaning, together with the weaning to oestrus interval, confirmed that no sows spontaneously ovulated during lactation that weren't detected. Although there appeared to be a trend towards higher live weight loss throughout lactation for the sows housed in Swing crates, the type of farrowing housing did not affect the percentage of live weight loss over the course of lactation. However, average piglet weight gain and growth rate over the course of lactation was greatest for piglets suckling sows in the SISO and Swing lactation housing compared to conventional lactation housing.

Some unintended differences occurred in the average sow live weight at day 1 of lactation for sows housed in the conventional and SISO pens compared to the swing pens, with the sows in the swing pens having a heavier live weight. This resulted from the random allocation of sows to treatment at shed entry, and has the potential to influence subsequent outcomes, including piglet growth and lactation oestrus expression.

The suckling stimulus exerted on the lactating sow is often regarded as the primary cause of inhibited ovarian activity during lactation. Sows that had the ability to escape their piglets, nursed their piglets 10% less and their piglets consumed 65% more solid food than sows and piglets housed in conventional farrowing crates (Pajor et al., 2002). By not confining the sow for the entirety of lactation Stolba et al., (1990) demonstrated a reduction in social contact and piglet suckling frequency resulting in an increase of lactation oestrus. The occurrence of lactation oestrus from group housing sows in groups of 2 to 7 sows and their litters from 21 days post-farrowing with a boar was investigated by Rowlinson et al., (1975). Of the 180 sows group housed in lactation, 100% exhibited a lactation oestrus with a mean grouping to oestrus interval of 11.15 ± 0.28 days (Rowlinson et al., 1975). Similarly, Rowlinson and Bryant (1982) demonstrated that by group housing lactating sows from day 20 of lactation, compared to singly housed sows, a higher incidence of lactation oestrus is observed, with this incidence further increased when a boar was added to the group pen. Together, these studies suggest that the lactation housing system can reduce the contact between the sow and her piglets and this can allow for a lactation oestrus to occur as long as there is a boar stimulus. Therefore, the lack of lactation oestrus expression in the current study is possibly due to the housing systems not allowing for a sufficient reduction in suckling intensity.

The lack of lactation oestrus expression could also be attributed to the effect of season, as was indicated by the data in Chapter Three. As the study was conducted during the hottest months of the year, it is conceivable that a seasonally induced reduction in fertility could have had a significant effect (Prunier et al., 1996). Seasonal infertility is mediated by the decrease in melatonin that results from extended day lengths during summer, and the negative impacts of elevated temperature (Ramírez et al., 2009). Both reduced melatonin levels and heat induced suppression of lactation feed intake suppress LH release and impair ovarian follicle growth and the Australian summer is known to cause a severe seasonal infertility problem (Peltoniemi et al., 1999; Ramírez et al., 2009). The various manifestations of seasonal infertility are delayed onset of puberty, decreased farrowing rates, pregnancy losses, reduced litter size, and a prolonged weaning to oestrus interval (Bertoldo et al., 2012). Lopes et al., (2014) demonstrated a severe effect of season on the weaning to oestrus interval, with 11.6% of sows experiencing a weaning to oestrus interval of greater than 10 days in summer / autumn. It is generally accepted within a commercial piggery that sows are expected to return to oestrus within 4-7 days of weaning. In the current study, the weaning to oestrus interval was within this expected range and there were no differences in the weaning to oestrus interval between treatments. Therefore, further understanding of whether season influenced the outcomes of the study would require replication during the months of winter / spring.

The use of boar exposure to stimulate the attainment of puberty and post-weaning, where it facilitates oestrus detection and can reduce the interval from weaning to ovulation, has been well documented (Pearce and Paterson, 1992; Soede 1993; Knox et al., 2002; Patterson et al., 2002; Behan et al., 2005). The use of fence-line boar exposure (Chapter Two) and full physical boar exposure (Chapter Four) for the attainment of a lactation oestrus has also been established. In previous studies 56% and 76% of multiparous sows receiving fence-line or full physical boar exposure exhibited a lactation oestrus (Chapter Two; Chapter Four). Recently, exposing multiparous sows to boar exposure, compared to no boar exposure, increased the expression of lactation oestrus from 9% to 61% (van Wettere et al., 2013). Undoubtedly, the use of direct contact with a mature boar will elicit a greater lactation oestrus response, however, in previous studies the sow was also removed from the farrowing crate for 15-20 minutes and taken to a detection mating area for the purpose of boar exposure, which may have provided additional stimuli compared to the current study. It is possible that a level of anticipation is created when the sow is removed from the farrowing crate for boar exposure, further stimulating the sow to express a lactation oestrus (Gerritsen et al., 2005). Patterson et al., (2002) demonstrated that prepubertal gilts provided with direct boar exposure in a detection mating area exhibited puberty 10.2 days earlier compared to sows given fence-line exposure in the gilt pen. Therefore the complexities of the stimulus provided by physical boar exposure and removing the sow from the farrowing crate seem to be stronger than the boar stimulus provided in this study.

