THE EFFECT OF LIGHT IN THE CREEP AREA AND TEMPERATURE ON THE USAGE OF THE CREEP AREA IN ORGANIC SUCKLING PIGLETS

MASTER'S THESIS

WRITTEN BY

ANNA OLLMANN

SUPERVISORS:

UNIV.PROF. DR. CHRISTOPH WINCKLER

UNIV.PROF. LENE JUUL PEDERSEN

DR. SARA HINTZE, PH.D.

DR. WERNER HAGMÜLLER

VIENNA, OCTOBER 2ND, 2019

AFFIDAVIT

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

_____

Date, Signature

ACKNOWLEDGEMENTS

I want to thank my team of supervisors, Christoph Winckler, Sara Hinze, Lene Juul Pedersen and Werner Hagmüller, for their support, for answering my many questions and giving valuable feedback.

Thank you, Resi and Martin for helping me when I got stuck, for your input and support. Without you it wouldn't have been the same!

A very special thanks goes to my brother Tobias, for writing an amazing software for me! It was fun to work together and see how great it turned out.

Thank you, Mom and Dad for being there for me and providing a safe haven to come home to when I needed it. I know I can always count on you.

I also want to thank my aunt Maria for letting me stay at her place and borrow her car during the experiment. It was great spending time with you and cooking together.

A big thank you goes to the entire team at the research farm, for helping me with my experiment over such a long period. You were always there to provide answers and solutions when I needed them.

Thank you, Hanni, Julia, Nadine, Karin, Elli, Patricia and Sabrina for giving me lots of support and for making my time at university an amazing experience.

And last but not least, I would like to thank Bioschwein Austria Vertriebs GmBH for providing financial support during the experiment by covering the travel expenses.

ABSTRACT

Free farrowing is mandatory in organic farming according to the Commission Regulation (EC) No 889/2008. However, there are concerns in free farrowing pens regarding piglet mortality due to crushing. To reduce this risk, creep areas are provided to lure the piglets away from the sow. The more attractive these areas are, the higher is the piglets' motivation to spend more time there. The aim of this thesis was to investigate if light in the creep area and temperature have an impact on (1) the latency of individual piglets to enter the creep area, (2) the latency for 75 % of the litter to use the creep area for at least 10 minutes, and (3) the total time individual piglets spend in the creep area and (4) piglet crushing. Thirty Large White sows from 8 batches with in total 427 piglets were studied between August 2017 and January 2018. Half of the litters were provided with light in the creep area (LIGHT), the other half had access to dark creep areas (DARK). All pens were video recorded, and creep area use of the individually marked piglets was continuously analysed for 72h postpartum. More piglets entered the creep area with LIGHT, and the latency to enter tended to be shorter compared to DARK. The latency to enter decreased with an increasing temperature quotient (temperature difference between pen and creep area divided by pen temperature) for DARK, and vice versa for LIGHT. More litters reached the 75 % criterion with LIGHT, but the latency was longer than for DARK. The duration piglets stayed in the creep area was not affected by the treatment but increased with a higher temperature quotient. Crushing tended to be lower for LIGHT compared to DARK but was not influenced by temperature. In conclusion, light in the creep area led to piglets exploring the creep area sooner than without light, which increases the chances of a higher usage, even though this was not the case in this study. Further research is needed to determine the optimal light intensity and gradient.

ZUSAMMENFASSUNG

Freies Abferkeln ist laut EU-Verordnung (EG) Nr. 889/2008 in der biologischen Landwirtschaft verpflichtend. Allerdings sind in freien Abferkelsystemen Erdrückungsverluste problematisch. Um dieses Risiko zu minimieren, werden Ferkelnester zur Verfügung gestellt, die die Ferkel von der Sau weglocken sollen. Je attraktiver die Nester sind, desto höher ist die Motivation der Ferkel, mehr Zeit dort zu verbringen. Das Ziel dieser Studie war es, den Einfluss von Licht im Nest und der Temperatur zu untersuchen im Hinblick auf (1) die Latenz bis zur ersten Nestnutzung individueller Ferkel, (2) die Latenz, bis 75% des Wurfes mind. 10 Minuten im Nest verbringen, und (3) die Dauer, die individuelle Ferkel im Nest verbringen und (4) Erdrückungsverluste. Insgesamt 427 Ferkel von 30 Edelschwein-Sauen wurden in 8 Durchgängen zwischen August 2017 und Jänner 2018 untersucht. Die Hälfte der Würfe hatte Licht im Nest (LIGHT), die andere Hälfte hatte kein Licht (DARK). Alle Buchten wurden gefilmt und die Nutzung der individuell markierten Ferkel wurde 72h postnatum kontinuierlich analysiert. Mehr Ferkel betraten das Nest bei LIGHT, und die Latenz war tendenziell kürzer als bei DARK. Die Latenz sank mit steigendem Temperaturquotienten (Temperaturdifferenz zwischen Bucht und Nest dividiert durch die Buchtentemperatur) bei DARK, und umgekehrt bei LIGHT. Mehr Würfe erreichten das 75% Kriterium bei LIGHT, aber die Latenz war länger als bei DARK. Die Dauer der Nestnutzung wurde durch den Faktor Licht nicht beeinflusst, aber sie stieg mit steigendem Temperaturquotienten an. Es wurden tendenziell weniger Ferkel bei LIGHT als bei DARK erdrückt, während es keinen Einfluss des Temperaturquotienten gab. Durch die frühere Erkundung des Nests bei LIGHT steigt die Wahrscheinlichkeit einer höheren Nutzungsdauer, auch wenn das in dieser Studie nicht der Fall war. Weitere Studien sind notwendig, um die optimale Lichtintensität und den optimalen Lichtgradienten zu finden.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBRIVIATIONS

EOF…… END OF FARROWING

HI……HUMAN INFLUENCE

IOR…… INTRA-OBSERVER RELIABILITY

OBS……..……OBSERVATION

1 Introduction

This paper is divided into two parts. The first part is a literature review on pre-weaning piglet mortality and how it can be reduced. The second part describes the experiment that was carried out to investigate the effect of light in the creep area and temperature on the usage of the creep area in organic suckling piglets.

In part I, the natural behaviour of sows and piglets during the first days after farrowing is described. This includes resting behaviour of the piglets and the usage of a nest which sows build for their litters. Next, factors influencing pre-weaning mortality are illustrated. The cause of death of a new-born piglet cannot always be singled down to one factor, which is why several potentially influencing aspects, such as the influence of heat balance, colostrum intake, piglet body weight and selection for e.g. higher piglet survival maternal abilities are briefly described.

Then, strategies to reduce pre-weaning piglet mortality are discussed, starting with the confinement of the sow during and after farrowing, followed by the usage of a creep area where the piglets can rest. Regarding the confinement, after shortly describing the legal situation in selected countries, it is discussed whether confined systems are able to reduce piglet mortality and what impact they have on sow welfare. Alternatives to confined farrowing are shown, leading to the last chapter of part I, the creep area. First, functions of the creep area are illustrated with the main goal of reducing piglet mortality. Finally, ways to improve the usage of the creep area are shown, which include temperature regulation, management and handling of the piglets, farrowing environment and light.

Light in the creep area as a way to reduce piglet mortality is the focus of the experiment described in part II. After giving a brief introduction to the topic, the experimental design, video analysis, intra-observer reliability and statistical analysis are described. At the end of part II, the results of the study are described and compared to other existing literature.

Finally, all the findings of part I and II are concluded, and implications for piglet production are presented.

2 Part I: A brief introduction to pre-weaning piglet mortality and how to reduce it

Pre-weaning mortality of live-born piglets varies greatly, with values ranging from 5 % (Andersen et al., 2007) over 10 - 15 % (Weary et al., 1996; Herpin et al., 2002; Valros et al., 2003; KilBride et al., 2012) to more than 20 % (Edwards, 2002; Andersen et al., 2007). Most deaths occur during the first few days after farrowing (Dyck and Swierstra, 1987; Marchant et al., 2001; Pedersen et al., 2011; KilBride et al., 2012; Kirkden et al., 2014). Neonatal piglet mortality remains not only an economical issue of the pig industry, but also a welfare issue, which seems to be linked to intensive production systems (Herpin et al., 2002).

2.1 Natural sow and piglet behaviour during the first days after farrowing

The following paragraph focuses on the nest, which sows usually build for their litter before farrowing. Understanding the sows' and piglets' behaviour regarding the use of this nest is important when discussing piglet mortality and the factors influencing it.

During the first two days postpartum, the sow spends most of the time (90 %) in the nest (Stangel and Jensen, 1991). There is, however, great variation between individual sows. One study was done on sows that were kept in pens with the possibility to enter an area that the piglets could not reach. It was found that some sows spent more than half of their time away from the piglets after the first week, while others took until the fifth week or never spent that much time away at all (Pajor et al., 2000).

Another study found that piglets prefer to rest in proximity to the sow for the first three days of life, independent of air temperature or the location of the heat lamp (Hrupka et al., 1998). This can be confirmed by Vasdal et al. (2009a) who found that only very few piglets rest alone or together, and without contact to the sow during the first three days of life, regardless of the environment (Vasdal et al., 2009a). In addition to preferring to rest near the sow, new-born piglets also prefer other litter mates over comfortable temperatures: a study showed that when placing an anaesthetized piglet in a cold area, piglets preferred to rest near this piglet even when offered a heated area. From this result it was concluded that the motivation to stay near other piglets is stronger than the attraction to a heated creep (Hrupka et al., 2000a).

Considering the nest leaving behaviour of the piglets, the time spent away from the nest foraging increases gradually. The piglets explore only the close surroundings on the first two days, with or without their mother. Later, they follow the sow further away (Stolba and Wood-

Gush, 1989; Stangel and Jensen, 1991; Pitts et al., 2002). In a study on nest leaving behaviour of free ranging domestic sows, the sows and their litters abandoned their nests on average 10.4 days postpartum. The time the sow and the piglets spent outside the nest increased during the last 5 days before leaving the nest entirely (Jensen and Redbo, 1987).

2.2 Factors that influence pre-weaning piglet mortality

Cause of death cannot always be attributed to one single factor but is often rather complex as shown in Figure 1. Chilling can be caused by low birthweight and low viability, reduced colostrum intake or by sub-optimal ambient temperature. Together with poor maternal behaviour, this can lead to lethargy and starvation, which can then lead to overlying. Starvation and reduced colostrum intake can make the piglets more prone to diseases which might lead to death.

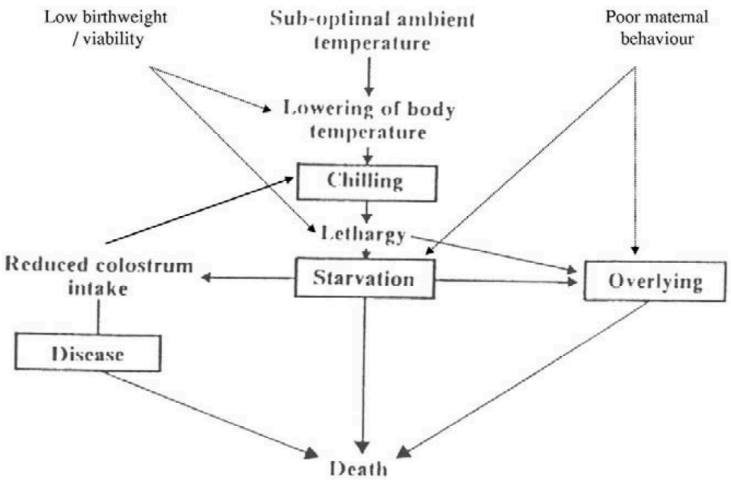


Figure 1: Interactive events occurring in the chilling-starvation-overlying-disease complex (Edwards, 2002, modified from English & Morrison, 1984).

The most frequent causes of death of suckling piglets include hypothermia, starvation and crushing (Weary et al., 1996; Valros et al., 2003; Kirkden et al., 2014). According to Marchant et al. (2001), crushing by the sow might be the reason for up to 75 % of early mortality in non-confined farrowing environments (Marchant et al., 2001).

2.2.1 The role of heat balance and colostrum intake

A decreased intake of colostrum of new-born piglets can lead to chilling and to a reduced eagerness and aggressiveness during nursing. A lack of nutrients for thermogenesis and missing immunoglobulins might lead to starvation and lethargy, and make the piglets more vulnerable to be crushed by their mother (Herpin et al., 2002).

After birth, the piglets experience a decrease in ambient temperature of 15 - 20°C, and their energy supply changes from glucose transportation across the placenta to colostrum intake, which is low in carbohydrates but high in fat content, and which they must uptake by themselves in regular intervals (Herpin et al., 2002). New-born piglets must adapt fast by utilising fatty acids as energy supply and by developing thermoregulatory functions. The lower critical body temperature for hypothermia, which is the lower limit of the thermoneutral zone is about 34°C for new-born piglets (Herpin et al., 2002). That is why early and regular uptake of colostrum (and later of milk) as well as the development and maintenance of thermoregulatory functions play an important role in piglet survival (Herpin et al., 2002). Maintaining a constantly high body temperature (i.e. homeothermy) depends on the balance between heat loss and heat production. Heat loss is influenced by the environment and the piglets' physiology, and heat production must vary to keep up with the demand.

New-born piglets are poorly insulated having very little hair, they are wet from foetal fluids and, in contrast to most other mammals, they do not have brown adipose tissue. To maintain their homeothermic balance they must therefore rely on shivering thermogenesis, which is why the skeletal muscles are important for thermoregulation (Herpin et al., 2002). Another strategy is huddling behaviour: Piglets are strongly attracted to stay near other piglets, they are drawn towards the udder when a piglet is resting there, but can also be attracted to a creep area for the same reason (Hrupka et al., 2000a; b).

2.2.2 Body weight

Piglets with a low body weight are more likely to die before weaning, one of the reasons being that cold resistance decreases with body weight at birth (Le Dividich et al., 1991; Herpin et al., 2002). This is because small piglets take longer to reach the udder and take in colostrum than heavier piglets. Body weight at birth is considered an important endogenous factor that has an impact on neonatal piglet vitality, growth and mortality rate (Hoy et al., 1994).

It was found that pre-weaning piglet mortality depends on litter size, with piglets from large litters being at greater risk (Herpin et al., 2002; Weber et al., 2007). This might be because piglets in large litters take longer to reach the udder for colostrum intake and are prone to gain weight more slowly (Vasdal et al., 2011). Devillers et al. (2007) found that litter size is negatively linked to average piglet weight: the individual piglet weight was 25g lower for an increase of one piglet per litter. Also, colostrum production is not influenced by litter size, meaning there is less colostrum available per piglet in larger litters (Devillers et al., 2007).

2.2.3 Selecting sows for better piglet survival

Pre-weaning mortality can be decreased directly by selecting sows for piglet survival, or indirectly by selecting for decreased litter size (Herpin et al., 2002; Pedersen et al., 2006; Andersen et al., 2009; Vasdal et al., 2009a). A Brazilian study on 280 piglets from 25 litters with different breeding values showed that farrowing survival and early postnatal survival increased with better breeding values for pig survival (Leenhouwers et al., 2001).

Another aspect is the selection for lean tissue growth; it has been shown that it can lead to heavier piglets at birth, but they are less mature, which might increase mortality (Herpin et al., 1993). This effect was shown by McKay (1993), who found that selection for reduced back fat thickness and higher growth rates after weaning increased pre-weaning mortality (McKay, 1993).

As mentioned above, one of the major causes of pre-weaning mortality is piglet crushing, which is why sow behaviour plays an important role and could be used for culling decisions. Sows show different piglet mortality rates due to crushing, ranging from 0 to 30.8 %. The difference between sows was bigger than expected by chance, suggesting that selection for better maternal abilities can increase piglet survival (Jarvis et al., 2005). It should be mentioned though that these differences between sows could not only stem from individual maternal traits and thus repeatable across parities, but they could also be due to specific events during parturition (e.g. disease, heat stress, etc.) causing different mortality rates. The maternal behaviour during and after farrowing is described further in the following paragraph (2.2.4).

2.2.4 Maternal behaviour

Different sows often show different maternal behaviour, which affects piglet growth and survival. Especially in loose farrowing environments, it is crucial to improve maternal abilities by directly selecting for more attentive mothers (Vasdal et al., 2009a; Blomberg, 2010). The sows' responsiveness to piglets' screaming when handled is a possible trait for selection (Vangen et al., 2005). This was shown by a Norwegian study which found that sows that did not crush any piglets within the first four days postpartum responded sooner to the piglets' screams and nosed them more frequently when changing their resting position. These sows also showed longer nest building behaviour and were more restless when the piglets were taken away; in other words, they were "better mothers" than sows that crushed two or more piglets within the first four days after farrowing (Andersen et al., 2005).

Valros et al. (2003) demonstrated that sows show individual attributes when it comes to activity level and frequency of position changes from standing to lying. Moreover, before lying down, rooting seems to be relevant to decrease piglet crushing and is therefore an important aspect of maternal behaviour (Valros et al., 2003).

Maternal behaviour is not strictly genetic. The farrowing environment and availability of resources may also be important to improve piglet survival: The quantity and timing of rooting and nest building before farrowing can improve parturition and postpartum maternal behaviour (Herskin et al., 1998; Thodberg et al., 1999; Blomberg, 2010). Providing sawdust for rooting and nest building can shorten the duration of parturition and reduce piglet crushing around parturition, especially for young sows. Older sows seemed to lack the experience with sawdust and did thus not show the same response (Cronin et al., 1993). Providing sand or straw was found to have positive effects on maternal behaviour, increasing piglet survival when compared to sows that were kept on a concrete floor with no added rooting material (Herskin et al., 1998).

2.3 Approaches to reduce piglet mortality

2.3.1 Confinement of the sow during farrowing

This chapter describes the characteristics of and differences between confined and loose farrowing systems. In this chapter, confined farrowing is referred to as crates or farrowing crates, and loose farrowing as pens.

It is common to keep sows in farrowing crates during lactation because it is believed that crating sows reduces neonatal mortality by preventing crushing (Pedersen et al., 2011; Lambertz et al., 2015). The following paragraph first describes which countries prohibited crates, and where they are still in use, followed by an overview of studies that examined how well crates work with respect to piglet mortality. Then, some common problems of farrowing crates are described, before closing off with alternatives to confined farrowing.

2.3.1.1 Legal situation in selected countries

In Switzerland, Sweden and Norway, the use of farrowing crates during lactation is forbidden.

The number of farrowing sows kept in confinement is high with 97 % in Denmark, 90 % in Germany and 83 % in France (EFSA, 2007). On average, about 95 % of pig farms in the EU use confined farrowing systems (Johnson and Marchant-Forde, 2009). To the author's knowledge, there are no official number about farrowing crates for Austria. In 2018, 2.7 % of all pigs in Austria were kept on organic farms (Grüner Bericht, 2019). In organic farming, the

minimum surface area for farrowing sows with piglets up to 40 days old is 7.5 m^2 indoors and 2.5 m^2 outdoors. Animals must always be provided with enough space to stand, lie down, turn around and stretch easily (Commission Regulation (EC) No 889/2008.), thus prohibiting farrowing crates. It can therefore be assumed that in Austria, the number of sows kept in farrowing crates is similar to the EU average.

There has been a debate in Austria in 2009 that led to a pledge to ban farrowing crates by 2033 (Baxter et al., 2017). Until then, sows can be confined for up to five days before farrowing until the end of the suckling period. The surface area for sows and their litters must be at least 4 m^2 for piglets weighing on average up to 10 kg, and 5 m^2 for piglets weighing on average more than 10 kg. Starting on January 1st, 2033, the pens for sows and their piglets in Austria must have a surface area of 5.5 m^2 and it is not allowed to confine sows permanently anymore. Crating sows will only be allowed during the not further defined "critical period" of the suckling piglets for their protection. After this period, sows must be allowed to move freely (1. Tierhaltungsverordnung, 2017).

2.3.1.2 Do farrowing crates really work?

A report by the European Food Safety Authority (EFSA) concluded that piglet mortality and welfare on farms are still a problem. They pointed out, however, that it is difficult to conclude about the effect of the farrowing environment on the mortality rate because of its big variation in different systems. Piglet mortality cannot be reduced to one factor, it depends on many variables that are different on each farm (EFSA, 2007). One variable influencing piglet mortality is the sow: A study examining the variability in crushing mortality found that certain sows crushed fewer or more piglets than others, and also, that crushing occurred more frequently in pens than in crates. The authors concluded that farrowing crates might conceal these differences between sows (Jarvis et al., 2005). A Swiss study comparing 655 farms using either confined or loose farrowing came to the conclusion the farrowing system had no influence on total piglet losses, but it was found that there were more deaths due to crushing in pens while there were more deaths from other causes in crates. The authors claim that worries about higher piglet mortality in pens are unfounded, as long as the pens have an adequate size (Weber et al., 2007). In Table 1, there is an overview of piglet mortality in loose and confined farrowing systems. There is a great variety between the results, with mortality rates ranging from around 10 % to over 30 %.

Table 1. Overview of piglet mortality in loose and confined farrowing systems.

Source	***Loose Farrowing***	***Confined Farrowing***	***Comments***
Blackshaw et al. (1994)	*32*	*14*	*N=16;* *Live-born mortality [%]*
Jarvis et al. (2005)	+	-	*N=122* *Crushing was more frequent in pens than in crates, numbers not found*
Cronin and Smith (1992)	*16.5*	*10.5*	*N=64* *Live-born pre-weaning mortality [%]*
Singh et al. (2016)	=	=	*N=672* *Farrowing in crate; loose housing from day 3. Piglet mortality from day 3 until weaning.*
Weber et al. (2007)	*Total: 1.4* *Crushed: 0.62* *Other: 0.79*	*1.42* *0.52* *0.89*	*N=63,661* *Losses per litter*
Barnett et al. (2001)	*11.3 - 24.2*	*12.7 - 19.7* *10 % is achievable*	*N not given.* *Piglet mortality [%]*
Lambertz et al. (2015)	=	=	*N=168* *Farrowing in crate, loose housing from day 7*
Hales et al. (2015)	*21.4*	*17.9*	*N=2,139* *Live-born mortality [%]*
O 'Reilly et al. (2006)	*13*	*10*	*N not given. Data from 67 Farms* *Pre-weaning mortality [%]*
Cronin et al. (2000)	*16 - 17*	*16 - 17*	*N=146* *Live-born mortality [%]*
Pedersen et al. (2011)	=	=	*N=103* *No effect of housing on stillborn, crushed or starved piglets*
Wientjes et al.(2012)	*20.9 - 33.3*	*n.a.*	*N=137* *Live-born pre-weaning mortality [%] in organic litters*
Wallenbeck et al. (2009)	*18.9 (organic)* *14 (conventional)*	*n.a.*	*N=144* *Live-born pre-weaning mortality [%]*
Thorsen et al.(2017)	*12.6*	*n.a.*	*N=38* *Live-born mortality [%] until day 7.* *Housed in organic A-frame huts*

N…Total number of litters

Note that not all authors included the exact numbers, these results were therefore compared using +, - and =. Also note that mortality was often given in different units, such as live-born mortality, mortality for a certain period of time etc. An explanation to the unit is given in the comments-column. Sometimes, the unit was not further specified in the paper.

