Inaugural-Dissertation zur Erlangung der Doktorwürde

der Tierärztlichen Fakultät der Ludwig-Maximilians-Universität

München

# Comparison of the behaviour of piglets raised in an artificial rearing system or reared by the sow

von Magdalena Stefania Rzezniczek

aus Beuthen

München 2015

Aus dem Veterinärwissenschaftlichen Department der Tierärztlichen Fakultät
der Ludwig-Maximilians-Universität München

Lehrstuhl für Tierschutz, Verhaltenskunde, Tierhygiene und Tierhaltung

Arbeit angefertigt unter der Leitung von Univ.-Prof. Dr. Dr. Michael Erhard

Angefertigt am
Bundesamt für Lebensmittelsicherheit und Veterinärwesen (BLV)
Zentrum für tiergerechte Haltung: Wiederkäuer und Schweine
Ettenhausen, Schweiz

Mentor: Dr. Roland Weber

**Gedruckt mit Genehmigung der Tierärztlichen Fakultät**

**der Ludwig-Maximilians-Universität München**

| | |
|---|---|
| **Dekan:** | Univ.-Prof. Dr. Joachim Braun |
| **Berichterstatter:** | Univ.-Prof. Dr. Dr. Michael H. Erhard |
| **Korreferent/en:** | Univ.-Prof. Dr. Holm Zerbe |

Tag der Promotion: 18. Juli 2015

# Table of contents

# 1. General introduction

Over the past 15 years, litter size in the pig-breeding sector has improved considerably (Tomiyama et al., 2011; Vidović et al., 2012; Rutherford et al., 2013). Nowadays, the litter size in terms of the number of live-born piglets often exceeds the limited number of available and functional teats at the sow's udder (Baxter et al., 2013; Rutherford et al., 2013). Further adverse effects of increasing litter size are piglets' reduced mean birth weight, a higher variation in birth weight within the litter and an increase in the number of piglets born weak or undersized (Milligan et al., 2002; Quiniou et al., 2002; Wolf et al., 2008; Akdag et al., 2009; Andersen et al., 2011).

As a result, new husbandry systems for rearing surplus piglets have been developed in addition to the widespread use of split suckling, supplementary milk feeding, cross-fostering and nurse sows (Baxter et al., 2013). This includes the possibility of removing surplus piglets within a few days after birth from the sow and raising them in artificial piglets rearing systems (recommended by Provimi B.V., the Netherlands, and ATX Suisse GmbH, Switzerland; Baxter et al., 2013).

However, previous studies on the effects of weaning at an age of 3 weeks have shown that piglets performed an abnormal behaviour pattern termed belly nosing, characterised by rhythmic up-and-down movements with the snout directed to the body of a pen mate (Fraser, 1978). It was also demonstrated that piglets separated from the sow at the age of 56 to 92 hours spent 2.4 % of the time with belly nosing between days 2 and 12 post weaning (Widowski et al., 2005). Similarly, Li and Gonyou (2002) reported that 81 % of the piglets weaned at 12 to 14 days of age spent on day 7 following weaning an average of 2.4 % of the time nosing the belly of pen mates, whereby a belly nosing segment lasted an average of 538 s. It was also found that belly nosing increases in frequency and duration as piglets' weaning age decreases (Metz and Gonyou, 1990; Bøe, 1993; Main et al., 2005; Jarvis et al., 2008).

Moreover, due to restricted space, piglets weaned at the age of 3 weeks into cages with a space allowance of 0.15 $m^2$ or 0.20 $m^2$ per piglet performed less play and more aggressive behaviour than piglets reared by the sow in a farrowing pen of 8 $m^2$ (Worsaae and Schmidt, 1980). Likewise, Gardner et al. (2001b) reported that piglets weaned at the age of 12 to 14 days spent more time lying when housed in pens with a space allowance of 0.4 $m^2$ per piglet compared with piglets provided with 0.15 $m^2$ per piglet. Finally, it has been suggested that housing piglets in pens lacking environmental stimuli like bedding material could result in a higher level of manipulation directed at pen mates (van Putten and Dammers, 1976; Dybkjaer, 1992; Bøe, 1993).

The present study was carried out according to the Swiss authorisation procedure for mass-produced farm animal housing systems that evaluates housing systems and equipment with regard to animal welfare and to the requirements of the Swiss animal welfare legislation (Wechsler, 2005). It was performed with the commercially available artificial piglet rearing system 'Rescue Deck' at the Agroscope's swine barn in Tänikon (Switzerland). Piglets from two to four litters were removed from the sow at the age of 3 to 6 days and transferred to the artificial piglet rearing system. Their behaviour was recorded and compared with that of piglets reared by the sow in a loose farrowing pen. Since there are no studies published in scientific journals about piglets' behaviour in commercially available artificial piglet rearing systems, and since the two rearing environments differed in several aspects, such as the earlier separation from the sow, feeding on artificial milk, the earlier weaning from milk, the smaller group size, the smaller space allowance (and therefore a higher density), the lower quality and quantity of bedding material and being mixed with non-littermates in the piglets raised artificially compared with the piglets reared by the sow, differences in piglets' behaviour were expected, and the findings of the present study were supposed to provide new information in terms of animal welfare about the consequences of removing piglets from the sow at the age of 3 to 6 days and raising them in an artificial piglet rearing system.

# 2. Literature review

## 2.1 Selections for larger litter size

Over the past two decades, considerable increase in piglet litter size has been achieved, in particular by rising sow fertility (Rutherford et al., 2013). In Switzerland, for instance, the number of live born piglets per litter in the Large White breed increased from 11.44 in 2004 to 12.91 in 2013, and in the Landrace breed from 11.13 in 2004 to 12.86 in 2013 (SUISAG, Zahlen und Projekte, 2004, 2013). Similarly, in Germany a considerable increase in the number of live born piglets per litter has been reported with 12.2 in 2008/2009 and 13.5 in 2013/2014 (Topigs Norsvin, Sauenplanerauswertung 2013/14). Moreover, Rutherford et al. (2013) found that due to genetic selection for growing piglet litter size in Denmark, the number of total born piglets per litter increased with an average of 0.3 piglets per year from 12.1 in 1996 to 16.6 in 2011, and the number of live born piglets from 11.2 in 1996 to 14.8 in 2011. On closer inspection at individual breeds in Denmark, it was also shown that in the Landrace breed the total number of piglets born per litter increased from 13.0 in 1998 to 15.6 in 2013, and in the Large White breed from 11.4 in 1998 to 16.0 in 2013 (Danish Pig Research Centre Annual Reports, 1999, 2013). Finally, Tomiyama et al. (2011) reported that in Japan the total number of piglets at birth increased by about 1.0 piglet from 2003 to 2008, and Vidović et al. (2012) noted that in Serbia the genetic influence on litter size over eight generations amounted to an average of 0.25 more live born piglets per generation from 2001 to 2011.

In addition to genetic improvements towards larger litter size, non-genetic factors like improvements in sow nutrition and in management also have an impact on litter size (Rutherford et al., 2013). However, as non-genetic factors are not transmitted over several generations, their effect is short-term.

With regard to nutrition, Rutherford et al. (2013) concluded that adequate nutrition of gilts and sows is essential for the health of the sow and thus for the physiological development of the piglets. For example, sows which were additionally fed with L-carnitine during gestation and/or lactation achieved a higher number of piglets born alive (Musser et al., 1999). An

increase in litter size was also observed in sows which had previously litters of 12 or less piglets and were then fed with supplementary dextrose and lactose during the last week of gestation and lactation (Van den Brand et al., 2009). A positive impact on oocyte maturity and embryo survival was also noted when gilts were fed with high fibre diets (Ferguson et al., 2006, 2007).

Better gilt and sow management, less maternal stress and a less fearful relationship between sows and humans have also been regarded to have a positive impact on the sow's reproductive performance (Rutherford et al., 2013). For example, Hemsworth et al. (1999) observed that fearful behaviour of sows towards humans during lactation, characterised by a rapid withdrawal of sows in reaction to a human's close approach, was correlated with more stillborn piglets. Restraint stress of pregnant sows during the late period of gestation was also found to be associated with more diseased and dead piglets in the suckling phase, as prenatal stress is possibly linked with adverse effects on the immune system of the foetuses (Tuchscherer et al., 2002). In line with this, Jarvis et al. (2006) reported that daughters from prenatally stressed sows, which experienced stress by social mixing during the third trimester of gestation, had fewer live born piglets.

## 2.2 Implications for piglets due to larger litter size

In a recent review, Rutherford et al. (2013) concluded that increasing the number of live born piglets is associated with adverse effects on the welfare of piglets with regard to biological factors.

As reported by Foxcroft et al. (2006) and Rutherford et al. (2013), prenatal piglets in large litters may be exposed to intrauterine crowding and to restrictions in uterine capacity and, thus, experience competition for access to uterine space, blood supply and nutrients.

Increasing litter size has been found to be linked with a reduced mean birth weight, a higher variation in birth weight within the litter, a higher percentage of small piglets weighing 1 kg

or less, a greater risk for stillbirths as well as for piglets dying within 24 hours after birth (Johnson et al., 1999; Milligan et al., 2002; Quiniou et al., 2002; Canario et al., 2006; Wolf et al., 2008; Akdag et al., 2009; Vanderhaeghe et al., 2010; Andersen et al., 2011).

Low birth weight piglets are affected by reduced vitality to reach the udder for the first time after birth, by lower rectal temperature 24 hours post-partum and by reduced growth rate (Herpin et al., 1996). In addition, Pedersen et al. (2011) reported that piglets with low birth weight and with reduced rectal temperature after birth are at a greater risk of being crushed and of dying due to starvation or diseases.

Several studies have shown that high variation in piglets' birth weight resulted in high variation in survival rate, and that large litters with piglets of low birth weight were considerably disadvantaged with regard to mean weaning weight and survival until weaning compared with smaller litters containing piglets of higher mean birth weight (Milligan et al., 2002; Akdag et al., 2009). In line with this, Auldist et al. (1998) found a decrease in average growth rate of piglets until weaning when litter size increased from 6 to 14.

Availability of colostrum and milk can be a limiting factor in large litters. As production of colostrum is not influenced by litter size, less colostrum is provided per piglet in larger litters (Devillers et al., 2007). And even though milk production in total increases as litter size increases (Auldist et al., 1998; Kim et al., 1999; King, 2000), milk intake per individual piglet also decreases in large litters (Kim et al., 1999; King, 2000).

Piglets in large litters are confronted with increased teat competition, as only a limited number of available and functional teats is able to provide colostrum and milk to the piglets (Milligan et al., 2001; Andersen et al., 2011; Baxter et al., 2013; Rutherford et al., 2013). Piglets from large litters were observed to miss a higher percentage of nursing episodes, to have a lower teat consistency score, to have a greater number in teat disputes before milk ejection, and to spend more time in teat disputes after milk ejection (Milligan et al., 2001). Similarly, Fraser (1975) reported that piglets in large litters were more often fighting at the sow's teats and affected by injuries on their faces. The higher risk of piglet mortality in large litters is probably due to the fact that piglets with problems to compete with littermates for

teats suffer from hunger, and that starving piglets are likely to be crushed by the sow (Milligan et al., 2001; Andersen et al., 2011). Compared with small piglets, heavier piglets are able to drink a greater amount of milk, as they engage in more vigorous massaging before milk let-down, which is necessary to increase blood flow and adequate release of oxytocin (Fraser, 1984; King et al., 1997; King, 2000; Rutherford et al., 2013).

## 2.3 Management interventions to deal with large litter size

Since the number of piglets born alive may exceed the number of functional teats, several management interventions, such as split suckling, additional milk feeding in the farrowing pen, cross-fostering, rearing by nurse sows, split weaning, and early removal of piglets from the sow in combination with the use of artificial piglet rearing systems, have been developed to deal with the adverse effects of large litters and the resulting problem of surplus piglets (Baxter et al., 2013; Rutherford et al., 2013).

### 2.3.1 Split suckling

When split suckling is used, large litters are split into two groups by removing the heavy and strong piglets for a short period of time, thus facilitating access to the sow's udder for the light and weak piglets (Kyriazakis and Edwards, 1986; Donovan and Dritz, 2000; Baxter et al., 2013). It was shown that split suckling is most beneficial for large litters, as it results in a reduction in the variation of average daily gain (Donovan and Dritz, 1996, 2000). A higher weight gain in light piglets within the first 3 days of life was also reported by Kyriazakis and Edwards (1986), but no difference could be observed on day 19 of lactation.

### 2.3.2 Additional milk feeding in the farrowing pen

Feeding piglets with additional milk replacer in the farrowing pen is another option to raise large litters that remain with the mother sow. It was found that piglets receiving liquid milk replacer in addition to sow milk were heavier at weaning and tended to suffer less from pre-weaning mortality (Wolter et al., 2002). Similarly, Azain et al. (1996) reported that piglets provided with milk replacer during lactation had a higher average piglet weight and a higher total litter weight at weaning. With regard to average milk replacer intake and weaning weight of piglets, these authors also mentioned that supplementation was more useful for piglets during warmer months than during the cool season, since feed intake and milk production of sows were lower under heat exposure.

### 2.3.3 Cross-fostering

A common method to balance litter size between sows is to use cross-fostering (Robert and Martineau, 2001; Baxter et al., 2013). Piglets are relocated from their biological mother to another lactating sow with fewer piglets, while taking factors into account like litter size, gender and weight of the piglets, maternal behaviour of the sow, milk production, position of teats at the udder and number of functional teats (Baxter et al., 2013). If carefully managed, cross-fostered piglets were found to have a higher survival rate than piglets remaining with their biological mother (Cecchinato et al., 2008). However, mortality was higher and body weight was lower in cross-fostered, low birth weight piglets raised in large litters consisting of high birth weight littermates (Deen and Bilkei, 2004). Furthermore, more missed suckling episodes and a greater amount of time spent in disputes over teats were observed after cross-fostering in low birth weight piglets reared in large litters composed of average and high birth weight piglets (Deen and Bilkei, 2004). Cross-fostering performed several times during lactation can be detrimental to piglets, because of more fighting at the udder, more injuries apparent on the face and body, more unsuccessful nursing episodes, and a lower body weight at weaning (Robert and Martineau, 2001).

### 2.3.4 Nurse sows

To deal with large litters, nurse sows may be used to rear a second litter composed of piglets of other sows with large litters once the sow's own piglets have been weaned (Baxter et al., 2013). Since nurse sows are exposed to an extended lactation period, they have to be in good physical condition, and high feed intake is necessary during lactation to ensure sufficient milk production (EFSA, 2011). However, as relationships between the mother sow and the piglets of the original litter as well as a stable suckling order at the udder have already been established before the transfer to the nurse sow, piglets could be adversely affected by this rearing method (Baxter et al., 2013).

### 2.3.5 Split weaning

When split weaning is used, large litters are divided into groups of heavier and lighter piglets, which are weaned at different times (Pluske and Williams, 1996; Baxter at el., 2013). In a study of Pluske and Williams (1996), for example, lighter piglets weaned at the age of 29 days had a higher growth rate and body weight than control piglets weaned at the age of 22 days.

### 2.3.6 Artificial piglet rearing systems

A relatively new management technique to deal with large litters and surplus piglets is to raise them in artificial piglet rearing systems (Baxter et al., 2013). From the age of 2 to 3 days of life and after colostrum intake, piglets are removed from the sow and transferred to such housing systems (recommended by Provimi B.V., the Netherlands, and ATX Suisse GmbH, Switzerland; Baxter et al., 2013). Under Swiss legislation, there are no stipulations with regard to the weaning age of piglets. According to EU legislation, "no piglets shall be weaned from the sow at less than 28 days of age unless the welfare or health of the dam or the piglets

would otherwise be adversely affected", and "piglets may be weaned up to 7 days earlier if they are moved into specialised housings which are emptied and thoroughly cleaned and disinfected before the introduction of a new group and which are separated from housings where sows are kept, in order to minimise the transmission of diseases to the piglets" (Council Directive 2008/120/EC).

## 2.4 Artificial piglet rearing systems in Switzerland

Currently, two artificial piglet rearing systems are commercially available in Switzerland to raise piglets removed early from the sow. These are the so called 'Rescue Deck' (Rescue Deck® System, S&R Resources LLC, USA) and the 'Nursery' (Nursery®, ATX® Suisse GmbH, Switzerland). Both housing systems are composed of several functional areas. Piglets in the Nursery are allowed to sleep in a defined heated area, to urinate and defecate in a dunging area, and to drink artificial milk and water as well as to eat solid feed in a feeding area. Piglets in the Rescue Deck are also provided with a heated lying area and a combined feeding/dunging area.

In the Swiss authorisation procedure for mass-produced farm animal housing systems that evaluates housing systems and installations with regard to the animal welfare and to the requirements of the Swiss animal welfare legislation (Wechsler, 2005), the Rescue Deck and the Nursery were approved for a limited period of time and under following conditions: A maximum of 7 and 26 piglets up to 10 kg may be housed in one Rescue Deck and one Nursery, respectively. In addition, the slot-width of the slatted floor may not exceed 9 mm, and half of the total floor area must be provided with a lying area in which the floor has a maximum of 2 % degree of perforation. Finally, the lying area must have a non-slip floor, which has to be covered daily with fresh bedding material, such as long straw, cut straw, *Miscanthus giganteus* or dedusted wood shavings (BLV, 24.11.2010).