Housing lactating sows in pens designed to allow them a greater range of movement has been shown to reduce the contact between the sow and her piglets (Stolba et al., 1990). The suckling induced suppression of LH and FSH is removed once the sow has been weaned (De Rensis et al., 1993b). However, after the third week post-partum low frequency, high amplitude LH pulses occur indicating that the suckling induced suppression of LH is not absolute (Varley and Foxcroft 1990; Foxcroft 1992). The increased growth rate and average piglet weight gain over the course of lactation seen in the SISO and the Swing-sided pen indicate that suckling frequency and intensity may have been increased compared to the conventional lactation crate. Therefore, the level of the suckling stimulus in the current experiment was not sufficiently reduced by the different housing treatments to elicit a lactation oestrus response. However, further studies monitoring suckling frequency and piglet behaviour in these housing systems are required. Chapter Two demonstrated that lactation oestrus expression increased as the number of piglets split weaned was increased from 3 to 7. In a similar study, the split weaning of litters down to 7 piglets at day 18 of lactation increased the capacity of both multiparous and primiparous sows to express a lactation oestrus, when also provided with boar exposure (Chapter Four). In contrast to this study, Soede et al., (2012) demonstrated that 68% of multiparous sows which were intermittently suckled expressed a lactation oestrus with a recorded boar sound, but without the presence of a boar; further demonstrating the need for a measurable reduction in suckling intensity. This current study therefore, highlights the need for a physical reduction in suckling intensity, whether that be through split weaning or intermittent suckling, or a more complex housing system such as a group lactation system, to bring about a consistent lactation oestrus response.

In conclusion, in the current study, low confinement housing, from day 7 of parturition and boar exposure, using a boar crate, did not provide a sufficient stimulus to bring about a lactation oestrus response. Removing the sow from her lactation accommodation and providing her with direct boar exposure may have elicited a greater response; however, investigations should be conducted in all seasons to determine the effect of summer on lactation oestrus expression. The growth of the litter was not negatively affected by the lactation pens. This study provides further information on the requirements of the modern Australian sow to stimulate a lactation oestrus. However, it is recommended that further investigation is conducted on the effects of alternative lactation accommodation, including group housing, on the incidence of lactation oestrus.