2.3.1.3 Problems concerning sow welfare

Despite the potential benefits concerning piglet mortality, there is an ongoing discussion about farrowing crates negatively influencing the sows' health and natural behaviour, thus posing restrictions on sow welfare (Jarvis et al., 2001; Verhovsek et al., 2007; Baxter et al., 2011). Sows that are kept in farrowing crates are severely limited in their freedom to move, which can lead to frustration. It is not possible for them to choose a nest site, to select areas with appropriate floor temperatures for thermoregulation and to express nest-building behaviour (EFSA, 2007). The latter is triggered by hormones, so the sows have an internal motivation for nest building behaviour regardless whether the pen design allows it or not (EFSA, 2007). It has been shown that sows that are not able to perform nest-building behaviour due to missing space and substrate are physiologically stressed during farrowing and lactation (Jarvis et al., 1997). Other consequences of confining sows can be reduced activity, abnormal behaviours and even aggression towards other sows (Hansen and Vestergaard, 1984a). One study showed that sows that were kept loose during gestation, but were moved to a crate a week before the planned farrowing date needed birth assistance and suffered from the MMA complex more often than sows that were kept loosely during farrowing (Hansen and Vestergaard, 1984b). Moreover, sows showed longer intervals between the birth of individual piglets in crates compared to pens (Biensen et al., 1996). Longer birth intervals have a negative impact on piglet mortality since they increase the probability of stillbirths (Zaleski and Hacker, 1993).

2.3.1.4 Alternatives to confined farrowing

There are several reasons why free farrowing has not yet been implemented in countries where farrowing crates are still allowed. The biggest concern is piglet mortality, but management, safety for the farmer and economic sustainability are also relevant (Baxter et al., 2012). Regarding piglet mortality, it is argued that genetic selection has not focused very much on maternal abilities because maternal behaviour can only be shown to a small extend in farrowing crates. As mentioned in paragraph 2.2.4, good motherly instincts can benefit piglet survival, and selection for good mothers might help to adopt free farrowing systems more widely (Jarvis et al., 2005). New government legislation and consumers' choices put a growing pressure on better welfare in pig farms, trying to abolish the use of farrowing crates and promoting free farrowing. There are many alternatives to crates, but they are not accepted by many farmers yet. Examples of alternative farrowing systems include group farrowing, outdoor farrowing and design indoor pens which have separated lying and dunging areas (Baxter et al., 2012).

2.3.2 Provision of a creep area

In the following paragraphs, functions and different strategies on how to increase the usage of the creep area are illustrated. It should be noted here that creep areas may look very differently in the studies cited below, ranging from a closed heated box with a small entrance to a heat lamp placed in the open pen.

2.3.2.1 Functions of the creep area

Individual farrowing units are designed in a way that the piglets should rest in the creep area between suckling bouts (Vasdal et al., 2009a) which has several reasons. One important function of the creep area is reducing the risk of piglet crushing by the sow. Therefore, it is of importance that the latency until the piglets use the creep area is reduced to a minimum, and that the duration of creep area use is high. The extent of the use depends on how attractive the creep area is for the piglets, or, alternatively, how unattractive the pen or crate is (Berg et al., 2006; Vasdal et al., 2009a; Pedersen et al., 2013). Other functions are the beneficial temperature difference and the possibility to treat the piglets.

2.3.2.2 How to increase the usage of the creep area

2.3.2.2.1 Temperature

The sows' thermal comfort zone is around 18 – 20°C (Zhang and Xin, 2000; Vasdal et al., 2010), while new-born piglets prefer temperatures from approx. 30 - 34°C to avoid hypothermia (Zhang and Xin, 2000; Herpin et al., 2002; Schormann and Hoy, 2006; Vasdal et al., 2010). The knowledge about the piglets' thermal preferences can be used to attract piglets to use the creep area: A study found that creep area use correlates with ambient air temperature; a higher temperature led to a higher latency of first entry, and the piglets spent less time in the creep area (Burri et al., 2009). This can be confirmed by Pedersen et al. (2013) who found that the creep area usage was highest at 15°C ambient temperature, as compared to 20°C or 25°C (Pedersen et al., 2013). An Australian study found that for each increase by 1°C on the heating mat of the creep area, its use was increased by about 2.1 %. Furthermore, for every 1°C increase in ambient temperature, the use of the creep area decreased by about 4.8 % (Morello et al., 2019). This is in contrast with (Hrupka et al., 1998) who found that piglets prefer the proximity of the sow for the first three days postnatum, independent of air temperature or location of the heat lamp (Hrupka et al., 1998). It was even observed that piglets prefer to rest near an anaesthetized piglet in a cold area when offered a heated area (Hrupka et al., 2000a). Floor

heating in the sow area has negative effects on the usage of the creep area because piglets are less motivated to seek out additional heat sources (Houbak et al., 2006).

2.3.2.2.2 Management: placing piglets in the creep area

To decrease the risk of being crushed by the sow, many farmers try to increase the usage of the creep area between suckling bouts (Vasdal et al., 2009a). Often, the piglets are closed inside the creep area while the sow is being fed during the first two to three days, so that the chances of being crushed are reduced when the sow lies down after feeding. However, in a study investigating the effect of locking the piglets in the creep area of individual loose farrowing pens, it was found that is has no effects on piglet mortality or creep area use (Berg et al., 2006). A study that was carried out using 67 loose housed sows on Norwegian farms found that placing the piglets in the creep area without drying them before increased the latency to suckle and decreased weight gain, which both has a negative effect on piglet survival. However, placing them in the creep area after drying them showed lower postnatal mortality and better weight gain, compared to all other treatments (Vasdal et al., 2011). Another study compared three different management procedures around farrowing (placing piglets under the heat lamp with or without drying them vs control). It was found that crushing occurred in only 13.6 % of all litter in the treatment with drying, followed by the treatment without drying (34.8 %) and control (47.9 %). Postnatal mortality was lower when piglets were put under a heat lamp with or without drying, compared to the control group (Andersen et al., 2009). These two studies indicate that there is a link between placing the piglets in the creep area and piglet mortality. They do, however, not mention how the use of the creep area was affected by the treatment and if there was a link between usage of the creep area and piglet mortality.

The results presented above are in contrast with a study comparing 39 herds in Norway which found that placing the piglets in the creep area or drying them did not affect piglet mortality. However, the authors pointed out that it was unclear how many piglets in each litter were affected by these procedures (Andersen et al., 2007).

2.3.2.2.3 Farrowing environment

A study that compared loose and confined farrowing found that a higher number of piglets were found in the creep area in the crates compared to the pens. The difference was bigger between 24 until 48 hours postpartum than on the two proceeding days. Consequently, the time the piglets spent resting near the sow was higher in the pens, and it decreased over time after parturition in both systems. The authors concluded that the increased use of the creep area in

the farrowing crate may be because of the slatted floor in the crate and the shorter distance between creep area and sow (Vasdal et al., 2009a). Another study found similar results, with piglets in farrowing crates spending twice as much time under the heat lamp than piglets in pens (Blackshaw et al., 1994). Considering the floor type in the creep area, piglets prefer to rest on a soft and flexible material, such as a water bed (Ziron and Hoy, 2003). The location should be near the resting area of the sow so that it can be accessed easily (Zhang and Xin, 2001). It is also suggested to use a simulated udder, i.e. a soft warm object that smells like the sows' udder, to draw the piglets' attention to the creep area (Lay et al., 1998).

2.3.2.2.4 Light

As mentioned above, to the author's knowledge there is only a limited number of studies directly examining the effects of light in the creep area on its usage.

Larsen et al. (2015) compared three different heat sources in the creep area of farrowing crate systems: (1) standard infrared lamp (130 Lx), (2) radiant heater with additional light (130 Lx) and (3) radiant heater without additional light. There was artificial light (300 Lx) from 06:00 am to 06:00 pm in the farrowing house. The number of piglets in the creep area was recorded using scan sampling every 10 minutes for three hours during daytime and nighttime, respectively, on day 1, 2, 3, 7, 14 and 21 postpartum. The authors found that piglets spent more time in the dark creep area, especially during the evening observation period. Therefore, they concluded that piglets prefer to sleep in the dark and recommended to turn off the lights in the creep overnight, and to use other heat sources than infrared lamps (Larsen et al., 2015). A study carried out by Parfet & Gonyou (1991) found similar results but in a different study design, as the piglets were removed from the farrowing environment and put in multiple choice arenas. The piglets were then confronted with three differently lit boxes (bright: 11 Lx, dim: 5.5 Lx and dark). Areas that were dim or dark were equally attractive, while bright areas were chosen less frequently (Parfet and Gonyou, 1991).

In contrast, Tanida et al. (1996) found that piglets preferred lighter areas. One-week old piglets were separated from the sow and given the choice to go to differently lit boxes. There were several different runs, such as light to light, light to dark or dark to light. Piglets tended to go to lighter boxes, and they preferred to go to dark areas when there was a little beam of light to guide them (Tanida et al., 1996). These results are in contrast with the studies mentioned above. This could be due to a different experimental setup and the age of the piglets.

A recent study examined 108 sows on a commercial Australian pig farm with a loose farrowing system. They compared light (300 Lx) and dark (4 Lx) creep areas with a mat surface temperature of either 30°C or 35°C. For each combination of treatments (light and dark, 30°C and 35°C), six sows and their litters were recorded for 72 hours continuously after farrowing to measure the latency to enter the creep area for the first time and the latency for 30 % and 75 % of the litter to remain in the creep for at least 10 consecutive minutes. The 84 sows that remained were scanned daily every 15 minutes from 08:00 – 17:00 for the first three days postnatum for the piglets' location in the pen. Piglets spent on average 7.2 % more time in the bright creep areas compared to the dark ones ($p < 0.01$). However, piglets tended to take longer to enter the bright creep for the first time postpartum ($p = 0.06$). The latency for 30 % of the litter to remain in the creep area for at least 10 minutes tended to be shorter ($p = 0.08$) for bright creep areas, whereas there was no significant difference between bright and dark creeps to reach 75 % ($p = 0.49$). The authors concluded that the use of the creep area could be increased by light and a higher temperature in the creep area (Morello et al., 2019).

3 Part II: Experiment

3.1 Introduction

During the first days after farrowing, good management is important to keep piglet mortality to a minimum (Kirkden et al., 2014). In modern farrowing systems, the aim is to keep the piglets away from the sow, thus reducing the chances of piglet crushing between the periods of suckling (Vasdal et al., 2010). This is particularly important in loose farrowing systems where the sow can move more freely (Baxter et al., 2015).

However, piglets have a natural urge to stay near the sow after farrowing because being close to the teats will help to gain warmth, establish a teat order, reduce the risk of being caught by predators and allow a high intake of colostrum, therefore increasing the chances of the piglets' survival (Baxter et al. 2011; Weary et al. 1996; Vasdal et al. 2010). Proximity to the udder is important within the first 24 hours (Baxter et al., 2011) or even for a period of up to 2-3 days postnatum *(*Berg et al. 2006; Vasdal et al. 2010). Despite the benefits of staying near the sow, there is a risk of being crushed by the sow when piglets remain close to the udder, a risk which is increased when the piglets have low energy reserves. Piglets with low weight gain are more likely to take that risk, as they spend more time in proximity to the sow (Weary et al., 1996; Baxter et al., 2011).

One way of keeping the piglets away from the sow is by providing a heated creep area where the piglets can stay between suckling bouts (Wheeler et al., 2008). Piglets tend to seek out a heated creep area because of the temperature difference to the sow's lying area. It is beneficial for both the sow and the piglets, since sows prefer a lower room temperature than piglets (Houszka et al., 2001). Additionally, a creep area makes it possible to separate the piglets from the sow for treatments (e.g. castration or vaccinations) or examinations (Baxter et al., 2011).

In order to increase the usage of the creep area, the aim is to make it more attractive for the piglets. There are different approaches to achieve this, such as increased temperature in the creep area, lower ambient temperature, slatted floor in the sow area etc. (Schormann and Hoy, 2006; Wheeler et al., 2008; Vasdal et al., 2009a). Another approach is providing light in the creep are. There is, however, only a limited number of studies on the influence of light on the usage of the creep area (Parfet and Gonyou, 1991; Tanida et al., 1996; Larsen et al., 2015; Morello et al., 2019). Their findings are rather controversial: Two studies found that piglets prefer dark or dimly lit areas over bright areas (Parfet and Gonyou, 1991; Larsen et al., 2015).

The other two studies found that piglets preferred light over darkness (Tanida et al., 1996; Morello et al., 2019). All four studies are described in chapter 2.3.2.2.4.

The objectives of the present study were to add knowledge about the effect of temperature and light on the usage of the creep area. To assess the effect of temperature, a quotient of the difference between pen and creep area divided by pen temperature was calculated. The aims of the study were to find out if light or darkness in the creep area and temperature in pen and creep area have an influence on:

- *The latency for individual piglets of a litter to enter the creep area for the first time postpartum*
- *The latency until the first usage by at least 75 % of the litter for at least 10 minutes*
- *The total duration of the individual usage per day*
- *Piglet mortality due to crushing from the sow*

We hypothesized that:

I. The latency of individual piglets to enter the creep area for the first time postnatum is (a) shorter when there is light in the creep area compared to darkness, and (b) it decreases with an increasing temperature quotient.

II. The latency for at least 75 % of the litter to use the creep area for at least 10 minutes for the first time postnatum is (a) shorter when there is light in the creep area compared to darkness, and (b) it decreases with an increasing temperature quotient.

III. The total duration of the individual usage per day is (a) higher when there is light in the creep area compared to darkness, and (b) it increases with an increasing temperature quotient.

IV. Piglet mortality due to crushing from the sow is (a) lower when there is light in the creep area compared to darkness, and (b) lower with an increasing temperature quotient.

3.2 Materials and methods

3.2.1 Experimental design

3.2.1.1 Experimental facility

The experiment took place from April 2017 until January 2018 at the research farm run by the Higher Federal Institute for Agriculture and Research Raumberg-Gumpenstein, field office Thalheim b. Wels, Austria. The farm keeps 40-50 sows (large white, F1 and F2) and one Pietrain boar for semen collection. Farrowing took place about every three weeks.

3.2.1.2 Animals

In total, 33 sows in 8 batches were selected to take part in the experiment. If possible, five sows were used for each batch, being the number of identical pens available. If there were more than five sows in one batch, they were chosen randomly. The four gilts in the experiment were chosen in a way that they were counterbalanced over the different treatments (LIGHT or DARK) and pens (1-5). Three sows were excluded from the experiment because fostered piglets had already used the creep area in the farrowing pen where they had been born, or because the marks of most piglets from the litter were not clear enough to recognize them in the videos (see chapter 3.2.1.5 for a description of piglet marking). The average parity of the remaining 30 sows was 3.4 (ranging from 1 to 8). Individual piglets were not considered for the analysis if they were manually put in the creep area to warm up, or if the marking was not visible well enough to recognize them in the videos. They were also excluded if too many mistakes were made during video analysis, i.e. if the sum of all errors was greater than 12h per day. An example of such an error includes when a piglet was not logged out of the creep area between having been logged in twice, which occurred when the sow was blocking the view to the entrance of the creep area. These errors are further explained in chapter 3.2.2.3. Thus, a total number of 358 out of 427 piglets was analysed.

3.2.1.2.1 Housing

Farrowing sows were housed in five identical WelCon pens. Figure 2 shows the designated paths of a sow through the pen.

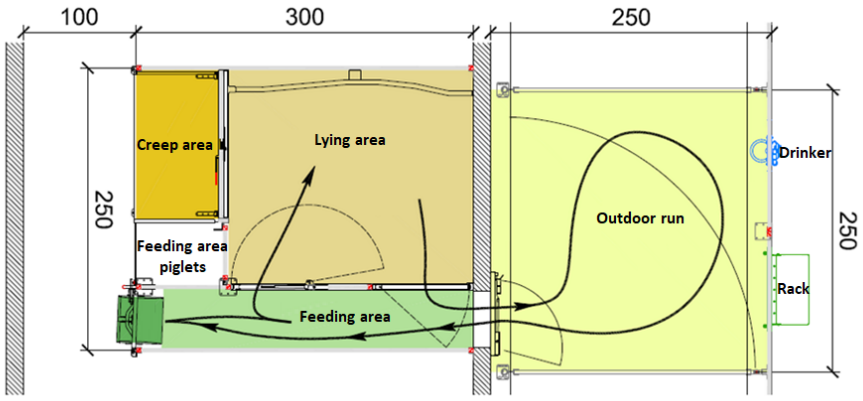


Figure 2. Plan of the WelCon pen. Arrows indicate the path of the sow (Schauer Agrotronic GmbH, 2017).

From the lying area the sow exits the pen through the back door to enter the outdoor run with a water and a roughage trough. Going back to the resting area she passes the feeding aisle and enters through the front door. Some sows used the front door to access the feed trough, and some used the back door to enter from the outdoor run. Piglets can access feeding aisle and outdoor run at an early age. The area for feeding the piglets was used to collect them for veterinary treatments and marking their backs. In the present study, there were no rails (indicated as a tilted line) in the lying area.

The floor in the creep area was made of wood, while the floor in the rest of the pen (indoor and outdoor) was made from concrete. Sows were always provided with chopped straw or sawdust as bedding material so that the floor was covered. The walls indoors were made from wood as well, except for the wall separating resting area and feeding stall, which was made from steel. The inside of the stable is shown in the following figures (Figure 3-Figure 5).

Figure 3. All five pens as seen from indoors

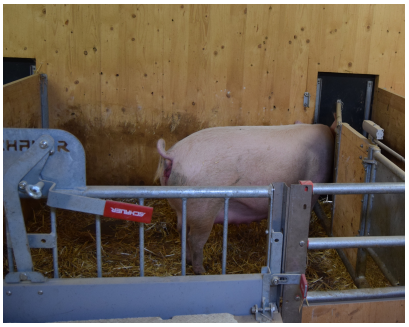


Figure 4. A sow exiting the resting area

Figure 5: A sow standing in the feeding aisle

Sows were put in their pens on average 7 days (ranging from 0-17 days) prior to the expected farrowing date. The sows were fed twice a day at around 06:00 am and 12:30 pm. Water was provided ad libitum in the outdoor run. Two days before the planned farrowing date the sows were provided with 1 kg of straw for nest building, in addition to the bedding material. If needed, 0.5 - 1 kg of straw was added daily until farrowing. The pen and outdoor run were cleaned out every morning.

3.2.1.3 Treatment

Half of the litters were assigned to the treatment LIGHT (light intensity of about 4 - 6 Lx in the creep area), while the other half did not have light in the creep area (DARK). For the LIGHT treatment, each creep area was equipped with a band of white LEDs with a length of 1 m. They were covered with an iron mesh, but the measured intensity was still very bright (around 17 Lx). To dim the light to the required 4-6 Lx, a fabric tape was attached to the iron mesh, covering all LEDs (see Figure 6).

Light intensity was measured using a lux meter. The sensor was put on the floor in the centre of the closed creep area, facing upwards to know the light intensity that piglets face when in the creep area.

Figure 6. Marked piglets sleeping in a lit creep area.

The LED lights covered by a typed iron mesh are visible on the left wall.

To measure the light intensity that piglets experience when approaching the creep area, the sensor was put on the floor 50 cm away from the entrance, facing towards the light. At night, an intensity of approximately 2 Lx was measured there. Table 2 shows how the treatments were distributed in a way that they were evenly distributed over the pens and batches and how many sows per batch were used for this experiment.

Table 2. Distribution of sows over the 5 pens, 8 batches and two treatments (DARK = grey background, LIGHT = no background).

Batch\Pen	***1***	***2***	***3***	***4***	***5***	***Date***
1		*35*	*37*	*49*	*74*	*31.08.17*
2	*Excl.*	*71*	*39*	*56*	*70*	*22.09.17*
3	*1*	*2*		*60*	*41*	*13.10.17*
4	*78*	*77*	*Excl.*	*43*	*85*	*01.11.17*
5	*79*	*81*	*Excl.*	*65*	*92*	*23.11.17*
6	*67*				*47*	*07.12.17*
7			*24*	*20*	*83*	*31.12.17*
8	*86*	*63*	*53*	*73*	*84*	*21.01.18*

Excl. … sows that were excluded from the experiment. Numbers indicate the individual sow. The date indicates the first farrowing in each batch

3.2.1.4 Heating and temperature measurement

The temperature in the creep area was maintained using infrared heaters that emitted no light. There were two air temperature sensors in every creep area. One was in the top left front corner (as seen when standing in front of it) and the other was on the wall beneath the lights, 10 cm above the floor. Temperature and humidity were sent to a server every 10 minutes. The intention was to keep the temperature in the creep area at 30°. However, this was not always successful because it was not easy to adjust the heating. In addition, the temperature measured by the sensors was higher (on average 4.6°C higher in the middle, 1.3°C higher in the back of the creep area) than when measured using an infrared thermometer. Another sensor was placed on the wall in the stable in front of pen 3. Again, temperature and humidity were sent to a server every ten minutes. Average temperatures are shown in Table 3. A quotient was used to show the influence of temperature on the usage of the creep area, since both pen and creep area temperature varied. The quotient increases with a decreasing pen temperature and an increasing temperature difference. It was calculated as follows:

$$T_{Quotient} = \frac{\Delta T}{T_{Pen}}$$

Table 3. Average temperatures in °C for all batches.

Batch	$T_{Creep\ area}$	T_{Pen}	ΔT	$T_{Quotient}$
1	*26.42*	*19.42*	*7.01*	*0.36*
2	*27.74*	*20.57*	*7.17*	*0.35*
3	*27.66*	*18.15*	*9.50*	*0.52*
4	*23.58*	*15.34*	*8.24*	*0.54*
5	*20.59*	*12.62*	*10.07*	*0.79*
6	*23.32*	*10.63*	*12.68*	*1.20*
7	*24.64*	-	-	-
8	*24.51*	*15.36*	*9.16*	*0.60*

ΔT refers to the difference between creep area and pen; the quotient is ΔT divided by pen temperature. The missing values in batch 7 are due to a malfunctioning sensor.