The Nursery (2.6 x 1.65 m plus 0.7 x 0.6 m) can be placed either within the swine barn or outside in an external mobile container (ATX Suisse GmbH, Switzerland). It consists of a

heated piglet box with bedding material on the floor, an automatic feeder placed on the partially slatted floor of the activity area, and a dunging area. Two radiation heaters are mounted in the lid of the piglet box, which is positioned lower to the activity area and is separated from this area by a curtain made of non-transparent stripes. The activity area has a partially slatted floor made of triangular steel grates. Artificial milk and solid feed are provided at defined intervals in the automatic feeder and kept warm in the heated trough. Water is available in a plastic container in the activity area (ATX Suisse GmbH, Switzerland).

More detailed information on the Rescue Deck investigated in the present study can be found in the enclosed paper accepted by Applied Animal Behaviour Science (see Chapter 4 Publication and Figures 1 and 2 in Appendix).

## 2.5 Early versus natural weaning

Early weaning of piglets is associated with changes likely to affect the piglets' welfare, such as the separation from the sow, the urge to drink artificial milk or eat solid feed instead of sucking milk on the sow's teats, and the mixing with unfamiliar piglets in an unknown environment (Martin, 1984; Worobec, 1997; Gardner, 2000; Weary et al., 2008). Moreover, the piglets have to start ingestion of artificial milk without the presence of a sow that initiates suckling episodes, in particular when piglets are young (Newberry and Wood-Gush, 1985; Worobec, 1997).

Natural weaning of piglets, which can last several weeks under semi-natural conditions (Newberry and Wood-Gush, 1985; Jensen, 1986; Jensen and Recén, 1989; Stolba and Wood-Gush, 1989; Bøe, 1991), is a process of gradual transition from dependence on the sow's milk to growing intake of solid feed (Martin, 1984; Jensen and Recén, 1989; Petersen, 1994; Worobec, 1997; Worobec et al., 1999; Bench, 2005) when availability of milk and motherly care is slowly declining (Martin, 1984; Bøe, 1991; Bench, 2005; Widowski et al., 2008).

Compared with early weaned piglets, piglets reared by the mother continue to have access to warm, high digestible milk, which they drink synchronously with their littermates in about 20 to 24 nursing episodes per day (Fraser, 1980; de Passillé and Rushen, 1989; Bøe, 1991; Jensen et al., 1991; Worobec, 1997). Suckling behaviour at the udder is considerably influenced by the behaviour and vocalisation of the sow (Worobec, 1997). For instance, rhythmical grunting of the sow performed at a high rate is used by the piglets as an indicator that milk becomes available at the udder within a short time (Schön et al., 1999). During the first week of life, in particular, piglets give preference to vocalisations performed by the mother over nurse gruntings produced by an unfamiliar sow (Puppe et al., 2003). During this period, suckling bouts are initiated by the sow and terminated mostly by the piglets (Newberry and Wood-Gush, 1985; Jensen et al., 1991). The sow initiates a suckling bout by grunting, or she reacts to approaching piglets by grunting and providing them access to the udder (Newberry and Wood-Gush, 1985; Wechsler and Brodmann, 1996). Piglets, in turn, learn to respond to the grunting of the sow by coming close to the exposed udder and sucking from a preferential teat (Newberry and Wood-Gush, 1985; Puppe et al., 2003). With increasing age, suckling episodes are mostly initiated by the piglets as they approach the sow's udder, whine, grunt deeply, suck at the teats and perform vigorous massaging movements on the udder (Newberry and Wood-Gush, 1985; Bøe, 1991; Jensen et al., 1991; Wechsler and Brodmann, 1996). Also with increasing age, nursing bouts are more and more terminated by the sow, probably due to unwillingness of the sow to be massaged (Newberry and Wood-Gush, 1985; Jensen and Recén, 1989; Bøe, 1991; Jensen et al., 1991). As piglets get older, the sow stands more often during suckling, and the piglets spend less time lying close to the mother (Jensen and Recén, 1989; Bøe, 1991). Decreasing number of suckling bouts, less time that sows spend with their offspring in daytime, decreasing milk production and increasing intake of solid feed by piglets are further signs, indicating that weaning under natural and semi-natural conditions is a gradual process in piglets, which does not take place abruptly from one day to the next, compared with commercial breeding systems and here in particular with early weaning (Newberry and Wood Gush, 1985; Jensen and Recén, 1989; Bøe, 1991; Widowski et al., 2008).

### 2.5.1 Segregated Early Weaning (SEW)

Early weaning in combination with spatial segregation of the piglets from the sow is known as 'Segregated Early Weaning' (SEW) (Worobec et al., 1999). Segregated early weaning has been used, in particular, in the North American swine industry as a management strategy to improve the health status and performance of piglets by reducing pathogens that could be harmful to piglets' health in the farrowing unit (Worobec, 1997; Robert et al., 1999; Patience et al., 2000; von Borell, 2000). This has been achieved by weaning piglets at an age of 7 to 21 days (most commonly aged 12 to 16 days) and subsequently keeping them separate in all-in all-out production systems on-site or off-site (Worobec, 1997; Worobec et al., 1999; Patience et al., 2000; von Borell, 2000). It was recommended to do the weaning and segregation at a time when the piglets' passive immunity, which is due to maternal antibodies provided in the colostrum, is sufficiently high (Fangman and Tubbs, 1997; Maxwell and Sohn, 1999; von Borell, 2000). The management strategy aims to reduce or even avoid the risk that potential pathogens and thus infectious diseases are transmitted vertically from the mother sow to the offspring (Fangman and Tubbs, 1997; Maxwell and Sohn, 1999; Worobec et al., 1999; von Borell, 2000).

Since weaning piglets early and raising them without contact to the sow is related to major changes and challenges in the housing conditions of piglets, segregated early weaning has been discussed with regard to animal welfare (Robert et al., 1999; von Borell, 2000). For instance, weaning of piglets at the age of 7 days was found to result in a higher percentage of time the animals perform belly nosing, show escape behaviour and display drinking at the nipple drinker, and in a smaller proportion of time they spend feeding and interacting with pen mates, compared with piglets weaned at 14 or 28 days of age (Worobec et al., 1999). Likewise, piglets weaned at the age of 14 days spent more time with belly nosing and less time with feeding compared with piglets weaned at 28 days of age (Worobec et al., 1999).

## 2.6 Impact of early weaning and housing conditions on piglets' behaviour

### 2.6.1 Belly nosing

Irrespective of whether early separation from the sow is applied in practice to deal with large litters by using artificial piglet rearing systems, or to reduce vertical transmission of pathogens from sows to piglets by using segregated early weaning, previous studies on the behaviour and welfare of piglets weaned at an age of 3 weeks have shown that raising piglets without contact to the sow is associated with the occurrence of an abnormal behaviour pattern termed "belly nosing" (Fraser, 1978; Worsaae and Schmidt, 1980). Belly nosing is characterised by rhythmic up-and-down movements with the snout directed to the belly of a pen mate (Fraser, 1978).

In a study of Jarvis et al. (2008), however, belly nosing was also observed in piglets at the age of 28 days before they were separated from the sow on day 42. Similarly, Orgeur et al. (2001) reported a stable but considerably lower level of belly nosing in piglets remaining with the sow compared with piglets weaned early at the age of 6 days. Jarvis et al. (2008) discussed that the performance of belly nosing by piglets that are still with the sow could be the piglets' reaction to shortened sucking and massaging at the udder as the sow starts to wean the litter by limiting access to the udder and reducing the quantity of milk (Jarvis et al., 2008). Interrupted or unsuccessful suckling behaviour at the udder can also result from sudden, loud noise (Algers and Jensen, 1985) or may occur when the sow suffers pain due to mastitis. Pedersen et al. (1998) also assumed that intensified competition between littermates at the udder may lead to reduced willingness of the sow to nurse the litter and thus to an accelerated process to wean the piglets.

Various investigations on the time course of belly nosing in piglets weaned at the age of 7 to 24 days have shown that belly nosing gradually increases shortly after weaning, reaches the highest level approximately 2 to 3 weeks post weaning and then decreases again (Gonyou et al., 1998; Worobec et al., 1999; Gardner et al., 2001a, 2001b; Bench and Gonyou, 2006, 2009). Belly nosing was found to be performed with a high variation between individual piglets in proportion of time and with a considerable percentage of piglets not showing this

behaviour (Li and Gonyou, 2002). Li and Gonyou (2002) reported a positive correlation of belly nosing with standing and a negative one with lying and eating.

In previous studies, belly nosing was described to be similar to suckling behaviour (Fraser, 1978; Weary et al., 1999) and in particular to the vigorous massaging movements that piglets perform at the sow's udder before and after milk ejection (Worobec et al., 1999; Li and Gonyou, 2002). Suckling behaviour at the sow's udder consists normally of a short udder massage with rapid up-and-down movements of the snout before milk ejection, followed by slow non-nutritive sucking and fast nutritive sucking on the teats, and is terminated with a longer period of udder massage after milk intake, performed more slowly compared with the initial massaging movements (Gill and Thomson, 1956; Whittemore and Fraser, 1974; Fraser, 1980; Rushen and Fraser, 1989). Stimulation of the sow's udder by massaging before milk let-down is an essential element of suckling behaviour, since oxytocin is released by this stimulation, which is necessary to cause milk ejection (Ellendorff et al., 1982; Algers et al., 1990; Gardner, 2000). The function of the final udder massage, which is highly variable in the percentage of participating piglets (Bøe and Jensen, 1995), is still not fully understood (Torrey and Widowski, 2006). The "restaurant hypothesis" assumes that piglets can order up and control the milk production of the following suckling by performing this final massage (Algers and Jensen, 1985). In line with this, Jensen et al. (1998) reported that lower milk intake resulted in longer and more intensely massaging behaviour performed by piglets after milk ejection, but higher milk intake in turn did not lead to a decrease in final udder massage. In addition, milk output was not considerably affected by the duration of final massage (Jensen et al., 1998). According to Torrey and Widowski (2007), the final udder massage is linked with the piglets' nutritional need, since piglets involved in longer massaging behaviour after milk let-down were found to grow at a slower rate.

After farrowing, the piglets' body temperature decreases rapidly if they are exposed to a cold environment (Welch and Baxter, 1986). The udder is a particularly warm and soft body region of the sow, and piglets make use of the udder to huddle and sleep there, especially when ambient temperature declines (Welch and Baxter, 1986; Stangel and Jensen, 1991). In addition to milk, softness and warmth (Welch and Baxter, 1986), the udder provides comfort (Newberry and Swanson, 2001), tactile stimulation (Gardner, 2000) and social contact (Li and Gonyou, 2002; Bench and Gonyou, 2007) to the piglets. Li and Gonyou (2002) observed that

belly nosing and social interactions were performed in sequence by weaned piglets and therefore assumed that social motivation and belly nosing could have common underlying cause.

As a general pattern, it was found that belly nosing increases as weaning age of the piglets decreases (Algers, 1984; Metz and Gonyou, 1990; Bøe, 1993; Main et al., 2005; Jarvis et al., 2008). For instance, Gonyou et al. (1998) noticed that piglets weaned at the age of 12 days spent more time belly nosing than piglets weaned at the age of 21 days, and Weary et al. (1999) reported that piglets weaned at 2 weeks of age displayed more belly nosing than those weaned at 4 weeks of age. Finally, a higher level of belly nosing was performed by piglets weaned at the age of 7 days than by piglets weaned at 14 or 28 days (Worobec et al., 1999).

Since neither milk that was available in piglet diet nor diet of poor quality without milk had an impact on the occurrence of belly nosing, Gardner et al. (2001a) concluded that belly nosing does not seem to be related to feeding. In line with this, Bench and Gonyou (2007) found that belly nosing was not affected by the duration of the period during which liquid milk replacer was provided to weaned piglets. Widowski et al. (2005) suggested that belly nosing could be mainly caused by internal factor(s), as the amount of time the piglets spent with belly nosing the hour before and after feeding was similar and therefore not influenced by milk intake. Finally, Li and Gonyou (2002) observed that belly nosing and eating were not often performed in sequence, indicating that belly nosing is differently motivated than eating.

Belly nosing has also been considered to be exacerbated by housing environment. Dybkjaer (1992) observed that piglets weaned at the age of 4 weeks and housed at high density (0.15 $m^2$ per piglet) and without the provision of straw spent more time with belly nosing than piglets weaned at the same age but kept at low density (0.30 $m^2$ per piglet) and with straw. In line with this, Oostindjer et al. (2011) reported that piglets weaned at the age of 29 days into enriched pens of more space and the provision of straw, wood shavings, peat and branches performed less belly nosing, indicating better ability of these piglets to adjust to the numerous changes after weaning, compared with those piglets weaned at the same age but housed in barren pens with less space allowance and without substrate.

In previous studies, it was observed that environmental enrichment devices, used to imitate the sow's udder and to serve as an "outlet for oral activities" and "means of redirecting oral vices away from pen fittings and penmates" (Bench and Gonyou, 2006), as well as feeding devices, providing piglets with milk replacer and enabling them to perform nosing, massaging and sucking behaviour, are effective in reducing piglet-directed behaviour, such as belly nosing, belly sucking, and nosing, chewing and sucking pen mates' ears and tails (Widowski et al., 2005; Bench and Gonyou, 2006, 2007).

### 2.6.2 Sucking

Worsaae and Schmidt (1980) reported that piglets weaned at the age of 3 weeks directed much more sucking behaviour at pen mates than piglets that stayed with the sow. Similar results were obtained in a study comparing piglets weaned at 3 to 4 weeks of age with those weaned at 6 weeks of age (Algers, 1984; Bøe, 1993).

In addition to the strong need to massage the udder of the sow, piglets are highly motivated to suck on the teats, as their survival is highly dependent on successful sucking behaviour (van Putten and Dammers, 1976; Gardner, 2000; de Passillé, 2001). It is therefore not surprising that early weaned piglets direct not only belly nosing but also sucking behaviour to the body of pen mates (van Putten and Dammers, 1976). According to Widowski et al. (2005), devices which give piglets the opportunity to practise nutritive and non-nutritive sucking after weaning possibly have a calming effect on piglets.

### 2.6.3 Manipulation of pen mates

Piglets are motivated to explore their environment by nibbling, nosing, chewing or taking objects into their mouth, probably to become familiar with their environment, to gain information and to identify other sources of food than the sow's milk (van Putten and

Dammers, 1976; Wood-Gush and Vestergaard, 1989; Petersen, 1994; Studnitz et al., 2007). Under natural and semi-natural conditions offering much environmental stimulation and space, nibbling and chewing directed at the ears, tails and other body parts of littermates is performed very rarely (Dybkjaer, 1992; Petersen, 1994).

Dybkjaer (1992), Bøe (1993) and van Putten and Dammers (1976) reported that piglets weaned at 3 to 4 weeks of age and raised under barren housing conditions with low space allowance and without bedding material were engaged more frequently and spent more time manipulating pen mates (nibbling, sniffing, rooting or chewing) than piglets of the same age housed in enriched pens providing more space and bedding material, such as straw or sawdust. Similarly, Oostindjer et al. (2011) observed a lower level of nibbling, sucking or chewing at pen mates' body and a higher level of exploratory behaviour in piglets weaned at the age of 29 days of age and introduced to pens with more space allowance and the provision of straw, wood shavings, peat and branches compared with piglets weaned at the same age but housed in barren pens with less space and without substrate that could be explored. It was therefore concluded that piglets housed in a barren environment redirect exploratory behaviour at pen mates (van Putten and Dammers, 1976; Dybkjaer, 1992; Bøe, 1993; Oostindjer et al., 2011). However, in these studies, space allowance was confounded with environmental enrichment.

Less exploratory behaviour and more oral manipulation directed at pen mates was also observed in piglets weaned at the age of 4 weeks and housed in barren pens without provision of straw compared with piglets introduced to enriched pens of the same pen size but supplied with deep straw bedding (Bolhuis et al., 2005). In line with this, Kelly et al. (2000) reported that piglets weaned at the age of 3 weeks, housed in pens with a space allowance of 0.23 $m^2$ per piglet and supplied with straw spent more time with straw-directed and less time with piglet-directed behaviour than piglets kept in flat-decks with the same space allowance but without straw. Similar results were found in a study comparing piglets weaned at the age of 6 weeks and housed in a barren or an enriched environment with the same space available per piglet but supplied with peat and straw (Beattie et al., 1996). It was therefore concluded that piglet-directed behaviour (nosing, rooting and chewing) is more influenced by environmental enrichment than by space allowance (Beattie et al., 1996; Kelly et al., 2000). However, Gardner et al. (2001b) reported that piglets weaned at the age of 12 to 14 days and kept in

pens with a high density (0.15 $m^2$ per piglet) performed more piglet-directed nosing than piglets housed at low density (0.4 $m^2$ per piglet).

Gardner et al. (2001b) suggested that the motivation to manipulate pen mates could be different from the motivation to show belly nosing because the two behaviour patterns differ in the time course after weaning. Manipulation of pen mates is performed at a high level already on the first day after weaning and continues to be shown at an almost constant intensity (Worobec et al., 1999; Gardner et al., 2001a, 2001b). In contrast, the level of belly nosing increases gradually after weaning, reaches a peak about 2 to 3 weeks post weaning and declines afterwards (Gonyou et al., 1998; Worobec et al., 1999; Gardner et al., 2001a, 2001b; Bench and Gonyou, 2006).

### 2.6.4 Play behaviour

Under semi-natural conditions, piglets most frequently show play behaviour at the age of 2 to 6 weeks (Newberry et al., 1988). Play behaviour is characterised by social interest in other piglets, by "having fun" (Špinka et al., 2001), by lack of seriousness and lethargy, and is assumed to be performed in a comparatively safe and relaxed as well as pleasurable and exciting emotional state (van Putten and Dammers, 1976; Špinka et al., 2001; Donaldson et al., 2002). Špinka et al. (2001) stated that play behaviour is also initiated by an environmental change and by new or unpredictable stimuli. Play behaviour is thought to be important to acquire new motor skills as well as to train new motion sequences (Newberry et al., 1988). Play behaviour has also been described as contagious, and it was hypothesized that it helps to learn how to deal with unforeseen situations, "to train for the unexpected" (Špinka et al., 2001), to improve social skills and to establish stable social relationships (Weary et al., 2008; Špinka et al., 2001). According to Hohenshell et al. (2000), playing can be regarded as "the best behavioral indicator of well-being".