5.6 Appendix 1

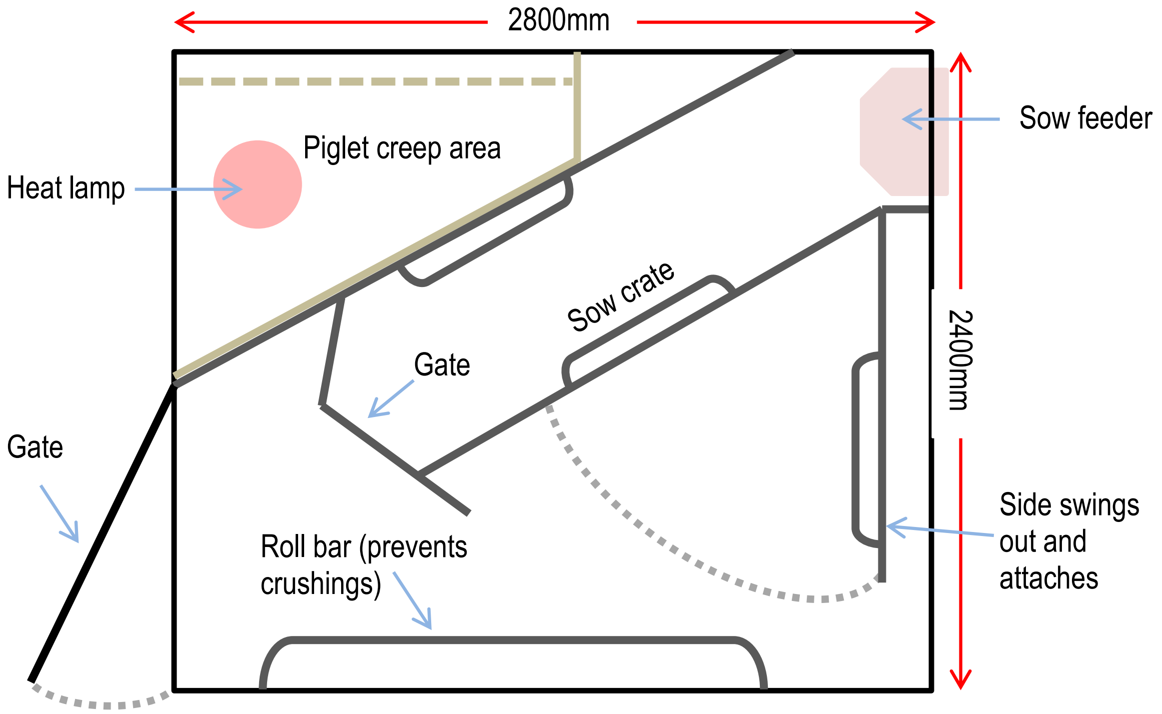

Figure 5.1 Swing sided pen floor plan

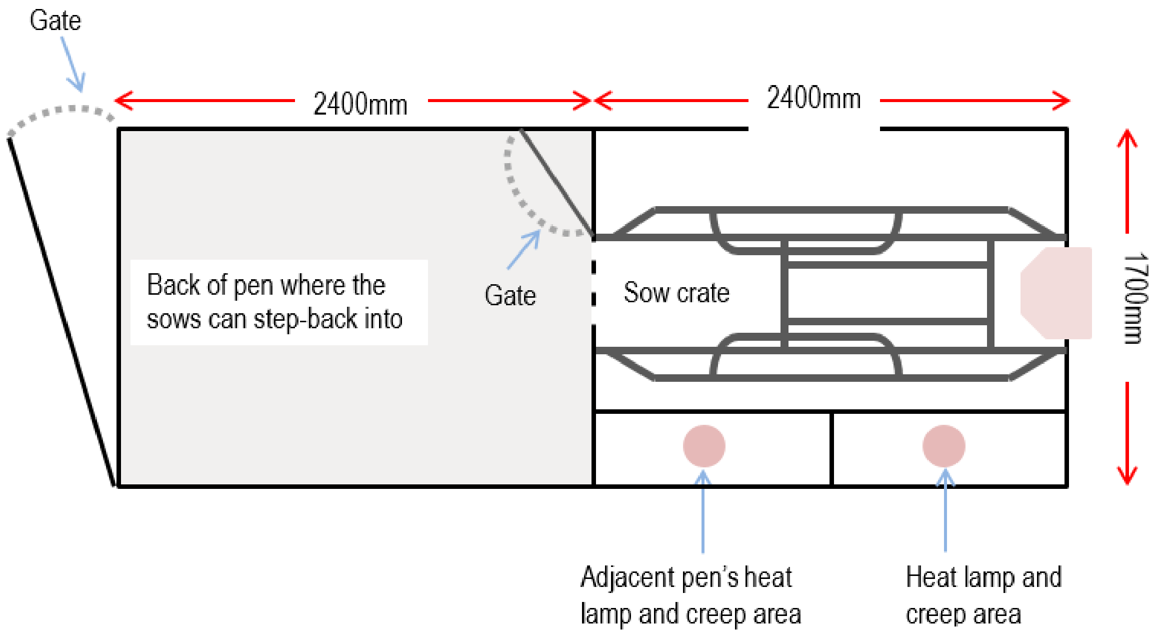

Figure 5.2 Step-in, step-out pen floor plan


Photo 5.1 A sow housed in an open swing crate with her piglets

Photo 5.2 A sow housed in a closed swing crate, prior to parturition

Photo 5.3 A sow housed in an open SISO crate (front view). The conventional crates used as control housing were exactly the same as the front crate in this picture, however, with the door closed.