3.2.1.5 Management procedures for piglets

Cross-fostering was performed within the first 24 h post-partum when necessary to even out litter sizes. All piglets were marked with a number within the first 24 h post-partum using an animal marking crayon (RAIDL MAXI, RAIDEX GmbH). They had to be remarked on a daily basis because the signs were only visible for 1-2 days. If piglets were marked wrong by accident, their entire back was painted black and they were excluded from further analysis. This happened to about 10 piglets. Some piglets had black spots due to their breed making marking impossible. Most piglets were weighed between their first and third day of life, depending on whether they were born on weekends, holidays or workdays. Sometimes, due to longer holidays, the piglets were only weighed on their fourth day of life. After weighing, the piglets were given ear tags and received an iron injection.

Figure 7. Marked piglets resting at the udder

When a piglet was found dead, a post-mortem examination was carried out to confirm the cause of death. The creep areas were cleared out when they were dirty or if the sow pushed in too much bedding material. To not interfere with the experiments, all employees at the farm were asked not to lock the piglets in the creep area, which is usually done during veterinary

treatments. Instead, the small area for piglet feeding was used, or they were put in boxes to carry out veterinary treatments. In order to lock the sow away from the piglets, the pen was adjusted so that the sow could be locked outside from the resting area. Castration never took place during the first three days of life.

3.2.2 Behaviour assessment and analysis

3.2.2.1 Video recording

In order to measure the usage of the creep area the piglets were video recorded for 72h continuously after farrowing. This period was chosen because piglets prefer to remain close to the udder for the first 2-3 days after farrowing *(*Berg et al. 2006; Vasdal et al. 2010), and it is when most of the piglet crushing occurs (Dyck and Swierstra, 1987; Marchant et al., 2000). One camera per farrowing pen was mounted above the resting area in a way that the entrance to the creep area was visible. An infrared light was used to record during night-time. The videos were recorded in black and white (see Figure 8) using Geovision NVR-SYS-i5.

The software was set to start recording a few days prior to the expected farrowing date and was adjusted after farrowing so that it recorded at least until 72h after the birth of the last piglet of each sow.

Figure 8. Screenshot of video recording. The entrance to the creep area is located at the sow's snout.

3.2.2.2 Ethogram

The sows' and piglets' behaviour were continuously recorded for 72h after the end of farrowing, adding up to 2,160 h of video material that was analysed. It was possible to speed up analysis by fast-forwarding when all piglets were asleep. Table 4 shows the different events that were analysed and how their start and end time was defined.

Table 4. Ethogram for the video analysis

Event	***Start***	***End***	***Comments***
Piglet enters/leaves creep area	*More than half of the body is in the creep area*	*More than half of the body is outside of the creep area*	*When sow blocks view to entrance: piglets are logged in/out when last/first visible*
Sow leaves/enters pen	*More than half of the body outside the pen*	*More than half of the body inside the pen*	*Does not count as leaving when sow tries to go out but comes back without having fully left*
Human influence	*Door is opened or other human influence visible*	*Door is closed, no human influence visible*	
Creep area closed	*Entrance to the creep area is closed*	*Entrance is opened*	*Piglets cannot enter/leave the creep area when it is closed. This duration was therefore excluded from analysis*
Farrowing ended	*Birth of last piglet (dead or alive)*	-	*To determine the start of the 72h observation period*

The sow leaving and entering the pen, as well as human influence were not included in statistical analysis. They are, however, still included in the Intra-observer reliability described in chapter 3.2.3.

3.2.2.3 Video analysis in Mangold Interact

The videos were analysed using Mangold Interact version 17.1 (see Figure 9). The individual sows were not analysed all at once, but in groups of one day (day zero: end of farrowing until midnight, day one and two: midnight until midnight, and day three: midnight until 72h after end of farrowing). The sows and days were randomly analysed to avoid a change in analysis over time. The author did all recording. Intra-observer reliability (IOR) was calculated before and after video analysis and is described in chapter 3.2.3.

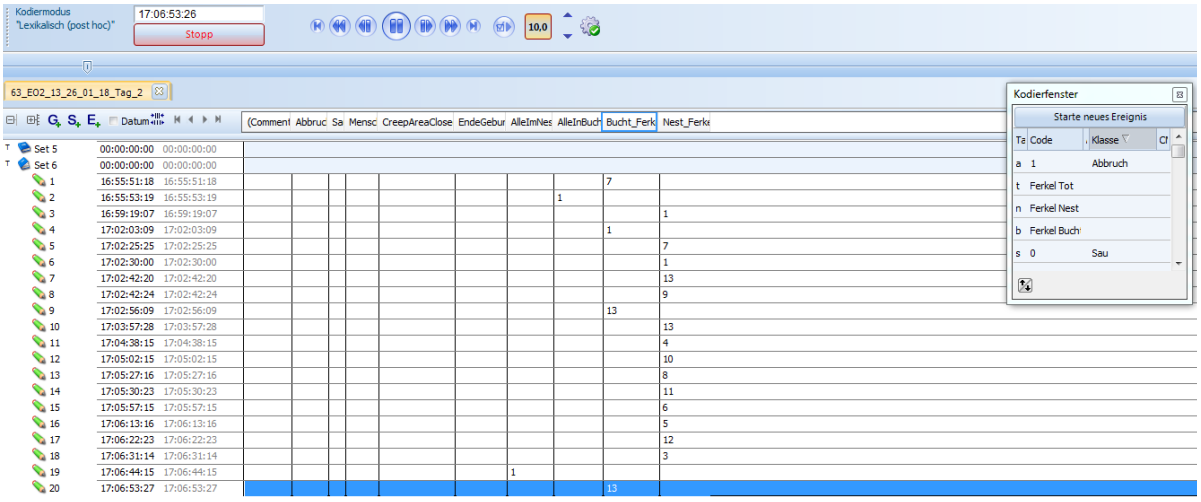


Figure 9. Screenshot of the video analysis in Interact: view of the main screen.

Numbers indicate an individual piglet leaving (Bucht_Ferkel) and entering (Nest_Ferkel) the creep area.

As shown in Figure 9, it was not calculated automatically for how long the individual piglets stayed in the creep area. Only the identity of entering and leaving piglets are recorded. As described above, the entrance to the creep area was not always visible, and so not all piglets were logged in and out correctly. Therefore, durations and the number of piglets in the creep area at a certain time could not simply be calculated in Excel. In order to do so, a software was written using Python. Using this software, it was possible to calculate the time individual piglets stayed in the creep area and number of piglets in the creep area. The errors could be identified as a piglet being logged in or out of the creep area twice in a row. They were then summarized per individual piglet in order to exclude piglets with a sum of errors higher than 12h per day from further analysis.

3.2.3 Intra-observer reliability (IOR)

Intra-observer reliability was calculated for the following variables: End of farrowing (EoF, farrowing of the last piglet), marked piglets (marked piglets enter creep area), undefined piglets (piglets without marking enter creep area), sow in outdoor run (sow leaves pen), human influence (HI, any human interference visible). The IOR was calculated in order to show the reliabilities of the different variables.

IOR was calculated twice: IOR1 was calculated in the beginning of video analysis, and IOR2 in the end. This was to see if and how the quality of the analysis changed over time. The data for IOR1 and IOR2 are described in the following section. Since the graphs for IOR1 and IOR2 were mostly very similar, only the graphs for IOR1 are shown and described below. The graphs for IOR2 can be found in the appendix.

For each variable in both IOR1 and IOR2, two observations (observation 1, observation 2) were carried out and analysed. They are referred to as OBS1 and OBS2. When calculating differences between the two observations, it was always OBS2 - OBS1. A negative difference between OBS1 and OBS2 in e.g. Onset Time would mean that OBS2 had an earlier Onset Time than OBS1.

First, videos were selected for each variable. Then, they were watched and analysed twice (OBS1 and OBS2), but mixed with other videos from other variables, so as not to remember certain events. Finally, the identified events were counted and statistically analysed.

3.2.3.1 End of farrowing (EoF)

A total number of 11 events was used for the calculation of the IOR1, 5 events were used for IOR2 for the end of farrowing (EoF). All events were identified in both observations in IOR1

and IOR2. Maximum, minimum and mean difference are shown in Table 5. The difference between IOR1 and IOR2 is rather small.

Table 5. EoF: Maximum, minimum and mean difference in Onset Time between events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*-00:01*	*00:05*
Min. difference	*00:00*	*00:00*
Mean difference	*00:00*	*00:01*

The distribution of the differences is shown in Figure 10.

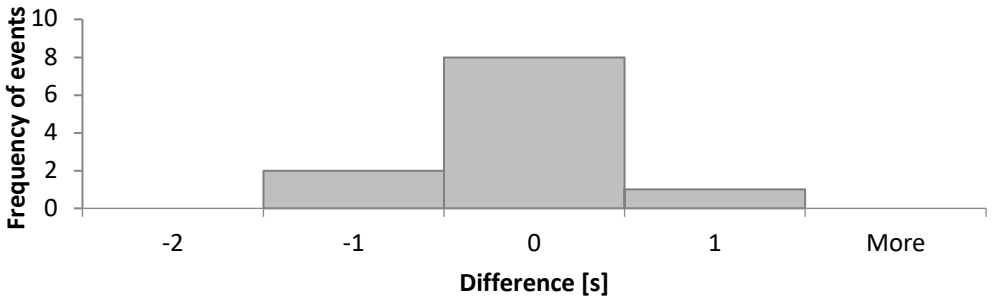


Figure 10. EoF: Differences in Onset Time between OBS1 and OBS2 (IOR1).

The relation between OBS1 and OBS2 is plotted in Figure 11.

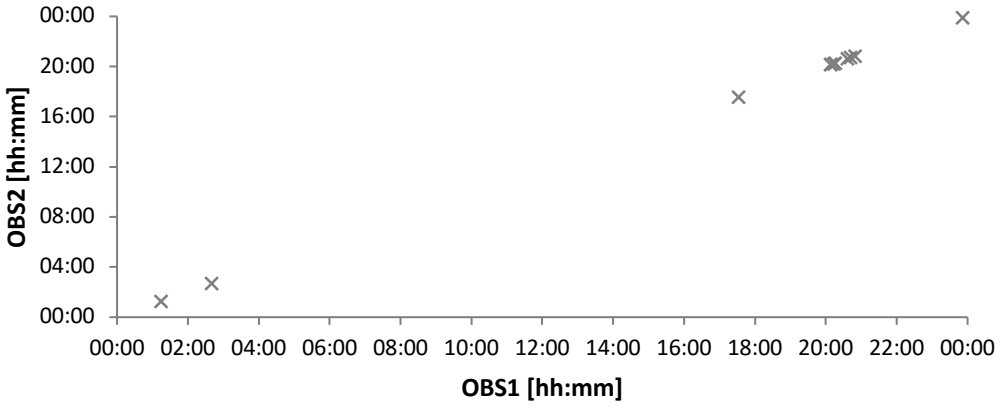


Figure 11. EoF: Relationship of Onset Times of events seen during OBS1 and OBS2 (IOR1).

3.2.3.2 Marked piglets

As shown in Table 6, more events were identified in both observations in IOR2 than in IOR1.

Table 6. Marked piglets: Summary of events.

	Number of events (IOR1)	***% (IOR1)***	***Number of events (IOR2)***	***% (IOR2)***
Total	*159*		*139*	
Total except open events	*131*	*100*	*109*	*100*
Identified in both observations	*103*	*78.63*	*100*	*91.74*
Identified in OBS1	*117*	*89.31*	*102*	*93.58*
Identified in OBS2	*114*	*87.02*	*103*	*94.50*

The total number describes all events that were identified in OBS1 or OBS2. The total number except open events excludes events that did not have an Offset Time because the video ended prior to the piglet leaving the creep area. These events were then used to compare observation one and two.

3.2.3.2.1 Onset Time

The Onset Time, i.e. the time the piglets enter the creep area, differed slightly between OBS1 and OBS2, OBS2 being on average 2s earlier in IOR1, and 2s later in IOR2 (see Table 7).

Table 7. Marked Piglet: Maximum, minimum and mean difference of Onset Time between the events with Onset Times in OBS1 and OBS2.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*00:04*	*03:37*
Min. difference	*00:00*	*00:00*
Mean difference	*-00:02*	*00:02*

These events consist of events identified in both observations and a few events that had no Offset Time because the video ended prior to the piglets leaving the creep area or because Offset Time was not identified in one of the observations.

Most of the events had an Onset Time only a few seconds apart in OBS1 and OBS2, as shown in Figure 12.

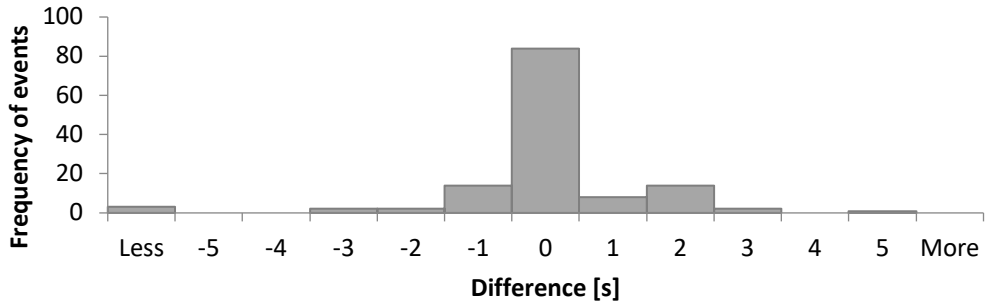


Figure 12. Marked Piglet: Differences in Onset Time between OBS1 and OBS2 (IOR1).

The majority of events had a very little difference between Onset Time in OBS1 and OBS2. The three events on the left were at -7s, -8s and -3min.

3.2.3.2.2 Duration

The mean difference between the durations in OBS1 and OBS2 was rather low in IOR1 as well as IOR2 (see Table 8).

Table 8. Marked Piglet: Maximum, minimum and mean difference of duration between events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*03:00*	*-03:36*
Min. difference	*00:00*	*00:00*
Mean difference	*00:02*	*-00:02*

In IOR1, there were 14 events in OBS1 and 11 events in OBS2, that were not identified during the other observation. The mean duration of these events was short at 13s and 6s, respectively (see Table 9).

Table 9. Marked Piglet: Durations of events only identified during one of the observations (IOR1).

	Number	***Max. Duration***	***Min. Duration***	***Mean duration***
OBS1	*14*	*42:46*	*00:04*	*00:13*
OBS2	*11*	*50:14*	*00:01*	*00:06*

In IOR2, there were only 2 events in OBS1 and 2 events in OBS2 that were not identified during the other observation (see Table 10), but the mean duration was much higher.

Table 10. Marked Piglet: Durations of events only identified during one of the observations (IOR2).

	Number	***Max. Duration***	***Min. Duration***	***Mean duration***
OBS1	*2*	*14:24*	*00:08*	*07:16*
OBS2	*2*	*19:00*	*00:12*	*09:36*

Figure 13 shows the distribution of durations. There are only slight differences between OBS1 and OBS2. There was a large amount of very short usages of the creep area.

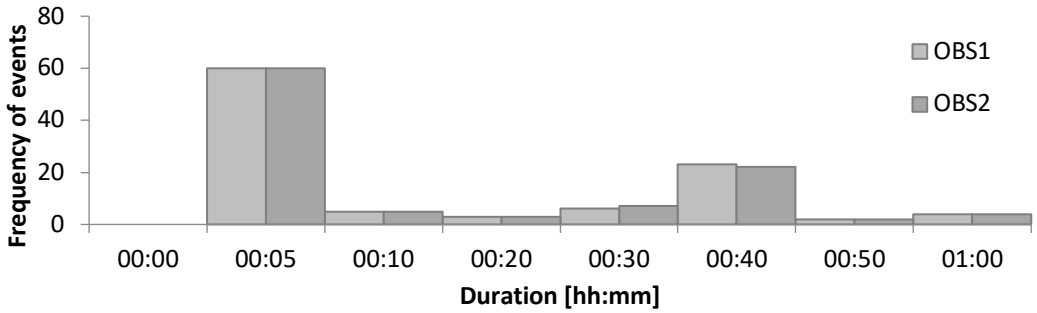


Figure 13. Marked Piglet: Distribution of Durations in OBS1 and OBS2 (IOR1).

Figure 14 shows the distribution of differences between the durations in OBS1 and OBS2. The majority of events had a difference of 0s or ±1s.

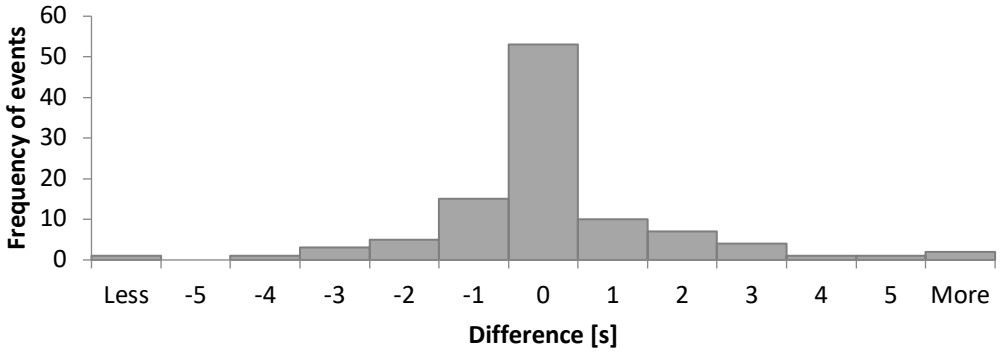


Figure 14. Marked Piglet: Differences in Duration between OBS1 and OBS2 (IOR1).

There is a strong, significant positive correlation between the two observations in IOR1 (r_s = 0.997, $p < 0.001$) and IOR2 (r_s = 0.998, $p < 0.001$). The relation between OBS1 and OBS2 is shown in Figure 15.

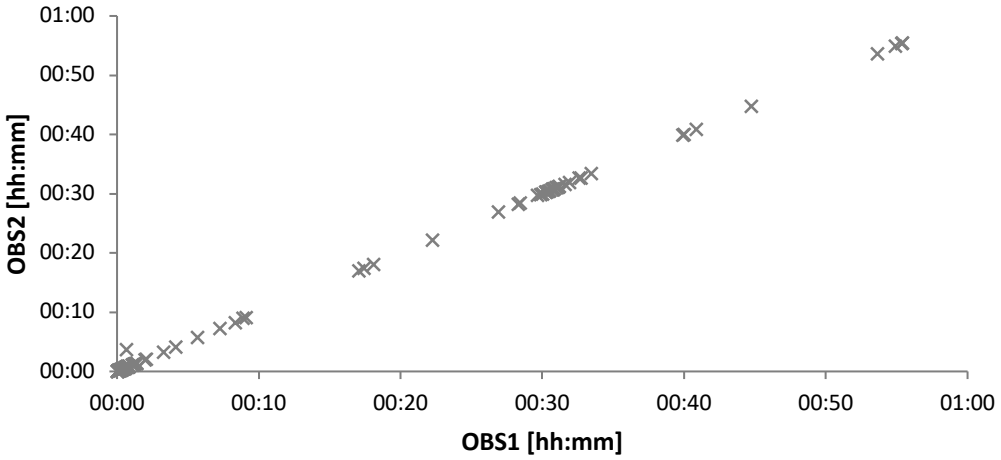


Figure 15. Marked Piglet: Relationship between the Durations of events seen during OBS1 and OBS2 (IOR1).

In Figure 16, the differences in duration are plotted. There are more events that are slightly below zero, meaning the events started a little earlier in OBS2 compared to OBS1.

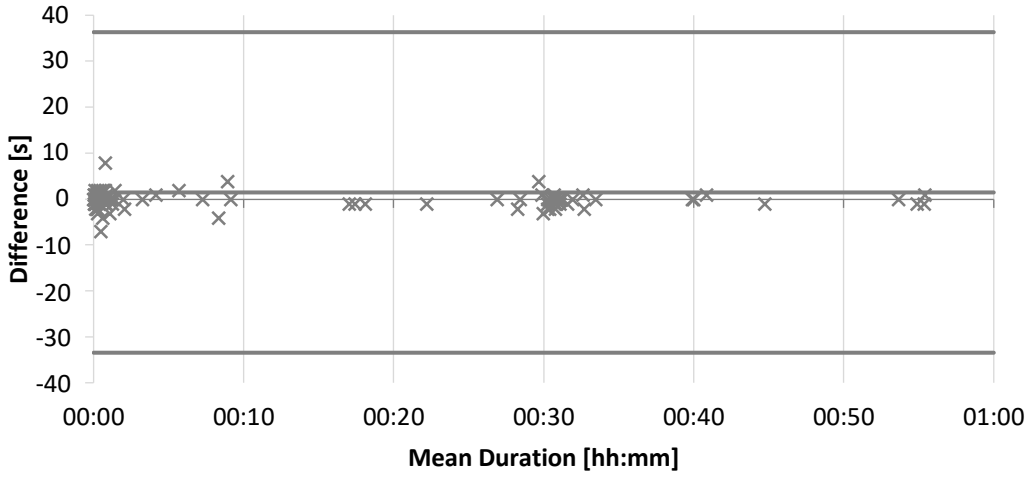


Figure 16. Marked Piglet: Bland&Altman Plot for all events identified in OBS1 and OBS2 (IOR1).

The lower and upper dark grey lines indicate lower and upper confidence limits, respectively. The dark grey line in the middle indicates the mean difference between the durations of OBS1 and OBS2. There is one value (difference 03:00, mean duration 02:09) which is not displayed in this graph. It is the reason the confidence limits are high; without this one event they would be at -4s and 3s.

3.2.3.3 Undefined piglets

For calculation the IOR1 for the undefined piglets (i.e. piglets that were not marked yet), 33 events were used, and 14 for IOR2. Thereof, 84.85 % and 92.86 % were identified in both observations, respectively (see Table 11).

Table 11. Undefined Piglet: Summary of events.

	Number of events (IOR1)	***% (IOR1)***	***Number of events (IOR2)***	***% (IOR2)***
Total	*37*		*16*	
Total except open events	*33*	*100*	*14*	*100*
Identified in both observations	*28*	*84.85*	*13*	*92.86*
Identified in OBS1	*31*	*93.94*	*14*	*100*
Identified in OBS2	*29*	*87.88*	*13*	*92.86*

The total number describes all events that were identified in OBS1 or OBS2. The total number except open events excludes events that did not have an Offset Time because the video ended prior to the piglet leaving the creep area. These events were then used to compare observation one and two.