As assumed by Newberry et al. (1988), raising piglets in housing systems with restricted space allowance and lacking objects to play with might prevent them from performing the entire range of playful behaviour. Play is a space demanding behaviour (Dybkjaer, 1992), and

piglets might be frustrated if it is restricted by physical constraints (Newberry et al., 1988). In line with this reasoning, Dybkjaer (1992) found a lower level of play behaviour in piglets weaned at the age of 4 weeks and housed in pens with a space allowance of 0.15 $m^2$ per piglet and without straw compared with piglets provided with 0.3 $m^2$ floor space per piglet and straw. More play behaviour was also performed by piglets weaned at the age of 29 days into enriched pens with more space allowance and the provision of straw, wood shavings, peat and branches compared with piglets housed after weaning in barren pens with less available space and without substrate that could be explored (Oostindjer et al., 2011). Furthermore, Bolhuis et al. (2005) observed less play behaviour in piglets weaned at the age of 4 weeks and kept in barren pens without straw than in piglets housed in enriched pens of the same pen size but offered straw. Finally, Worsaae and Schmidt (1980) reported that play behaviour was reduced in piglets weaned at 3 weeks of age and housed without straw in cages of 0.15 $m^2$ or 0.2 $m^2$ floor space per piglet compared with piglets remaining with the sow until weaning in a pen of 8 $m^2$ and supplied with straw.

Play behaviour in piglets has been regarded to be affected by weaning. Piglets weaned at the age of 8 weeks and moved with littermates to a pen provided with straw and the same size like the farrowing pen before weaning performed less playful behaviour than before they were weaned (Worsaae and Schmidt, 1980). However, in this study, weaning was confounded with moving to a new pen.

### 2.6.5 Aggressive behaviour

Aggressive behaviour seems to increase in piglets due to weaning. Worsaae and Schmidt (1980) weaned piglets at 8 weeks of age and introduced them with littermates into pens identical to the farrowing pen in terms of size and straw provision and found that the animals showed more fighting, biting and pushing after weaning. Similarly, Orgeur et al. (2001) reported a higher level of aggressive behaviour after weaning in piglets weaned early at the age of 6 days and kept either in the farrowing pen or moved to an identical pen, compared with piglets that remained with the sow.

In addition to weaning, housing conditions of the weaned piglets are likely to contribute to increased aggression. For example, Beattie et al. (1996) observed less head-thrusting and biting in piglets weaned at the age of 6 weeks and introduced into pens containing peat and straw, compared with piglets weaned at the same age into pens of the same size but without enrichment material. In this study, it was also found that the level of head-thrusting was similar in piglets kept in pens with straw and peat but differing in space availability. The authors therefore concluded that aggression of weaned piglets is more influenced by environmental enrichment than by space allowance. Contrary to this, Gardner et al. (2001b) reported that piglets weaned at 12 to 14 days of age and introduced into nursery pens of high density (0.15 $m^2$ per piglet) showed less biting, pushing, head-thrusting and chasing than piglets weaned at the same age but housed in nursery pens of low density (0.40 $m^2$ per piglet).

According to Fraser (1978), belly nosing directed at pen mates may also induce aggressive behaviour in weaned piglets, since belly nosed piglets are disturbed by these behaviour patterns and therefore could bite the performer piglets. In line with this, Beattie et al. (1996) explained aggressive behaviour observed in piglets weaned at the age of 6 weeks, such as head-thrusting and biting, as the piglets' reaction to being exposed to insistent chewing and massaging performed by pen mates. Fraser (1978) also suggested that weaned piglets disturbed by pen mates while resting might start attacking and fighting.

Aggressive biting of weaned piglets is also observed at the feeder (Fraser, 1978). Before weaning, the piglets of a litter assemble at the sow's udder during nursing episodes and suckle milk in a stable teat order at the same time, with a given piglet preferring a particular teat (McBride, 1963; Fraser, 1980; Newberry and Wood-Gush, 1985; de Passillé et al., 1988; de Passillé and Rushen, 1989). As a consequence, fights over teats and competition during suckling are reduced as well as the risk of missing suckling bouts (de Passillé et al., 1988). In contrast, piglets after weaning may not always get access to a feeding place at the feeder, due to limited space at the trough, and thus show aggressive behaviour during feeding (Fraser, 1984). Similarly, fighting and attacking between littermates at the feeding trough was observed in piglets weaned at the age of 3 weeks (Fraser, 1978).

Weary et al. (2008) stated that group composition at weaning has an effect on aggressive behaviour. For example, Hötzel et al. (2011) reported that agonistic interactions were more

frequent on days 0 (weaning day), 1, 2, 3 and 10 after weaning in piglets weaned at the age 21 days and housed in pens with unfamiliar piglets than in piglets weaned at the same age but moved together with familiar piglets to these pens and in piglets of the same age staying in the farrowing pen as a litter after being separated from the sow. Similarly, Gardner et al. (2001b) found that piglets weaned at the age of 12 to 14 days and housed with unfamiliar piglets performed considerably more aggressive behaviour on day 3 after weaning than piglets weaned at the same age but kept with littermates. In line with this, Colson et al. (2012) observed that piglets weaned at the age of 26 days and mixed with unfamiliar conspecifics displayed more fighting than piglets weaned at the same age but exposed to no social change. With regard to age at mixing, Pitts et al. (2000) reported that younger piglets had shorter fights and fewer injuries, while Devillers and Farmer (2009) observed increased aggressive behaviour in younger piglets on the day after weaning.

### 2.6.6 Resting

Fraser (1978) reported that piglets weaned at 3 weeks of age had problems to rest comfortably without interruption, as the animals often changed the position while huddling together. Jarvis et al. (2008) observed more postural changes in piglets weaned at the age of 12 days than in piglets weaned at 21 and 42 days of age. In addition, Orgeur et al. (2001) found that piglets weaned early at the age of 6 days and left in the farrowing pen or moved to a similar pen rested less in a lateral position than piglets raised by the sow.

Metz and Gonyou (1990) reported that piglets weaned at 2 and 4 weeks of age had a peak in resting time on the day of weaning and that piglets weaned at the age of 2 weeks showed a considerable decrease in resting behaviour over the following days. They suggested that this decrease was possibly due to the fact that resting on the expanded floor was uncomfortable for the younger piglets. Eriksson (2006) also found that piglets weaned at 5 and 7 weeks of age rested more on the day after weaning than in the period afterwards. Colson et al. (2006) reported that piglets weaned at the age of 21 and 28 days spent more time lying within the first six days after weaning than control piglets staying with the sow. In this study, weaned

piglets of both ages were also observed to lie more in litter cohesion than on the day before weaning and compared with the control group. This was explained by the piglets' difficulty to regulate their body temperature after weaning in combination with low food intake. Devillers and Farmer (2009) compared piglets weaned at 21 and 43 days of age and noted that piglets weaned earlier were more quiet and apathetic on the day of weaning. They assumed that piglets weaned at a younger age may have a delayed response to weaning compared with piglets weaned at an older age. In contrast, Davis et al. (2006) found that piglets weaned at the age of 14 days spent less time resting on the day of weaning and more time standing or moving during the overall nursery phase compared with piglets weaned at 21 days of age. They concluded that piglets weaned earlier may have more difficulties getting used to the changes in their environment.

Space allowance per piglet may also affect resting behaviour. Gardner et al. (2001b) reported that piglets weaned at the age of 12 to 14 days and raised at low density (0.4 $m^2$ per piglet) rested longer than those weaned at the same age but housed at high density (0.15 $m^2$ per piglet). The authors concluded that piglets kept at high density were possibly more often interrupted by active pen mates while resting.

Mixing at weaning has also been discussed as a factor influencing resting behaviour. Gardner et al. (2001b) observed that weaned piglets kept as a group with their littermates rested longer on the day after weaning compared with piglets mixed with non-littermates at weaning. Similarly, Hötzel et al. (2011) found that piglets weaned at the age of 21 days and housed with unfamiliar piglets had a lower resting frequency during ten days after weaning than piglets weaned at the same age but kept with familiar piglets.

Metz and Gonyou (1990) suggested that reduced resting time and restlessness in weaned piglets may also be associated with belly nosing. In accordance with this, Li and Gonyou (2002) observed that piglets showing more belly nosing spent less time lying and eating.

## 2.7 Impact of early weaning and housing conditions on piglets' welfare

According to Broom (1986, 1991), the welfare of an animal is "its state as regards its attempts to cope with its environment" and is "clearly affected by both failure to cope and difficulty in coping". Broom (1991) also stated that "when animals know how to control their interactions with their environment but are prevented from carrying out the action, the resulting frustration causes various abnormalities of physiology and behavior that are indicators of poor welfare". As examples for housing conditions resulting in frustration, Broom (1991) mentioned restricted space allowance and limited access to feed. He also claimed that "certain stimuli are of great importance to the survival of animals, so they may be sought very actively and their absence may result in poor welfare, as evidenced by various abnormalities of physiology and behavior". In support of this, he explained that the mother's teats are important stimuli for young mammals and that these may show persistent teat-seeking behaviour directed at body parts of pen mates after early weaning. Accordingly, van Putten and Dammers (1976) reported that piglets weaned at the age of 3 to 3.5 weeks and moved to flat-deck cages performed massaging, sucking and nibbling redirected at pen mates. They hypothesised that separating piglets early from the sow and raising them in an environment lacking appropriate stimuli results in unrewarded appetitive and conflict behaviour, indicating that their well-being might be adversely affected. Similarly, Worsaae and Schmidt (1980) concluded that the welfare of piglets separated from the sow at the age of 3 weeks and housed in cages at high density and with few environmental stimuli was impaired, as the animals showed pen mate directed oral behaviour, such as belly nosing and sucking, increased aggressive and reduced play behaviour. Likewise, Worobec et al. (1999) assumed that the welfare of piglets weaned at 7 days of age was reduced, since weaning was associated with belly nosing, escape behaviour accompanied by vocalisations, and a reduction in the time spent with feeding and interacting with pen mates. According to Bench (2005), abnormal behaviour patterns, such as belly nosing and belly sucking, indicate that piglets may suffer after weaning "through the gradual impairment of an animal's ability to interact with its environment".

Bolhuis et al. (2005) reported improved welfare in piglets weaned at the age of 4 weeks and housed in an enriched environment, since these animals performed more play behaviour and less manipulative behaviour redirected at pen mates than piglets kept in barren pens. Similarly, Kelly et al. (2000) considered that the welfare of piglets was increased by giving

them access to straw after weaning, as they spent less time in piglet-directed behaviour and more time in straw-directed behaviour. Finally, Newberry et al. (1988) stated that a high level of play behaviour, in particular at the age of 2 to 6 weeks, is likely to ensure piglet welfare.

# 3. Publication

Rzezniczek, M., Gygax, L., Wechsler, B., Weber, R., 2015. Comparison of the behaviour of piglets raised in an artificial rearing system or reared by the sow. Applied Animal Behaviour Science, accepted.

## Comparison of the behaviour of piglets raised in an artificial rearing system or reared by the sow

Magdalena Rzezniczek [a, b], Lorenz Gygax [a], Beat Wechsler [a], Roland Weber [c, *]

[a] Federal Food Safety and Veterinary Office, Centre for Proper Housing of Ruminants and Pigs, 8356 Ettenhausen, Switzerland

[b] Institute of Animal Welfare, Ethology and Animal Hygiene, Ludwig-Maximilians-University, Veterinärstr. 13/R, 80539 Munich, Germany

[c] Agroscope, Centre for Proper Housing of Ruminants and Pigs, 8356 Ettenhausen, Switzerland

* Corresponding author

Tel.: +41 58 480 33 74; fax: +41 52 365 11 90.

*E-mail address*: roland.weber@agroscope.admin.ch (R. Weber).

## Abstract

Over the last 15 years, rising sow fertility has led to a considerable increase in litter size. As a consequence, the number of live born piglets may outnumber the number of functional teats, and surplus piglets are removed from the sow at the age of 3-6 days and fed with artificial milk. The objective of this study was to compare the behaviour of piglets raised in a commercially available artificial rearing system (group size: seven piglets) with that of piglets reared by the sow in a loose farrowing pen (seven focal piglets observed per litter). The behaviour of 98 piglets raised artificially (7 batches) and 82 piglets reared by the sow (6 batches) was videotaped on days 4, 11 (artificially raised piglets only) and 18 after introduction of the piglets to the artificial rearing system. Belly nosing, manipulation of a pen mate, play-fighting, aggressive behaviour and resting were assessed by continuous focal observation twice a day in the periods from 05:00 to 10:15 and from 13:00 to 18:15. Data were analysed by using linear mixed-effects models.

Belly nosing was hardly ever observed in piglets reared by the sow, whereas the duration as well as the frequency of this behaviour increased between days 4 and 18 in piglets raised artificially. Moreover, artificially raised piglets spent more time manipulating a pen mate, showed less play-fighting, exhibited more aggressive behaviour and had shorter resting bouts compared with piglets reared by the sow. Finally, total duration of resting decreased from day 4 to day 18 in artificially raised piglets and increased in piglets reared by the sow.

It is concluded that piglets removed from the sow at an early age and raised artificially redirect massaging behaviour to their pen mates, resulting in high levels of belly nosing and indicating impaired animal welfare. Moreover, the small space allowance in the tested artificial rearing system may additionally account for behavioural differences observed between artificially raised piglets and piglets reared by the sow in a loose farrowing pen.

**Keywords**

Early weaning, Artificial piglet rearing system, Belly nosing, Play-fighting, Resting behaviour

# 1. Introduction

Over the last 15 years, rising sow fertility has led to an increase in litter size (Tomiyama et al., 2011; Vidović et al., 2012; Rutherford et al., 2013). Increased litter size is associated with more variation in piglets' birth weight and reduced pre-weaning survival (Milligan et al., 2002; Quiniou et al., 2002; Wolf et al., 2008; Akdag et al., 2009; Andersen et al., 2011). In addition, competition at the sow's udder is increased, and the number of live born piglets may outnumber the number of functional teats (Milligan et al., 2001; Andersen et al., 2011).

There are several management approaches to deal with surplus piglets (Baxter et al., 2013; Rutherford et al., 2013). Large litters are split into two groups by removing the heavy and strong piglets for a short period of time, thus facilitating access to the udder for the light and weak piglets ('split suckling'; Kyriazakis and Edwards, 1986; Baxter et al., 2013). A common method used to balance litter size between sows is cross-fostering (Cecchinato et al., 2008; Baxter et al., 2013). Piglets are relocated from their biological mother sow to another lactating sow with fewer piglets (Baxter et al., 2013). Furthermore, nurse sows may be used to rear a second litter composed of piglets of other sows once their own piglets have been weaned (Baxter et al., 2013). Finally, surplus piglets can be removed from the sow within a few days after birth, after colostrum intake, and raised in artificial piglet rearing systems (Baxter et al., 2013). They are first fed artificial milk, which is later replaced by solid feed (Baxter et al., 2013). The present study focused on one such artificial rearing system that is commercially available and was conducted according to the Swiss authorisation procedure for mass-produced farm animal housing systems that evaluates housing equipment with regard to animal welfare (Wechsler, 2005). Behaviour of piglets raised in this system was compared with piglets that remained with their mother. The two systems differed in several aspects. The most important of these aspects were the earlier separation from the mother, feeding on artificial milk, the earlier weaning from milk, the smaller group size, the smaller space allowance (and therefore a higher density), the lower quality of bedding material, and being mixed with non-litter mates in the piglets raised artificially compared to the piglets reared by the sow.

One of the said differences that seems relevant and was investigated previously concerns the so called “early weaning”. Weaning of piglets is associated with major changes in their housing conditions likely affecting their welfare. The piglets are separated from the sow, start to ingest solid feed early and are usually mixed with unfamiliar piglets in an unknown environment (Worobec, 1997; Gardner, 2000). Various studies on the effects of weaning at an age of 3 weeks have shown that piglets develop an abnormal behaviour pattern termed “belly nosing” (van Putten and Dammers, 1976; Fraser, 1978; Worsaae and Schmidt, 1980). The behaviour consists of rhythmic up-and-down movements with the snout directed to the body of a pen mate (Fraser, 1978). As a general pattern, it was found that belly nosing increases in frequency and duration as weaning age decreases (Metz and Gonyou, 1990; Bøe, 1993; Jarvis et al., 2008). For example, Gonyou et al. (1998) reported that piglets weaned at the age of 12 days spent more time belly nosing than piglets weaned at the age of 21 days. Similarly, piglets weaned at 7 days of age showed a higher level of belly nosing than those weaned at 14 or 28 days in a study by Worobec et al. (1999).

Mixing with non-littermates, crowding, and lack of straw after weaning may have additional effects on the piglets’ behaviour (Dybkjaer, 1992). For example, van Putten and Dammers (1976) as well as Bøe (1993) reported that piglets weaned at 3-4 weeks of age and kept in pens lacking environmental stimuli, such as bedding material, to elicit exploratory behaviour manipulated pen mates by nibbling, sniffing, rooting, or chewing. With decreasing space allowance, piglets weaned at the age of 2-3 weeks were found to show more piglet-directed nosing (Gardner et al., 2001), to play less (Worsaae and Schmidt, 1980), to perform more aggressive behaviour (Worsaae and Schmidt, 1980) and to spend less time lying (Gardner et al., 2001).