Photo 5.4 A sow housed in an open SISO crate with her piglets (back view). The conventional crates used as control housing consisted of the front crate, however, with the door closed.

CHAPTER SIX

General Discussion

Lactation length currently determines how many litters, and therefore pigs, a sow produces each year. The number of pigs sold per sow per year is the primary driver of profitability, and therefore piglet weaning age has been reduced to 21 – 24 days to maximize this key profit driver. Early weaning of piglets, especially light for age piglets, impedes their growth and development and has welfare implications due to the stressors of maternal separation and changes in nutritional demands (Cabrera et al., 2010). However, extending the weaning age will also reduce the number of litters weaned per year from an average of 2.4 litters - a key production benchmark. One management strategy to maintain the reproductive capacity of the sow, whilst extending lactation for the benefit of the piglet, is to stimulate her to ovulate and express oestrus in late lactation. One of the benefits of mating during lactation is that lactation length can be extended, thereby allowing “light” weight piglets a better chance of survival following weaning. The aims of the research reported in this thesis were to investigate mechanisms to reliably stimulate a lactation oestrus and ovulation in both multiparous and primiparous sows. Secondly, the aim was to determine the effect of these strategies on the growth of the piglets, as well as subsequent pregnancy rate, farrowing rate and litter size. The mechanisms investigated were focused on: reducing the suckling input to the sow through split weaning or low-confinement alternative lactation housing and fence, or full physical, boar exposure.

Split weaning, rather than intermittent suckling, was chosen to reduce the suckling intensity of the piglets, primarily due to the labour intensity required for intermittent suckling strategies and the difficulty of implementing intermittent suckling within a commercial setting. However, recently Downing et al., (2015) demonstrated the use of intermittent suckling to stimulate a lactation oestrus by placing a board in the farrowing crate between the piglets and sow. This simple method of separation, of 16 hours per day for three days from day 21 of lactation, resulted in 82% of sows mated in lactation and 92% of these sows successfully farrowing. When comparing these results to that of Chapter Fours, 89% of multiparous sows with the litter reduced to 7 piglets were mated in lactation, however, only 73% of these sows successfully farrowed. These results indicate that whilst split weaning was effective at reducing the suckling intensity of the piglets, further investigation is required into why there was a reduction in farrowing rate compared to Downing et al., (2015).

Chapter Two demonstrated that removing seven piglets from the lactating sow at day 18 postpartum produced the highest expression of lactation oestrus. However, split weaning to three or five piglets is quite low and not commercially viable and therefore, in Chapter Four, litters were split weaned to leave seven of the lightest piglets with the sow. This approach is more manageable and sustainable in terms of commercial production as fewer piglets are removed and the heavier piglets will be able to more readily cope with the stressors of an early weaning.

In Chapter Two, oestrus stimulation commenced on day 18 of lactation and expression of oestrus was observed within 4-7 days thereafter. The increased capacity of both multiparous and primiparous sows to exhibit oestrus by day 22 of lactation in response to a combination of boar exposure and reduced suckled litter size, compared with boar exposure alone, suggests suckling intensity is a major contributing factor to LH suppression and lactation anoestrus. Split weaning of three to seven piglets, in conjunction with fence-line or full physical boar exposure, increased the cumulative proportion of multiparous sows expressing a lactation oestrus by between 13-39%, compared to multiparous sows only receiving boar exposure. Using boar exposure alone was not sufficient stimulation to cause a high proportion of sows to exhibit lactation oestrus. In order to be commercially viable the practice of inducing a lactation oestrus needs to reliably stimulate a high proportion of sows to exhibit a lactation oestrus, within a known timeframe, with the remainder exhibiting oestrus soon after weaning.