3.2.3.3.1 Onset Time

The mean difference between the Onset Times in OBS1 and OBS2 low in both IOR1 and IOR2 (see Table 12).

Table 12. Undefined Piglet: Maximum, minimum and mean difference of Onset Time between the events with Onset Times in OBS1and OBS2.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*-01:01*	*00:16*
Min. difference	*00:00*	*00:00*
Mean difference	*-00:01*	*00:01*

The 31 events consist of 28 events identified in both observations and 3 events that had no Offset Time because the video ended prior to the piglets leaving the creep area or because Offset Time was not identified in one of the observations

Figure 17 shows the distribution of differences in Onset Time between OBS1 and OBS2. Most events very low differences with only few exceptions (one event at -01:01 and one event at 35s).

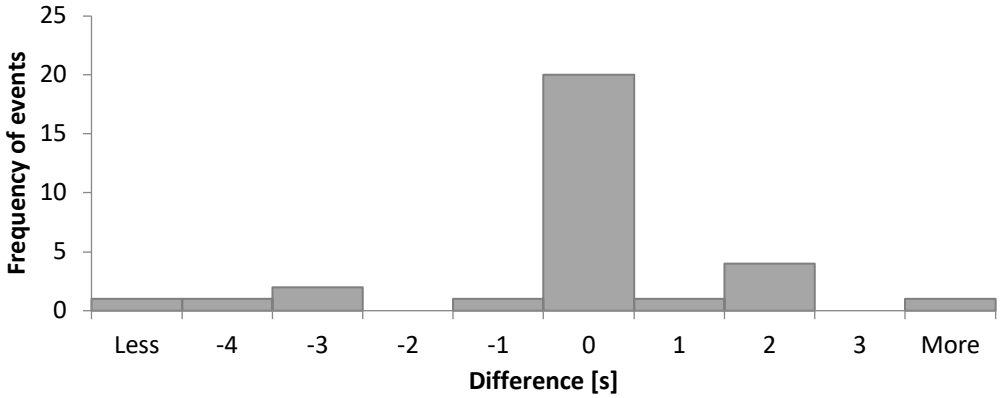


Figure 17. Undefined Piglet: Differences in Onset Time between OBS1 and OBS2 (IOR1).

3.2.3.3.2 Duration

As shown in Table 13, the mean difference in duration between OBS1 and OBS2 low in both IOR1 and IOR2.

Table 13. Undefined Piglet: Maximum, minimum and mean difference of duration between events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*01:00*	*-00:05*
Min. difference	*00:00*	*00:00*
Mean difference	*00:01*	*-00:01*

The events, that were only identified in one observation in IOR1, are shown in Table 14. The mean duration was 13s in OBS1, in OBS2 there was only one event which was 2s long.

Table 14. Undefined Piglet: Durations of events only identified during one of the observations (IOR1).

	Number	***Max. Duration***	***Min. Duration***	***Mean duration***
OBS1	*3*	*00:30*	*00:04*	*00:13*
OBS2	*1*			*00:02*

In IOR2, there was only one even that was identified in one of the two observations (see Table 15).

Table 15. Undefined Piglet: Duration of event only identified during one of the observations (IOR2).

	Number	***Duration***
OBS1	*1*	*00:05*

Figure 18 shows the distribution of durations in OBS1 and OBS2. The two observations show more or less the same curve with only slight differences.

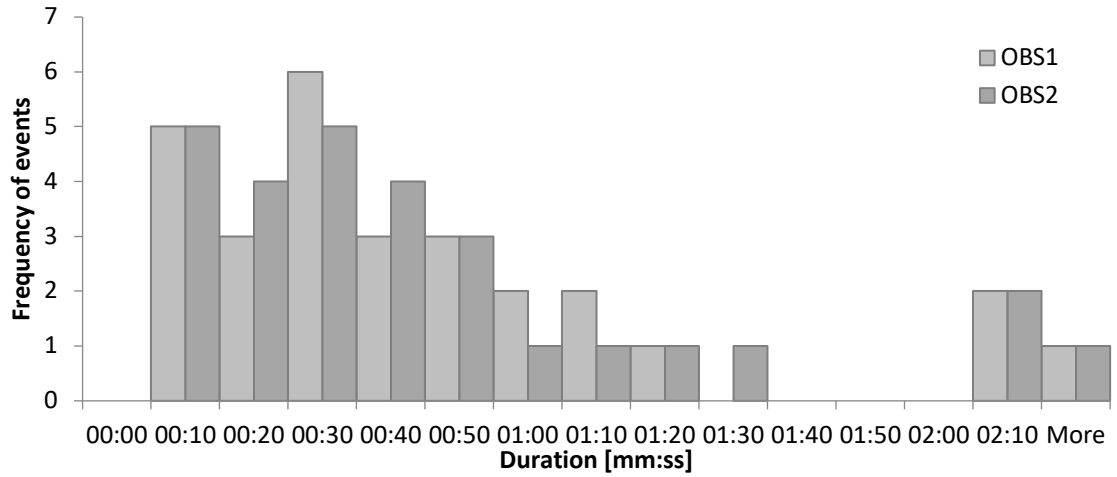


Figure 18. Undefined Piglet: Distribution of Durations in OBS1 and OBS2 (IOR1).

In Figure 19, the differences of the duration between OBS1 and OBS2 are shown. Most events had differences of ±5s, but some events were up to 1minute apart.

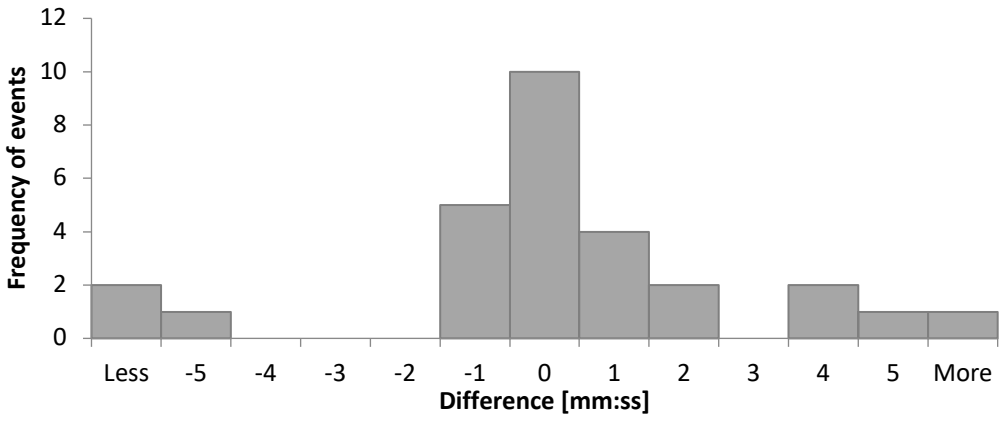


Figure 19. Undefined Piglet: Differences in Duration between OBS1 and OBS2 (IOR1).

Figure 20 shows that most events were aligned while there were a few events that were observed earlier or later in OBS2 compared to OBS1. There is a strong, significant positive correlation between the two observations in IOR1 (r_s=0.99, p<0.001) and IOR2 (r_s=0.97, p<0.001).

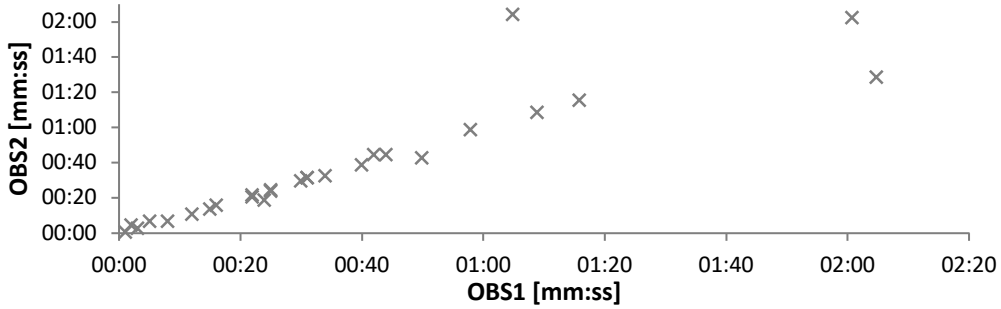


Figure 20. Undefined Piglet: Relation between the durations of events seen during OBS1 and OBS2 (IOR1).

The Bland&Altman plot in Figure 21 shows that most differences were below 10s, only two events had a difference of above 10s.

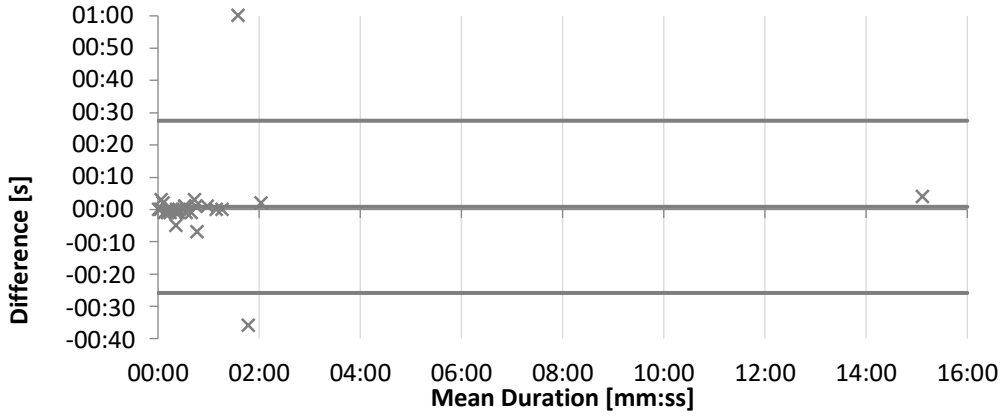


Figure 21. Undefined Piglet: Bland&Altman Plot for all events identified in OBS1 and OBS2 (IOR1).

The lower and upper dark grey lines indicate lower and upper confidence limits, respectively. The dark grey line in the middle indicates the mean difference between the durations of OBS1 and OBS2.

3.2.3.4 Sow in outdoor run

The two variables Onset Time (sow leaves pen) and Duration (Offset Time - Onset Time, meaning how long the sow spent outside) were analysed.

A total number of 16 events was used for the calculation of the IOR1 of Onset Time, and 16 events for IOR2. The number of events identified in OBS1, OBS2 and during both observations can be found in Table 16.

Table 16. Sow: Summary of events.

	Number of events (IOR1)	***% (IOR1)***	***Number of events (IOR2)***	***% (IOR2)***
Total	*16*	*100*	*15*	*100*
Identified in both observations	*14*	*87.50*	*15*	*100*
Identified in OBS1	*15*	*93.75*	*15*	*100*
Identified in OBS2	*15*	*93.75*	*15*	*100*

3.2.3.4.1 Onset Time

Table 17 shows that the mean difference between the onsets of the two observations was 0s for both IOR1 and IOR2.

Table 17. Sow: Maximum, minimum and mean difference of Onset Time between the events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*-00:05*	*00:02*
Min. difference	*00:00*	*00:00*
Mean difference	*00:00*	*00:00*

The differences in Onset Time between the two observations are shown in Figure 22. Most events were 0s or 1s apart, except for one event that happened 5s earlier in OBS2, compared to OBS1.

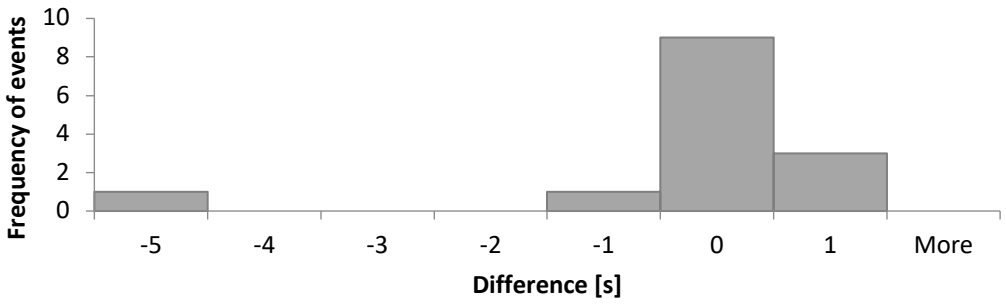


Figure 22. Sow: Differences in Onset Time between OBS1 and OBS2 (IOR1).

3.2.3.4.2 Duration

The difference between the durations in OBS1 and OBS2 was low in both IOR1 and IOR2, as shown in Table 18.

Table 18. Sow: Maximum, minimum and mean difference of duration between events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*-00:12*	*-00:21*
Min. difference	*00:00*	*00:00*
Mean difference	*-00:02*	*-00:01*

Two events (durations shown in Table 19) were not identified in both observations in IOR1, but only in either OBS1 or OBS2.

Table 19. Sow: Durations of events only identified during one of the observations (IOR1).

	Number of events	***Duration [mm:ss]***
OBS1	*1*	*01:08*
OBS2	*1*	*00:05*

In IOR2, all events were identified in both observations.

Figure 23 shows the distribution of the duration how long the sow spent in the outdoor run in OBS1 and OBS2. Except for one event at 06:00 minutes, the two observations are visually identical.

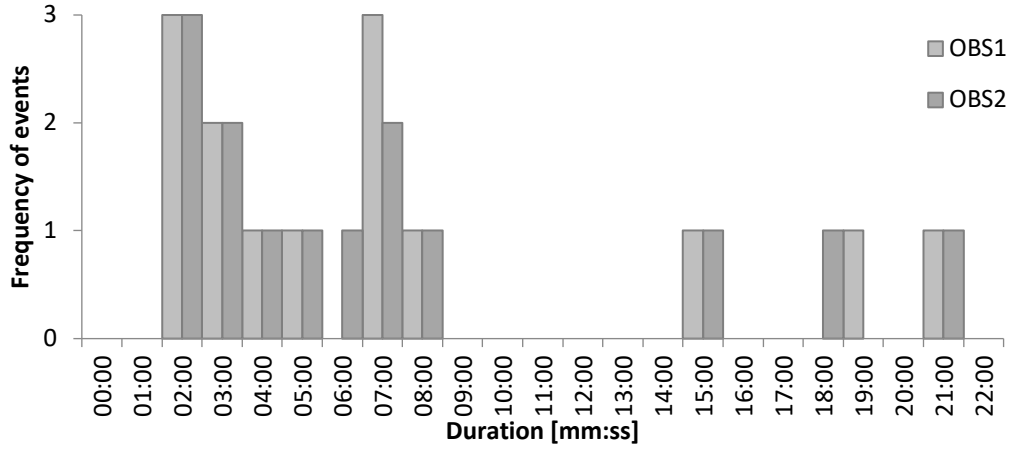


Figure 23. Sow: Distribution of Durations in OBS1 and OBS2 (IOR1).

The distribution of the differences in duration between the two observations is shown in Figure 24. There was no difference between OBS1 and OBS2 in 6 out of the identified 14 events. In another 6 cases, the events were observed a few seconds (max. -12s) sooner in OBS2, compared to OBS1. In two cases, the events were observed a few seconds earlier in OBS1, compared to OBS2.

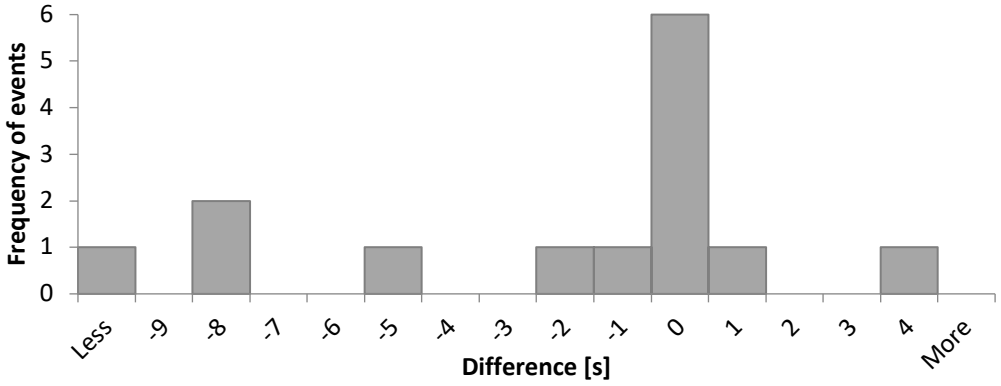


Figure 24. Sow: Differences in Duration between OBS1 and OBS2 (IOR1).

In Figure 25, there is a comparison of the durations of all 16 events identified in either OBS1 or OBS2 (two events), or in both (14 events). There is a strong, significant positive correlation between the two observations in IOR1 ($r_s = 0.996$, $p < 0.001$) and IOR2 ($r_s = 0.996$, $p < 0.001$).

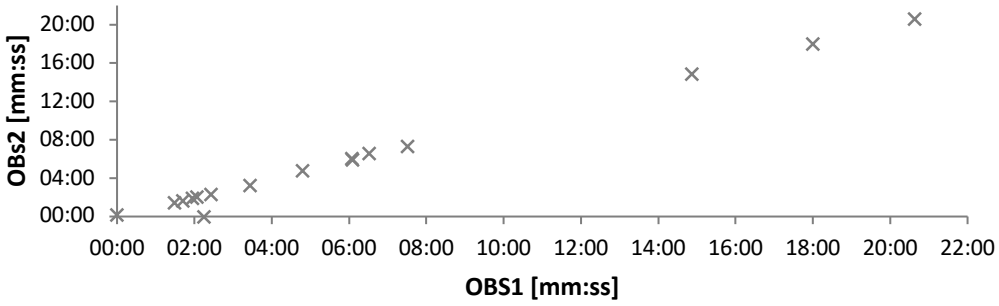


Figure 25. Sow: Relation between the durations of events seen during OBS1 and OBS2 (IOR1).

The Altman&Bland plot in Figure 26 shows that most differences were within the lower and upper confidence limits.

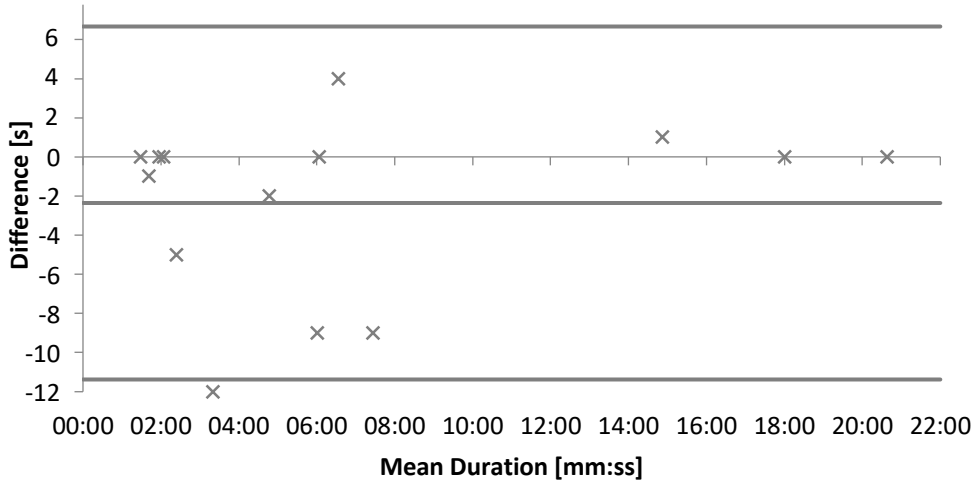


Figure 26. Sow: Bland&Altman Plot for all events identified in OBS1 and OBS2 (IOR1).

The lower and upper dark grey lines indicate lower and upper confidence limits, respectively. The dark grey line in the middle indicates the mean difference between the durations of OBS1 and OBS2.

3.2.3.5 Human influence (HI)

The two variables Onset Time (start of human influence) and Duration (Offset Time - Onset Time) were analysed.

For the calculation of IOR1, a total of 38 events was observed, and 16 for IOR2. The results are shown in Table 20.

Table 20. HI: Summary of events.

	Number of events (IOR1)	***% (IOR2)***	***Number of events (IOR1)***	***% (IOR2)***
Total	*38*	*100*	*16*	*100*
Identified in both observations	*28*	*73.7*	*16*	*100*
Identified in OBS1	*31*	*81.6*	*16*	*100*
Identified in OBS2	*35*	*92.1*	*16*	*100*

3.2.3.5.1 Onset Time

Table 21 shows the maximum, minimum and mean difference between the onset of all events identified during OBS1 and OBS2 for IOR1 and IOR2.

Table 21. HI: Maximum, minimum and mean difference of Onset Time between the events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*00:02*	*00:01*
Min. difference	*00:00*	*00:00*
Mean difference	*00:00*	*00:00*

Figure 27 shows the differences in Onset Time between OBS1 and OBS2.

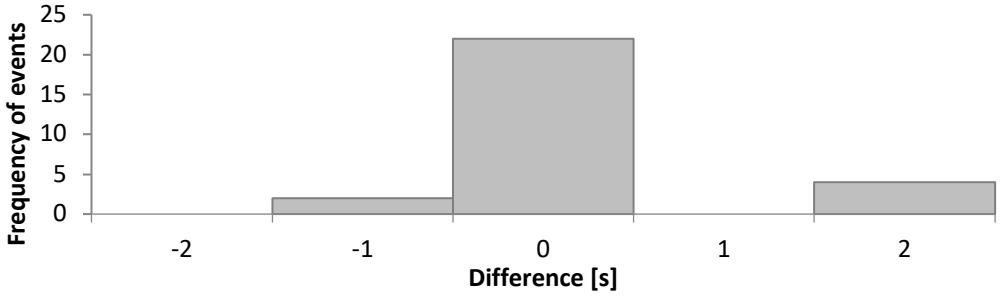


Figure 27. HI: Differences in Onset Time between OBS1 and OBS2 (IOR1).

3.2.3.5.2 Duration

In Table 22, the maximum, minimum and mean difference of the durations between both observations for IOR1 and IOR2 are shown.

Table 22. HI: Maximum, minimum and mean difference of duration between events identified in both observations.

	IOR1 [mm:ss]	***IOR2 [mm:ss]***
Max. difference	*00:09*	*-00:16*
Min. difference	*00:00*	*00:00*
Mean difference	*00:00*	*-00:01*

Table 23 shows the duration of the eight events that were only identified in either OBS1 or OBS2 in IOR1.

Table 23. HI: Durations of events only identified during one of the observations (IOR1).