Only few studies so far have investigated the behaviour of piglets separated from the sow within the first week postpartum. Orgeur et al. (2001) found that belly nosing and aggressive behaviour was more frequent in piglets reared artificially from day 6 onwards compared with piglets reared by the sow. Widowski et al. (2005) investigated the behaviour of piglets removed from the sow 56 to 92 h after birth and housed in nursery isolator tanks divided into a feeding, dunging and resting area. They provided the piglets with artificial milk four times per day by using different feeding systems and reported that piglets offered milk in a plastic

trough spent more time belly nosing as well as nosing, chewing or sucking ears and tails of pen mates than piglets fed artificial milk through baby-bottle nipples or an artificial udder.

The objective of this study was to compare the behaviour of piglets raised in two different rearing environments. The animals were either removed from the sow at the young age of 3-6 days and raised in a commercially available artificial piglet rearing system (group size: 7 piglets) or reared by the sow in a loose farrowing pen (7 focal piglets observed per litter). The study was conducted on an experimental farm on which we had full control of the two different rearing environments and several batches of animals were included. We specifically expected a high incidence of belly nosing in artificially raised piglets and were further interested in differences in manipulation of pen mates, play-fighting and aggressive as well as resting behaviour.

## 2. Materials and methods

### 2.1 Animals, farrowing pens, and experimental design

A total of 180 purebred Swiss Large White piglets stemming from seven batches were investigated between March 2012 and September 2013. Piglets were born in loose farrowing pens measuring 2.3 x 3.2 m. The pens were partitioned by a timber wall (1.4 m long and 1.1 m high) into a nesting area with a straw-bedded solid concrete floor (2.3 x 1.4 m) and a dunging area with a partly slatted floor (2.3 x 1.2 m). Several handfuls of cut straw were added daily to the nesting area. The pens were equipped with a nipple drinker for the sow, a bowl drinker for the piglets, a feeding trough and a piglet box (1.4 x 0.5 m; height: 0.5 m). The piglet box provided a heating plate fitted in the lid and a straw-bedded rubber mat on the floor. Within 24 h after birth, all piglets were marked individually with numbered ear tags. All male piglets were castrated within the first 2 weeks of age under analgesia and isoflurane anaesthesia. According to Swiss animal welfare legislation, tail docking and canine teeth clipping were not carried out. For the experiment, piglets were assigned to two treatment groups: artificially raised piglets ($n$ = 98) and piglets reared by the sow ($n$ = 82).

During seven batches, 14 piglets from three to five litters per batch (seven male and seven female piglets) were removed from the sow 2 days after the birth of the last piglet in a given batch and distributed to two units of a commercially available artificial piglet rearing system, so-called 'Rescue Decks' (Rescue Deck® System, S&R Resources LLC, USA). This procedure ensured that all piglets received sufficient colostrum. The 14 piglets per batch were distributed in such a way that each Rescue Deck housed seven piglets from two to four litters (with a maximum of five piglets from the same litter to ensure at least some minimal mixing that reflected the practical use of the Rescue Decks). They were healthy and normally sized, and piglets assigned to the two Rescue Decks were balanced in respect to sex and age. The maximum difference in age was 4 days. Piglets introduced to the Rescue Decks were on average 4.2 days old (range across batches: 3-6 days) and weighed on average 2.1 kg (range: 1.6-3.1 kg). All 14 piglets in the two Rescue Decks served as focal piglets for behavioural observations.

During six of the seven batches, two litters (average litter size: 11.8 piglets, range: 5-14 piglets) were not manipulated and reared by their respective mothers in the farrowing pen (control treatment). In a given batch, seven piglets from each of the two litters (five piglets in the one litter that did not have at least seven piglets) were selected as focal animals for behavioural observations (seven male and seven female piglets balanced across litters). The weight of these focal piglets was matched to the weight of the piglets reared in the Rescue Decks considering both the average weight and the weight range. Solid feed (pre-starter and starter feed) for the piglets was provided daily on the rubber mat of the piglet box from about the sixth day onwards (range: 2-9 days) until weaning.

Piglets were removed from the Rescue Decks at an average age of 33.9 days (range: 31-36 days) and an average weight of 7.9 kg (range: 4.7-11.1 kg). One piglet died on day 14 after introduction to the Rescue Deck. Piglets weaned from the farrowing pens had an average age of 31.6 days (range: 22-37 days) and an average weight of 8.0 kg (range: 5.2-12.0 kg). None of the focal piglets reared by a sow died.

All procedures involving animal handling and treatment were approved by the Cantonal Veterinary Office Thurgau (Switzerland, permit no. F1/12).

## 2.2 Artificial piglet rearing system

The two Rescue Decks were placed in a separate compartment at the Agroscope's swine barn in Tänikon (Switzerland). They were installed on a frame approximately 1 m above the floor and consisted of a white plastic box (1.34 x 0.82 m; height: 0.54 m) with a transparent viewing window in the front. According to Swiss animal welfare legislation, one Rescue Deck provided space for 7 piglets up to 10 kg (available floor space per piglet: 0.15 $m^2$). The Rescue Decks were structured into a feeding/dunging area in the front part of the box and a lying area (0.69 x 0.82 m) in the rear part of the box. The two areas were separated by a transparent curtain made of plastic stripes. The lying area was covered by a white, non-transparent plastic lid that contained a hole for a 250-W infrared heat lamp. The slatted floor in the feeding/dunging area was made of plastic-coated, rhombic expanded metal, and had a maximum slot-width of 9 mm. The floor in the lying area was covered with a rubber mat, on which fresh bedding (chopped and sieved *Miscanthus giganteus* or dedusted wood shavings) was provided daily (approximately 70 g per day and Recue Deck). To avoid that the bedding material was shifted from the rubber mat to the slatted floor, a wooden block (2 cm high) was fixed on the ground separating the lying from the feeding/dunging area.

The milk system consisted of a storage bin, a ring line composed of plastic tubes, and two cups with a diameter of 11 cm per Rescue Deck. The cups were attached on the slatted floor in the front part of the feeding/dunging area near the transparent viewing window. Each cup had a nipple in the middle, which could be operated by the piglets by pushing it slightly to one side. Artificial milk ('Rescue Milk', Provimi B.V., Rotterdam, the Netherlands) was prepared fresh twice a day and was available ad libitum to the piglets. To familiarise piglets with the functionality and location of the milk cup system, they were trained to drink from the cups by dipping each piglet's snout 2-4 times into the cup during their first 2 days in the Rescue Deck. Due to the lack of space at the milk cups, it was not possible for all piglets to drink artificial milk simultaneously. The storage bin and the plastic tubes of the ring line were cleaned and disinfected once a week with a liquid alkaline detergent (Halapur MP, Halag Switzerland, Aadorf, Switzerland). The artificial milk was replaced by solid feed when the cumulative per-piglet-consumption of milk reached an average of 3.9 kg dry matter (range: 3.5-4.4 kg of dry matter per piglet). Piglets then had an average weight of 5.7 kg (range: 3.9-8.3 kg) and had spent on average 14.2 days (range: 13-16 days) in the Rescue Decks. Water

was provided ad libitum in the feeding/dunging area from the third day onwards and offered in a third cup identical to the two milk cups in terms of shape and functionality. A feeder (Kane Creep Feeder KCF-9, Agro Weber GmbH, Lenggenwil, Switzerland; 24 x 14 cm, height: 33 cm) was mounted on the wall of the lying area from on average the sixth day (range: 4-8 days) onwards to provide fresh solid feed (pre-starter and starter feed) twice a day.

### 2.3 Behavioural observations

Behaviour of all focal piglets was videotaped and scored on each observation day by continuous focal observation in the periods from 05:00 to 10:15 and from 13:00 to 18:15. Artificially raised piglets of batches 1-6 were observed on day 4 after introduction to the Rescue Decks, those of batches 4-7 on day 11, and those of batches 1-7 on day 18. The behaviour of focal piglets reared by the sow (batches 1-6) was recorded on days 4 and 18 after piglets of a given batch had been transferred to the Rescue Decks. Observation day 11 was added for piglets raised artificially from batch 4 onwards to better differentiate the effects of the age of the piglets and the change in diet on behaviour. As a consequence, artificially raised piglets were observed on days 4 and 11 when they were still provided with artificial milk and on day 18 when they were fed solely on solid feed. Due to special management events and technical problems (e.g. medical treatment of piglets' eyes, delayed provision of solid feed), video recording was postponed as an exception for up to 2 days to ensure that the piglets were undisturbed for at least 48 h before behavioural observation.

To facilitate videotaping, lights in the farrowing room, in the piglet box (Everlight MR 16 LED-lamp warm white 5W 50°, EVERLIGHT Electronics Europe GmbH, Karlsruhe, Germany) of the farrowing pen, and in the room where the Rescue Decks were located remained switched on during the days of video recording. To videotape piglet behaviour in a Rescue Deck, a video camera was mounted approximately 1.5 m above the feeding/dunging area, and a mini-dome camera was attached above the lying area directly under the lid. In the farrowing room, one video camera per farrowing pen was mounted approximately 2.5 m above the floor, and mini-dome cameras were fixed directly under the lids of the piglet boxes.

One day before the focal piglets were videotaped, they were marked individually by different blue patterns on their backs.

For behavioural scoring, only one piglet was chosen at any time and observed continuously for 15 min in a previously determined random order. Each artificially raised piglet and each focal piglet reared by the sow were thus scored three times in the morning sessions and three times in the afternoon sessions. The recordings on days 4, 11 and 18 of batches 1-6 were evaluated by one observer, whereas the recordings on days 11 and 18 of batch 7 were analysed by a second observer who had undergone previous training. Definitions of the evaluated behavioural patterns are listed in Table 1.

**Table 1: Definitions of evaluated behavioural patterns.**

| Behavioural pattern | Definition |
|---|---|
| Belly nosing | Repetitive, rhythmic up-and-down movement with the snout (Fraser, 1978) on the body of a pen mate, especially performed on the skin behind the ear and on the abdomen between the front and the hind limbs |
| Manipulation of a pen mate | Nosing, nibbling or sucking on the body of a pen mate (Torrey and Widowski, 2006) |
| Aggressive behaviour | A single short attacking, biting, pushing and head thrusting directed at a pen mate (McGlone, 1986) |
| Play-fighting | Scampering, hopping, head tossing, pivoting, shaking objects (Newberry et al., 1988), running around with rapid changes in direction (Camerlink and Turner, 2013), running by throwing themselves on the floor or against a pen mate (Worsaae and Schmidt, 1980), or a repeated or longer lasting attacking, biting, pushing, head thrusting or chasing of a pen mate (McGlone, 1986); play behaviour often led suddenly to fighting encounters or to a continuous change between play behaviour and (playful) fighting within a short period of time |
| Resting | Lying laterally or ventrally (Kelly et al., 2000) |

### 2.4 Statistical analysis

Durations and counts of occurrences of specific behavioural patterns were calculated across the 90 min of observation per animal and day and were analysed by using linear mixed-effects models in R (version 3.0.2; R Core Team, 2013) with the lmer method from the lme4 package (Bates et al., 2014). For the statistical analyses of these data, we were faced with two issues. First, the durations of most behaviour patterns were limited at low durations, that is, towards zero but some (specifically resting) were also limited by the maximum observation time. Second, the total observation period of 90 min per animal and day varied by up to 45 s due to technical aspects of the scoring software used. To account for these aspects and make all observations fully comparable, we calculated the proportion of the observation time and the frequency (counts of occurrences divided by the observation time) to reflect duration and occurrence of the specific behavioural patterns, respectively. Model assumptions were checked based on a graphical analysis of residuals in respect to the normal distribution of errors and random effects as well as the homoscedasticity of the errors. To satisfy these assumptions, the outcome variables needed to be transformed and we used the logit and log transformation for the proportion of time and the frequency of specific behavioural patterns, respectively (Table 2). For the proportion of time, we could have used the arc-sinus-square-root transformation but we preferred the logit transformation because the natural base to the power of the estimated parameters can be interpreted as odds-ratios. For both transformations, zeroes were replaced by a value 10 % smaller than the lowest recorded data value larger than zero and ones would have been replaced analogously for the logit-transformation if they had occurred. If at all, this procedure led to a data set that was slightly more conservative than the raw data set by making these extreme observations somewhat less extreme. Such a replacement is biologically meaningful in the sense that the subjects' motivation for performing a specific behaviour is unlikely ever nil even if the behaviour was not observed. Using the lowest recorded data value estimated the detection threshold for this behaviour, and zeros are replaced by this detection threshold.

Random effects were the animal nested in pen nested in batch. Fixed effects were treatment (factor with two levels: artificially raised or reared by the sow), day (coded as a continuous variable with possible values 4, 11 and 18) and their interaction. This model assumed a linear pattern across days on the transformed scale of the outcome variable, that is, a continuous

increase or decrease from day 4 to 11 to 18. Whether this assumption was justified was tested with a further fixed effect, an indicator for non-linearity. This indicator for non-linearity was set to one for day 11 of the artificially raised piglets and otherwise to zero. Significance of this indicator of non-linearity then indicated that day 11 in the artificially raised piglets deviated from the linear pattern, whereas non-significance suggested that the pattern could not be differentiated statistically from a linear one. This maximum model (treatment plus day, their interaction and the indicator for non-linearity) corresponded to a model that would have used day as a factor and was reduced in a step-wise backwards approach using likelihood-ratio tests between nested models differing in their fixed effects. The main effects of treatment and day were always retained in the final model. Only statistically significant influences of fixed effects are mentioned in the results.

**Table 2: Outcome variables, their transformation, model chosen in a step-wise backwards selection approach, and test statistics ($\chi^2$) and *P*-values for the fixed effects.**

| Outcome variable | Parameter | Transformation | Best model[1] | Treatment | Day | Treatment x day | Indicator for non-linearity |
|---|---|---|---|---|---|---|---|
| Belly nosing | Duration | Logit | t x d | | | *P*<0.001; $\chi_1^2$ =40.53 | *P*=0.37; $\chi_1^2$ =0.81 |
| Belly nosing | Frequency | Log | t x d | | | *P*<0.001; $\chi_1^2$ =33.65 | *P* =0.66; $\chi_1^2$ =0.19 |
| Manipulation of a pen mate | Duration | Logit | t + d | *P* <0.001; $\chi_1^2$ =22.73 | *P*=0.91; $\chi_1^2$ =0.01 | | *P*=0.96; $\chi_1^2$ =0.003 |
| Manipulation of a pen mate | Frequency | Log | t + d | *P*<0.001; $\chi_1^2$ =23.24 | *P*=0.01; $\chi_1^2$ =6.62 | | *P*=0.76; $\chi_1^2$ =0.09 |
| Play-fighting | Duration | Logit | t x d | | | *P*=0.02; $\chi_1^2$ =5.26 | *P*=0.14; $\chi_1^2$ =2.15 |
| Aggressive behaviour | Frequency | Log | t + d + inl | *P*<0.001; $\chi_1^2$ =20.96 | *P*=0.42; $\chi_1^2$ =0.66 | | *P*=0.004; $\chi_1^2$ =8.16 |
| Resting | Duration | Logit | t x d | | | *P*<0.001; $\chi_1^2$ =20.53 | *P*=0.69; $\chi_1^2$ =0.16 |
| Average resting bout length | Duration | Logit | t + d | *P*<0.001; $\chi_1^2$ =16.61 | *P*=0.64; $\chi_1^2$ =0.22 | | *P*=0.051; $\chi_1^2$ =3.82 |

[a] t = treatment, d = day, inl = indicator for non-linearity of the day effect.

## 3. Results

Belly nosing was hardly ever observed in piglets reared by the sow, with the exception of one piglet which performed belly nosing twice within 25 s on day 18. With piglets raised artificially, the duration as well as the frequency of belly nosing increased monotonously between days 4 and 18 (Fig. 1a and b; Table 2).

Throughout the observation period, artificially raised piglets spent more time manipulating a pen mate than piglets reared by the sow, and the level was constant from days 4 to 18 for both treatment groups (Fig. 1c; Table 2). With regard to the frequency of manipulation of a pen mate, a higher level was noticed in artificially raised piglets than in piglets reared by the sow, and a monotonous decline from days 4 to 18 was observed for both treatment groups (Fig. 1d; Table 2).

Piglets reared by the sow displayed play-fighting longer than artificially raised piglets, and the decrease in duration from days 4 to 18 was stronger in piglets raised artificially (Fig. 1e; Table 2).

Aggressive behaviour was shown more frequently by artificially raised piglets than by piglets reared by the sow. In piglets raised artificially, frequency of aggressive behaviour increased from days 4 to 11 and decreased from days 11 to 18 (Fig. 1f; Table 2).

Duration of resting increased from days 4 to 18 in the piglets reared by the sow, and decreased monotonously between days 4 and 18 in artificially raised piglets (Fig. 1g; Table 2). Throughout the observation period, average resting bout length was longer in piglets reared by the sow than in artificially raised piglets (Fig. 1h; Table 2).