On average, multiparous sows exhibited a lactation oestrus within 4-5 days from the commencement of split weaning and boar exposure treatment which is comparable to the normal weaning to oestrus interval. A similar finding, using intermittent suckling in conjunction with boar exposure to establish an ovulation during lactation, was demonstrated by Langendijk et al., (2009). Ovulatory sows were observed to ovulate synchronously within 6-7.5 days after the commencement of intermittent suckling, whereas sows classified as anovulatory did not ovulate within the first 14 days of treatment (Langendijk et al., 2009). A major barrier to the commercial uptake of lactation oestrus protocols is that we do not know why some sows will ovulate in lactation and others will not. Anovulatory and ovulatory sows did not differ in terms of feed intake; body weight loss from day 0 to 21 postpartum; litter size following cross-fostering or at the start of intermittent suckling; piglet weight gain; or the effectiveness of the boar to stimulate an ovulation (Langendijk et al., (2009). What is consistent across studies is that sows that ovulate following litter separation during lactation have a lower amplitude of LH pulses with a higher frequency, compared to anovulatory sows, with LH secretion again inhibited following the resumption of suckling (Armstrong et al., 1988; Langendijk et al., 2007; Langendijk et al., 2009). In addition, Langendijk et al., (2009) observed that up to one third of anovulatory sows, had comparable follicle growth to ovulatory sows, including growth of follicles up to ovulatory size, but did not exhibit an increase in oestradiol concentrations, in contrast to ovulatory sows. This suggests that differences in follicular differentiation and maturation may also contribute to variation between sows in their response to intermittent suckling; however, the specific mechanisms underlying the failure of oestradiol production are not known (Langendijk et al. 2009).

Boars are most commonly used to stimulate puberty in the gilt, but are also used post-weaning where the boar facilitates oestrus detection, reduces the interval from weaning to ovulation and also assists during the artificial insemination process to increase fertilisation rates (Brooks and Cole 1970; Dyck 1988; Kemp et al., 2005; Soede 1993; Langendijk et al., 2000). It is evident from the data in this thesis that lactation anoestrus can be overcome in a high proportion of sows with the use of boar exposure, however, the use of boar exposure in conjunction with split weaning has proven to be more effective at bringing about a lactation oestrus. The proportion of primiparous and multiparous sows detected to have ovulated in lactation spontaneously (without boar exposure) was between 0-8% and 5-24% respectively, compared to 36-47% of primiparous sows and 47-76% of multiparous sows that received boar exposure only. Therefore, to stimulate the greatest proportion of both multiparous and primiparous sows to express a lactation oestrus within 4-5 days from the commencement of treatment, it is recommended that boar exposure is combined with a reduction in the suckling stimulus in late lactation.

Comparison of multiparous to primiparous sows, in studies reported in Chapters Three and Four, demonstrated that a greater percentage of multiparous sows will exhibit a lactation oestrus than primiparous sows. The conclusion that first parity sows are less likely than older sows to ovulate during lactation is supported by Soede et al., (2012) who observed lactation oestrus, in response to intermittent suckling, in only 23% of first parity sows, compared to 68% of multiparous sows. Soede et al., (2012) indicated that second parity sows exhibited the highest rates of lactation oestrus expression and the parities thereafter experienced a significant decrease in the proportion expressing a lactation oestrus in response to intermittent suckling. Therefore, it is evident multiparous sows will achieve the highest rate of lactation ovulation, irrespective of the technique used to achieve it. Reducing the suckled litter size of primiparous sows to seven piglets in late lactation did significantly increase lactation oestrus expression, but a higher proportion of multiparous sows responded to this treatment with expression of lactation oestrus (Chapter Four). The reasons for lower proportions of lactation oestrus expression in primiparous sows aren't clear; however, it is generally accepted that primiparous sows will experience a diminished reproductive capacity post-weaning compared to multiparous sows. The primiparous sow is still maturing and growing compared to the older parity sow, and experiences a greater loss of body reserves, and compromised follicle growth and development during lactation, leading to an increased weaning to oestrus interval, compared to the multiparous sow (Vesseur et al., 1997; Quesnel et al., 2007; Kemp and Soede, 2012). A clear loss in live weight over the course of lactation was detected in primiparous sows, when compared to multiparous sows. However, whether the extent of live weight loss was sufficient to significantly impact on the reproductive capacity and lactation oestrus expression is unclear (Thaker and Bilkei, 2005). Therefore, given the relatively low expression of lactation oestrus exhibited by primiparous sows, despite reducing the suckling intensity and providing full physical boar exposure, it may be necessary to assess the additional use of exogenous gonadotrophins to stimulate primiparous sows to exhibit a lactation oestrus. However caution should be taken with such protocols in the metabolically challenged primiparous sow as the potential negative effects of a pre-weaning pregnancy in the primiparous sow may outweigh any advantages.