	Number	***Max. Duration***	***Min. Duration***	***Mean duration***
OBS1	*3*	*00:13*	*00:01*	*00:05*
OBS2	*7*	*00:07*	*00:01*	*00:02*

In IOR2, all events were identified in both observations.

Figure 28 shows the distribution of the duration of HI in OBS1 and OBS2. There is no visual difference between the two observations.

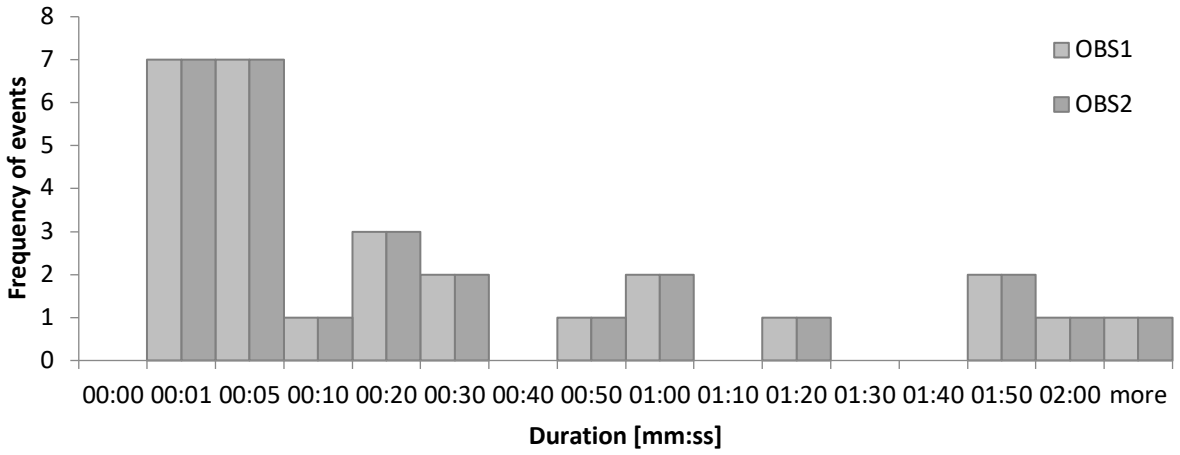


Figure 28. HI: Distribution of Durations in OBS1 and OBS2 (IOR1).

There are minor differences between the durations in OBS1 and OBS2, which range from -9s to 5s. The frequency of differences in duration are shown in Figure 29.

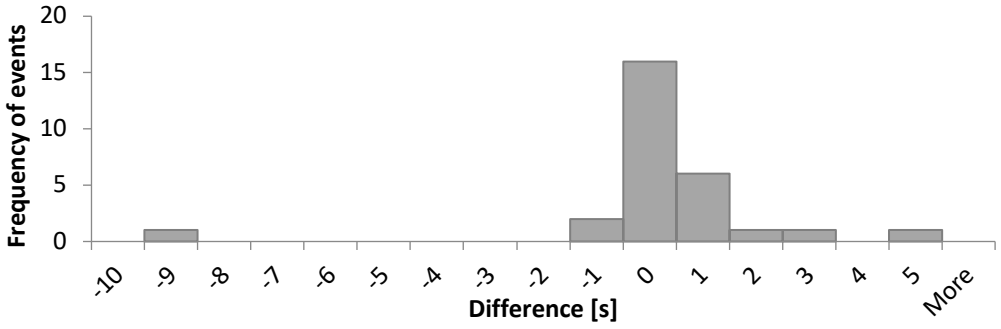


Figure 29. HI: Differences in Duration between OBS1 and OBS2 (IOR1).

There is a strong, significant positive correlation between the two observations in IOR1 (r_s = 0.989, $p < 0.001$) and IOR2 (r_s = 0.959, $p < 0.001$). As it can be seen in Figure 30, there were only minor differences duration between OBS1 and OBS2.

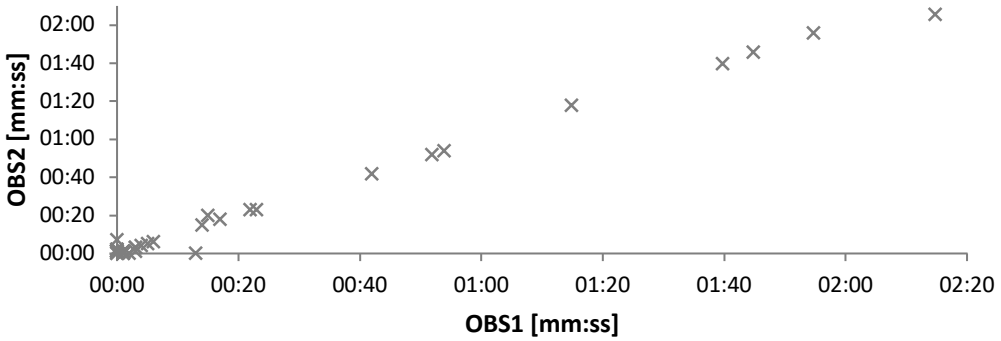


Figure 30. HI: Relation between the durations of events seen during OBS1 and OBS2 (IOR1).

In the Bland&Altman plot below (Figure 31), it is shown that the difference between the durations of events observed in OBS1 and OBS2 only differ slightly, and mostly for very short events only.

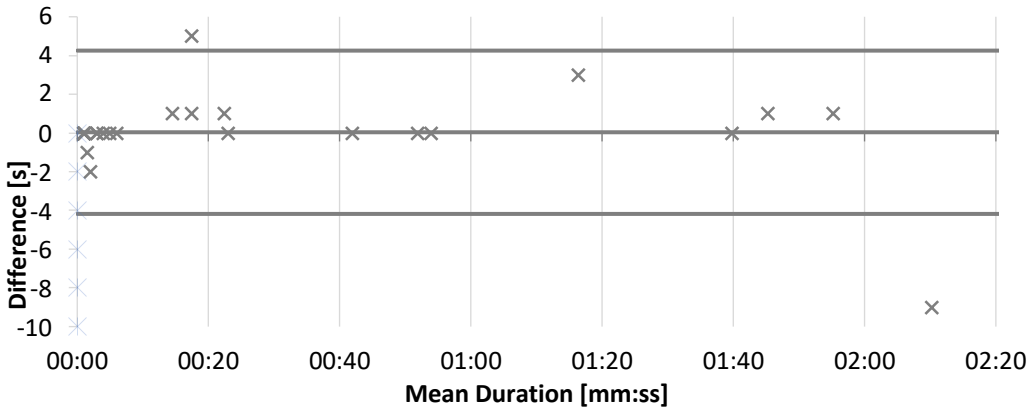


Figure 31. HI: Bland&Altman Plot for all events identified in OBS1 and OBS2 (IOR1).

The lower and upper dark grey lines indicate lower and upper confidence limits, respectively. The dark grey line in the middle indicates the mean difference between the durations of OBS1 and OBS2.

3.2.4 Statistical analyses

All graphs were created either in Excel version 16.26 or SPSS version 24.

To describe the intra-observer reliability, histograms of all data used for calculation (e.g. end of farrowing, marked piglet entering creep area etc.) were first used to assess whether they were normally distributed. Mainly due to right-skewed distribution, this was not the case and, consequently, Spearman correlation coefficients were calculated to compare the two observations. The coefficients were calculated using SPSS version 24.

The analyses regarding the research questions were carried out in SAS version 9.4. An overview of models and fixed and random effects considered is given in Table 24. Linear mixed models were used to assess the latency variables, the total usage of the creep area and the effects on piglet mortality rate due to crushing. To analyse the number of litters reaching 75 % of piglets in the creep area, a generalized linear model was used, because the target variable was binomial (more than 75 % of the litter staying in the creep area for more than 10 minutes or not). In the latter model, only the treatment effect but not the effect of temperature was included because of too many missing temperature data due to malfunctioning sensors.

Residuals were graphically analysed. They were normally distributed for all models except the duration of stay in the creep area per day. Transformation of the data using square root and different logarithmic transformations did not improve distribution of residuals. Therefore, untransformed data were used as input. The results regarding the duration of stay in the creep area per day should therefore be treated with caution.

For all analyses, a significance level of $p = 0.05$ was chosen.

Table 24. Overview of statistical models, showing fixed and random effects.

Research question	***Model***	***Fixed effects***	***Random effects***
Latency to enter the creep area	*Linear mixed model*	*Treatment, temperature quotient, treatment*temperature quotient*	*Sow nested in Batch*
Number of litters reaching at least 75 % of piglets in the creep area	*Generalized linear mixed model*	*Treatment*	*Batch*
Latency to reach 75 % of piglets in creep area	*Linear mixed model*	*Treatment, temperature quotient, treatment*temperature quotient*	*Batch*
Duration of stay in the creep area for days 1,2,3 individually	*Linear mixed model*	*Treatment, temperature quotient, day, treatment*quotient, treatment*day, quotient*day*	*Day nested in Sow nested in Batch*
Duration of stay in the creep area for 72h	*Linear mixed model*	*Treatment, temperature quotient, treatment*temperature quotient*	*Sow nested in Batch*
Percentage of crushed piglets out of life born piglets	*Linear mixed model*	*Treatment, temperature quotient, treatment*temperature quotient*	*Batch*

3.3 Results

3.3.1 Latency of individual piglets to enter the creep area

The percentage of piglets that never entered the creep area over the course of this experiment was 18.0 (DARK) and 1.1 (LIGHT). As shown in Figure 32, during the first 18 hours there was just a small difference between the two treatments, but towards the end of day one, many LIGHT piglets entered the creep area. From day two onwards, the difference between LIGHT and DARK did not increase much further.

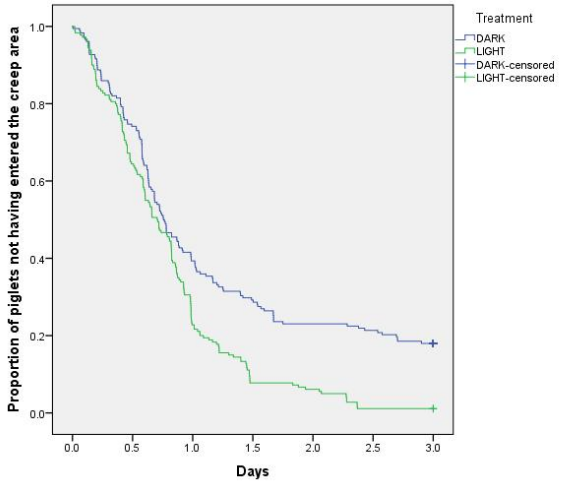


Figure 32. Survival function showing the proportion of piglets not having entered the creep area over time, for the treatment LIGHT and DARK

Assuming a latency of three days for the piglets that never entered the creep area, the average latency for all piglets to enter the creep area was 1.21 and 0.77 days (p = 0.13) in the treatments DARK and LIGHT, respectively (see Figure 33a). When excluding the piglets that never entered the creep area during the first three days, the average latency tended to be shorter (p=0.07) for LIGHT (0.75 days) than DARK (0.8 days) as shown in Figure 33b and Table 25).

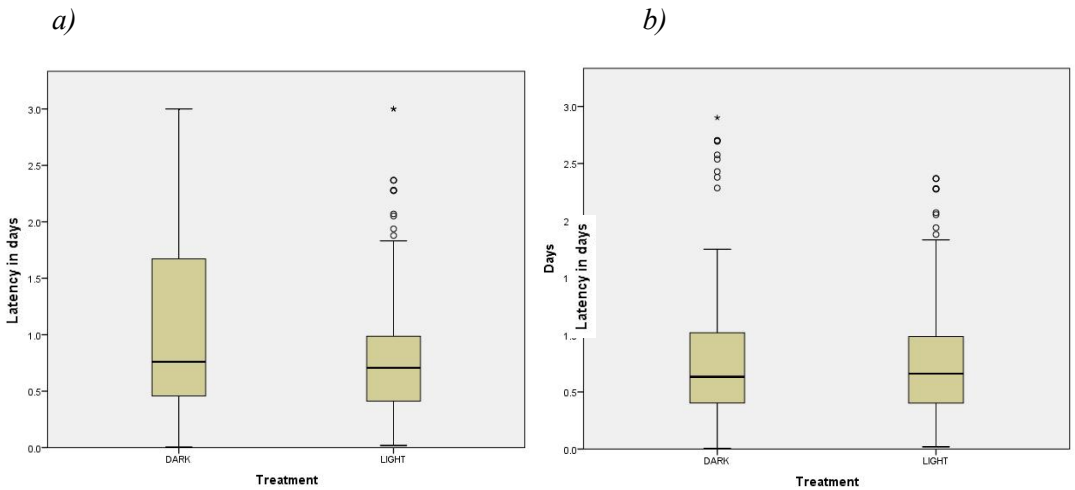


Figure 33. Latency in days to enter the creep area for the treatments DARK and LIGHT, a) considering all piglets and b) excluding piglets that never entered the creep area.

Table 25 shows the test statistics for the effects for all piglets and for only piglets which entered the creep area. For the former, there were no significant effects. For the latter, treatment had a tendency to have an impact, LIGHT having a lower latency than DARK.

The interaction between temperature quotient and treatment had a tendency to impact the latency to enter the creep area. DARK and an increasing temperature quotient resulted in a lower latency, while for the treatment LIGHT the latency increased with an increasing temperature quotient (Table 25; Figure 34b).

Table 25. Test statistics for the effects of the factors treatment, temperature quotient and their interaction on the latency to enter the creep area for all piglets and for the piglets only, which entered the creep area, respectively.

	All piglets		***Only piglets which entered the creep area***	
Factor	*F value*	*Pr > F*	*F value*	*Pr > F*
Treatment	*2.27*	*0.13*	*3.39*	*0.07*
Temperature quotient	*0.06*	*0.81*	*0.81*	*0.37*
*Temperature quotient*treatment*	*0.66*	*0.42*	*2.90*	*0.09*

Figure 34a and b compare the association between temperature quotient and latency for all piglets and for only piglets which entered the creep area.

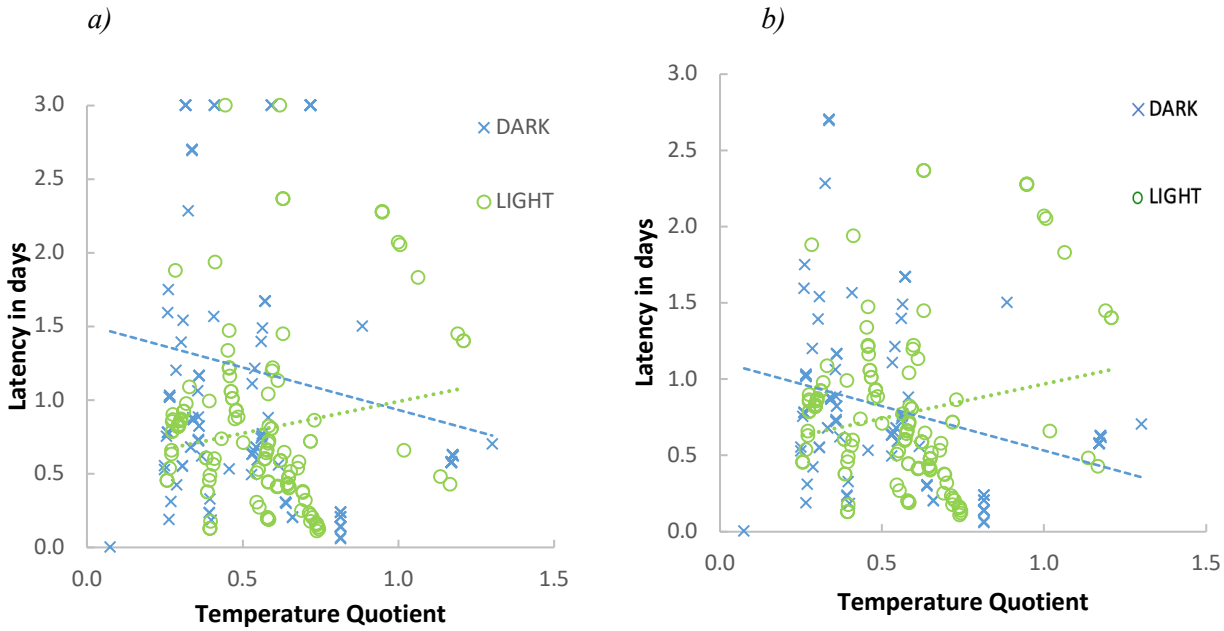


Figure 34. Association between the temperature quotient and the latency to enter the creep area for the two treatments LIGHT and DARK (a) when considering all piglets, b) when considering only the piglets, which entered the creep area).

3.3.2 Litters entering and staying in the creep area

In 16 out of all 30 litters, at least 75 % of all piglets spent more than 10 minutes in the creep area at the same time. As shown in Table 26, more litters did so (p=0.09) in the treatment LIGHT (10 litters, 66 %) compared to DARK (6 litters, 40 %).

Table 26. Overview of the two treatments light and no light and how many litters reached 75 % in the creep area

Treatment	***Reached 75 %***	***Number of litters***
DARK	*No*	*9*
	Yes	*6*
LIGHT	*No*	*5*
	Yes	*10*

For the litters that reached the criterion, the average latency to enter and stay in the creep area was 0.74 days (DARK) and 1.4 days (LIGHT). Figure 35 shows the proportion of litters from the treatment LIGHT and DARK that did not reach the 75 % criterion over time. Litters in the treatment DARK reached the criterion earlier on the first day, but then stopped, while litters from the treatment LIGHT continued to enter and stay in the creep area.

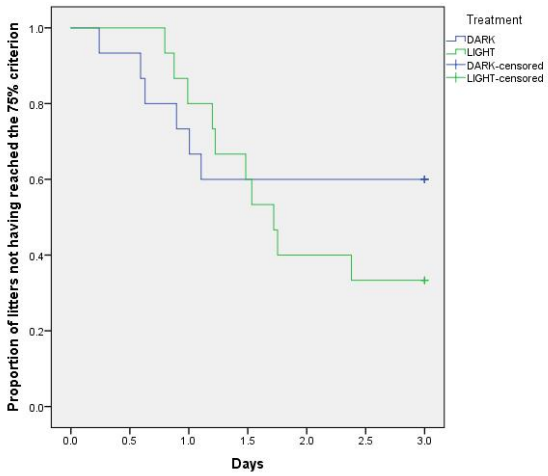


Figure 35. Survival function showing the proportion of litters that did not reach the 75 % in the creep area over time, comparing LIGHT and DARK.

Figure 36a indicates that an increasing temperature quotient may have reduced the latency to reach the 75 % criterion (75 % of the litter in the creep area at the same time for at least 10 min). The effect seems to be stronger for the treatment DARK compared to LIGHT. It should be noted that this graphic includes the litters that never reached 75 %, for which a latency of 3 days was assumed. Since there were some litters that had no temperature quotient due to missing data, and only 16 litters reached 75 % of the piglets in the creep area (shown in Figure 36b), it was not possible to statistically analyse the influence of the temperature quotient on the latency.

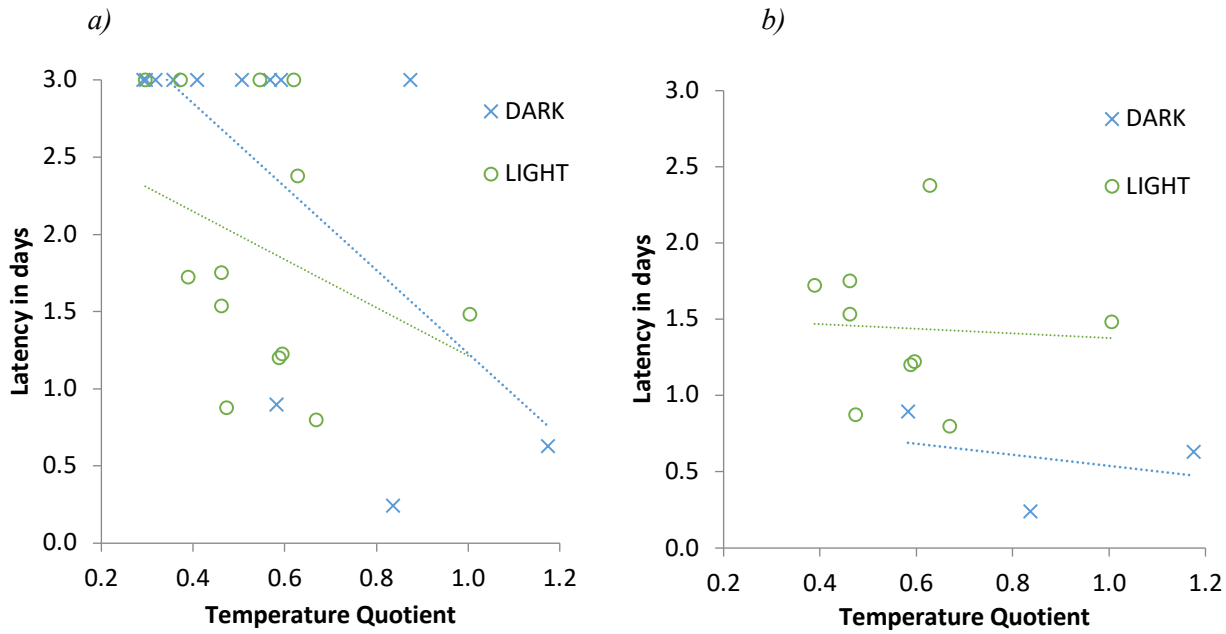


Figure 36. Association of the temperature quotient and the average latency to reach 75 % of each litter's piglets to remain in the creep area for more than 10 minutes for the two treatments LIGHT and DARK a) including and b) excluding litters that never reached the 75 %.

3.3.3 Time individual piglets spent in the creep area

The time that piglets spent in the creep area numerically increased from day one to day three (Figure 37). Neither treatment nor day had a significant effect on the usage of the creep area and there was also no significant interaction between the factors treatment and day (see Table 27).

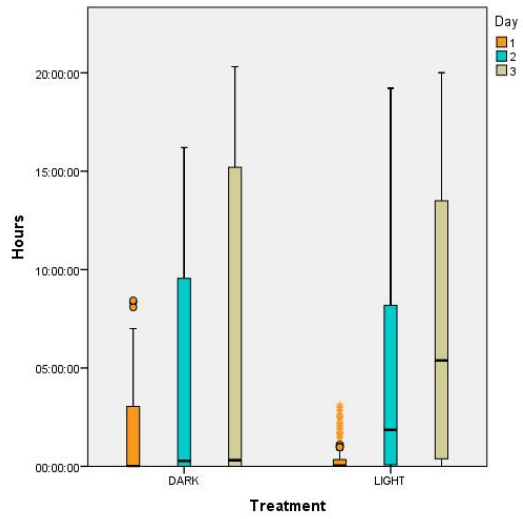


Figure 37. Average total time spent on day 1, day 2 and day 3 in the creep area in the treatments LIGHT and DARK.