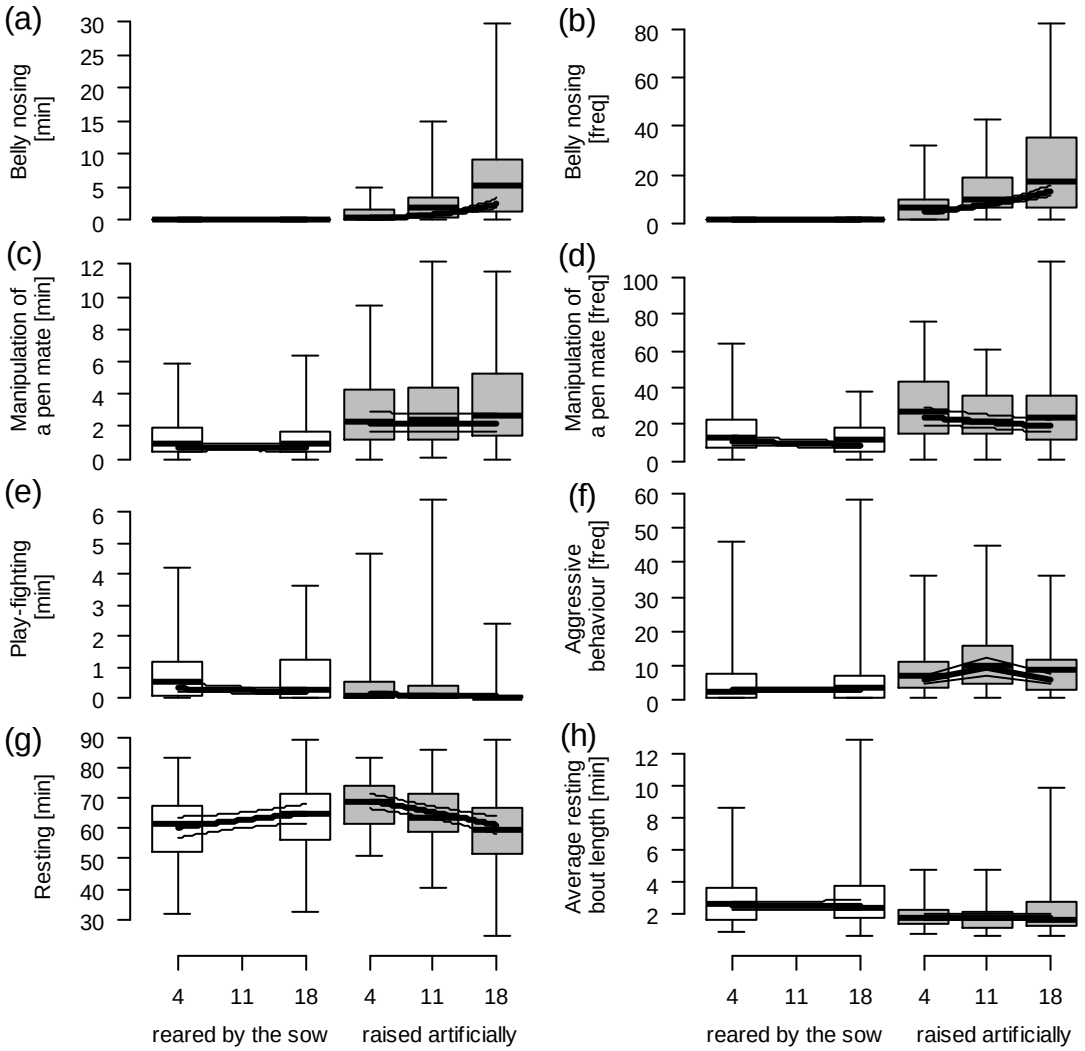


**Fig. 1:**

Duration of belly nosing (a), frequency of belly nosing (b), duration of manipulation of a pen mate (c), frequency of manipulation of a pen mate (d), duration of play-fighting (e), frequency of aggressive behaviour (f), duration of resting (g), and average resting bout length (h) per piglet per 90 min on days 4, 11, and 18 when piglets were either reared by the sow or raised artificially. On days 4 and 11 all piglets were provided with milk, whereas on day 18 piglets with the sow still had her milk available but piglets raised artificially were fed with solid feed only. *Box-and-whisker plots: boxes = 1st and 3rd quartile, thick lines = median, whiskers = range from minimum to maximum value. Thick trend-lines = model estimation, thin trend-lines = 95% credible intervals.*

## 4. Discussion

The current study compared two systems for raising piglets, an artificial rearing system in which piglets were removed from their mothers early and when piglets remained with their mothers. Given the comparison of two complete systems and some decisions in our experimental design, many variables differed between the two treatment groups and were therefore confounded. These aspects included age of piglets at separation from the mother, quality of the milk, age of piglets at weaning from milk, group size, space allowance (and density), mixing with piglets from other litters, quality of bedding material, and the room where the two rearing systems were set-up on the farm. That is, all differences found and discussed below can potentially be caused by any of these differences. For the practical purpose of the current assessment of the artificial rearing system as a whole, the specific causal effect is less relevant and therefore an assessment of the artificial rearing system in comparison to be raised by the mother can be made. For the understanding of the differences in piglet behaviour and with a view on potential improvements of such a system, causal understanding of the behavioural differences is important and previous investigations allow for well-informed guesses as to which differences in the systems lead to the behavioural differences observed.

In the present experiment, artificially raised piglets regularly showed belly nosing whereas piglets reared by the sow hardly ever performed this abnormal behaviour. Moreover, the duration as well as the frequency of belly nosing increased monotonously in artificially raised piglets between days 4 and 18 after introduction to the Rescue Decks. These observations are in line with the results of previous studies showing that belly nosing almost never occurs before weaning or is observed on a considerably higher level in piglets weaned than in those that remain with the sow (van Putten and Dammers, 1976; Fraser, 1978; Worsaae and Schmidt, 1980; Orgeur et al., 2001). In agreement with observations made in the present study, belly nosing is considered to be similar to suckling behaviour (Fraser, 1978; Weary et al., 1999) and in particular to the vigorous massaging movements that piglets perform at the sow's udder before and after milk ejection (Worobec et al., 1999; Li and Gonyou, 2002). Lacking an adequate object to massage, weaned piglets redirect this behaviour pattern to the body of pen mates (van Putten and Dammers, 1976; Dybkjaer, 1992), probably because the

mates' soft and warm body surface is similar to the sow's udder and therefore attractive to the piglets (Welch and Baxter, 1986).

Manipulation of a pen mate with behaviour patterns (nosing, nibbling, sucking) other than belly nosing was performed by artificially raised piglets and piglets reared by the sow in the present study. However, such behaviour occurred for longer time periods and at a higher rate in artificially raised piglets. As sucking was included in 'manipulation of a pen mate', it is likely that artificially raised piglets showed more manipulation because they redirected sucking behaviour at pen mates (qualitative observations; van Putten and Dammers, 1976). Drinking artificial milk from a milk cup is also a motor pattern that differs much from sucking milk at the sow's teats, as reported by Gardner (2000).

In the present study, artificially raised piglets were provided with a relatively small amount of wood shavings or *M. giganteus* as bedding material in the lying area, whereas piglets reared by the sow had straw in larger quantity offered in the nesting area. It is thus possible that the lower quality or quantity of bedding material in the artificial piglet rearing system induced less exploratory and manipulative behaviour in artificially raised piglets compared with piglets reared by the sow, and that the former redirected such behaviour (nosing, nibbling) to other piglets resulting in increased levels of manipulation of pen mates. In line with this interpretation, Dybkjaer (1992) and Bøe (1993) reported that piglets weaned at 4 weeks of age and raised in barren housing conditions manipulated pen mates more frequently by nibbling, sniffing, rooting or chewing than piglets weaned at the same age but housed in enriched pens with bedding material, such as straw.

In addition to the impact of bedding material, the difference in space allowance between the two rearing systems compared in the present study could have had an effect on the level of manipulation of a pen mate. Space allowance for artificially raised piglets was 0.15 $m^2$ per piglet, whereas piglets reared by the sow in a farrowing pen were offered 7.36 $m^2$ for 5-14 piglets (and their mother). Gardner et al. (2001) found that piglets weaned at the age of 12-14 days and kept at high density (0.15 $m^2$ per piglet) showed more piglet-directed nosing compared with piglets housed at a lower density (0.4 $m^2$ per piglet). In conditions with low space allowance, spatial proximity of neighbouring piglets may enhance manipulation of pen

mates, and manipulated piglets may find it difficult to escape such manipulation due to spatial conditions (Gardner et al., 2001).

In the present study, piglets reared by the sow displayed play-fighting longer than artificially raised piglets, and the decrease in duration from day 4 to 18 was stronger in piglets raised artificially. This pattern is likely caused by the difference in space allowance between the two compared rearing systems. Accordingly, Worsaae and Schmidt (1980) and Dybkjaer (1992) reported that a reduction in space allowance for piglets weaned at the age of 3-4 weeks resulted in a decrease in play behaviour, and Chaloupková et al. (2007) found that pre-weaned piglets showed a higher level of locomotor and social play when offered more space. However, in these studies as well as in the present study, space allowance was confounded with environmental enrichment, which could also have an effect on the occurrence of play behaviour.

Artificially raised piglets in the present study showed more aggressive behaviour than piglets reared by the sow, and the frequency of aggressive interactions increased in the former from day 4 to 11 and decreased from day 11 to 18. This pattern may be due to the lack of space at the milk cups in the artificial piglet rearing system in combination with increasing size of the piglets. On day 11, at most 2 piglets had access to one milk cup at the same time, and a maximum of 4 piglets could drink at the same time from the two milk cups available. On day 18, artificial milk had been replaced by solid feed in the Rescue Decks, and piglets ate less often simultaneously. The high frequency of aggressive behaviour shown by artificially raised piglets could also be linked to the high levels of belly nosing and manipulation of pen mates observed in these piglets. Similarly, Fraser (1978) reported that piglets occasionally bit at pen mates in response to being belly nosed. The two rearing environments compared in the present study also differed in group composition. Piglets reared by the sow were reared as intact litters, whereas artificially raised piglets stemmed from two to four litters and were mixed. This may have had an effect on aggression level, as a change in group composition at weaning was found to result in an increase in agonistic interactions (Weary et al., 2008; Hötzel et al., 2011; Colson et al., 2012). Contrary to this, Jarvis et al. (2008) reported that aggression after weaning also occurs in piglets that are not mixed. They hypothesised that, even without social mixing, separation from the sow may result in changes in the piglets' social relationships and hierarchy.

In artificially raised piglets, duration of resting decreased between days 4 and 18, whereas this duration increased from day 4 to 18 in piglets reared by the sow. Moreover, average resting bout length was shorter in artificially raised piglets than in piglets reared by the sow throughout the observation period. This pattern could be due to the low space allowance provided to the artificially raised piglets. Accordingly, Gardner et al. (2001) found that piglets weaned at 12-14 days of age rested longer when kept at a low density (0.4 $m^2$ per piglet) compared with piglets housed at a higher density (0.15 $m^2$ per piglet). The results of the present study suggest that lying behaviour in artificially raised piglets was increasingly affected by space allowance as they grew in size from day 4 to 18. In addition to space allowance, changeover of artificial milk to solid feed could also affect resting behaviour in piglets. However, in the present study, duration of resting decreased monotonously in artificially raised piglets between days 4 and 18 and did not change markedly between days 11 and 18 when artificial milk was replaced by solid feed.

The piglets in the two rearing conditions were kept in separate compartments for reasons of hygiene. As a consequence, location was confounded with treatment. However, it seems rather unlikely that the differences between the two rooms led to the differences in behaviour. For example, even if the barn-climate was slightly different in the two rooms no large differences in respect to belly nosing and manipulation of other pen mates would be expected. In line with this, differences in behaviour similar to those reported here were found in piglets raised in another artificial rearing system, the so-called ‘Nursery’, compared to piglets reared by the sow in a loose farrowing pen (Rzezniczek et al., 2014).

To understand the causation of the behavioural differences between the two systems that we observed and if one wanted to develop the artificial rearing system further in respect to animal welfare, additional experiments would be necessary. The starting points for such experiments could be seen in the different interpretations as suggested above. For example, if belly nosing is to be reduced, the influence of the specific way of milk intake (suckler versus cup) or the availability of a stimulus eliciting massaging behaviour (such as an artificial udder) could provide a starting point for further research. If one wanted to increase play behaviour and reduce interruptions of lying, experiments with increasing space allowance should be conducted first. Finally, if aggression was to be reduced, an experiment could be conducted that increases the number of piglets that can feed simultaneously.

## 5. Conclusions

The results of the present study indicate that the welfare of piglets removed from the sow at the age of 3-6 days and raised in an artificial piglet rearing system is impaired. Compared with piglets reared by the sow in a loose farrowing pen, artificially raised piglets showed high and increasing levels of belly nosing, more manipulation of pen mates, more aggressive behaviour and less play-fighting and resting behaviour than piglets reared by the sow in a loose farrowing pen. Whereas the occurrence of belly nosing is likely to be linked to early separation from the sow, with piglets redirecting massaging behaviour to their pen mates, other differences in behaviour may be due to the small space allowance in the tested artificial rearing system. As piglets grew in this system, they were limited in play-fighting, their resting behaviour was disturbed, and they directed more manipulative and aggressive behaviour at the pen mates. As a consequence, more research is needed to improve the housing conditions of piglets raised in commercially available artificial piglet rearing systems with regard to animal welfare.

### Conflict of interest

We herewith confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

### Acknowledgements

We would like to thank G. Jöhl, A. Hagenbüchle, and B. Ammann for taking care of the piglets, U. Marolf, H. Bollhalder, and B. Kürsteiner for technical support, S. Schönenberger and H.-R. Ott for producing devices specially designed for the artificial piglet rearing system, and N. Kammerlander for helping to analyse recordings. This study was financed by the Federal Food Safety and Veterinary Office (Project no. 2.12.02).

## References

Akdag, F., Arlsan, S., Demir, H., 2009. Effect of parity and litter size on birth weight and the effect of birth weight variations on weaning weight and pre-weaning survival. Journal of Animal and Veterinary Advances 8, 2133-2138.

Andersen, I.L., Naevdal, E., Bøe, K.E., 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (*Sus scrofa*). Behavioral Ecology and Sociobiology 65, 1159-1167.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2014. lme4: linear mixed-effects models using Eigen and S4, R package version 1.0-6, http://CRAN.R-project.org/package=lme4

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Animal Welfare 22, 219-238.

Bøe, K., 1993. The effect of age at weaning and post-weaning environment on the behaviour of pigs. Acta Agriculturae Scandinavica Section A, Animal Science 43, 173-180.

Camerlink, I., Turner, S.P., 2013. The pig's nose and its role in dominance relationships and harmful behaviour. Applied Animal Behaviour Science 145, 84-91.

Cecchinato, A., Bonfatti, V., Gallo, L., Carnier, P., 2008. Survival analysis of preweaning piglet survival in a dry-cured ham-producing crossbred line. Journal of Animal Science 86, 2486-2495.

Chaloupkova, H., Illmann, G., Bartos, L., Spinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Applied Animal Behaviour Science 103, 25-34.

Colson, V., Martin, E., Orgeur, P., Prunier, A., 2012. Influence of housing and social changes on growth, behaviour and cortisol in piglets at weaning. Physiology & Behavior 107, 59-64.

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

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

Gardner, J.M., 2000. Investigations into the causation of belly-nosing in early-weaned piglets. M.Sc. Thesis, University of Guelph, Canada.

Gardner, J.M., Duncan, I.J.H., Widowski, T.M., 2001. Effects of social "stressors" on belly-nosing behaviour in early-weaned piglets: is belly-nosing an indicator of stress? Applied Animal Behaviour Science 74, 135-152.

Gonyou, H.W., Beltranena, E., Whittington, D.L., Patience, J.F., 1998. The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. Canadian Journal of Animal Science 78, 517-523.

Hötzel, M.J., de Souza, G.P.P., Costa, O.A.D., Machado Filho, L.C.P., 2011. Disentangling the effects of weaning stressors on piglets' behaviour and feed intake: changing the housing and social environment. Applied Animal Behaviour Science 135, 44-50.

Jarvis, S., Moinard, C., Robson, S.K., Sumner, B.E.H., Douglas, A.J., Seckl, J.R., Russell, J.A., Lawrence, A.B., 2008. Effects of weaning age on the behavioural and neuroendocrine development of piglets. Applied Animal Behaviour Science 110, 166-181.

Kelly, H.R.C., Bruce, J.M., English, P.R., Fowler, V.R., Edwards, S.A., 2000. Behaviour of 3-week weaned pigs in Straw-Flow®, deep straw and flatdeck housing systems. Applied Animal Behaviour Science 68, 269-280.

Kyriazakis, I., Edwards, S.A., 1986. The effect of “split-suckling” on behaviour and performance of piglets. Applied Animal Behaviour Science 16, 92.

Li, Y., Gonyou, H.W., 2002. Analysis of belly nosing and associated behaviour among pigs weaned at 12-14 days of age. Applied Animal Behaviour Science 77, 285-294.

McGlone, J.J., 1986. Agonistic behaviour in food animals: review of research and techniques. Journal of Animal Science 62, 1130-1139.

Metz, J.H.M., Gonyou, H.W., 1990. Effect of age and housing conditions on the behavioural and haemolytic reaction of piglets to weaning. Applied Animal Behaviour Science 27, 299-309.

Milligan, B.N., Fraser, D., Kramer, D.L., 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. Applied Animal Behaviour Science 73, 179-191.

Milligan, B.N., Fraser, D., Kramer, D.L., 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science 76, 181-191.

Newberry, R.C., Wood-Gush, D.G.M., Hall, J.W., 1988. Playful behaviour of piglets. Behavioural Processes 17, 205-216.

Orgeur, P., Hay, M., Mormede, P., Salmon, H., Le Dividich, J., Nowak, R., Schaal, B., Levy, F., 2001. Behavioural, growth and immune consequences of early weaning in one-week-old Large-White piglets. Reproduction Nutrition Development 41, 321-332.

Quiniou, N., Dagorn, J., Gaudré, D., 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livestock Production Science 78, 63-70.

R Core Team, 2013. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Animal Welfare 22, 199-218.

Rzezniczek, M., Gygax, L., Wechsler, B., Weber, R., 2014. Impact of an artificial rearing system on the behaviour of early weaned piglets. KTBL-Schrift 505, 192-201 (in German with English summary).