Stimulating a lactating sow to express a lactation oestrus has been a concept researched since the 1970's with varying success (Crighton 1970; Rowlinson et al., 1975; Cox and Britt 1982; Rowlinson and Bryant 1982; Cox et al., 1988). However, the modern sow is different from the sow from 20 to 40 years ago. The effects of lactation weight loss on the weaning to oestrus interval are much less pronounced than in the 1980's when they could be as high as 23 days, compared to 4-7 days in current commercial practice (Kemp and Soede 2012). The success of the modern sow has been achieved through better management, better breeding programs, and a better understanding of the gestating and lactating sow's nutritional requirements. The incidence of a spontaneous lactation oestrus, where the sow has spontaneously ovulated during lactation with no litter reduction or boar exposure, can be attributed to the prolificacy of the modern sow. Possibly, the selection for reduced weaning to oestrus intervals has influenced the resumption of high frequency and low amplitude LH release from the hypothalamus to occur prior to piglet removal. The occurrence of a spontaneous oestrus, determined by either a standing reflex or a high progesterone concentration (> 4 ng/ml) two days post-weaning, was between 5-24% for multiparous sows (Chapter Two and Four) and 8% for primiparous sows (Chapter Four). The commercial consequence of an undetected spontaneous lactation ovulation is a delayed weaning to oestrus interval, decreased reproductive capacity and the possibility that the best reproductively sound sows will be culled out of the herd early. The high incidence of 24% of multiparous sows spontaneously ovulating during lactation in the absence of a boar, with a further 5% of sows exhibiting a lactation oestrus on day 18 of lactation when first exposed to a boar indicates that the modern sow is becoming predisposed to ovulating in lactation. The use of lactation oestrus management presents as a possible strategy to more effectively manage these hyperprolific sows.

For the successful implementation of lactation oestrus protocols they need to be commercially practical and cause no decrease in the subsequent reproduction of the sow – including subsequent pregnancy and farrowing rates and litter size born. Indications from the results in this dissertation are somewhat conflicting. Some results suggested that mating sows in lactation, compared to post-weaning, had no effect on the total born or total born alive of the subsequent litter size. However, results most notably from Chapter Four showed a decrease in the subsequent total born and born alive and a decrease in farrowing rate; and, results from Chapter Three indicated a higher rate of stillbirths when mating occurs in lactation making lactation oestrus protocols less desirable. It has previously been recommended that to achieve the best reproductive output, insemination of sows during lactation should not occur before 21 days post-partum and lactation should not continue beyond the first week of pregnancy as it is known to reduce the farrowing rate and subsequent litter size (Gaustad-Aas et al., 2004; Soede et al., 2012). The majority of sows, within the studies conducted in this thesis, are consistent with this recommendation; however, further studies should be conducted to determine the cause of the reduced farrowing rates, reduced total born and increased stillbirths when sows are mated during lactation. Data from Chapter Four, although it was not significant, demonstrated that multiparous sows that were split weaned and mated post-weaning had 2.1 more total born piglets at the subsequent litter than multiparous sows which had no litter reduction. Therefore split weaning potentially improved follicular growth leading to the improved farrowing rate for the sows that were anoestrus during lactation and mated post-weaning.

Mahan and Lepine (1991) and Pluske and Williams (1996) reported that piglet weight at weaning, regardless of weaning age, is a major determinant of subsequent growth post-weaning. Chapter Two investigated the post-weaning growth of the piglets split weaned at day 18 of lactation up to day 40 of age and demonstrated that growth is not adversely compromised by the early weaning. This study also demonstrated that regardless of the age the piglet is weaned, it will still experience a post-weaning growth check. Piglets from split weaned litters that were allowed to remain on the sow experienced an increased growth rate between days 17 and weaning, compared to piglets split weaned or piglets from sows with a complete litter, thereby allowing lighter piglets to catch up in growth possibly by reduced competition for teats. Therefore, there is great benefit in extending the weaning age for the benefit of the light weight piglet. For this to be achieved lactation oestrus management could only be applied to continuous mating systems that have a weaning age of 25 days or more and a clear benefit to the piglet. The benefit of split weaning is primarily to the lighter piglet, if the heavier piglets are removed, thereby allowing them greater access to the teat.