Table 27. Test statistics for the effects of the factors treatment, day, temperature quotient and their interaction on the usage of the creep area per day.

Factor	***F value***	***Pr > F***
Treatment	*0.73*	*0.39*
Day	*0.17*	*0.84*
*Treatment*day*	*1.18*	*0.31*
Temperature quotient	*21.45*	*< 0.001*
*Temperature quotient*treatment*	*0.37*	*0.54*
*Temperature quotient*day*	*2.28*	*0.10*

The usage of the creep area depended on the temperature quotient; for both treatments, the time spent in the creep area was higher with an increasing temperature quotient on all days. There was no effect of the interaction between temperature quotient and treatment. The interaction between temperature quotient and day tended to impact the time spent in the creep area with a stronger association of creep area usage and temperature quotient with increasing age (see Table 27, Figure 38-Figure 40).

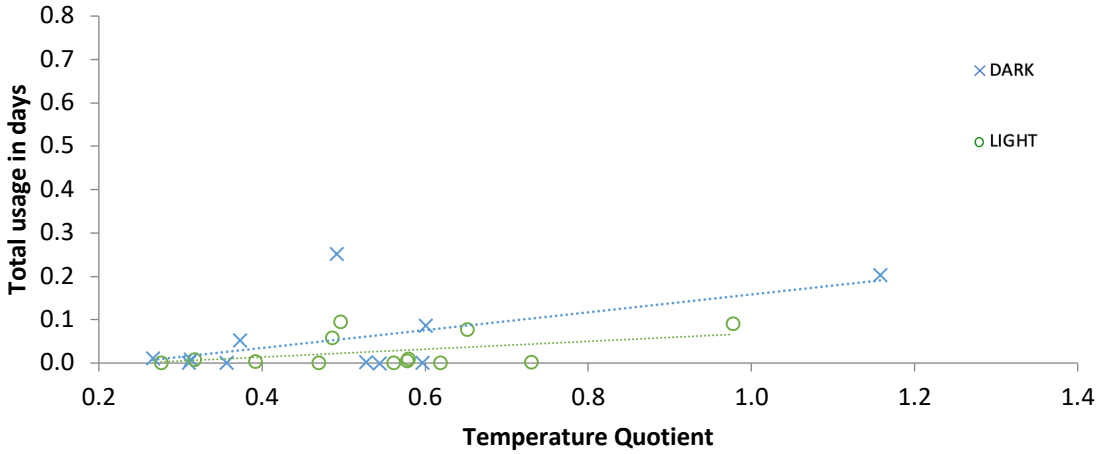


Figure 38. Association of the average creep area usage per litter on day 1 with the temperature quotient for the treatments LIGHT and DARK.

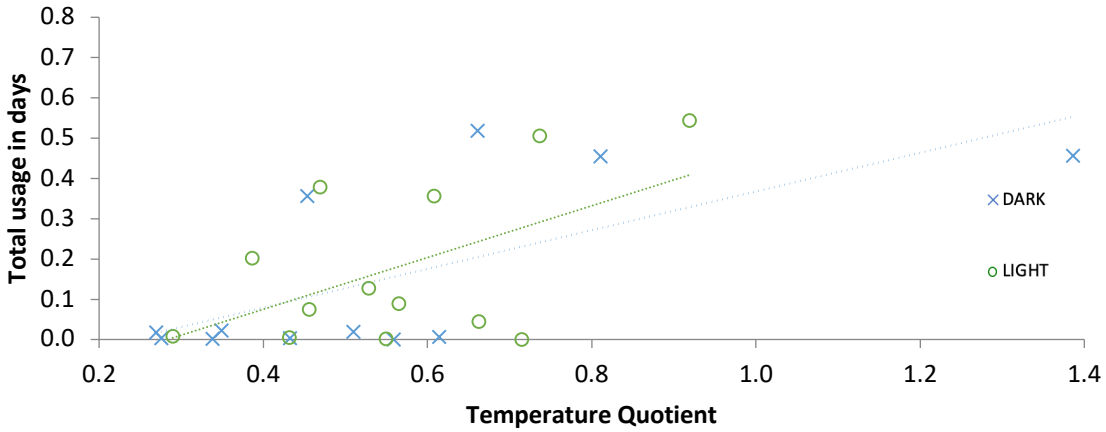


Figure 39. Association of the average creep area usage per litter on day 2 with the temperature quotient for the treatments LIGHT and DARK.

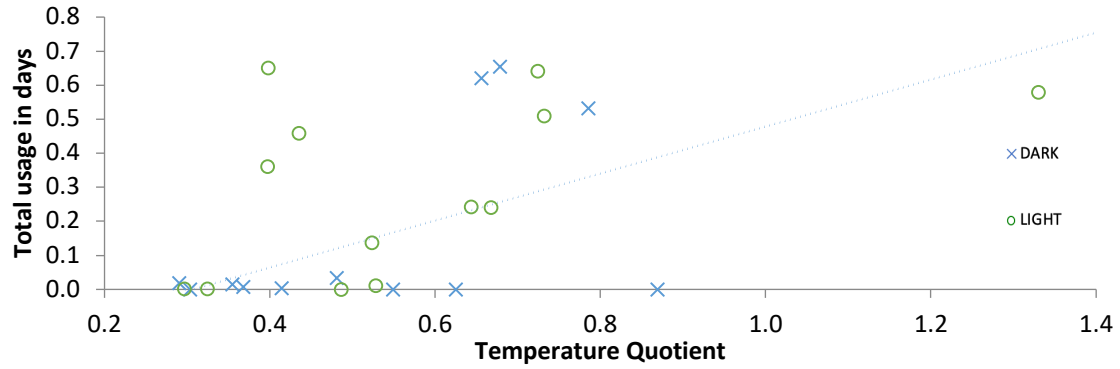


Figure 40. Association of the average creep area usage per litter on day 3 with the temperature quotient for the treatments LIGHT and DARK.

Figure 41 shows the usage of the creep on the first three days as affected by the temperature quotient. The treatment had no influence on the total usage of the creep area, the usage depended on the temperature quotient only (see Table 28). An increased temperature quotient led to a higher usage of the creep area.

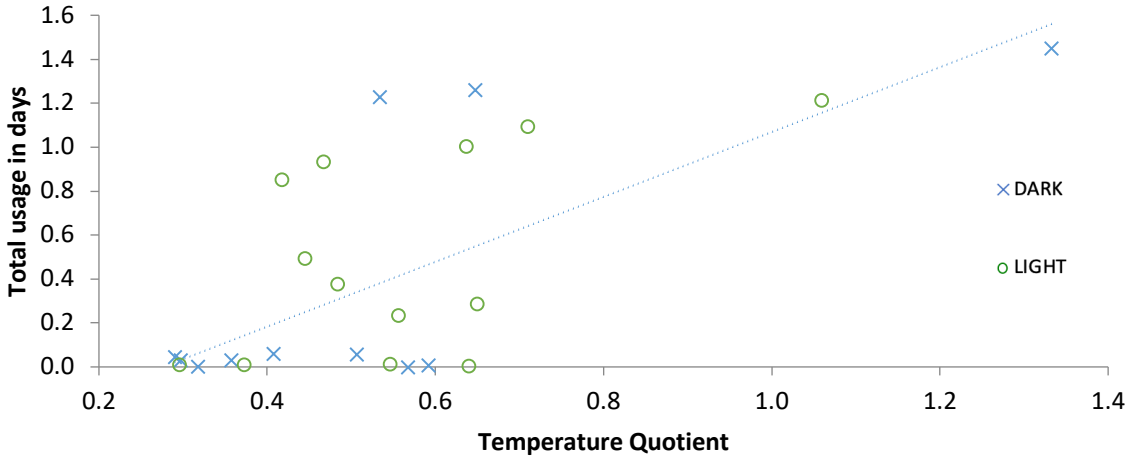


Figure 41. Association of the average creep area usage per litter on day 1-3 with the temperature quotient for the treatments LIGHT and DARK.

Table 28. Test statistics for the effects of the factors treatment, temperature quotient and their interaction on the usage of the creep area during the first 72h (days 1-3).

Factor	***F value***	***Pr > F***
Treatment	*0.11*	*0.74*
Temperature quotient	*6.78*	*0.01*
*Temperature quotient*treatment*	*0.85*	*0.36*

3.3.4 Piglet crushing

In total, 15 % or 64 of 427 liveborn (incl. fostered) piglets were crushed within the first 72h (see Table 29).

Table 29. Overview of piglet crushing during the experiment, comparing the two treatments LIGHT and DARK.

	Liveborn±Fostered	***Crushed within the first 72h***	***Percentage***
DARK	*213*	*38*	*17.8*
LIGHT	*214*	*26*	*12.1*
Total	*427*	*64*	*15.0*

Mortality rate due to crushing tended to be lower in LIGHT than in DARK, whereas the temperature quotient and the interaction between temperature quotient and treatment had no influence, as shown in Table 30.

Table 30. Test statistics for the effects of the factors treatment, temperature quotient and their interaction on piglet crushing.

Factor	***F value***	***Pr > F***
Treatment	*3.39*	*0.08*
Temperature quotient	*1.46*	*0.25*
*Temperature quotient*treatment*	*2.15*	*0.16*

3.4 Discussion

3.4.1 Discussion of the methods

In this section, a brief overview of issues in data recording and analysis is given. Regarding data recording, there were difficulties with marking the piglets. The markings were clearly visible for only about 24h, which is why it was necessary to mark the piglets on a daily basis. Additionally, the markings were sometimes difficult to read, which led to events not being recorded during video analysis and consequently errors in the data structure (e.g. two piglets are thought to wear the same number and are therefore erroneously recorded to have entered the creep area twice in a row without exiting). Regarding data analysis, these errors led to the data not being suitable for a simple analysis in e.g. Excel. It was necessary to write specific software to analyse the output from Mangold INTERACT, which is described in chapter 3.2.2.3.

To avoid this in future experiments, a longer lasting stockmarking product is recommended. No better option was found due to restrictions in piglet size (e.g. a stamper would require too much pressure on the piglets back) and chemical components (i.e. that cannot be used on animals). One solution would be to mark the piglets with different colours, but it would require video recordings in colour instead of black and white, as it was the case for this experiment.

Another issue was the weighing of the piglets, since we originally planned to analyse piglet weight as well. However, due to the several days during the experiment, when most of the stockpersons were off duties, piglets were weighed at different ages (days 1 – 4), which is why weight was not included in the statistical analysis. It is crucial but even more difficult to draw especially light piglets (who have an even stronger urge to stay near the udder for more milk) away from the sow to avoid piglet crushing. That is why it would have been interesting to see if there is an association between weight and usage of the creep area.

Regarding the usage of the creep area, it seemed that it was lower than usual on this farm during the experiment, according to the stockpersons. When there is no experiment, the employees place all piglets into the creep area for a short period of time after farrowing so that the piglets can get used to it. This was not done during the experiment, because the aim was to measure the piglets' motivation to step into the creep area by themselves. This might cause the piglets to take more time to start entering and staying in the creep area because they are not forced to get to know it. Although one study showed there was no impact of placing piglets in the creep area on its usage (Berg et al., 2006), more studies, especially regarding lit creep areas are

necessary, since it has been shown that placing piglets in the creep area was able to reduce piglet mortality (Andersen et al., 2009).

3.4.2 Discussion of the results

The aim of this study was to investigate the effects of light (LIGHT) or darkness (DARK) in the creep area in farrowing pens on its usage for the first three days postnatum. It was found that more piglets entered the creep area in total, and the latency to enter tended to be shorter for LIGHT compared to DARK, respectively. However, the interaction between temperature quotient and treatment had an impact as well; the latency decreased with an increasing quotient for DARK, and vice versa for LIGHT. More litters reached the 75 % criterion (at least 75 % of the litter spent at least 10 minutes in the creep area) with LIGHT, but the latency to reach 75 % for LIGHT piglets was higher than for DARK piglets. Treatment had no influence on the duration piglets spent in the creep area. However, a higher temperature quotient led to an increased usage of the creep area. The interaction between temperature quotient and day tended to have an impact as well with a larger impact of the quotient in terms of an increase of the usage with a higher quotient when the piglets were older (from day 1 to day 3). Piglet crushing within the first three days postnatum tended to be on average 5.7 percentage points lower for LIGHT litters compared to DARK litters, while the temperature quotient had no influence on piglet crushing

3.4.2.1 Influence of light treatment on usage of the creep area

The latency to enter the creep area was shorter for LIGHT piglets, which may indicate that light makes the creep area more interesting to explore. Contrarily, Morello et al. (2019) found that piglets tended to take longer to enter when there was light in the creep area (Morello et al., 2019). There was, however, a difference in light intensity in the creep area (300 Lx in the study by Morello et al. vs. 4-6 Lx in the current experiment), which may indicate that piglets prefer dim over bright areas. This assumption is supported by the study from Parfet and Gonyou (1991) who found that dark (2.8 Lx) and dim (5.5 Lx) areas were equally attractive, while bright (11 Lx) areas were less attractive (Parfet and Gonyou, 1991). The experimental design of the latter study was very different though, as piglets were placed in an unfamiliar area to choose between three differently lit boxes. Not only light intensity per se, but also the light gradient between creep area and farrowing pen might play a role in making the creep area more attractive for piglets: Tanida et al. (1996) found that piglets follow light beams and go from darker to lighter areas (Tanida et al., 1996). However, piglets in the study by Tanida et al. were already one week old while piglets in our study were new-borns, which might have affected their preferences towards light. Besides light in the creep area, also light and photoperiod in

the farrowing room may impact the usage of the creep area: Mutton (1987) showed that when the light intensity in the pen is high (400-700 Lx), piglets cannot differentiate between light in the creep area and light in the pen and were therefore not as easily attracted to the creep areas (Mutton, 1987). Piglets are more active in general during the light period compared to the dark period (Berkeveld et al., 2007). Increased piglet activity due to light in the creep area might lead to more exploration, causing the piglets to discover it earlier than when there is no light. This might be especially important in autumn/winter when there is less natural daylight; the light from the creep area could cause more activity and exploration, possibly leading to an earlier usage. Due to the experiment being carried out from late August until late January, an effect of a different daylight period on piglet activity should not be expected.

Regarding the photoperiod, it was found that a longer light period increases piglet activity (Simitzis et al., 2013). In the current experiment, no artificial light was provided in the farrowing room except for the periods when the stockworkers or the author were present.

Regarding the latency until 75 % of the litter stayed in the creep area for at least 10 minutes, our findings are rather controversial. While more litters reached the 75 % criterion with LIGHT within 72h after end of farrowing, the latency was higher for LIGHT piglets than for DARK piglets. Morello et al. (2019) also examined the latency to reach the same 75 % criterion, and they additionally examined the latency for 30 % of the litter to stay in the creep area for at least 10 minutes. While it is not clear how many litters reached these 30 % and 75 % criteria over the 72h period, Morello et al. found that the latency of 30 % to enter and stay in the creep area was shorter with light, and there was no influence of the light treatment for 75 % (Morello et al., 2019). The results from the current study and from Morello et al. are rather contradictory, which raises the question if 72h was an appropriate period to examine in the present study, or if piglets need more time to reach the criterion. Both the current study and Morello et al. examined only the first 72h postnatum. This period is, however, the most crucial time, since this is when most crushing occurs (Dyck and Swierstra, 1987; Marchant et al., 2000). It is difficult to explain why in this experiment more litters reached the 75 % with LIGHT but it took them longer than DARK litters, especially since the latency for individual piglets to enter was shorter with LIGHT.

Finally, regarding the duration of stay for individual piglets, there was no influence of the light treatment on the time spent in the creep area, meaning light did neither encourage nor discourage piglets from using it. This can be confirmed by a study that concluded that light did not attract piglets to spend more time in the creep area, even though a stronger light and a different creep area design was used. At night, piglets showed a higher usage of the dark creep

area compared to the lit one, which might indicate different light preferences during day and night (Larsen et al., 2015). However, Morello et al. (2019) found that piglets spent more time in the creep area with light, but again with stronger light in the creep area and again a different creep area design (Morello et al., 2019). A study that examined growing pigs found that they spend more time in the dimmest area (2.4 Lx, which is not far from the 5 Lx used in the present study) compared to the brightest (400 Lx) when allowed to choose from differently lit areas (Taylor et al., 2006). These were however pigs that were much older, possibly having different needs and preferences regarding light. Since pigs have dichromatic vision, they are able to see colour (Jankevicius and Widowski, 2003) and it might be interesting to look at different colours of light in the creep area in future studies.

3.4.2.2 Influence of temperature on usage of the creep area

The findings regarding the association between temperature and the first entry to the creep area by individual piglets are contradictory; there was an unexpected interaction effect between treatment and temperature quotient: DARK piglets had a shorter latency to enter the creep area with an increasing temperature quotient, which was the predicted effect of temperature. A higher ambient temperature leads to a higher latency to enter the creep area (Burri et al., 2009), and to a decreased usage (Pedersen et al., 2013). However, the results in the current experiment for LIGHT piglets were exactly the opposite, meaning they had a higher latency to enter with an increasing temperature quotient, and it is difficult to explain why this was the case.

Regarding the time individual piglets spent in the creep area, it was found that a higher temperature quotient led to a higher usage, while there was no interaction effect between treatment and temperature quotient. Gradauer (2019) also found that a higher temperature quotient led to a higher usage of the creep area (Gradauer, 2019). The quotient was used in order to analyse the effect of pen and creep area temperature and the temperature difference on the usage of the creep area (see further explanations in chapter 3.2.1.4). The advantage of the quotient can be explained by the following example: A temperature difference between creep area and pen of 10°C may have very different effects on the piglets, depending if the pen temperature is 10° or 20°C. Combining temperature difference and pen temperature, the quotient takes that into account. Most other studies did not use this quotient but rather used absolute pen and creep area temperatures.

Morello et al. (2019) found that that for every increase by 1°C of the heating mat of the creep area, its use was increased by about 2.1 %. Furthermore, for every 1°C increase in ambient temperature, the use of the creep area decreased by about 4.8 % (Morello et al., 2019). This finding can be supported by a study by Burri et al. (2009) who found that piglets spent less

time in the creep area with increasing pen temperature, and by a study by Schormann and Hoy (2006), who found that piglets spent more time in the creep area at 18°C ambient temperature compared to 26°C (Schormann and Hoy, 2006; Burri et al., 2009).

It should be noted that, although heating was done via infrared heaters, only the air temperature was measured, which may not be sufficient to determine the thermal conditions that piglets experience when exposed to infrared heating (Vasdal et al., 2009b).

Overall, creep area temperature and ambient temperature have an effect on the usage and on the latency to enter the creep area. However, Hrupka et al. (1998) state that for the first three days postnatum, piglets prefer the proximity of the sow, independent of air temperature or location of the heat lamp (Hrupka et al., 1998). Vasdal et al. (2009a) found that only very few piglets rest alone or together, and without contact to the sow during the first three days of life, regardless of the environmental conditions (Vasdal et al., 2009a). Some studies found that placing piglets in a heated creep area has no effect on piglet mortality (Berg et al., 2006; Andersen et al., 2007), while another one found that piglet mortality was reduced by placing piglets under a heat lamp (Andersen et al., 2009). Placing piglets in the creep area does not impact piglet activity and piglet location (Berg et al., 2006). Piglets even prefer to rest near an anaesthetised piglet in a cold area when offered a heated area (Hrupka et al., 2000a). This indicates that, even though light and temperature play a role in the use of the creep area, other factors might still be more important to new-born piglets, and it shows how difficult it is to draw piglets away from their mothers.

3.4.2.3 Influence of light treatment and temperature on piglet crushing

As described earlier, the aim of having a creep area is to reduce the risk of piglet crushing by keeping the piglets away from the sow between suckling bouts (Vasdal et al., 2010). In this experiment, piglet crushing within the first 72h tended to be considerably lower in the LIGHT treatment compared to DARK. This is in contrast to Morello et al. (2019) who did not find an association between piglet mortality and light treatment in the creep area (Morello et al., 2019).

Conversely, duration of individual stay in the creep area did not differ between the treatments, following that the lower rate of piglet crushing was not caused by an increased usage of the creep area. There is, however, the possibility of the LIGHT piglets spending more time in the creep area during times that are most dangerous (e.g. when the sow is laying down), without having an increased total duration in the creep area. This has not been analysed in the current experiment but would explain the lower rate of piglet crushing in LIGHT.

It can also be argued that light might have an impact on the sow, allowing her to see her litter at night, thus avoiding crushing. However, studies that examined light intensity in the farrowing room (50, 400, 500, or 700 Lx in the farrowing room for 18 h daily) and daily photoperiod (8h or 20h) did not find any differences in piglet mortality because of light (Mutton, 1987; Simitzis et al., 2013, respectively). It would be interesting to further analyse the time of the crushing to see if light played a role during night-time.

In this experiment, there was no association between temperature and piglet crushing. This is again in contrast with findings from Morello et al. (2019), who found that an increased ambient temperature tended to reduce piglet deaths (Morello et al., 2019). However, Morello et al. analysed total piglet mortality, including other causes than crushing as well.

It should again be mentioned that piglet mortality is a multifactorial problem. It could also have been influence be factors that have not been controlled or analysed in this study, such as litter size, parity, health or body condition of the sow. Results need therefore be treated with caution, also considering the sample size of 30 sows.

4 Conclusions

The total duration that individual piglets spent in the creep area was not influenced by the treatment. Since some studies showed an increased usage of a lit creep area, it should be further examined which light intensity and light gradient between pen and creep area piglets prefer. Light in the creep area did, however, draw the piglets to explore the creep area sooner compared to when there was no light. This at least increases the chances of the piglets starting to regularly use the creep area sooner, even though this was not the case in the present study. Piglet crushing tended to be lower with by light in the creep area, although it could have been influence by other factors as well. Dimmed light in the creep area seems to be a promising approach to reduce piglet mortality due to crushing. Further research is required to determine if light colour also plays a role in latency to enter and usage of the creep area.

As shown in several other studies, an increased temperature quotient led to an increased usage of the creep area. According to good practice, it is recommended to keep the creep area warm enough for the piglets to avoid hypothermia (30-34°C), and the pen at the sows' preferred 18-20°C to increase the temperature quotient and thus creep area usage.