Tomiyama, M., Kubo, S., Takagi, T., Suzuki, K., 2011. Evaluation of genetic trends and determination of the optimal number of cumulative records of parity required in reproductive traits in a Large White pig population. Animal Science Journal 82, 621-626.

Torrey, S., Widowski, T.M., 2006. Is belly nosing redirected suckling behaviour? Applied Animal Behaviour Science 101, 288-304.

van Putten, G., Dammers, J., 1976. A comparative study of the well-being of piglets reared conventionally and in cages. Applied Animal Ethology 2, 339-356.

Vidović, V., Lukač, D., Štrbac, L., Višnjić, V., Punoš, D., Šević, R., Krnjajić, J., Stupar, M., 2012. Genetic trend for certain traits in pigs using different selection criteria. Animal Science and Biotechnologies 45, 274-279.

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

Weary, D.M., Jasper, J., Hötzel, M.J., 2008. Understanding weaning distress. Applied Animal Behaviour Science 110, 24-41.

Wechsler, B., 2005. An authorisation procedure for mass-produced farm animal housing systems with regard to animal welfare. Livestock Production Science 94, 71-79.

Welch, A.R., Baxter, M.R., 1986. Responses of newborn piglets to thermal and tactile properties of their environment. Applied Animal Behaviour Science 15, 203-215.

Widowski, T.M., Yuan, Y., Gardner, J.M., 2005. Effect of accommodating sucking and nosing on the behaviour of artificially reared piglets. Laboratory Animals 39, 240-250.

Wolf, J., Zakova, E., Groeneveld, E., 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science 115, 195-205.

Worobec, E.K., Early Weaning in Swine: A Behavioural Assessment, (M.Sc. thesis) 1997, University of Guelph; Canada.

Worobec, E.K., Duncan, I.J.H., Widowski, T.M., 1999. The effects of weaning at 7, 14 and 28 days on piglet behaviour. Applied Animal Behaviour Science 62, 173-182.

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

# 4. General discussion

The results of the present study are already discussed in Chapter 3, but more detailed comments and information are provided in this chapter.

## 4.1 Impact of an artificial rearing system on the behaviour of piglets removed early from the sow

### 4.1.1 Belly nosing

In the present study, the behaviour of artificially raised piglets and piglets reared by the sow differed qualitatively. Belly nosing virtually never occurred in the latter, whereas it was observed regularly in the former. Furthermore, the duration and frequency of belly nosing increased monotonously in artificially raised piglets from day 4 to 18 after separation from the sow. These observations are in agreement with those of previous studies reporting a considerably higher level of belly nosing in piglets removed from the sow compared with piglets staying with the sow and showing that this behaviour almost never occurs before weaning (van Putten and Dammers, 1976; Fraser, 1978; Worsaae and Schmidt, 1980; Orgeur et al., 2001). Similarly, several authors reported that belly nosing increases after weaning in piglets weaned at the age of 3 up to 24 days (Fraser, 1978; Gonyou et al., 1998; Worobec et al., 1999; Widowski et al., 2005).

In line with observations made in the present study, Fraser (1978) and Weary et al. (1999) considered belly nosing to be similar to suckling behaviour and in particular to the vigorous up-and-down massaging movements of the snout piglets perform at the sow's udder before and after milk letdown (Worobec et al., 1999; Li and Gonyou, 2002). Without an adequate object to massage, that is the udder of the sow, belly nosing is redirected at pen mates (van Putten and Dammers, 1976; Dybkjaer, 1992), which also have a soft and warm body surface comparable to the skin of the sow's udder (Welch and Baxter, 1986). Although the intake of

artificial milk is ensured in artificially raised piglets, their motivation to massage the udder is not fulfilled and thus massaging movements are performed with the snout on the soft body parts of pen mates, in particular on the abdomen between the front and hind limbs or on the skin behind the ears.

With the exception of one piglet on day 18, which was reared by the sow and performed belly nosing twice within a short time, belly nosing was only observed in artificially raised piglets in the present study. In other studies, however, belly nosing was reported to be at a stable, but considerably lower level in piglets remaining with the sow (Orgeur et al., 2001) or to be performed by a steadily increasing proportion of piglets until weaning (Jarvis et al., 2008), possibly due to impaired, shortened or terminated suckling behaviour at the udder (Jarvis et al., 2008).

Given the results of the present study, the changeover from artificial milk to solid feed between days 11 and 18 after separation from the sow does not affect belly nosing in artificially raised piglets, as this behaviour increased monotonously from day 4 to 11 as well as from day 11 to 18. This is supported by previous findings showing that belly nosing was not linked with feeding, as both good quality diet with milk and poor quality diet without milk products and with a relatively high level of soybean meal did not influence belly nosing (Gardner et al., 2001a). It is probably also in line with the assumption that belly nosing is most likely affected by internal factor(s) and not by milk feeding (Widowski et al., 2005).

In the present study, belly nosing was observed on days 11 and 18, on average 3.8 days before and 3.4 days after artificial milk was replaced by solid feed, respectively. However, piglet behaviour was not recorded between days 11 and 18, immediately before and after the changeover in diet. Thus, further video recordings occurring closer to the time when artificial milk is replaced by solid feed would be helpful to provide more detailed information whether the change in diet has an effect on belly nosing.

In addition to the absence of the sow, housing environment before and after weaning may also have impact on the performance of belly nosing (Oostindjer et al., 2011, 2014). With regard to this, Oostindjer et al. (2011) reported that piglets weaned at the age of 29 days and kept in enriched pens with more space allowance and the provision of straw, wood shavings, peat and

branches performed less belly nosing than piglets weaned at the same age but housed in barren pens with less space allowance and without substrate that could be explored. They also observed that piglets raised in barren pens before weaning and switched to enriched pens after weaning showed a lower level of belly nosing postweaning, while piglets housed in enriched pens before weaning and changed to barren pens after weaning displayed a higher level of belly nosing postweaning. Finally, they noted that piglets switched from enriched pens before weaning to barren pens after weaning performed more belly nosing after weaning compared with piglets housed in barren pens both before and after weaning. It has thus been suggested that piglets' behaviour after weaning was impaired due to the loss of the enriched housing environment that piglets already knew and were familiar to before weaning and that it is recommended to make enrichment also available to piglets after they were weaned, when enriched pens were already provided to them before weaning (Oostindjer et al., 2011, 2014). In line with this, in the present study, artificially raised piglets were exposed to a change in the housing environment. Before they were removed from the sow at the age of 3 to 6 days and raised in the artificial piglet rearing system, they were housed in a loose farrowing pen with more space allowance and the provision of straw, whereas after separation from the sow they were provided with less space per piglet and bedding material in smaller quantity and lower quality.

### 4.1.2 Manipulation (nosing, nibbling, sucking)

In the present study, manipulation of a pen mate was defined as nosing, nibbling or sucking on body parts of pen mates. This behaviour was observed in artificial raised piglets as well as in piglets reared by the sow but was performed on a higher level, both in duration and frequency, by artificially raised piglets. As sucking was included in 'manipulation of a pen mate', it could be that the higher level of manipulation of a pen mate was due to artificially raised piglets redirecting sucking behaviour at pen mates (van Putten and Dammers, 1976). This interpretation is in line with the results of previous studies showing that piglets weaned at 3 weeks of age performed exclusively (van Putten and Dammers, 1976) or at a considerable higher level (Worsaae and Schmidt, 1980) sucking at pen mates than piglets staying with the sow. Similar to the strong motivation to massage the sow's udder before and after milk

ejection, piglets also want to suck on her teats (van Putten and Dammers, 1976; Gardner, 2000), as it is usually the case when nutritive and non-nutritive sucking on the sow's teats is performed by piglets (Rushen and Fraser, 1989). As piglets are not able to be in contact with the sow and in particular with the sow's udder after weaning, they redirect sucking at pen mates (van Putten and Dammers, 1976). According to Widowski et al. (2005), devices which give piglets the opportunity to practise nutritive and non-nutritive sucking after weaning are likely to have a calming effect on piglets. Gardner (2000) also reported that "oral stimulation obtained from both nutritive and non-nutritive sucking has behavioural and physiological benefits" and that non-nutritive sucking can be considered "as a means for piglets to obtain the necessary tactile stimulation".

Sucking at pen mates observed in weaned piglets in the present study could also be explained by the fact that motor patterns performed to drink artificial milk from a milk cup and feed on solid feed from a feeder are different from motor patterns performed to suck milk at the sow's teats (Gardner, 2000). In future studies, nosing and nibbling at pen mates should be recorded and analysed separately from sucking at pen mates to gain more detailed information on the occurrence of these behaviour patterns in artificially raised piglets.

In the present study, artificially raised piglets were offered a relatively small quantity of chopped and sieved *Miscanthus giganteus* or wood shavings as bedding material in the lying area, whereas a larger amount of cut straw was provided in the nesting area to piglets reared by the sow. It is likely that the lower quality and quantity of bedding material used in the artificial piglet rearing system resulted in less exploratory behaviour directed at bedding material and in more manipulative behaviour, such as nosing and nibbling, directed at pen mates. This interpretation is in agreement with van Putten and Dammers (1976) reporting that piglets weaned at 3 to 3.5 weeks of age and housed in a "poor environment" without bedding material and with low space allowance manipulated ears, tails, limbs, hoofs and other body parts of pen mates more frequently than piglets remaining with the sow in a "rich environment" with bedding material and higher space allowance. Petersen et al. (1995) also found that rooting and chewing directed at the body of pen mates was reduced in enriched housing conditions offering straw, logs and branches, and that the piglets spent considerable time rooting, biting and chewing the enrichment material. However, manipulating behaviour

in the enriched pens could not be eliminated in total, probably due to the provision of less attractive enrichment material, to early weaning or to restricted space (Petersen et al., 1995).

Space allowance has also been considered as factor influencing nosing and nibbling of pen mates. Gardner et al. (2001b) found more piglet-directed nosing in piglets housed at high density after weaning compared with piglets kept at low density. They concluded that manipulation of pen mates is facilitated by low space allowance and that piglets standing, lying or moving at close distance are not able to avoid such behaviour. In the present study, the 5 to 14 piglets (average litter size: 11.8 piglets) reared by the sow were housed in a farrowing pen of 7.36 $m^2$, whereas the 7 artificially raised piglets kept in the artificial piglet rearing system had an average total floor area of 1.06 $m^2$. Consequently, the former piglets were provided with considerably more space than the latter. Moreover, the two housing systems differed in quality and quantity of bedding material, which possibly also had an influence on nosing and nibbling. In future studies, space allowance and bedding material should be varied independently to assess their effect on behaviour redirected at pen mates.

In agreement with previous observations on the time course of piglet-directed behaviour (Worobec et al., 1999; Gardner et al., 2001a, 2001b), nosing, nibbling or sucking of pen mates occurred on a high level in the present study on day 4 after weaning, remained at an almost constant level until day 18, and differed from belly nosing with regard to time course.

### 4.1.3 Play-Fighting

In the present study, piglets reared by the sow showed a higher level of play-fighting than artificially raised piglets. Moreover, the duration of this behaviour decreased more strongly in the latter. This could be due to the difference in space allowance between the two rearing systems, and this effect was possibly exacerbated with increasing size of the artificially raised piglets. This interpretation is in line with previous studies showing that piglets weaned at the age of 3 to 4 weeks performed less play behaviour when kept at high density and without the provision of straw (Worsaae and Schmidt, 1980; Dybkjaer, 1992). Play behaviour was also

observed to increase again as soon as more space and environmental enrichment like straw was offered to piglets (Worsaae and Schmidt, 1980). Finally, Chaloupková et al. (2007) reported that piglets provided with more space and straw in a pre-weaning housing system performed a higher level of locomotor and social play. They concluded that bedding material, in addition to pen size, may be important to elicit play behaviour, since straw can vary in position and structure due to the piglets' behaviour. In the present study, wood shavings and *Miscanthus giganteus* used as bedding material for the artificially raised piglets were possibly less likely to stimulate play-fighting than the straw offered to the piglets reared by the sow in a loose farrowing pen.

### 4.1.4 Aggressive behaviour

In the present study, aggressive behaviour was observed more frequently in artificially raised piglets than in piglets reared by the sow. After an increase in frequency in the artificially raised piglets from day 4 to 11, the frequency decreased again from day 11 to 18. This pattern is likely to be caused by the lack of space at the milk cups as piglets gradually grew. Piglets are highly motivated to drink milk synchronously with other piglets (de Passillé and Rushen, 1989), but this was not possible for the artificially raised piglets in the present study. In particular, the high level of aggressive behaviour observed on day 11 is likely to be explained by the fact that a maximum of four out of seven piglets could drink at the same time from two milk cups. The lower level of aggressive behaviour on day 4 may be attributed to the fact that the piglets were smaller. On day 18, artificial milk had been replaced by solid feed, and piglets were less often observed to eat all at the same time, resulting in less competition.

In addition to space allowance during feed intake, restricted total space allowance and lack of bedding material have been considered to affect agonistic interactions in weaned piglets (Worsaae and Schmidt, 1980; Beattie et al., 1996). The results of the present study are in support of this assumption, as artificially raised piglets showed more aggressive behaviour and were raised at a higher density and given lower quality and quantity of bedding material than the piglets reared by the sow.

The higher level of aggressive behaviour in the artificially raised piglets may also be associated with the higher incidence of belly nosing and manipulation of pen mates observed in these piglets. In agreement with a suggestion made by Fraser (1978) and Beattie et al. (1996), piglets receiving belly nosing and manipulation by others were possibly disturbed and therefore attacked and bit these piglets. Orgeur et al. (2001) observed that the time course of post weaning aggressive behaviour was similar to that of belly nosing after weaning and, therefore, assumed that butts, bites and pursuits in piglets weaned at the age of 6 days were elicited by belly nosing. Beattie et al. (1996) reported a similar pattern concerning the incidence of aggressive and harmful social behaviour, such as nosing or tail biting, in piglets weaned at the age of 6 weeks. However, in the present study, aggressive and piglet redirected behaviour did not follow a similar time course.

In the present study, the two rearing systems differed in group composition in that piglets reared by the sow were not manipulated and thus reared as intact litters, whereas artificially raised piglets were mixed from two to four litters. Such grouping of early weaned piglets is a common practice and was thus also applied in the present study. However, according to previous studies, a change in group composition of piglets at weaning is known to result in increased agonistic interactions (Weary et al., 2008; Hötzel et al., 2011; Colson et al., 2012). Contrary to this, Jarvis et al. (2008) found that aggression can also occur in piglets that are not mixed at weaning. The authors hypothesised that, even without social mixing, separation from the sow may result in changes in the piglets' social relationships and hierarchy. In the present study, group composition, space allowance during feeding, total space allowance, and bedding material were confounded, as the two rearing systems differed in these aspects. It is therefore not possible to identify the reason for the increased aggressive behaviour observed in the artificially raised piglets.

### 4.1.5 Resting

In the present study, average resting bout length was at a consistently lower level in the artificially raised piglets from day 4 to 18 compared with piglets reared by the sow. Fraser

(1978) also reported that piglets weaned at 3 weeks of age had problems to rest without interruption, since changes in resting position often occurred when the animals tried to huddle together. As a result, sleeping piglets were awakened and responded by attacking, biting and thrusting pen mates (Fraser, 1978).

The shorter average resting bout length observed in the artificially raised piglets may also be explained by the fact that the animals could not drink and eat synchronously at the milk cups and at the feeder, respectively. As a consequence, piglets that had access to milk cups first started resting, while other piglets drank and lie down later, thus disturbing piglets that were already resting.

Moreover, in the present study, duration of resting increased monotonously from day 4 to 18 in the piglets reared by the sow, but decreased in the artificially raised piglets, which also rested longer on day 4. Similarly, Metz and Gonyou (1990) reported a peak in resting time on the day of weaning and a decrease in resting duration over time in piglets weaned at the age of 2 weeks, and Eriksson (2006) observed that more piglets rested on the day after weaning than thereafter. Finally, Devillers and Farmer (2009) found that piglets weaned at 21 days of age showed more resting behaviour on the day of weaning and a decrease to the next day compared with piglets weaned at an older age. They indicated that piglets weaned at a younger age had a delayed response to weaning, as they were more quiet and apathetic immediately after weaning than piglets weaned at an older age.

In accordance with previous studies, the longer resting duration observed in the artificially raised piglets on day 4 can also be explained by the fact that resting and huddling together provides piglets with warmth, softness, comfort and social contact, stimuli they lost when removed from the sow and that may be especially important during the initial phase after separation (Welch and Baxter, 1986; Li and Gonyou, 2002; Bench, 2005). Under natural and semi-natural conditions, piglets are “confined to the nest” (Worobec et al., 1999) within the first week of life, in the sense that they stay in the farrowing nest, away from the other members of the sow’s group (Stolba and Wood-Gush, 1989). At that time, they are little active but rather rest and huddle “as a concerted group” (Bench, 2005) at the sow’s udder or close to each other, in particular after suckling (Worobec et al., 1999; Bench, 2005; Bench and Gonyou, 2007). Similarly, Jensen (1986) reported that the sow and the piglets remained

in the nest for the whole first day after farrowing, and that they still spent 82 % of the time in the nest on day 4 post-partum.

The longer duration of resting shown by the artificially raised piglets on day 4 may also be attributed to the absence of the sow, which usually initiates suckling and synchronises not only feeding but also resting of the piglets, in particular when these are young (Newberry and Wood-Gush, 1985; Worobec, 1997). Behaviour and vocalisation of the sow are important signals indicating that milk will become available within a short period of time to the piglets (Worobec, 1997; Schön et al., 1999). Without the sow, piglets have to find their own synchronised and cyclical daily rhythm and "to initiate their own maintenance behaviour" (Worobec, 1997).