One contentious issue with regard to the commercial implementation of lactation oestrus is the increased labour component. Within this dissertation, apart from the final study (Chapter Five), sows were taken from the farrowing crate to the boar which would dramatically increase labour costs. However, this strategy was not intended to be the industry best practice, but rather to determine the maximal level of lactation oestrus expression that could be achieved. The cost of the increased labour, compared to the potential increase in production from heavier piglets at weaning, needs to be quantified and a cost benefit analysis conducted for individual farms, as it will differ between farms. Chapter Five within this dissertation investigated the use of alternative farrowing crates which potentially allowed the sow to reduce the suckling frequency herself, whilst bringing the boar into the farrowing house, thereby eliminating that extra labour component. Unfortunately, low lactation oestrus rates were observed in this trial, which may relate to the timing of the trial in January and February, within the Australian summer. The exact cause of the low lactation oestrus rates observed in studies in Chapter Five could either be summer infertility, a decrease in suckling intensity was not established in the alternative housing systems, or insufficient stimulation was provided through fence-line boar exposure, whilst the boar was housed in a crate. The latter is the most likely as while the boar is housed in a crate for transport around the farrowing house, the amount of saliva produced indicated a low level of interest in the sows. Whilst a boar crate is effective post-weaning, the function of the boar is only for oestrus detection and not stimulation. Therefore, lactation oestrus management strategies that allow for sufficient stimulation by the boar, whilst not removing the sow from the crate and bringing the boar into the farrowing house, will have to be investigated further.

To our knowledge, the capacity of sows to exhibit a lactation oestrus has not been investigated during the months where season or photoperiod can have its greatest influence. The studies in Chapter Two and Four were conducted within the cooler months of the year; however, a proportion of the study in Chapter Three and all of the study reported in Chapter Five, were conducted when temperatures were higher and days were longer, specifically in January-March when conventionally weaned sows typically experience a seasonally induced reduction in fertility (Prunier et al., 1996). Seasonal infertility is mediated by the decrease in melatonin that results from extended day lengths during summer and the negative impacts of elevated temperature (Ramírez et al., 2009). The capacity of the sow to exhibit a lactation oestrus and ovulate during lactation was possibly diminished during the summer months due to a seasonally induced suppression of LH release and ovarian follicle growth. The increased capacity of the sow to express lactation oestrus during the cooler months of the year is detailed in Figure 6.1. Whilst this data is by no means conclusive, it does emphasize the need to investigate the effect of summer infertility on lactation oestrus in order to overcome this issue before commercial application of lactation oestrus is undertaken. It is the view of the author that to be commercially viable the practice of mating in lactation needs to be conducted on a large scale and the effects of the summer months investigated further. Whether additional stimulation such as injectable gonadotrophins, although not a desirable approach, is required in conjunction with boar exposure and litter manipulation during the summer months should also be assessed.