5 References

1. Tierhaltungsverordnung 2017. RIS - Gesamte Rechtsvorschrift für 1. Tierhaltungsverordnung - Bundesrecht konsolidiert, Fassung vom 11.10.2017. RIS. Retrieved on 11 October 2017, from *https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20003820*.

Andersen IL, Berg S, Bøe KE, Fraser DF, Thompson BK, Jensen P and Simmins PH 2005. Crushing of piglets by the mother sow (Sus scrofa) - purely accidental or a poor mother? Applied Animal Behaviour Science 93, 229–243.

Andersen IL, Haukvik IA and Bøe KE 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal 3, 592–597.

Andersen IL, Tajet GM, Haukvik IA, Kongsrud S and Bøe KE 2007. Relationship between postnatal piglet mortality, environmental factors and management around farrowing in herds with loose-housed, lactating sows. Acta Agriculturae Scandinavica, Section A - Animal Science 57, 38–45.

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

Baxter EM, Adeleye OO, Jack MC, Farish M, Ison SH and Edwards SA 2015. Achieving optimum performance in a loose-housed farrowing system for sows: The effects of space and temperature. Applied Animal Behaviour Science 169, 9–16.

Baxter EM, Andersen IL and Edwards SA 2017. Sow welfare in the farrowing crate and alternatives. Advances in Pig Welfare. A Volume in Herd and Flock Welfare 2, 27–72.

Baxter EM, Lawrence AB and Edwards SA 2011. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. Animal 5, 580–600.

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

Berg S, Andersen IL, Tajet GM, Haukvik IA, Kongsrud S and Bøe KE 2006. Piglet use of the creep area and piglet mortality – effects of closing the piglets inside the creep area during sow feeding time in pens for individually loose-housed sows. Animal Science 82, 277–281.

Berkeveld M, Langendijk P, Bolhuis JE, Koets AP, Verheijden JHM and Taverne MAM 2007. Intermittent suckling during an extended lactation period: Effects on piglet behavior1. Journal of Animal Science 85, 3415–3424.

Biensen NJ, Von Borell EH and Ford SP 1996. Effects of Space Allocation and Temperature on Periparturient Maternal Behaviors, Steroid Concentrations, and Piglet Growth Rates 1,2. Journal of Animal Science 74, 2641–2648.

Blackshaw JK, Blackshaw AW, Thomas FJ and Newman FW 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. Applied Animal Behaviour Science 39, 281–295.

Blomberg M 2010. Maternal behaviour in pigs and its relation to piglet performance and survival. Bachelor's Thesis. Sveriges lantbruksuniversitet.

Bundesministerium für Nachhaltigkeit und Tourismus. Grüner Bericht 2019.

Burri M, Wechsler B, Gygax L and Weber R 2009. Influence of straw length, sow behaviour and room temperature on the incidence of dangerous situations for piglets in a loose farrowing system. Applied Animal Behaviour Science 117, 181–189.

Commission Regulation (EC) No 889/2008. Official Journal of the European Union.

Cronin G.M. and Smith J.A. 1992. Effects of accommodation type and straw bedding around parturition and during lactation on the behaviour of primiparous sows and survival and growth of piglets to weaning. Applied Animal Behaviour Science 33, 191–208.

Cronin GM, Lefébure B and McClintock S 2000. A comparison of piglet production and survival in the Werribee Farrowing Pen and conventional farrowing crates at a commercial farm. Australian Journal of Experimental Agriculture 40, 17–23.

Cronin GM, Schirmer BN, Mccallum TH, Smith JA and Butler KL 1993. The effects of providing sawdust to pre-parturient sows in farrowing crates on sow behaviour, the duration of parturition and the occurrence of intra-partum stillborn piglets. Applied Animal Behaviour Science Elsevier Science Publishers B.V 36, 301–315.

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

Le Dividich J, Mormède P, Catheline M and Caritez JC 1991. Body composition and cold resistance of the neonatal pig from European (Large White) and Chinese (Meishan) breeds. Biology of the neonate 59, 268–77.

Dyck GW and Swierstra EE 1987. Causes of piglet death from birth to weaning. Canadian Journal of Animal Science 67, 543–547.

Edwards S. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livestock Production Science 78, 3–12.

EFSA 2007. Scientific Opinion of the Panel on Animal Health and Welfare on a request from the Commission on Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets. EFSA Journal 572, 3–13.

Gradauer T 2019. Influence of the temperature difference between sow area and creep area on the creep area use and the mortality rate of organic suckling piglets. Unpublished Master's Thesis. University of Life Sciences, Vienna.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2015. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality. Journal of Animal Science 93, 4079–4088.

Hansen LL and Vestergaard K 1984a. Tethered versus loose sows: ethological observations and measures of productivity. I. Ethological obersations during pregnancy and farrowing. Annales de Recherches Vétérinaires 15, 245–256.

Hansen LL and Vestergaard K 1984b. Tethered versus loose sows: ethological observations and measures of productivity: II. Production results. Annales de Recherches Vétérinaires 15, 185–193.

Herpin P, Damon M and Le Dividich J 2002. Development of thermoregulation and neonatal survival in pigs. Livestock Production Science 78, 25–45.

Herpin P, Le Dividich J and Amaral N 1993. Effect of selection for lean tissue growth on body composition and physiological state of the pig at birth. Journal of Animal Science 71, 2645–2653.

Herskin MS, Jensen KH and Thodberg K 1998. Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows. Applied Animal Behaviour Science 58, 241–254.

Houbak B, Thodberg K, Malmkvist J and Pedersen L 2006. Effects of pen floor heating on piglets' use of heated area 0-120 h postpartum. In ISAE 2006: Proceedings of the 40th International congress of the ISAE, p. 156.

Houszka HM, Strøm JS and Morsing S 2001. Thermal conditions in covered creep areas for piglets. Transactions of the ASAE (American Society of Agricultural Engineers) 44, 1859–1863.

Hoy S, Lutter C, Wähner M and Puppe B 1994. The effect of birth weight on the early postnatal vitality of piglets. DTW. Deutsche tierärztliche Wochenschrift 101, 393–396.

Hrupka BJ, Leibbrandt VD, Crenshaw TD and Benevenga NJ 1998. The effect of farrowing crate heat lamp location on sow and pig patterns of lying and pig survival. Journal of Animal Science 76, 2995–3002.

Hrupka BJ, Leibbrandt VD, Crenshaw TD and Benevenga NJ 2000a. The effect of thermal environment and age on neonatal pig behavior. Journal of Animal Science 78, 583–591.

Hrupka BJ, Leibbrandt VD, Crenshaw TD and Benevenga NJ 2000b. Effect of sensory stimuli on huddling behavior of pigs. Journal of Animal Science 78, 592–596.

Jankevicius M. and Widowski T. 2003. Does balancing for color affect pigs' preference for different flavored tail-models? Applied Animal Behaviour Science 84, 159–165.

Jarvis S, D'Eath R and Fujita K 2005. Consistency of piglet crushing by sows. Animal Welfare 14, 43–51.

Jarvis S, Lawrence AB, McLean KA, Deans LA, Chirnside J and Calvert SK 1997. The effect of environment on behavioural activity, ACTH, β-endorphin and cortisol in pre-farrowing gilts. Animal Science 65, 465–472.

Jarvis S, Van der Vegt BJ, Lawrence AB, McLean KA, Deans LA, Chirnside J and Calvert SK 2001. The effect of parity and environmental restriction on behavioural and physiological responses of pre-parturient pigs. Applied Animal Behaviour Science 71, 203–216.

Jensen P and Redbo I 1987. Behaviour during nest leaving in free-ranging domestic pigs. Applied Animal Behaviour Science 18, 355–362.

Johnson AK and Marchant-Forde JN 2009. Welfare of Pigs in the Farrowing Environment. In The Welfare of Pigs. Springer Netherlands, pp. 141–188.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 104, 281–291.

Kirkden RD, Broom DM and Andersen IL 2014. Invited review: piglet mortality: management solutions. Journal of Animal Science 91, 3361–3389.

Lambertz C, Petig M, Elkmann A and Gauly M 2015. Confinement of sows for different periods during lactation: effects on behaviour and lesions of sows and performance of piglets. Animal 9, 1373–1378.

Larsen MLV, Pedersen LJ and Thodberg K 2015. Does light attract piglets to the creep area? Animal 9, 1032–

1037.

Lay DC, Haussmann MF, Buchanan HS and Daniels MJ 1998. Danger to piglets due to crushing can be reduced by the use of a simulated udder. Swine Research Report, 46.

Leenhouwers JI, De Almeida CA, Nior J, Knol EF and Van Der Lende T 2001. Progress of farrowing and early postnatal pig behavior in relation to genetic merit for pig survival 1. Journal of Animal Science 79, 1416–1422.

Marchant JN, Broom DM and Corning S 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. Animal Science 72, 19–28.

Marchant JN, Rudd AR, Mendl MT, Broom DM, Meredith MJ, Corning S and Simmins PH 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Veterinary Record 147, 209–214.

McKay RM 1993. Preweaning losses of piglets as a result of index selection for reduced backfat thickness and increased growth rate. Canadian Journal of Animal Science 73, 437–442.

Morello GM, Marchant-Forde JN, Cronin GM, Morrison RS and Rault J-L 2019. Higher light intensity and mat temperature attract piglets to creep areas in farrowing pens. Animal 13, 1696–1703.

Mutton WJ 1987. The influence of photoperiod and light intensity on the farrowing sow and litter. BSAP Occasional Publication 11, 137–138.

O 'Reilly KM, Harris MJ, Mendl M, Held S, Moinard C, Statham P, Marchant-Forde J and Green LE 2006. Factors associated with preweaning mortality on commercial pig farms in England and Wales. Veterinary Record 159, 193–196.

Pajor EA, Kramer DL and Fraser D 2000. Regulation of Contact with Offspring by Domestic Sows: Temporal Patterns and Individual Variation. Ethology 106, 37–51.

Parfet KA and Gonyou HW 1991. Attraction of newborn piglets to auditory, visual, olfactory and tactile stimuli. Journal of Animal Science 69, 125–133.

Pedersen LJ, Berg P, Jorgensen G and Andersen IL 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. Journal of Animal Science 89, 1207–1218.

Pedersen LJ, Jørgensen E, Heiskanen T and Damm BI 2006. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. Applied Animal Behaviour Science 96, 215–232.

Pedersen LJ, Malmkvist J, Kammersgaard T and Jørgensen E 2013. Avoiding hypothermia in neonatal pigs: Effect of duration of floor heating at different room temperatures1. Journal of Animal Science 91, 425–432.

Pitts AD, Weary DM, Fraser D, Pajor EA and Kramer DL 2002. Alternative housing for sows and litters Part 5. Individual differences in the maternal behaviour of sows. Applied Animal Behaviour Science 76, 291–306.

Schauer Agrotronic GmbH 2017. WelCon. Translated into English by Theresia Gradauer. Retrieved on 2 April 2017, from *http://nature-line.com/abferkeln/freilaufbucht-welcon-bio/*.

Schormann R and Hoy S 2006. Effects of room and nest temperature on the preferred lying place of piglets-A brief note. Applied Animal Behaviour Science 101, 369–374.

Simitzis PE, Veis D, Demiris N, Charismiadou MA, Ayoutanti A and Deligeorgis SG 2013. The effects of the light regimen imposed during lactation on the performance and behaviour of sows and their litters. Applied

Animal Behaviour Science 144, 116–120.

Singh C, Verdon M, Cronin GM and Hemsworth PH 2016. The behaviour and welfare of sows and piglets in farrowing crates or lactation pens. Animal 11, 1210–1221.

Stangel G and 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 and Wood-Gush DGM 1989. The behaviour of pigs in a semi-natural environment. Animal Production 48, 419–425.

Tanida H, Miura A, Tanaka T and Yoshimoto T 1996. Behavioral responses of piglets to darkness and shadows. Applied Animal Behaviour Science 49, 173–183.

Taylor N, Prescott N, Perry G, Potter M, Sueur C Le and Wathes C 2006. Preference of growing pigs for illuminance. Applied Animal Behaviour Science 96, 19–31.

Thodberg K, Jensen KH, Herskin MS and Jørgensen E 1999. Influence of environmental stimuli on nest building and farrowing behaviour in domestic sows. Applied Animal Behaviour Science 63, 131–144.

Thorsen CK, Schild S-LA, Rangstrup-Christensen L, Bilde T and Pedersen LJ 2017. The effect of farrowing duration on maternal behavior of hyperprolific sows in organic outdoor production. Livestock Science 204, 92–97.

Valros A, Rundgren M, Špinka M, Saloniemi H and Algers B 2003. Sow activity level, frequency of standing-to-lying posture changes and anti-crushing behaviour-within sow-repeatability and interactions with nursing behaviour and piglet performance. Applied Animal Behaviour Science 83, 29–40.

Vangen O, Holm B, Valros A, Lund MS and Rydhmer L 2005. Genetic variation in sows' maternal behaviour, recorded under field conditions. Livestock Production Science 93, 63–71.

Vasdal G, Andersen IL and Pedersen LJ 2009a. Piglet use of the creep area-Effects of breeding value and farrowing environment. Applied Animal Behaviour Science 120, 62–67.

Vasdal G, Glaerum M, Melišová M, Bøe KE, Broom DM and Andersen IL 2010. Increasing the piglets' use of the creep area - A battle against biology? Applied Animal Behaviour Science 125, 96–102.

Vasdal G, Østensen I, Melišová M, Bozděchová B, Illmann G and Andersen IL 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science 136, 225–231.

Vasdal G, Wheeler EF and Bøe KE 2009b. Effect of infrared temperature on thermoregulatory behaviour in suckling piglets. Animal 3, 1449–1454.

Verhovsek D, Troxler J and Baumgartner J 2007. Peripartal behaviour and teat lesions of sows in farrowing crates and in a loose-housing system. Animal Welfare 16, 273–276.

Wallenbeck A, Gustafson G and Rydhmer L 2009. Sow performance and maternal behaviour in organic and conventional herds. Acta Agriculturae Scandinavica A: Animal Sciences 59, 181–191.

Weary DM, Pajor EA, Thompson BK and Fraser D 1996. Risky behaviour by piglets: a trade off between feeding and risk of mortality by maternal crushing? Animal Behaviour 51, 619–624.

Weber R, Keil N, Fehr M and Horat R 2007. Piglet mortality on farms using farrowing systems with or without crates. Animal Welfare 16, 277–279.

Wheeler EF, Vasdal G, Flo A and Boe KE 2008. Static space requirements for piglet creep area as influenced by radiant temperature. Transactions of the ASAE (American Society of Agricultural Engineers) 51, 271–278.

Wientjes J, Soede N, Van der Peet-Schwering C, Van den Brand H and Kemp B 2012. Piglet uniformity and mortality in large organic litters: Effects of parity and pre-mating diet composition. Livestock Science 144, 218–229.

Zaleski HM and Hacker RR 1993. Variables related to the progress of parturition and probability of stillbirth in swine. The Canadian veterinary journal = La revue veterinaire canadienne 34, 109–113.

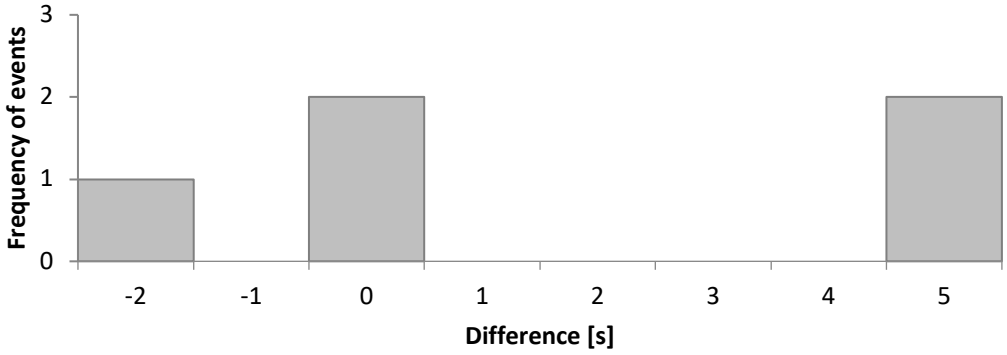
Zhang Q and Xin H 2000. Modeling heat mat operation for piglet creep heating. Transactions of the ASAE 43, 1261–1267.

Zhang Q and Xin H 2001. Responses of Piglets to Creep Heat Type and Location in Farrowing Cage. Applied Engineering in Agriculture 17, 515–519.

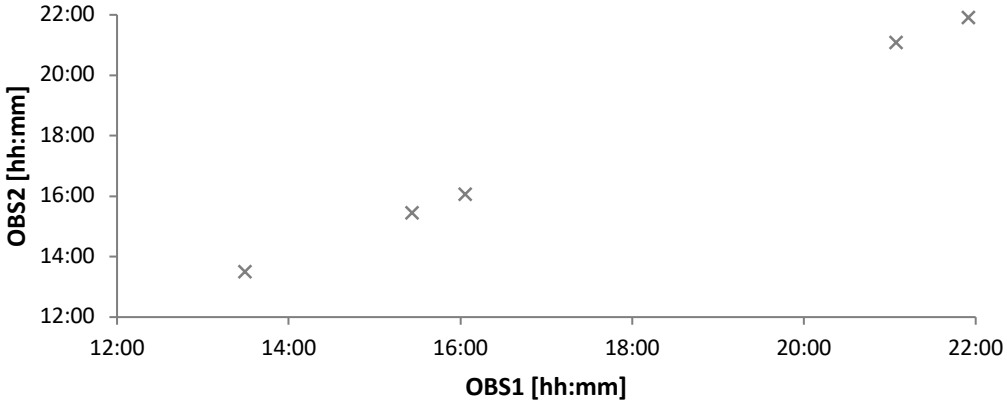
Ziron M and Hoy S 2003. Effect of a warm and flexible piglet nest heating system-the warm water bed-on piglet behaviour, live weight management and skin lesions. Applied Animal Behaviour Science 80, 9–18.

6 Appendix

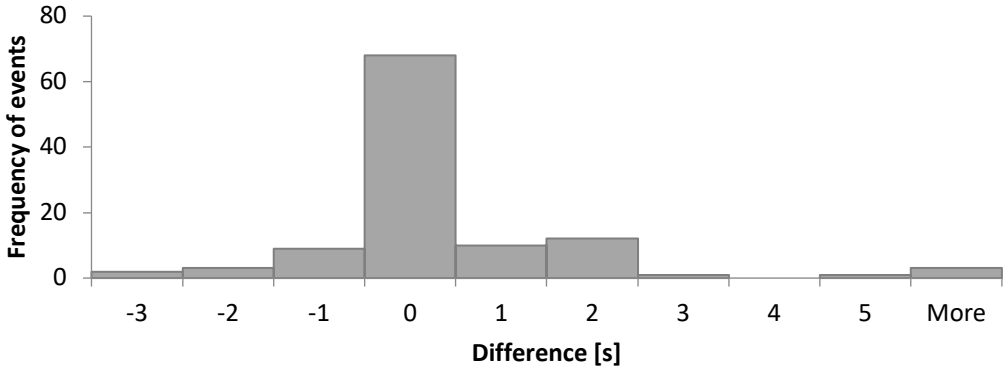
6.1 Graphs IOR2



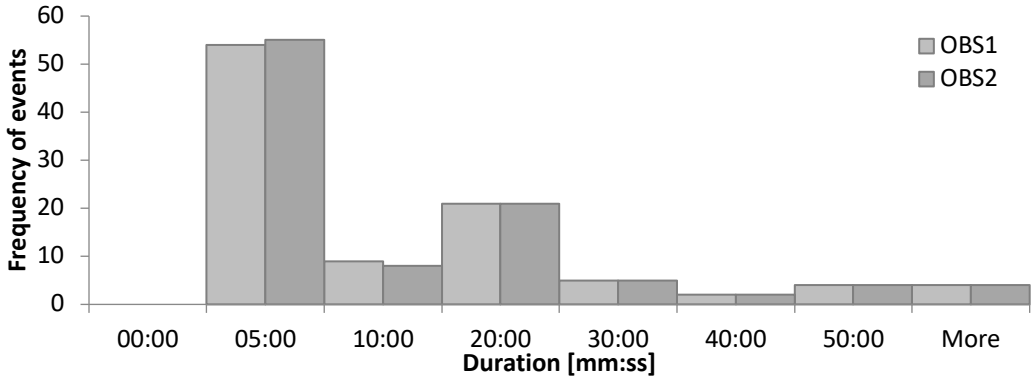
EoF: Differences in Onset Time between OBS1 and OBS2.



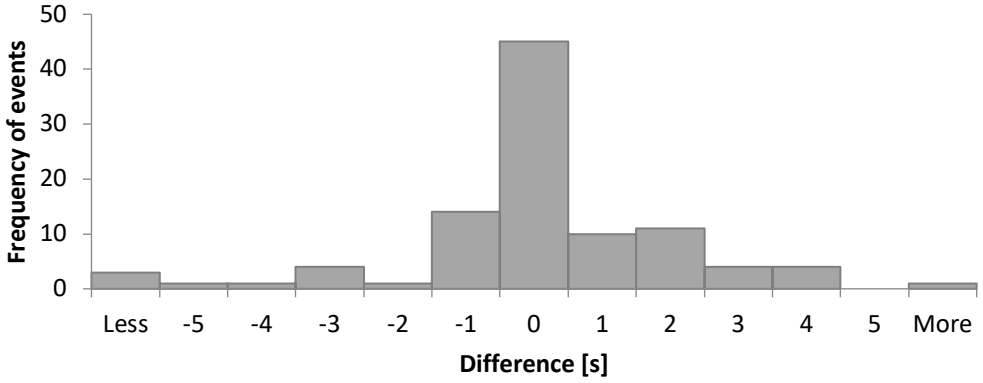
EoF: Relationship of Onset Times of events seen during OBS1 and OBS2.



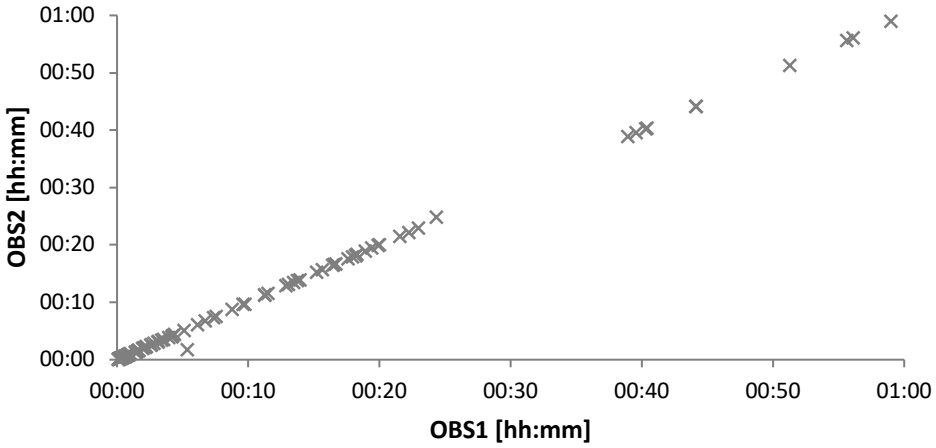
Marked Piglet: Differences in Onset Time between OBS1 and OBS2.