The decrease in resting between days 4 and 18 in the artificially raised piglets is possibly due to the low space allowance in the artificial piglet rearing system in combination with increasing body size of the growing piglets. As a consequence, lying piglets were interrupted in their resting behaviour by piglets that were active in the lying area or fed at the feeder located in the lying area. Accordingly, Gardner et al. (2001b) observed that piglets weaned at the age of 12 to 14 days into pens of low density (0.4 $m^2$ per piglet) rested longer compared with piglets weaned at the same age but housed at higher density (0.15 $m^2$ per piglet).

Finally, the increase in belly nosing observed in the artificially raised piglets from day 4 to 18 could account for the decrease in the duration of resting during the same period of time. Piglets exposed to belly nosing were possibly disturbed in their resting behaviour, and piglets performing belly nosing may have spent less time resting. In line with this, Metz and Gonyou (1990) suggested that shortened resting time and restlessness in piglets weaned at the age of 2 weeks could be associated with belly nosing. Also, Li and Gonyou (2002) found a negative correlation between belly nosing and lying in piglets weaned at the age of 12 to 14 days, in that piglets which spent more time with belly nosing spent less time with lying and eating.

## 4.2 Impact of an artificial rearing system on the welfare of piglets removed early from the sow

The results of the present study indicate that removing piglets from the sow at the age of 3 to 6 days and raising them in an artificial piglet rearing system has negative effects on their welfare. The behaviour observed in these piglets shows that they have difficulties to cope with the changes associated with early weaning and the new housing conditions. Compared with piglets reared by the sow in a loose farrowing pen, artificially raised piglets performed belly nosing, an abnormal behaviour pattern, and both the frequency and the duration of this behaviour increased over time. In addition, they showed more manipulation of pen mates, more aggressive behaviour, less play-fighting and less resting behaviour. The occurrence of belly nosing is likely to be related to the absence of the sow, whereas the other differences in behaviour are probably associated with the limited space allowance and the insufficient enrichment in the tested artificial piglet rearing system. The results of the present study are in line with observations made in previous studies showing that removing piglets from the sow at the age of 1 to 3 weeks of age and housing them at high density and with little environmental stimuli results in changes in their behaviour (van Putten and Dammers, 1976; Worsaae and Schmidt, 1980; Worobec et al., 1999). Similarly, Oostindjer et al. (2011) reported that the behaviour and welfare of piglets was negatively affected by the lack of enrichment in the postweaning housing environment, as piglets weaned into barren pens with less space allowance and without the provision of substrate that could be explored performed more belly nosing and manipulative behaviour and less play and exploratory behaviour. The occurrence of massaging, sucking and nibbling behaviour redirected at pen mates, an increased level of aggressive behaviour, and a reduction in play behaviour are considered as indicators of reduced animal welfare (van Putten and Dammers, 1976; Worsaae and Schmidt, 1980; Worobec et al., 1999).

Farmers in the pig-breeding sector are in a dilemma, as they have to deal with increasing litter size and the problem of surplus piglets. On the one hand, raising surplus piglets without the sow in artificial piglet rearing systems is associated with considerable changes in piglets' behaviour and impaired animal welfare. On the other hand, it is unacceptable to let viable surplus piglets starve or die. Consequently, more studies are needed to improve the housing

conditions of piglets raised in commercially available artificial rearing systems with regard to animal welfare and to reduce the level of abnormal oral behaviour shown by these piglets. In the longer term, however, genetic selection for an adequate litter size is needed.

As the objective of the present study was to compare two rearing environments - a commercially available artificial piglet rearing system and a loose farrowing pen in which the piglets were reared by the sow -, several factors differed between these two rearing conditions, such as age of piglets at separation from the sow, quality of milk, age of piglets at weaning from milk, space allowance (and therefore density), quality and quantity of bedding material, group size and group composition. Thus, future experimental studies are needed to identify the contribution of each single factor to the observed differences in piglets' behaviour.

# 5. Conclusions

It is concluded that piglets removed early from the sow and raised artificially redirect massaging behaviour at pen mates, resulting in high levels of belly nosing and indicating impaired animal welfare. In addition, the limited space allowance and insufficient enrichment of the tested artificial piglet rearing system may account for changes in manipulation of a pen mate, aggressive behaviour, play-fighting and resting observed in artificially raised piglets, compared with piglets reared by the sow in a loose farrowing pen.

# 6. Zusammenfassung

Ziel der Untersuchung war es, das Verhalten von Ferkeln, die im Alter von 3 bis 6 Lebenstagen von der Sau getrennt und in einer handelsüblichen technischen Ferkelamme untergebracht wurden, mit dem Verhalten von Ferkeln zu vergleichen, die bei der Sau in einer Abferkelbucht, in der sich die Sau frei bewegen konnte, aufwuchsen.

Die Verhaltenserfassung von 98 Ferkeln in der technischen Ferkelamme (7 Umtriebe; Gruppengröße 7 Ferkel) und 82 Ferkeln in der Abferkelbucht (6 Umtriebe; 7 Fokustiere pro Wurf) fand am Tag 4, 11 (nur in der technischen Ferkelamme) und 18 nach Belegung der technischen Ferkelamme statt. Verhaltensparameter wie das Belly nosing, das Bearbeiten von Buchtgenossen, Spiel/Kampfverhalten, aggressives Verhalten und Ruheverhalten wurden mittels kontinuierlicher Fokustierbeobachtung zweimal täglich in den Zeiträumen von 05:00 bis 10:15 Uhr sowie von 13:00 bis 18:15 Uhr erfasst. Die statistische Auswertung erfolgte mit linearen gemischten Effekte Modellen.

Belly nosing wurde bis auf eine Ausnahme nie bei den Ferkeln in der Abferkelbucht beobachtet, wohingegen ein Anstieg sowohl in der Dauer als auch in der Häufigkeit vom 4. bis zum 18. Tag bei den Ferkeln in der technischen Ferkelamme festzustellen war. Zudem verbrachten die Ferkel in der technischen Ferkelamme mehr Zeit mit dem Bearbeiten von Buchtgenossen, zeigten weniger Spiel/Kampfverhalten, wiesen mehr aggressives Verhalten auf und hatten kürzere Liegeperioden verglichen mit Ferkeln, die bei der Muttersau in der Abferkelbucht verblieben. Die Ruhedauer nahm bei den Ferkeln in der technischen Ferkelamme von Tag 4 zu Tag 18 ab und bei den Ferkeln in der Abferkelbucht zu.

Die Ergebnisse der Untersuchung zeigen, dass das Wohlbefinden von Ferkeln, die früh von der Muttersau getrennt werden und in einer technischen Ferkelamme aufwachsen, beeinträchtigt sein dürfte, da sie Massageverhalten in Form von Belly nosing an den Körper von Buchtgenossen richten, was eine Verhaltensstörung ist. Das geringe Platzangebot und die ungenügende Anreicherung der Haltungsumwelt in der untersuchten technischen Ferkelamme dürften für weitere Unterschiede im Verhalten von Ferkeln in der technischen Ferkelamme und in der Abferkelbucht verantwortlich sein.

# 7. Summary

The aim of the study was to compare the behaviour of piglets removed from the sow at the age of 3 to 6 days and transferred to a commercially available artificial piglet rearing system with the behaviour of piglets reared by the sow in a loose farrowing pen.

The behaviour of 98 piglets raised artificially (7 batches; group size 7 piglets) and 82 piglets reared by the sow (6 batches; 7 focal piglets observed per litter) was recorded on days 4, 11 (artificially raised piglets only) and 18 after piglets were housed in the artificial piglet rearing system. Belly nosing, manipulation of a pen mate, play-fighting, aggressive behaviour, and resting were assessed by continuous focal observation twice a day in the periods from 05:00 to 10:15 and from 13:00 to 18:15. Data were analysed by using linear mixed-effects models.

Belly nosing was hardly ever observed in piglets reared by the sow, whereas the duration as well as the frequency of this behaviour increased between days 4 and 18 in artificially raised piglets. Moreover, artificially raised piglets spent more time manipulating a pen mate, showed less play-fighting, displayed more aggressive behaviour and had shorter resting bouts compared with piglets reared by the sow. Finally, total duration of resting decreased from day 4 to day 18 in artificially raised piglets and increased in piglets reared by the sow.

The results of the study show that the welfare of piglets removed early from the sow and raised artificially is likely to be impaired, as they direct massaging behaviour to the body of pen mates resulting in high levels of belly nosing, an abnormal behaviour. The limited space allowance and insufficient enrichment of the housing environment in the tested artificial piglet rearing system probably account for additional behavioural differences found between artificially raised piglets and piglets reared by the sow in a loose farrowing pen.

# 8. References

Akdag, F., Arlsan, S., Demir, H., 2009. Effect of parity and litter size on birth weight and the effect of birth weight variations on weaning weight and pre-weaning survival. Journal of Animal and Veterinary Advances 8, 2133-2138.

Algers, B., 1984. Early weaning and cage rearing of piglets; Influence on behaviour. Zentralblatt für Veterinärmedizin Reihe A 31, 14-24.

Algers, B., Jensen, B., 1985. Communication during suckling in the domestic pig. Effects of continuous noise. Applied Animal Behaviour Science 14, 49-61.

Algers, B., Rojanasthien, S., Uvnäs-Moberg, K., 1990. The relationship between teat stimulation, oxytocin release and grunting rate in the sow during nursing. Applied Animal Behaviour Science 26, 267-276.

Andersen, I.L., Naevdal, E., Bøe, K.E., 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (Sus scrofa). Behavioral Ecology and Sociobiology 65, 1159-1167.

ATX Suisse GmbH, Switzerland, http://www.atx-suisse.ch/cms/upload/schweine/Nursery_Flyer_1.pdf (01.10.2014).

Auldist, D.E., Morrish, L., Eason, P., King, R.H., 1998. The influence of litter size on milk production of sows. Animal Science 67, 333-337.

Azain, M.J., Tomkins, T., Sowinski, J.S., Arentson, R.A., Jewell, D.E., 1996. Effect of supplemental pig milk replacer on litter performance: seasonal variation in response. Journal of Animal Science 74, 2195-2202.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2014. lme4: linear mixed-effects models using Eigen and S4, R package version 1.0-6, http://CRAN.R-project.org/package=lme4.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Animal Welfare 22, 219-238.

Beattie, V.E., Walker, N., Sneddon, I.A., 1996. An investigation of the effect of environmental enrichment and space allowance on the behaviour and production of growing pigs. Applied Animal Behaviour Science 48, 151-158.

Bench, C.J., 2005. Environmental and genetic factors influencing the development of belly nosing in the early-weaned pig. Ph.D.Thesis, University of Saskatchewan, Canada.

Bench, C.J., Gonyou, H.W., 2006. Effect of environmental enrichment at two stages of development on belly nosing in piglets weaned at fourteen days. Journal of Animal Science 84, 3397-3403.

Bench, C.J., Gonyou, H.W., 2007. Effect of environmental enrichment and breed line on the incidence of belly nosing in piglets weaned at 7 and 14 days-of-age. Applied Animal Behaviour Science 105, 26-41.

Bench, C.J., Gonyou, H.W., 2009. Ontogeny of belly nosing in pigs weaned at 14 days of age: A study from weaning to 13 weeks of age. Canadian Journal of Animal Science 89, 187-194.

BLV Bundesamt für Lebensmittelsicherheit und Veterinärwesen, 24.11.2010, http://www.blv.admin.ch/themen/stallliste/index.html?lang=de&streamSl=P_46237_10, http://www.blv.admin.ch/themen/stallliste/index.html?lang=de&streamSl=P_46238_10 (01.10.2014).

Bøe, K., 1991. The process of weaning in pigs: when the sow decides. Applied Animal Behaviour Science 30, 47-59.

Bøe, K., 1993. The effect of age at weaning and post-weaning environment on the behaviour of pigs. Acta Agriculturae Scandinavica Section A, Animal Science 43, 173-180.

Bøe, K., Jensen, P., 1995. Individual differences in suckling and solid food intake by piglets. Applied Animal Behaviour Science. 42, 183-192.

Bolhuis, J.E., Schouten, W.G.P., Schrama, J.W., Wiegant, V.M., 2005. Behavioural development of pigs with different coping characteristics in barren and substrate-enriched housing conditions. Applied Animal Behaviour Science 93, 213-228.

Broom, D.M., 1986. Indicators of poor welfare. British Veterinary Journal 142, 524-526.

Broom, D.M., 1991. Animal welfare: concepts and measurement. Journal of Animal Science 69, 4167-4175.

Camerlink, I., Turner, S.P., 2013. The pig's nose and its role in dominance relationships and harmful behaviour. Applied Animal Behaviour Science 145, 84-91.

Canario, L., Cantoni, E., Le Bihan, E., Caritez, J.C., Billon, Y., Bidanel, J.P., Foulley, J.L., 2006. Between-breed variability of stillbirth and its relationship with sow and piglet characteristics. Journal of Animal Science 84, 3185-3196.

Cecchinato, A., Bonfatti, V., Gallo, L., Carnier, P., 2008. Survival analysis of preweaning piglet survival in a dry-cured ham-producing crossbred line. Journal of Animal Science 86, 2486-2495.

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Applied Animal Behaviour Science 103, 25-34.

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

Colson, V., Martin, E., Orgeur, P., Prunier, A., 2012. Influence of housing and social changes on growth, behaviour and cortisol in piglets at weaning. Physiology & Behavior 107, 59-64.

Council Directive 2008/120/EC, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0120&from=DE (01.10.2014).

Danish Pig Research Centre (PRC) Annual Report 1999, http://www.pigresearchcentre.dk/~/media/Files/PDF%20-%20Aarsberetning%20VSP%20English/LU_AnnualReport_1999.ashx (12.10.2014).

Danish Pig Research Centre (PRC) Annual Report 2013, http://www.pigresearchcentre.dk/~/media/Files/PDF%20-%20Aarsberetning%20VSP%20English/Aarsberetning_2013_UK.ashx (12.10.2014).

Davis, M.E., Sears, S.C., Apple, J.K., Maxwell, C.V., Johnson, Z.B., 2006. Effect of weaning age and commingling after the nursery phase of pigs in a wean-to-finish facility on growth, and humoral and behavioral indicators of well-being. Journal of Animal Science 84, 743-756.

Deen, M.G.H., Bilkei, G., 2004. Cross fostering of low-birthweight piglets. Livestock Production Science 90, 279-284.

de Passillé, A.M., 2001. Sucking motivation and related problems in calves. Applied Animal Behaviour Science 72, 175-187.

de Passillé, A.M.B., Rushen, J., Hartsock, T.G., 1988. Ontogeny of teat fidelity in pigs and its relation to competition at suckling. Canadian Journal of Animal Science 68, 325-338.

de Passillé, A.M.B., Rushen, J., 1989. Suckling and teat disputes by neonatal piglets. Applied Animal Behaviour Science 22, 23-38.

Devillers, N., Farmer, C., Le Dividich, J., Prunier, A., 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1, 1033-1041.

Devillers, N., Farmer, C., 2009. Behaviour of piglets weaned at three or six weeks of age. Acta Agriculturae Scandinavica, Section A - Animal Science 59, 59-65.

Donaldson, T.M., Newberry, R.C., Špinka, M., Cloutier, S., 2002. Effects of early play experience on play behaviour of piglets after weaning. Applied Animal Behaviour Science 79, 221-231.

Donovan, T., Dritz, S.S., 1996. Effects of split-nursing management on growth performance in nursing pigs. Conference Paper, 78-82.

Donovan, T.S., Dritz, S.S., 2000. Effect of split nursing on variation in pig growth from birth to weaning. Journal of the American Veterinary Medical Association 217, 79-81.

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

EFSA, Technical Report, 2011, http://www.efsa.europa.eu/de/supporting/doc/178e.pdf (01.10.2014).

Ellendorff, F., Forsling, M.L., Poulain, D.A., 1982. The milk ejection reflex in the pig. The Journal of Physiology 333, 577-594.

Eriksson, M., 2006. Behaviour and growth of piglets weaned at 5 and 7 weeks of age in an organic environment. Examensarbeit 278, Swedish University of Agricultural Sciences, Sweden.

Fangman, T.J., Tubbs, R.C., 1997. Segregated early weaning. Swine Health and Production 5, 195-198.

Ferguson, E.M., Slevin, J., Edwards, S.A., Hunter, M.G., Ashworth, C.J., 2006. Effect of alterations in the quantity and composition of the pre-mating diet on embryo survival and foetal growth in the pig. Animal Reproduction Science 96, 89-103.

Ferguson, E.M., Slevin, J., Hunter, M.G., Edwards, S.A., Ashworth, C.J., 2007. Beneficial effects of a high fibre diet on oocyte maturity and embryo survival in gilts. Reproduction 133, 433-439.

Foxcroft, G.R., Dixon, W.T., Novak, S., Putman, C.T., Town, S.C., Vinsky, M.D.A., 2006. The biological basis for prenatal programming of postnatal performance in pigs. Journal of Animal Science 84, E105-E112.

Fraser, D., 1975. The 'teat order' of suckling pigs: II. Fighting during suckling and the effects of clipping the eye teeth. The Journal of Agricultural Science 84, 393-399.

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

Fraser, D., 1980. A review of the behavioural mechanism of milk ejection of the domestic pig. Applied Animal Ethology 6, 247-255.

Fraser, D., 1984. The role of behavior in swine production: A review of research. Applied Animal Ethology 11, 317-339.

Gardner, J.M., 2000. Investigations into the causation of belly-nosing in early-weaned piglets. M.Sc. Thesis, University of Guelph, Canada.