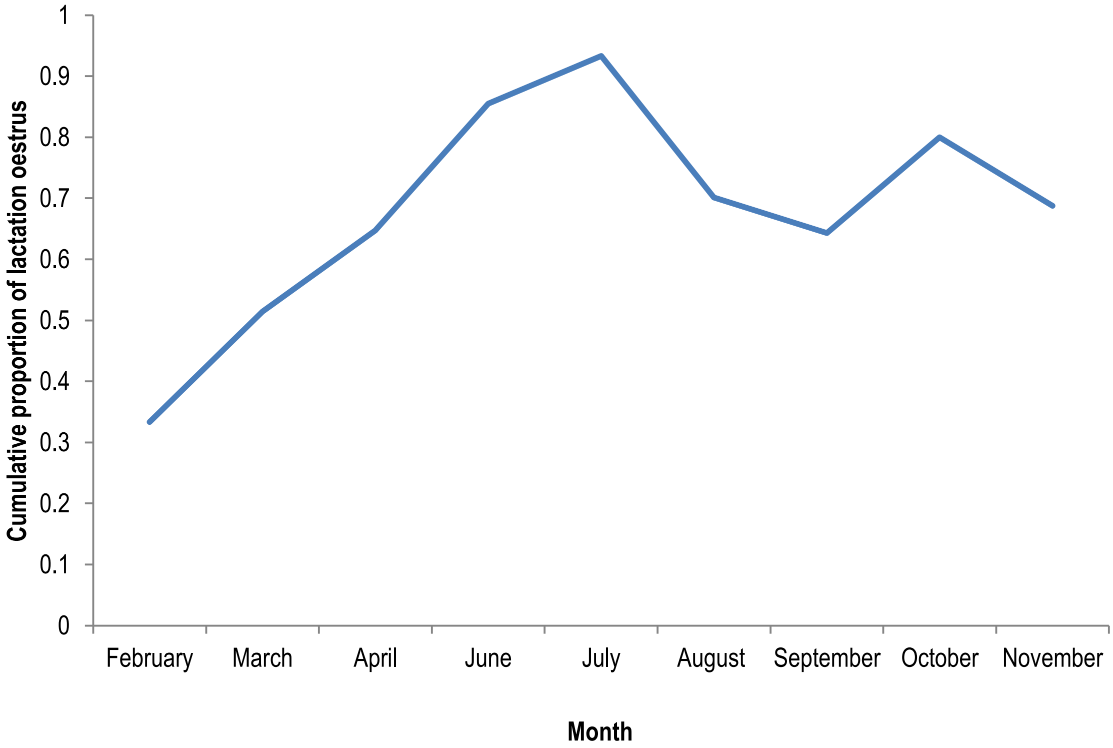

Figure 6.1 Cumulative proportion of lactation oestrus expression from multiparous sows only during the months February to November. These data were combined from the studies conducted within Chapters Two, Three and Four.

The benefits of inducing a lactation oestrus are the increased lactation length, the possibility for a gradual weaning process and the possibility of uncoupling mating from the weaning process. The overall aim for the investigation and development of lactation oestrus management systems within the Australian pork industry is to allow flexible management strategies which could potentially be used for low confinement housing systems. The subject of lactation crates and reduced sow confinement during lactation to benefit the welfare and survival of the piglet is beyond the scope of this dissertation. However, should producers choose to move toward group lactation housing systems, where the sow is removed from the conventional farrowing crate in the second or third week of lactation, with the boar housed close by, lactation oestrus could be a viable option to manage the lactating sow. As the time a piglet spends suckling is reduced in a farrowing pen compared to a lactation crate (Stolba et al., 1990) there is a risk that the sow will ovulate during lactation at a time unknown to the producer therefore disrupting the production flow. A high incidence of spontaneous lactation oestrus was demonstrated recently in sows housed in a PigSAFE pen from birth and then moved into a group lactation system 14 days prior to weaning (Morrison et al., 2015). Twenty-seven percent of sows housed firstly in the PigSAFE pen exhibited a lactation oestrus compared to 9% of sows housed firstly in a farrowing crate (Morrison et al., 2015). However, these rates of oestrus expression are still not high enough to be able to take advantage of lactation oestrus systems. Rather, the producer needs to manage sows showing signs of lactation oestrus in loose housing systems to ensure weaning to oestrus intervals are not extended severely. Group lactation systems will need to be investigated comprehensively for the incidence of lactation oestrus within the Australian climate, the effect on piglet survival and welfare, and the optimal sow group dynamic incorporating adequate boar stimulation before any such system is implemented.

In conclusion, this dissertation has demonstrated that day 18 post-partum is the optimal time to begin lactation oestrus stimulation by incorporating both reduced suckling intensity through split weaning and boar exposure to result in a high proportion of sows ovulating during lactation which then translates into a good farrowing rate. The synchrony of lactation oestrus expression is comparable to the weaning to oestrus interval as on average lactation oestrus expression occurred between 4-5 days from the commencement of stimulation. However, the response of primiparous sows to lactation oestrus stimulation was quite poor and therefore further investigation into the best strategy, possibly with the use of exogenous gonadotrophins, to stimulate a high proportion of lactation oestrus in the primiparous sow is required. The impact of season on the expression of lactation oestrus cannot be fully elucidated; further investigation is required comparing lactation oestrus expression across all seasons. If the eventual outcome within the Australian pork industry is to move toward low confinement lactation housing systems, lactation oestrus may serve as a reproductive management system to maintain production efficiency. However, should the sow remain within conventional lactation housing systems, a lactation oestrus management system should only be conducted if weaning age is 25 days or more and a cost benefit analysis should be conducted to determine if such a system is appropriate for the individual producer.

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