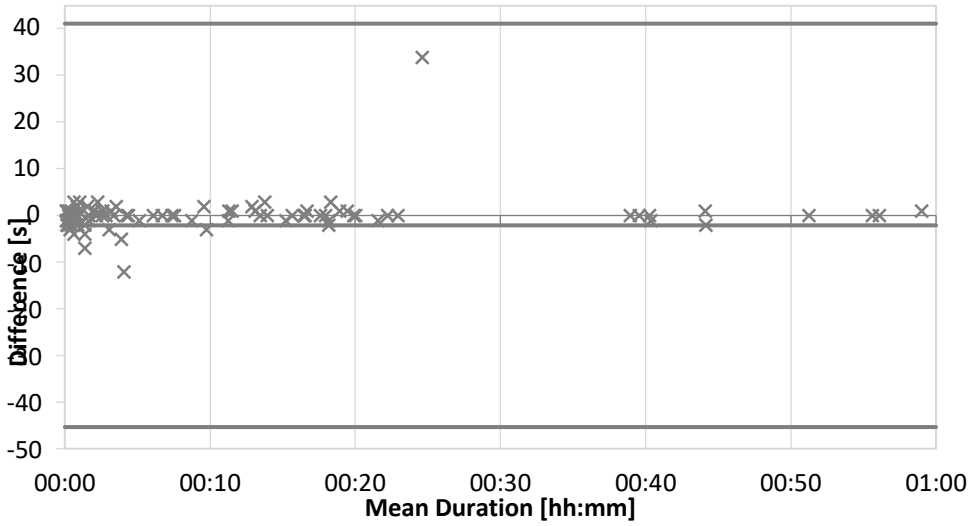
Marked Piglet: Distribution of Durations in OBS1 and OBS2.



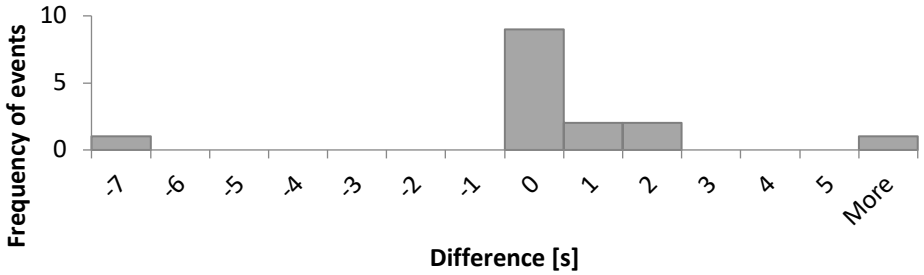
Marked Piglet: Differences in Duration between OBS1 and OBS2.



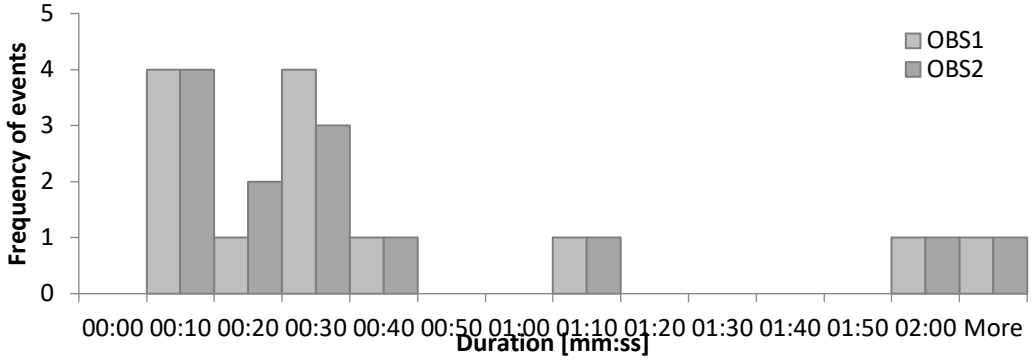
Marked Piglet: Relationship between the Durations of events seen during OBS1 and OBS2.



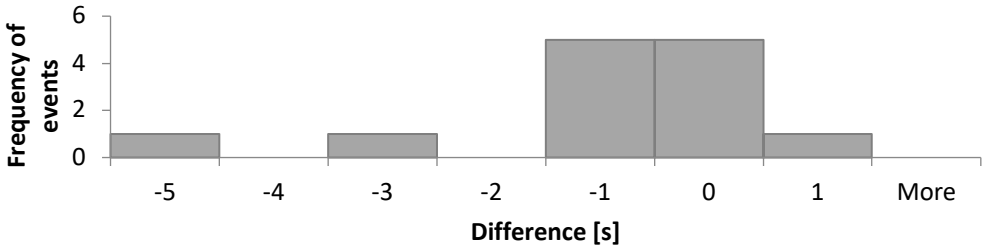
Marked Piglet: Bland&Altman Plot for all events identified in OBS1 and OBS2.



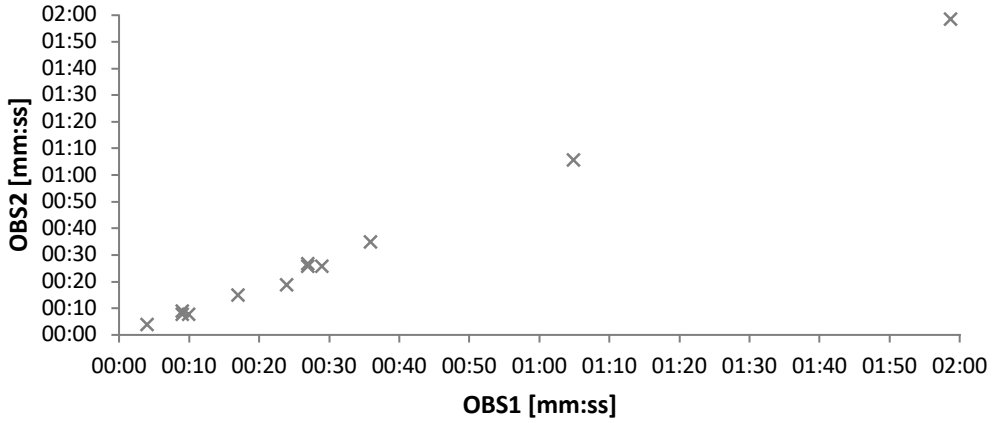
Undefined Piglet: Differences in Onset Time between OBS1 and OBS2.



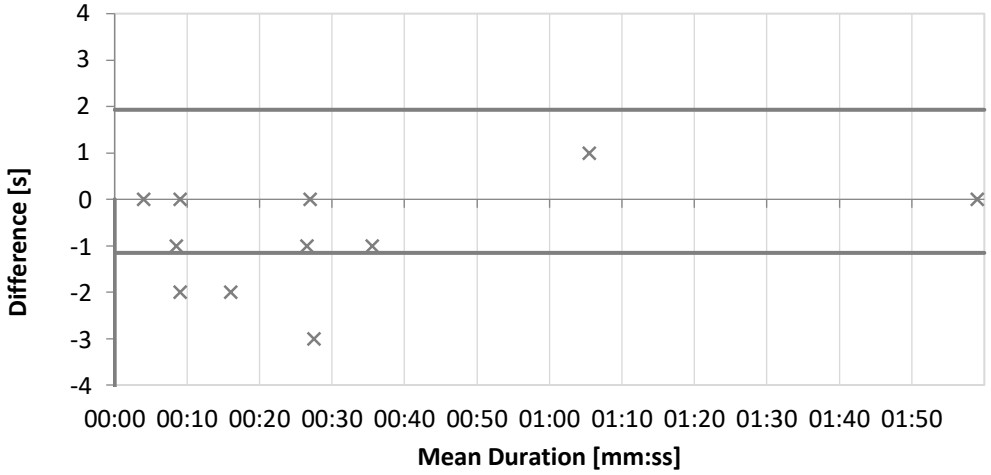
Undefined Piglet: Distribution of Durations in OBS1 and OBS2.



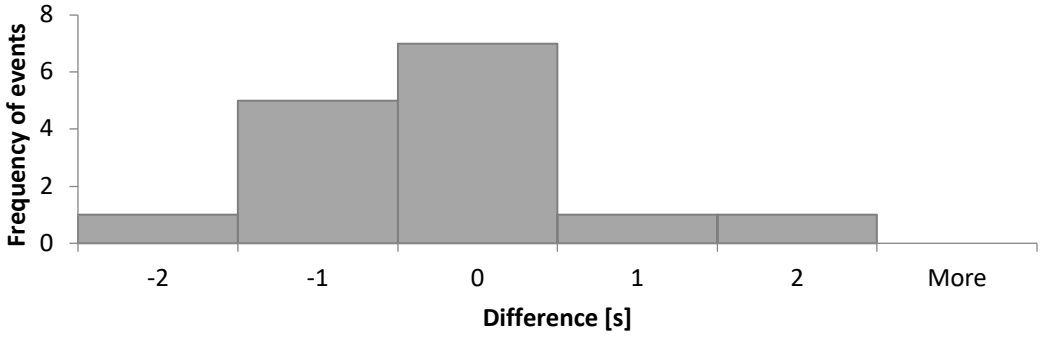
Undefined Piglet: Differences in Duration between OBS1 and OBS2.



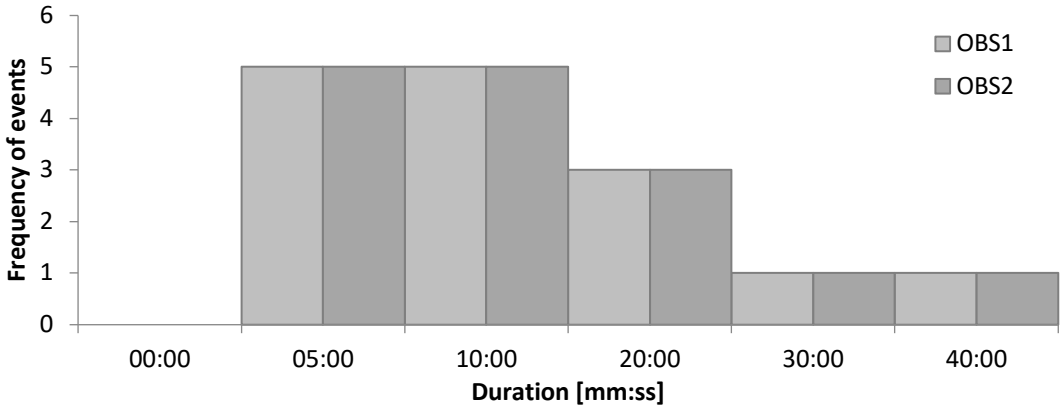
Undefined Piglet: Relation between the durations of events seen during OBS1 and OBS2.



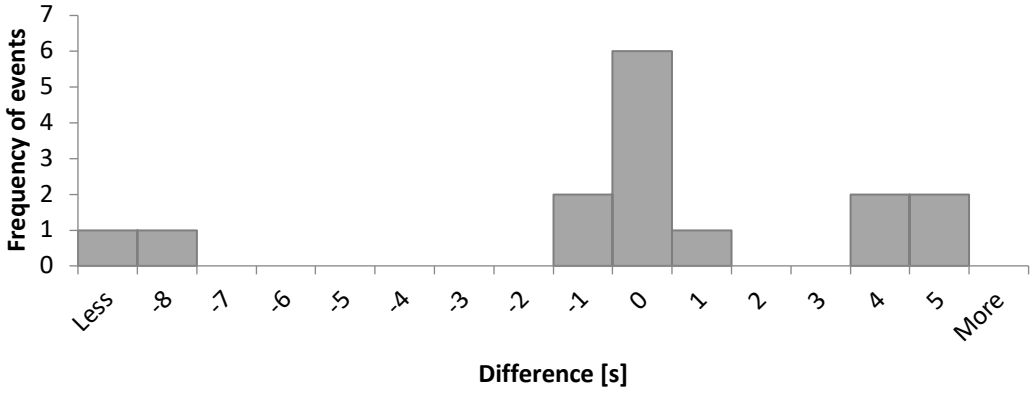
Undefined Piglet: Bland&Altman Plot for all events identified in OBS1 and OBS2.



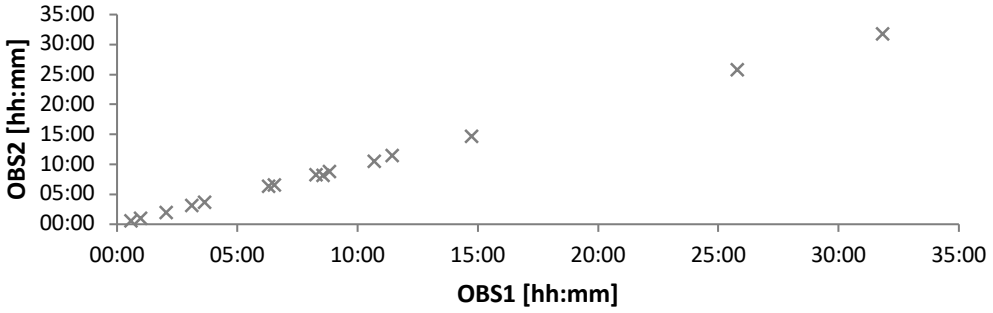
Sow: Differences in Onset Time between OBS1 and OBS2



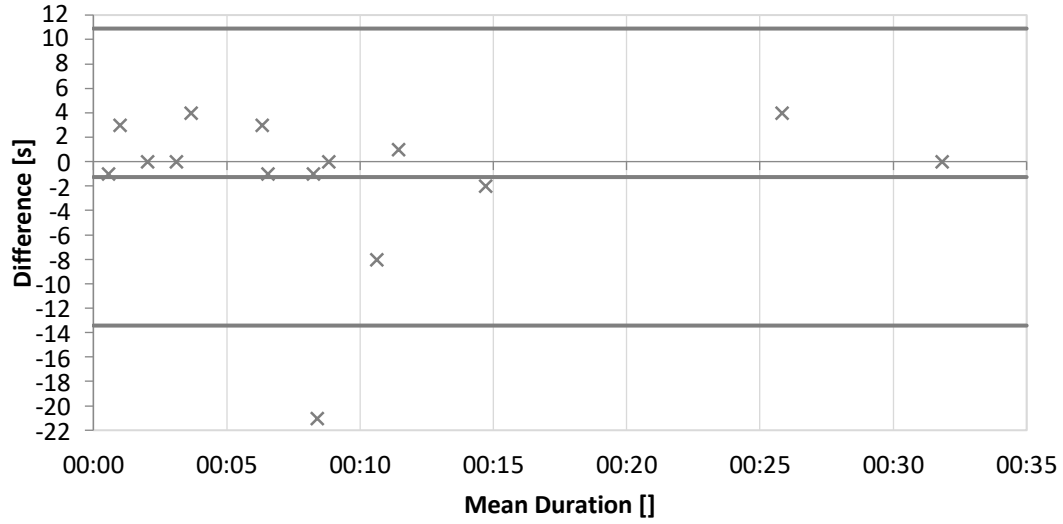
Sow: Distribution of Durations in OBS1 and OBS2.



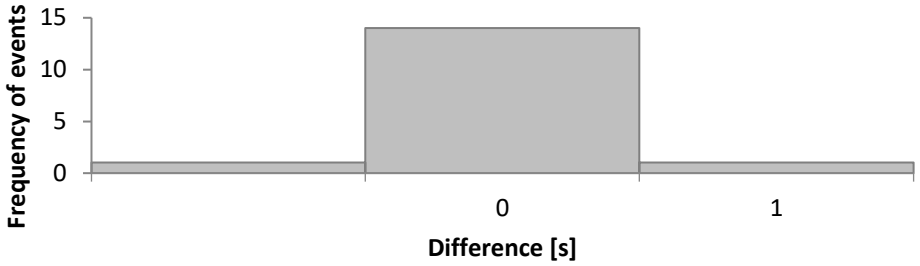
Sow: Differences in Duration between OBS1 and OBS2.



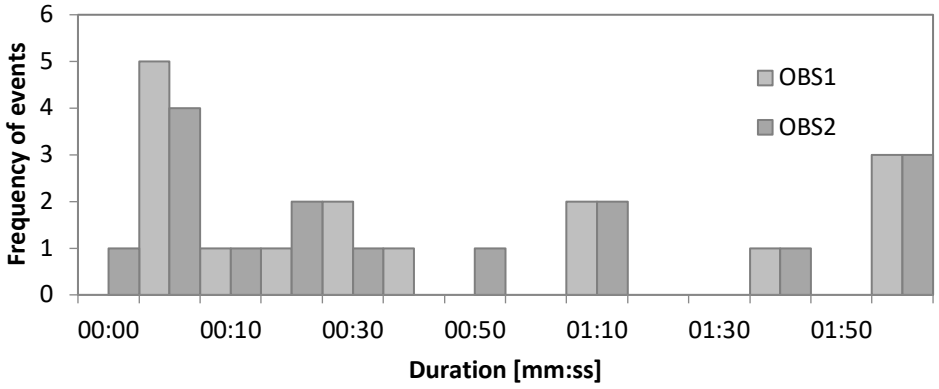
Sow: Relation between the durations of events seen during OBS1 and OBS2.



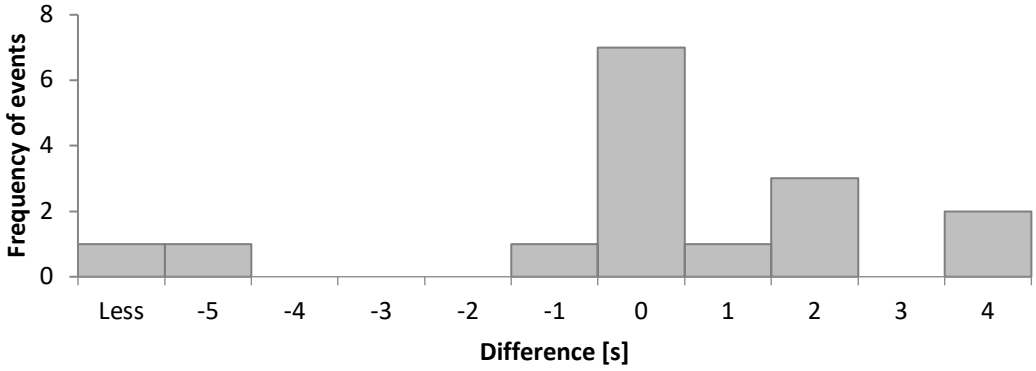
Sow: Bland&Altman Plot for all events identified in OBS1 and OBS2.



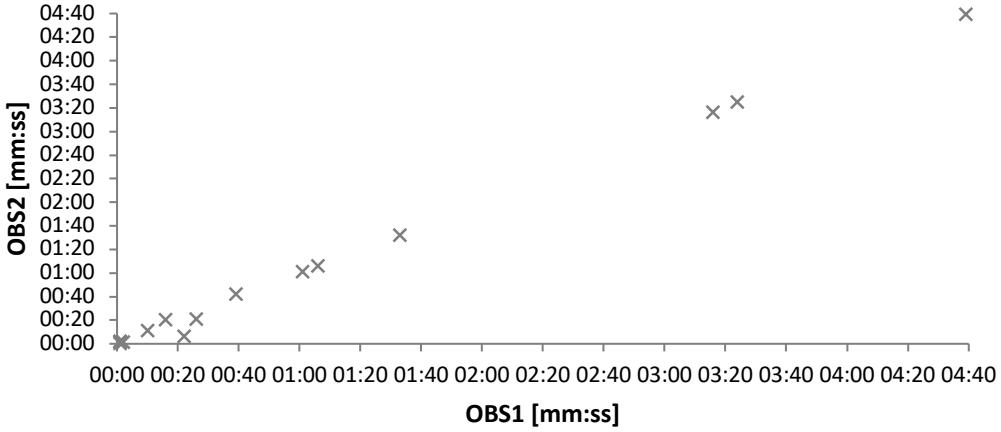
HI: Differences in Onset Time between OBS1 and OBS2.



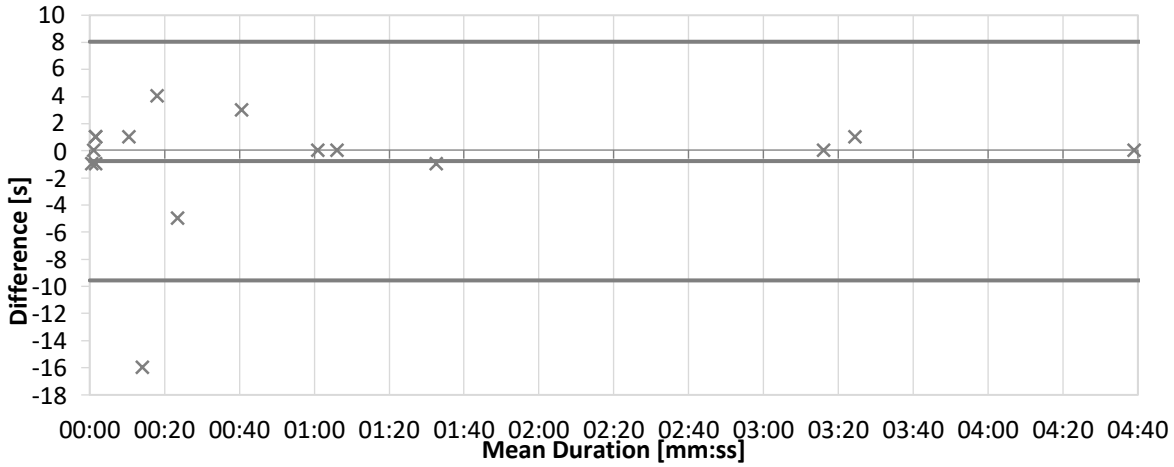
HI: Distribution of Durations in OBS1 and OBS2.



HI: Differences in Duration between OBS1 and OBS2.



HI: Relation between the durations of events seen during OBS1 and OBS2.



HI: Bland&Altman Plot for all events identified in OBS1 and OBS2.