Gardner, J.M., de Lange, C.F.M., Widowski, T.M., 2001a. Belly-nosing in early-weaned piglets is not influenced by diet quality or the presence of milk in the diet. Journal of Animal Science 79, 73-80.

Gardner, J.M., Duncan, I.J.H., Widowski, T.M., 2001b. Effects of social "stressors" on belly-nosing behaviour in early-weaned piglets: is belly-nosing an indicator of stress?, Applied Animal Behaviour Science 74, 135-152.

Gill, J.C., Thomson, W., 1956. Observations on the behaviour of suckling pigs. The British Journal of Animal Behaviour 4, 46-51.

Gonyou, H.W., Beltranena, E., Whittington, D.L., Patience, J.F., 1998. The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. Canadian Journal of Animal Science 78, 517-523.

Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., Coleman, G.J., 1999. A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets. Applied Animal Behaviour Science 65, 43-52.

Herpin, P., Le Dividich, J., Hulin, J.C., Fillaut, M., De Marco, F., Bertin, R., 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067-2075.

Hohenshell, L.M., Cunnick, J.E., Ford, S.P., Kattesh, H.G., Zimmerman, D.R., Wilson, M.E., Matteri, R.L., Carroll, J.A., Lay, D.C., 2000. Few differences found between early- and late-weaned pigs raised in the same environment. Journal of Animal Science 78, 38-49.

Hötzel, M.J., de Souza, G.P.P., Costa, O.A.D., Machado Filho, L.C.P., 2011. Disentangling the effects of weaning stressors on piglets' behaviour and feed intake: Changing the housing and social environment. Applied Animal Behaviour Science 135, 44-50.

Jarvis, S., Moinard, C., Robson, S.K., Baxter, E., Ormandy, E., Douglas, A.J., Seckl, J.R., Russell, J.A., Lawrence, A.B., 2006. Programming the offspring of the pig by prenatal social stress: Neuroendocrine activity and behaviour. Hormones and Behavior 49, 68-80.

Jarvis, S., Moinard, C., Robson, S.K., Sumner, B.E.H., Douglas, A.J., Seckl, J.R., Russell, J.A., Lawrence, A.B., 2008. Effects of weaning age on the behavioural and neuroendocrine development of piglets. Applied Animal Behaviour Science 110, 166-181.

Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domestic pigs. Applied Animal Behaviour Science 16, 131-142.

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

Jensen, P., Stangel, G., Algers, B., 1991. Nursing and suckling behaviour of semi-naturally kept pigs during the first 10 days postpartum. Applied Animal Behaviour Science 31, 195-209.

Jensen, P., Gustafsson, M., Augustsson, H., 1998. Teat massage after milk ingestion in domestic piglets: An example of honest begging? Animal Behaviour 55, 779-786.

Johnson, R.K., Nielsen, M.K., Casey, D.S., 1999. Responses in ovulation rate, embryonal survival, and litter traits in swine to 14 generations of selection to increase litter size. Journal of Animal Science 77, 541-557.

Kelly, H.R.C., Bruce, J.M., English, P.R., Fowler, V.R., Edwards, S.A., 2000. Behaviour of 3-week weaned pigs in Straw-Flow®, deep straw and flatdeck housing systems. Applied Animal Behaviour Science 68, 269-280.

Kim, S.W., Osaka, I., Hurley, W.L., Easter, R.A., 1999. Mammary gland growth as influenced by litter size in lactating sows: impact on lysine requirement. Journal of Animal Science 77, 3316-3321.

King, R.H., Mullan, B.P., Dunshea, F.R., Dove, H., 1997. The influence of piglet body weight on milk production of sows. Livestock Production Science 47, 169-174.

King, R.H., 2000. Factors that influence milk production in well-fed sows. Journal of Animal Science 78, 19-25.

Kyriazakis, I., Edwards, S.A., 1986. The effect of "split-suckling" on behaviour and performance of piglets. Applied Animal Behaviour Science 16, 92.

Li, Y., Gonyou, H.W., 2002. Analysis of belly nosing and associated behaviour among pigs weaned at 12-14 days of age. Applied Animal Behaviour Science 77, 285-294.

Main, R.G., Dritz, S.S., Tokach, M.D., Goodband, R.D., Nelsen, J.L., Loughin, T.M., 2005. Effects of weaning age on postweaning belly-nosing behavior and umbilical lesions in a multi-site production system. Journal of Swine Health and Production 13, 259-264.

Martin, P., 1984. The meaning of weaning. Animal Behaviour 32, 1257-1259.

Maxwell, C.V., Sohn, K.S., 1999. The pros and cons of SEW system - Review. Asian-Australasian Journal of Animal Sciences 12, 226-232.

McBride, G., 1963. The "teat order" and communication in young pigs. Animal Behaviour 11, 53-56.

McGlone, J.J., 1986. Agonistic behaviour in food animals: review of research and techniques. Journal of Animal Science 62, 1130-1139.

Metz, J.H.M., Gonyou, H.W., 1990. Effect of age and housing conditions on the behavioural and haemolytic reaction of piglets to weaning. Applied Animal Behaviour Science 27, 299-309.

Milligan, B.N., Fraser, D., Kramer, D.L., 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. Applied Animal Behaviour Science 73, 179-191.

Milligan, B.N., Fraser, D., Kramer, D.L., 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science 76, 181-191.

Musser, R.E., Goodband, R.D., Tokach, M.D., Owen, K.Q., Nelssen, J.L., Blum, S.A., Dritz, S.S., Civis, C.A., 1999. Effects of L-carnitine fed during gestation and lactation on sow and litter performance. Journal of Animal Science 77, 3289-3295.

Newberry, R.C., Wood-Gush, D.G.M., 1985. The suckling behaviour of domestic pigs in a semi-natural environment. Behaviour 95, 11-25.

Newberry, R.C., Wood-Gush, D.G.M., Hall, J.W., 1988. Playful behaviour of piglets. Behavioural Processes 17, 205-216.

Newberry, R., Swanson, J., 2001. Breaking Social Bonds, in: Keeling, L.J., Gonyou, H.W. (Eds.), Social Behaviour in Farm Animals, CAB International, pp. 307-331.

Orgeur, P., Hay, M., Mormede, P., Salmon, H., Le Dividich, J., Nowak, R., Schaal, B., Levy, F., 2001. Behavioural, growth and immune consequences of early weaning in one-week-old Large-White piglets. Reproduction Nutrition Development 41, 321-332.

Oostindjer, M., van den Brand, H., Kemp, B., Bolhuis, J.E., 2011. Effects of environmental enrichment and loose housing of lactating sows on piglet behaviour before and after weaning. Applied Animal Behaviour Science 134, 31-41.

Oostindjer, M., Kemp, B., van den Brand, H., Bolhuis, J.E., 2014. Facilitating 'learning from mom how to eat like a pig' to improve welfare of piglets around weaning. Applied Animal Behaviour Science 160, 19-30.

Quiniou, N., Dagorn, J., Gaudré, D., 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livestock Production Science 78, 63-70.

Patience, J.F., Gonyou, H.W., Whittington, D.L., Beltranena, E., Rhodes, C.S., Van Kessel, A.G., 2000. Evaluation of site and age of weaning on pig growth performance. Journal of Animal Science 78, 1726-1731.

Pedersen, L.J., Studnitz, M., Jensen, K.H., Giersing, A.M., 1998. Suckling behaviour of piglets in relation to accessibility to the sow and the presence of foreign litters. Applied Animal Behaviour Science 58, 267-279.

Pedersen, L.J., Berg, P., Jørgensen, G., Andersen, I.L., 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. Journal of Animal Science 89, 1207-1218.

Petersen, V., 1994. The development of feeding and investigatory behaviour in free-ranging domestic pigs during their first 18 weeks of life. Applied Animal Behaviour Science 42, 87-98.

Petersen, V., Simonsen, H.B., Lawson, L.G., 1995. The effect of environmental stimulation on the development of behaviour in pigs. Applied Animal Behaviour Science 45, 215-224.

Pitts, A.D., Weary, D.M., Pajor, E.A., Fraser, D., 2000. Mixing at young ages reduces fighting in unacquainted domestic pigs. Applied Animal Behaviour Science 68, 191-197.

Pluske, J.R., Williams, I.H., 1996. Split weaning increases the growth of light piglets during lactation. Australian Journal of Agricultural Research, 513-523.

Provimi B.V., the Netherlands,
http://www.provimi.co.za/cms/uploaded_files/RescuePig_de.pdf (01.10.2014).

Puppe, B., Schön, P.-C., Tuchscherer, A., Manteuffel, G., 2003. The influence of domestic piglets' (Sus scrofa) age and test experience on the preference for the replayed maternal nursing vocalisation in a modified open-field test. Acta Ethologica 5, 123-129.

R Core Team, 2013. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/.

Robert, S., Weary, D.M., Gonyou, H., 1999. Segregated early weaning and welfare of piglets. Journal of Applied Animal Welfare Science 2, 31-40.

Robert, S., Martineau, G.P., 2001. Effects of repeated cross-fosterings on preweaning behavior and growth performance of piglets and on maternal behavior of sows. Journal of Animal Science 79, 88-93.

Rushen, J., Fraser, D., 1989. Nutritive and nonnutritive suckling and the temporal organization of the suckling behaviour of domestic piglets. Developmental Psychobiology. 22, 789-801.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Animal Welfare 22, 199-218.

Rzezniczek, M., Gygax, L., Wechsler, B., Weber, R., 2014. Impact of an artificial rearing system on the behaviour of early weaned piglets. KTBL-Schrift 505, 192-201 (in German with English summary).

Schön, P.-C., Puppe, B., Gromyko, T., Manteuffel, G., 1999. Common features and individual differences in nurse grunting of domestic pigs (Sus scrofa): A multi-parametric analysis. Behaviour 136, 49-66.

Špinka, M., Newberry, R.C., Bekoff, M., 2001. Mammalian play: training for the unexpected. The Quarterly Review of Biology 76, 141-168.

Stangel, G., Jensen, P., 1991. Behaviour of semi-naturally kept sows and piglets (except suckling) during 10 days postpartum. Applied Animal Behaviour Science 31, 211-227.

Stolba, A., Wood-Gush, D.G.M., 1989. The behaviour of pigs in a semi-natural environment. Animal Science 48, 419-425.

Studnitz, M., Jensen, M.B., Pedersen, L.J., 2007. Why do pigs root and in what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment. Applied Animal Behaviour Science 107, 183-197.

SUISAG, Zahlen und Projekte 2004 and 2013, http://www.suisag.ch/Dokumente/tabid/111/Default.aspx (12.10.2014).

Tomiyama, M., Kubo, S., Takagi, T., Suzuki, K., 2011. Evaluation of genetic trends and determination of the optimal number of cumulative records of parity required in reproductive traits in a Large White pig population. Animal Science Journal 82, 621-626.

Topigs Norsvin, Sauenplanerauswertung 2013/14, http://www.topigs-snw.de/fileadmin/topigs/redakteure/bilder/Aktuelles/Sauenplanerauswertung14.pdf (26.02.2015).

Torrey, S., Widowski, T.M., 2006. Is belly nosing redirected suckling behaviour?, Applied Animal Behaviour Science 101, 288-304.

Torrey, S., Widowski, T.M., 2007. Relationship between growth and non-nutritive massage in suckling pigs. Applied Animal Behaviour Science 107, 32-44.

Tuchscherer, M., Kanitz, E., Otten, W., Tuchscherer, A., 2002. Effects of prenatal stress on cellular and humoral immune responses in neonatal pigs. Veterinary Immunology and Immunopathology 86, 195-203.

Van den Brand, H., Van Enckevort, L.C.M., Van der Hoeven, E.M., Kemp, B., 2009. Effects of dextrose plus lactose in the sows diet on subsequent reproductive performance and within litter birth weight variation. Reproduction in Domestic Animals 44, 884-888.

Vanderhaeghe, C., Dewulf, J., De Vliegher, S., Papadopoulos, G.A., de Kruif, A., Maes, D., 2010. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Animal Reproduction Science 120, 78-83.

van Putten, G., Dammers, J., 1976. A comparative study of the well-being of piglets reared conventionally and in cages. Applied Animal Ethology 2, 339-356.

Vidović, V., Lukač, D., Štrbac, L., Višnjić, V., Punoš, D., Šević, R., Krnjajić, J., Stupar, M., 2012. Genetic trend for certain traits in pigs using different selection criteria. Animal Science and Biotechnologies 45, 274-279.

von Borell, E., 2000. Tierschützerische Beurteilung des isolierten Frühabsetzens (Segregated Early Weaning, SEW) beim Schwein - eine Übersicht. Archiv für Tierzucht 43, 337-345.

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

Weary, D.M., Jasper, J., Hötzel, M.J., 2008. Understanding weaning distress. Applied Animal Behaviour Science 110, 24-41.

Wechsler, B., Brodmann, N., 1996. The synchronization of nursing bouts in group-housed sows. Applied Animal Behaviour Science. 47, 191-199.

Wechsler, B., 2005. An authorisation procedure for mass-produced farm animal housing systems with regard to animal welfare. Livestock Production Science 94, 71-79.

Welch, A.R., Baxter, M.R., 1986. Responses of newborn piglets to thermal and tactile properties of their environment. Applied Animal Behaviour Science 15, 203-215.

Whittemore, C.T., Fraser, D., 1974. The nursing and suckling behaviour of pigs. II. Vocalisation of the sow in relation to suckling behaviour and milk ejection. British Veterinary Journal 130, 346-356.

Widowski, T.M., Yuan, Y., Gardner, J.M., 2005. Effect of accommodating sucking and nosing on the behaviour of artificially reared piglets. Laboratory Animals 39, 240-250.

Widowski, T.M., Torrey, S., Bench, C.J., Gonyou, H.W., 2008. Development of ingestive behaviour and the relationship to belly nosing in early-weaned piglets: Early Weaning. Applied Animal Behaviour Science 110, 109-127.

Wolf, J., Zakova, E., Groeneveld, E., 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science 115, 195-205.

Wolter, B.F., Ellis, M., Corrigan, B.P., DeDecker, J.M., 2002. The effect of birth weight and feeding of supplemental milk replacer to piglets during lactation on preweaning and postweaning growth performance and carcass characteristics. Journal of Animal Science 80, 301-308.

Wood-Gush, D.G.M., Vestergaard, K., 1989. Exploratory behavior and the welfare of intensively kept animals. Journal of Agricultural Ethics 2, 161-169.

Worobec, E.K., 1997. Early weaning in swine: a behavioural assessment. M.Sc. Thesis, University of Guelph, Canada.

Worobec, E.K., Duncan, I.J.H., Widowski, T.M., 1999. The effects of weaning at 7, 14 and 28 days on piglet behaviour. Applied Animal Behaviour Science 62, 173-182.

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

# 9. Appendix

**Figure 1**

Artificial piglet rearing system ’Rescue Deck’

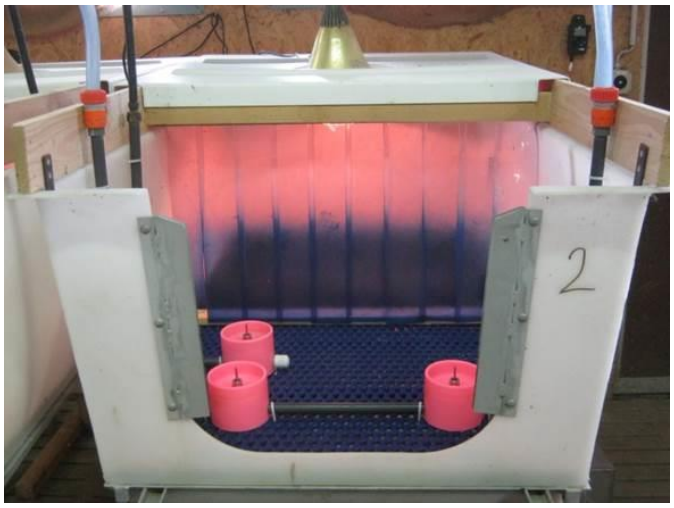


**Figure 2**

Feeding/dunging area of the artificial piglet rearing system ‘Rescue Deck’

# 10. Declaration on oath / Eidesstattliche Versicherung

I hereby declare, on oath, that I have written the present dissertation by my own and have not used other than the acknowledged resources and aids.

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst erfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

München, den 16.03.2015 Magdalena Rzezniczek

# 11. Acknowledgements

I thank all those who supported me in any way throughout this project and all those who helped, directly or indirectly, that this project became possible.

My special thanks go to

**Roland Weber** for choosing me as doctoral student for this project and for being the best supervisor I could ever get during this project.

**Beat Wechsler** for providing constructive help, comments and words of advice throughout this project and on all manuscripts.

**Lorenz Gygax** for valuable comments on all manuscripts and excellent statistical support and advice.

**Michael Erhard** for taking over the responsibility for this thesis at LMU München.

**The Swiss Federal Food Safety and Veterinary Office** for financing this project.

**Agroscope** for providing the animals, facilities and infrastructure in order to realise this project.

**The whole team of the Centre for Proper Housing of Ruminants and Pigs** for providing a positive, motivating and pleasant working atmosphere.

**Gallus Jöhl, Andreas Hagenbüchle, Barbara Ammann and Urs Marolf** for reliably taking care of the piglets and for having a wonderful time and experience at the Agroscope's swine barn in Tänikon.

**Urs Marolf** for reliable technical support at the swine barn.

**Hubert Bollhalder and Beat Kürsteiner** for technical support and advice.

**Silvio Schönenberger and Hans-Rudolf Ott** for producing devices specially designed for the artificial piglet rearing system.

**Heidi Hosp and Natacha Kammerlander** for being wonderful master students.

**My mother and sister** for always supporting me and being there for me.